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Screening of brinjal mutant lines for resistance to shoot and fruit borer based on morphological traits

Md. Ahsanul Haque[1], Pranto Das[1], Mehfuz Hasan[2], Md. Golam Rasul[2], Ahsan Habib[1], M. Mahbubur Rahman[1*]

[1] Department of Entomology, Faculty of Agriculture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh

[2] Department of Genetics and Plant Breeding, Faculty of Agriculture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh

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ABSTRACT

Brinjal (*Solanum melongena*) is a major vegetable in Bangladesh, grown year-round. The brinjal shoot and fruit borer (BSFB), *Leucinodes orbonalis*, causes severe crop loss up to 100%. Despite many available varieties, none have shown appreciable resistance to BSFB. Twenty-eight brinjal mutant lines were screened to identify resistance to BSFB based on morphological traits. Conducted at Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur from November 2020 to May 2021, found none of the lines resistant to BSFB. However, two lines (G9 and G24) showed tolerance to shoot infestation, while three were susceptible and 22 were highly susceptible. Regarding fruit infestation, none of the lines displayed resistance, but 10 lines (G1, G3, G9, G14, G15, G18, G19, G23, G24 and G28) exhibited moderate tolerance. Significant variation was observed in brinjal's morphological traits, including plant height, number of branches, leaves, leaf spines, leaf trichome, shoot diameter, and days to first flowering and fruiting. Shoot infestation showed positive correlations with plant height and shoot diameter, and negative correlations with the number of primary branches, leaves, leaf trichome, and spine density. Fruit infestation positively correlated with plant height, fruit size, weight, and days to first flowering and fruiting, while negatively correlating with branch and fruit count, fruit length, and leaf trichome density. Fruit yield varied significantly, with G6 recording the highest yield and G24 the lowest. These findings can assist breeding programs in developing BSFB-resistant brinjal varieties, thereby improving yield and reducing pest damage.

Introduction

Brinjal (*Solanum melongena* L.), also known as eggplant, is a widely cultivated vegetable in Southeast Asia including Bangladesh, grown year-round due to its popularity. In Bangladesh, over 53,664 hectares of land is utilized for brinjal cultivation, making up about 11.81% of the total vegetable cultivation area.

*Corresponding Author: Department of Entomology, Faculty of Agriculture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh, Email: mahbub.ent@bsmrau.edu.bd

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The brinjal production in 2020-2021 amounted to 587,212.03 tons (BBS, 2021). Brinjal accounted for 9.01% and 8.71% of all winter and summer vegetable production, respectively (BBS, 2021). Globally, brinjal ranks third among all vegetables in terms of production and is the second most important vegetable in Bangladesh, following potatoes (Rahman *et al*., 2016). Several biotic and abiotic factors have impact on brinjal yield, with insect pests being one of the most significant biotic factors. These insect pests considerably affect the quality and productivity of brinjal crops by causing direct damage (Raina and Yadav, 2018). The impact of insect pests is profound throughout the plant's developmental stages, from seedling emergence to fruit maturation (Amin *et al*., 2018). In Bangladesh, eight insect species have been identified as major pests, inflicting considerable damage on brinjal (Biswas *et al*., 1992). Among these, the brinjal shoot and fruit borer (BSFB), *Leucinodes orbonalis* Guenee (Lepidoptera: Noctuidae), is the most destructive pest, potentially causing up to 100% crop loss without effective control measures (Alam *et al*., 2003; Rahman, 2006; Prodhan *et al*., 2018). The damage from BSFB begins soon after seedling transplantation and continues until fruit harvest (Nishad *et al*., 2019). Crop losses due to this pest have been reported to reach up to 86% in Bangladesh (Das and Islam, 2014) and up to 95% in India (Singh *et al*., 2005). The management of this pest is particularly challenging as its larvae reside within the plant shoots or fruits (Alam *et al*., 2003).

Currently, farmers primarily rely on pesticide application to manage BSFB, aiming to produce blemish-free brinjal fruit and achieve maximum yield. However, the indiscriminate use of pesticides poses significant risks, including environmental contamination, bioaccumulation, biomagnification of toxic residues, and disruption of ecological balance (Khatun *et al*., 2023). This underscores the urgent need for safer pest management strategies. One effective and eco-friendly alternative is the use of host plant resistance. This approach is recognized as an important tool in bio-intensive pest management systems due to its environmental safety and economic soundness. Insect-resistant varieties provide pest control at essentially no additional cost to farmers (Prem Kishore, 2001). Despite the availability of numerous brinjal varieties in the subcontinent, including Bangladesh, none have demonstrated appreciable resistance to BSFB (Alam *et al*., 2003).

The morphological traits of brinjal shoots and fruits are critically linked to pest behaviors such as attraction, feeding, and oviposition. Therefore, identifying these traits in insect-resistant varieties holds significant practical importance. Understanding the specific morphological characteristics and biochemical defense mechanisms of brinjal genotypes that confer resistance against the BSFB is crucial for the effective selection of resistant plants (Alam *et al*., 2003). Exploiting host plant resistance through breeding can result in the development of superior high-yielding genotypes resistant to BSFB. Despite the promise of Bt transgenic technology for sustainable BSFB management (Rahman *et al*., 2016), the indefinite moratorium on the commercial cultivation of Bt brinjal necessitates alternative strategies. Consequently, systematically screening brinjal germplasm based on morphological traits becomes essential for identifying potential sources of resistance against BSFB.

In this context, the present investigation aims to screen brinjal mutant genotypes to identify elite sources of resistance. This study focuses on evaluating the response of different morphological traits of brinjal mutant lines to BSFB infestation. By analyzing these traits, the research provides critical insights that will aid in the selection and development of high-yielding brinjal varieties with enhanced resistance to shoot and fruit borer.

Materials and Methods

Experimental site

The experiment was carried out in the research field and laboratory of the Department of Entomology of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) Gazipur, Bangladesh from

November 2020 to May 2021. The experimental site is located at Madhupur Tract (24°04′ North latitude and 90°40′ East longitude) with an elevation of 8.3 meters from the sea level.

Experimental materials

Twenty-eight mutant lines of brinjal were used as experimental materials in the current study, as listed in Table 1. Healthy and disease-free seeds were collected from the Department of Genetics and Plant Breeding, BSMRAU, Gazipur.

Screening of brinjal mutant lines

The experiment was conducted following Randomized Complete Block Design (RCBD) with 28 treatments and 3 replications. Each unit plot measured 2.0 m × 1.0 m, accommodating two rows and six pits per bed. Thirty-day-old seedlings at the 3/4 leaf stage were transplanted with a plant-to-plant distance of 90 cm and a row-to-row distance of 80 cm. Spacing between blocks and plots was maintained at 1.0 m. The number of infested shoots on five tagged plants per plot were recorded weekly from seven days after transplantation until the fruiting stage. At harvest, fruits from each plot were collected separately, and the number of healthy and infested fruits was quantified to determine percent infestation. A total of 12 pickings were conducted at weekly intervals. Additionally, various quantitative and visual morphological parameters were assessed throughout the study.

Data collection and calculation

Quantitative data

Plant Height (cm): Plant height was measured from soil surface to the apex of the tallest branch, at the final harvest stage.

Number of primary branches per plant: It was counted during the peak fruiting stage of each tagged plant.

Shoot diameter: It was measured1 inch below the axillary tip on five randomly plants per replication at 30, 60, 90, and 120 days after transplanting.

Number of total shoots per plant: It was recorded at 7-day intervals for five tagged plants.

Number of infested shoots per plant: Recorded at 7-day intervals for five tagged plants.

Number of leaves per plant: It was counted from five randomly selected plants per replication.

Table 1. Details of the brinjal mutant lines used in the study

Mutant line no.	Line name	Mutant line no.	Line genotype name
G1	RRWE P3	G15	B BARIA
G2	RWE P3	G16	RPE P23
G3	LPE P13	G17	RWE P12
G4	RWE P4	G18	RRWE P2
G5	RPE P4	G19	LPE P9
G6	RPE P3	G20	RPE P17
G7	RWE P2	G21	RWE P5
G8	RPE P18	G22	LPE P3
G9	B BARIA	G23	LPE P10
G10	RPE P2	G24	RRWE P4
G11	RPE P1	G25	RPE P22
G12	LPE P1	G26	RPE P19
G13	RWE P1	G27	RPE P14
G14	LPE P12	G28	LPE P14

Leaf trichome density: Trichome density was measured on the lower leaf surface using a stereo binocular microscope at 60 days after transplanting following the method outlined by Naqvi *et al*., (2008).

Days to first flowering: This metric denotes the duration, in days, from transplantation to the emergence of the initial flower across any plant.

Days to first fruit set: The number of days from transplantation to the first fruit setting..

Fruit pedicel and calyx length: Measured from the stem junction to the fruit base, and from the fruit base to the calyx tip, respectively.

Total number of fruits per plant: The cumulative number of fruits from five randomly chosen plants, assessed at 7-day intervals until the final harvest.

Number of infested fruits per plant: It was recorded at 7-day intervals for five tagged plants, then averaged.

Fruit length (cm): At the second, fourth, and sixth picking stages, five randomly chosen fruits were longitudinally dissected and measured using a tape measure.

Fruit diameter (cm): At similar picking stages, five fruits were randomly sampled, and their girths were measured using a slide caliper.

Average fruit weight (g): Five fruits from each replication, sampled at the designated picking stages, were weighed individually.

Fruit yield per plant (kg): Harvested fruits from selected plants were weighed weekly, and the average weight per plant was determined after all harvests.

Qualitative data

Observations on leaf and calyx spine, fruit shape, and fruit color were recorded. Infestation rates for shoots and fruits were calculated.

The brinjal mutant line was classified according to the grade index of resistance by Subbaratnam and Butani (1981) and Ahmad et al., (2008), based on the average shoot and fruit infestation levels.

Data analysis

The data recorded from the field on different parameters were analyzed using the STATISTIX 10 computer package to determine the level of significance among twenty-eight brinjal mutant lines. One-way analysis of variance (ANOVA) followed by Tukey's Honestly Significant Difference (HSD) test (at 5% level of significance) was done for determining the variation of plant developmental phenomena, morphological characteristics of brinjal mutant lines. Correlation analysis among various studied parameters was executed using the statistical packages of the R program (version 4.1.2).

Results

Incidence of brinjal shoot and fruit borer at different growth stages of brinjal mutant lines

Shoot infestation: The percentage of shoot infestation caused by BSFB varied significantly across 28 mutant lines at different growth stages-vegetative, early fruiting, mid fruiting, and late fruiting-as evidenced in Table 2. Notably, during the vegetative stage, G17 exhibited the highest shoot infestation (12.96%), significantly differing from all other lines ($F_{27,54}$ = 64.23; P<0.01). Conversely, several lines exhibited no infestation during this stage. During the early fruiting stage, G4 recorded the highest infestation (24.91%), statistically differing from other lines, while G9 exhibited the lowest infestation (0.50%), statistically similar to several other lines (G8, G5, G6, G28, G24, and G1) with infestation percentages of 2.54%, 2.08%, 1.70%, 1.38%, 1.11%, and 0.79%, respectively. Similar trends were observed at mid and late fruiting stages, with infestation generally increasing over plant growth stages. Notably, minimum infestation was recorded at the vegetative stage for all lines, whereas maximum shoot infestation occurred at the mid-fruiting stage.

Table 2. Shoot infestation by brinjal shoot and fruit borer in twenty-eight brinjal mutant lines at various growth stages

Mutant line	Vegetative (30-60 DAT)	Shoot infestation at different fruiting stages of plant (%) ± SE			Mean %
		Early (61-90 DAT)	Mid (91-120 DAT)	Late (121-150 DAT)	
G1	0.00 ± 0.00 h	0.79 ± 0.12 j	3.35 ± 0.17 p	9.04 ± 0.03 cd	3.31± 0.12 lm
G2	5.59 ± 0.34 e	10.07 ± 1.15 ef	25.37 ± 1.73 def	14.44 ± 0.23 a	13.86 ± 1.15 ab
G3	0.00 ± 0.00 h	15.31 ± 0.58 c	22.69 ± 1.27 fg	5.46 ± 0.00 ij	10.86 ± 0.50 def
G4	0.00 ± 0.00 h	24.91 ± 0.06 a	17.96 ± 0.06 hij	10.68 ± 0.23 b	13.39 ± 0.17 abcd
G5	9.26 ± 0.46 c	2.08 ± 0.00 j	6.87 ± 0.12 no	8.836 ± 0.58 cde	6.76 ± 0.12 ijk
G6	10.18 ± 0.11 b	1.70 ± 0.12 j	10.27 ± 0.12 lm	9.55 ± 0.06 bc	7.92 ± 0.12 ghi
G7	0.00 ± 0.00 h	7.75 ± 0.17 h	12.92 ± 0.58 klm	7.72 ± 0.12 efg	7.10 ± 0.06 hijk
G8	8.79 ± 0.06 c	2.54 ± 0.06 j	9.62 ± 0.17 mn	9.78 ± 0.17 bc	7.68 ± 0.17 ghij
G9	0.00 ± 0.00 h	0.50 ± 0.00 j	3.60 ± 0.17 op	1.04 ± 0.01 m	1.28 ± 0.12 m
G10	0.00 ± 0.00 h	5.40 ± 0.81 i	19.05 ± 1.15 h	8.07 ± 0.04 defg	8.13 ± 0.06 ghi
G11	0.00 ± 0.00 h	9.20 ± 0.12 fgh	18.31 ± 0.17 hi	4.89 ± 0.17 ijk	8.10 ± 0.64 ghi
G12	0.00 ± 0.00 h	4.86 ± 0.06 i	15.56 ± 0.29 ijk	5.79 ± 0.06 hi	6.55 ± 0.29 ijk
G13	6.48 ± 0.23 d	12.28 ± 1.04 d	19.46 ± 1.50 gh	5.80 ± 0.17 hi	11.00 ± 1.16 cdef
G14	0.00 ± 0.00 h	16.38 ± 0.17 bc	30.50 ± 0.86 c	3.16 ± 0.06 lm	12.51 ± 0.52 bcde
G15	0.00 ± 0.00 h	4.89 ± 0.06 i	14.68 ± 0.06 jk	0.00 ± 0.00 n	4.89 ± 0.15 kl
G16	0.00 ± 0.00 h	9.49 ± 0.29 fgh	24.36 ± 0.17 ef	7.00 ± 0.26 gh	10.20 ± 0.61 efg
G17	12.96 ± 0.06 a	9.49 ± 0.28 fgh	28.47 ± 0.81 cd	0.00 ± 0.00 n	12.73 ± 1.04 bcde
G18	0.00 ±0.00 h	4.68 ± 0.00 i	15.13 ± 0.06 ijk	0.55 ± 0.06 n	5.09 ± 0.05 jkl
G19	0.00 ± 0.00 h	11.25 ± 0.14 def	34.97 ± 0.58 b	8.30 ± 0.58 def	13.63 ± 0.17 abc
G20	0.00 ± 0.00 h	17.11 ± 0.06 bc	40.41 ± 0.23 a	5.91 ± 0.52 hi	15.86 ± 1.73 a
G21	1.39 ± 0.22 g	15.66 ± 0.35 bc	24.98 ± 0.06 ef	4.84 ± 0.06 ijkl	11.71 ± 0.12 bcdef
G22	0.00 ± 0.00 h	12.43 ± 0.35 d	23.14 ± 0.06 ef	5.26 ± 0.12 ij	10.21 ± 0.52 efg
G23	0.00 ± 0.00 h	12.07 ± 0.04 de	25.00 ± 0.26 ef	7.48 ± 0.23 fg	11.13 ± 0.06 cdef
G24	0.00 ± 0.00 h	1.11 ± 0.06 j	3.33 ± 0.19 p	0.00 ± 0.00 n	1.11 ± 0.06 m
G25	0.00 ± 0.00 h	7.83 ± 0.48 gh	26.09 ± 0.50 de	4.02 ± 0.01 klm	9.48 ± 0.12fgh
G26	0.00 ± 0.00 h	9.82 ± 0.06 fg	30.50 ± 0.23 c	3.64 ± 0.17 lm	10.99 ± 0.17 cdef
G27	4.63 ± 0.12 f	17.50 ± 0.29 b	31.13 ± 0.06 c	2.85 ± 0.12 m	14.03 ± 0.58 ab
G28	0.00 ± 0.00 h	1.38 ± 0.06 j	13.23 ± 0.14 kl	4.53 ± 0.29 jkl	4.78 ± 0.06 kl

In columns, means followed by the same letter (s) indicate the statistically similar with each other at 5% level of significance with Tukey's HSD. DAT: Days after transplanting; SE: Standard Error

Regarding mean infestation, G20 exhibited the highest infestation at 15.86%, statistically similar to several other lines (G27, G2, G19, and G4) with infestation percentages of 14.03%, 13.86%, 13.63%, and 13.39%, respectively, while G24 showed the lowest infestation at 1.11%, statistically similar to G9 (1.28%) and G1 (3.31%), but statistically different from other lines. Additionally, G28, G15, and G18 manifested infestation percentages of 4.78%, 4.89%, and 5.09%, respectively.

Fruit infestation: The percentage of fruit infestation attributed to BSFB varied significantly among 28 mutant lines across different growth stages-early fruiting, mid-fruiting, and late fruiting-as indicated in Table 3. Notably, at the early fruiting stage, G17

Table 3. Fruit infestation by brinjal shoot and fruit borer in twenty-eight brinjal mutant lines at various growth stages

Mutant line	Fruit infestation at different fruiting stages of plant (%) ± SE			
	Early (60-90 DAT)	Mid (91-120 DAT)	Late (121-150 DAT)	Mean % infestation
G1	11.80 ± 0.58 lmno	21.86 ± 0.06 mn	32.05 ± 0.58 lm	21.90 ± 0.58 opq
G2	45.00 ± 1.73 b	56.39 ± 0.58a	84.52 ± 0.29 a	61.97 ± 1.73 a
G3	14.37 ± 0.17 lm	28.30 ± 0.67 ijkl	32.46 ± 0.12 lm	24.93 ± 0.18 no
G4	34.28 ± 0.12 cd	48.63 ± 0.17 bc	61.11 ± 0.06 c	48.00 ± 0.01 bcd
G5	26.51 ± 0.29 fg	38.05 ± 0.58 efg	47.77 ± 0.40 efgh	37.45 ± 0.58 gh
G6	25.75 ± 0.12 f-h	38.06 ± 0.29 efg	45.130 ± 0.08 ghij	36.31 ± 0.06 hi
G7	45.00 ± 2.89 b	54.25 ± 2.37 ab	55.55 ± 2.60 cd	51.60 ± 1.22 b
G8	26.13 ± 0.06 fg	32.02 ± 0.00 ghijk	36.50 ± 0.06 kl	31.55 ± 0.58 jkl
G9	6.81 ± 0.29 o	18.98 ± 0.06 n	29.16±0.06 m	18.32 ± 0.17 q
G10	45.00 ± 0.00 b	41.56 ± 1.15 de	51.89 ± 1.10 def	46.15 ± 0.06 cde
G11	33.03 ± 1.73 de	44.97 ± 0.23 cd	45.00 ± 2.52 ghij	41.00 ± 0.00 fg
G12	19.44 ± 0.26 jk	34.54 ± 0.17 fghi	52.27 ± 0.12 de	35.42 ± 0.23 hij
G13	37.50 ± 1.32 cd	35.480 ± 3.12 efgh	52.77 ± 2.15 de	41.95 ± 1.73 ef
G14	29.16 ± 0.10 ef	29.45 ± 0.06 hijk	33.75 ± 0.43 lm	30.79 ± 0.12 klm
G15	23.61 ± 0.35 ghij	18.57 ± 0.17 n	29.02 ± 0.01 m	23.73 ± 0.40 nop
G16	38.09 ± 1.15 c	52.83 ± 2.11 ab	45.83 ± 0.06 fghij	45.58±0.29 de
G17	52.27 ± 1.27 a	49.44 ± 2.23 bc	49.20 ± 2.41 efgh	50.30 ± 1.85 bc
G18	19.53 ± 0.29 jk	27.02 ± 0.58 klm	28.61 ± 0.23 m	25.05 ± 0.03 no
G19	23.33 ± 0.19 ghij	28.18 ± 0.06 jkl	36.66 ± 0.12 kl	29.39 ± 0.17 klm
G20	20.77 ± 0.45 h-j	30.42 ± 0.24 hijk	47.22 ± 0.13 efghi	32.80 ± 1.04 ijk
G21	49.20 ± 0.46 ab	50.95 ± 0.55 abc	73.33 ± 0.19 b	57.83 ± 0.48 a
G22	24.74 ± 0.12 fghi	27.13 ± 0.08 jklm	43.05 ± 1.53 hij	31.64 ± 0.12 jkl
G23	15.55 ± 0.29 kl	30.35 ± 0.17 hijk	36.66 ± 0.35 kl	27.52 ± 0.29 lmn
G24	10.26 ± 0.15 mno	18.27 ± 0.06 n	31.11 ± 0.06 lm	19.88 ± 0.12 pq
G25	9.09 ± 0.05 no	37.32 ± 1.56 efg	50.00 ± 0.00 defg	32.13 ± 0.06 ijk
G26	19.87 ± 0.50 ijk	33.33±0.19 fghij	40.17 ± 0.06 jk	31.12 ± 0.06 klm
G27	28.75 ± 2.38 ef	38.66 ± 2.43 ef	41.42 ± 2.55 ijk	36.28 ± 1.55 hi
G28	12.87 ± 0.06 lmn	23.50 ± 0.20 lmn	44.15 ± 0.06 ghij	26.84 ± 0.46 mn

In columns, each mean is the average of three replications and means followed by the same letter (s) indicate the statistically similar with each other at 5% level of significance with Tukey's HSD. DAT: Days after transplanting; SE: Standard Error

exhibited the highest infestation (52.27%), statistically comparable to several other lines such as G21, G10, G2, and G7. Conversely, G9 displayed the lowest infestation (6.81%), statistically similar to several other lines including G25, G24, G1, G28, and G3. This trend persisted across mid and late fruiting stages, with infestation increasing as the plants progressed through growth stages. The order of fruit infestation trends across growth stages was consistently late fruiting stage > mid fruiting stage > early fruiting stage. Considering the mean fruit infestation, G2 exhibited the highest infestation (61.97%), statistically comparable to G21 at 57.83%, but significantly different from all other lines ($F_{27,54}$ = 198.67; $P<0.01$). Following this trend, G7, G17, G4, G10, and G16 displayed fruit infestation rates of 51.60%, 50.30%, 48.00%, 46.15%, and 45.58%, respectively. Conversely, G9 recorded the lowest mean infestation at 18.32%, statistically similar to G24 and G1, but significantly different from all other mutant lines. Additionally, G15, G3, G18, and G28 showed infestation rates of 23.73%, 24.93%, 25.05%, and 26.84%, respectively.

Screening of brinjal mutant line against shoot and fruit borer infestation

Based on the screening scale used, it becomes apparent that none of the tested mutant lines exhibited resistance to shoot infestation caused by the BSFB. Among these lines, only two, specifically G9 and G24, demonstrated a degree of tolerance to shoot infestation, as evidenced by overall mean infestation levels below 2.0%. However, when considering fruit infestation, none of the lines exhibited resistance or tolerance to BSFB infestation. Instead, ten lines, including G1, G3, G9, G14, G15, G18, G19, G23, G24, and G28, were classified as moderately tolerant, recording overall mean fruit infestation levels ranging between 16.0% and 30.0%. In contrast, regarding shoot infestation, three lines, namely G15, G18, and G28, were categorized as susceptible. The majority of the lines, totaling twenty-two, exhibited a highly susceptible reaction to shoot infestation. Similarly, concerning fruit infestation, the susceptible group consisted of twelve lines, namely G5, G6, G8, G11, G12, G13, G16, G20, G22, G25, G26, and G27, while six lines, specifically G2, G4, G7, G10, G17, and G21, exhibited highly susceptible reactions (Table 4).

Morphological traits of brinjal plant influencing BSFB infestation

Plant height: Significant variation in plant height was observed among brinjal mutant lines (Table 5). The tallest plants were observed in G21 (107.57 cm), which was statistically similar to G22 (106.72 cm) and G3 (98.58 cm), but significantly different from the other mutant lines ($F_{27,54} = 51.50$; $P<0.01$). The minimum height was recorded in G8 (52.57 cm). In terms of infestation, G21 had higher shoot (11.71%) and fruit (57.83%) infestations while G8 had lower shoot (7.68%) and fruit (31.55%) infestations. Correlation studies revealed significant positive correlations (r = 0.281) between shoot infestation and plant height, and fruit infestation and plant height (r = 0.329) at $p \leq 0.05$ (Fig. 1).

Primary branches: The highest number of primary branches was recorded in G1 (22.00), followed by G20 (21.33), while the fewest were in G17 (12.16). G1, with the most branches, had lower shoot (3.31%) and fruit (21.90%) infestation. In contrast, G17, with the least branches, had higher shoot (12.73%) and fruit (50.30%) infestation (Table 5). Correlation studies showed negative correlations with infestation rates (r = -0.179 for shoot, r = -0.204 for fruit; $p \leq 0.05$) (Fig. 1).

Leaf number: The maximum number of leaves per plant (304.33) was recorded in the G1 line, significantly different from other lines ($F_{27,54} = 750.86$; $P<0.01$). This was followed by G24 (228.33), G18 (218.67), G11 (209.33), and G20 (206.33). The lowest number of leaves (88.67) was observed in G4, which was statistically similar to G13 but significantly different from other mutant lines, followed by G12 (109.33), G2 (110.00), G17 (111.33), and G7 (115.33). It was noted that the G1 with the highest number of leaves, had lower shoot (3.31%) and fruit (21.90%) infestations, while G4 , with the lowest leaves, exhibited higher shoot (13.39%) and fruit (48.00%) infestations (Table 5). Correlation studies showed significant negative correlations between leaf number and both shoot infestation (r = -0.342) and fruit infestation (r = -0.322) at $p \leq 0.05$ (Fig. 1).

Leaf trichome density: The highest leaf trichome density (number per 10 mm^2) was observed in G15, with a mean density of 87.00 trichomes, significantly greater than all other lines studied ($F_{27,54} = 41.61$; $P<0.01$). This was followed by G9 (77.25), G1 (69.75), G12 (69.00), G24 (68.75), and G18 (67.50), respectively. Conversely, the lowest trichome density was recorded in mutant line G21, with 47.5 trichomes, which was statistically similar to G10 (48.25), G7 (48.50), G11 (48.75), G5 (50.00), G26 (50.50), and G27 (51.25) as shown in Table 5. Mutant line G15, with highest trichome density, exhibited lower shoot (4.89%) and fruit (24.93%) infestations. In contrast, G21, with the lowest trichome density, had higher shoot (11.71%) and fruit (57.83%) infestations. Correlation analyses revealed strong negative relationship between trichome density and both shoot (r = -0.505) and fruit infestations (r = -0.647) (Fig. 1).

Leaf spines: Leaf spines were present only in G9 and G15 mutant lines, with an average of 16.72 and 18.44 spines per leaf, respectively. These lines exhibited lower shoot infestations, with G9 at 1.28% and G15 at 4.89%, compared to lines without leaf spines (Table 5). A negative correlation (r = -0.428) was found between the presence of leaf spines and shoot infestation by BSFB (Fig. 1).

Diameter of shoot: The brinjal mutant line G2 exhibited the largest diameter shoot (5.13 mm), which was statistically similar to that of G21 (5.01 mm), G7 (4.95 mm), G13 (4.84 mm), G5 (4.84 mm), and G17 (4.83 mm). Conversely, the smallest shoot diameter was recorded in G24 (2.95 mm), which was statistically similar to that of G1 (3.13 mm), G18 (3.43 mm), and G28 (3.49 mm) (Table 6). Notably, the line G2, with the largest shoot diameter, had a high shoot infestation rate of 13.86%, while G24, with the smallest shoot diameter, had the lowest infestation rate of 1.11%. A strong positive correlation (r = 0.689) was observed between the shoot diameter and the percentage of shoot infestation (Fig. 1).

Days to first flowering and fruiting: The data on as presented in Table 6, revealed Significant differences were observed in days to first flowering and fruiting among the brinjal mutant lines (Table 5). The maximum days to first flowering were recorded in G4 (54.16 days), followed by G13 (52.83 days) and G2 (51.66 days) while G28 recorded the minimum (28.00 days), statistically similar to G24 (28.33 days). For days to first fruiting, G13 took the longest (62.50 days), statistically similiar to G5 (61.50 days), while G28 had the shortest (32.50 days), significantly different from G16 (36.16 days), G10 (35.83 days), G26 (34.66 days), and G27 (34.66 days). There was a strong positive correlation between fruit infestation and both days to first flowering (r = 0.503) and days to first fruiting (r = 0.448) (Fig. 1).

Morphological traits of brinjal fruit influencing bsfb infestation

Fruit length: The fruit length exhibited noteworthy variations among the brinjal mutant lines, with G3 recording the highest fruit length (150.16 mm), significantly differing from G22 (138.79 mm), G23 (133.37 mm), G28 (131.12 mm), G19 (125.98 mm),

Table 4. Screening of brinjal mutant lines for shoot and fruit borer infestation

Infested parts	Level of infestation (%)	Brinjal mutant line	Categories	Grade
Shoot	< 2.0	G9, G24	Tolerant	T
	2.1-3.0	No	Moderately Tolerant	MT
	3.1-5.0	G1, G15, G18, G28	Susceptible	S
	> 5.0	G2, G3, G4, G5, G6, G7, G8, G10, G11, G12, G13, G14, G16, G17, G19, G20, G21, G22, G23, G25, G26, G27	Highly Susceptible	HS
Fruits	1-15	No	Tolerant	T
	16-30	G1, G3, G9, G14, G15, G18, G19, G23, G24, G28	Moderately Tolerant	MT
	31-45	G5, G6, G8, G11, G12, G13, G16, G20, G22, G25, G26, G27	Susceptible	S
	Above 46	G2, G4, G7, G10, G17, G21	Highly Susceptible	HS

Table 5. Morphological traits of brinjal plants across mutant lines

Mutant line	Plant Height (cm)	No. of primary branch/plant	No. of leaves/plant	Leaf trichomes (density/10 mm^2)	Number of spines per leaf	Diameter of top shoot (mm)	Days to first flowering (DAT)	Days to first fruiting (DAT)
G1	70.53 ± 0.08 fgh	22.00 ± 0.19 a	304.33 ± 2.23 a	69.75 ± 1.30 bc	0.00 ± 0.00	3.13 ± 0.05 hi	42.00 ± 0.25 de	45.00±0.53fg
G2	84.17 ± 0.29 de	17.50 ± 0.29 cdefg	110.00 ± 5.22 m	56.25 ± 1.01 efg	0.00 ± 0.00	5.13 ± 0.23 a	51.66 ± 0.58 ab	54.66±0.12d
G3	98.58 ± 1.88 abc	18.50 ± 0.48 bcdef	117.67 ± 0.15 klm	67.25 ± 1.59 cd	0.00 ± 0.00	4.48 ± 0.25 abcde	35.00 ± 0.29 jkl	42.00±0.12hi
G4	76.63 ± 2.29 efg	13.00 ± 0.96 ijk	88.67 ± 0.23 n	53.00 ± 0.00 fgh	0.00 ± 0.00	4.64 ± 0.15 abcd	54.16 ± 0.06 a	59.66±0.17 bc
G5	56.73 ± 0.06 ijk	19.66 ± 0.58 abcde	171.00 ± 2.08 h	50.00±0.58 gh	0.00 ± 0.00	4.84 ± 0.09 abc	48.16 ± 1.73 c	61.50±0.25 ab
G6	60.55 ± 2.26 hijk	20.83 ± 1.25 abc	192.00 ± 0.51 fg	51.50 ± 1.44 fgh	0.00 ± 0.00	4.54 ± 0.06 abcde	37.67 ± 0.35 ghij	45.00±0.58 fg
G7	94.37 ± 1.37 bcd	12.33 ± 0.00 k	115.33 ± 2.86 lm	48.50 ± 0.29 gh	0.00 ± 0.00	4.95 ± 0.14 ab	49.33 ± 0.19 bc	59.50±0.10 c
G8	52.57 ± 1.02 k	18.16 ± 0.10 bcdef	185.00 ± 0.40 g	52.00 ± 0.29 fgh	0.00 ± 0.00	4.51 ± 0.06 abcde	37.83 ± 0.10 fghi	43.66±0.30 gh
G9	68.72 ± 4.40 fghi	19.00 ± 0.38 abcdef	127.67 ± 1.00 j	77.25 ± 3.03 b	25.22 ± 1.07	4.00 ± 0.07 defg	35.00 ± 0.58 jkl	38.00±0.50 klm
G10	63.22 ± 0.45 hijk	19.00 ± 0.58 abcdef	192.33 ± 0.19 fg	48.25 ± 0.43 gh	0.00 ± 0.00	4.43 ± 0.05 bcde	32.66 ± 0.08 lm	35.83±0.06 no
G11	65.38 ± 2.18 ghij	19.50 ± 1.06 abcde	209.33 ± 1.00 cd	48.75 ± 1.30 gh	0.00 ± 0.00	4.56 ± 0.09 abcde	33.00 ± 0.51 klm	37.50±1.15 lmn
G12	88.20 ± 3.43 cde	15.83 ± 0.48 fghij	109.33 ± 0.13 m	69.00 ± 3.18 bc	0.00 ± 0.00	4.26 ± 0.03 cdef	35.00 ± 0.00 jkl	41.00±0.00 ij
G13	87.55 ± 3.97 cde	13.50 ± 0.87 hijk	95.67 ± 0.12 n	61.75 ± 1.30 cde	0.00 ± 0.00	4.84 ± 0.03 abc	52.83 ± 0.15 a	62.50±0.10 a
G14	80.47 ± 2.94 ef	12.83 ± 0.87 jk	117.00 ± 1.00 lm	59.75 ± 1.88 def	0.00 ± 0.00	4.49 ± 0.14 abcde	36.00 ± 1.15 hij	41.17±0.52 ij
G15	58.00 ± 0.19 hijk	13.50 ± 0.48 hijk	147.67 ± 0.21 i	87.00 ± 4.62 a	27.11 ± 0.48	3.63 ± 0.04 fgh	38.33 ± 0.19 fgh	40.50±0.29 ij
G16	58.32 ± 1.55 hijk	20.16 ± 0.10 abcd	173.67 ± 0.25 h	52.25 ± 0.43 fgh	0.00 ± 0.00	4.36 ± 0.04 bcde	33.16 ± 0.06 klm	36.16±0.58 mno
G17	88.85 ± 2.61 cde	12.16 ± 1.25 k	111.33 ± 1.61 m	53.00 ± 0.00 fgh	0.00 ± 0.00	4.83 ± 0.07 abc	40.50 ± 0.05 ef	43.66±0.10 gh
G18	61.43 ± 1.10 hijk	16.33 ± 0.19 efghi	218.67 ± 0.35 bc	67.50 ± 1.44 cd	0.00 ± 0.00	3.43 ± 0.09 ghi	44.00 ± 1.00 d	47.00±0.25 e
G19	76.37 ± 4.83 efg	14.33 ± 0.19 ghijk	123.50 ± 0.42 jkl	59.75 ± 2.17 def	0.00 ± 0.00	4.48 ± 0.04 abcde	37.66 ± 0.30 ghij	40.70±0.35 ij
G20	67.42 ± 0.14 ghij	21.33 ± 0.00 ab	206.33 ± 0.11 cd	55.75 ± 2.74 efgh	0.00 ± 0.00	4.55 ± 0.13 abcde	35.50 ± 0.29 ijk	39.83±0.10 jk
G21	107.57 ± 0.21 a	16.83 ± 0.29 defgh	172.67 ± 0.55 h	47.50 ± 0.58 h	0.00 ± 0.00	5.01 ± 0.17 ab	40.33 ± 0.58 efg	46.00±0.58 f
G22	106.72 ± 0.93 ab	15.83 ± 0.29 fghij	150.33 ± 0.17 i	54.25 ± 2.17 efgh	0.00 ± 0.00	4.58 ± 0.14 abcd	36.33 ± 0.00 hij	45.67±0.00 ef
G23	88.62 ± 3.24 cde	13.83 ± 0.48 hijk	129.67 ± 0.25 j	61.75 ± 1.30 cde	0.00 ± 0.00	4.59 ± 0.10 abcd	35.16 ± 0.25 ijkl	39.67±0.25 jk
G24	59.48 ± 0.30 hijk	18.66 ± 0.19 abcdef	228.33 ± 1.53 b	68.75 ± 0.72 c	0.00 ± 0.00	2.95 ± 0.07 i	28.33 ± 0.58 no	38.17±0.58 kl
G25	60.40 ± 2.08 hijk	19.16 ± 0.29 abcdef	203.33 ± 0.08 de	53.50 ± 0.00 efgh	0.00 ± 0.00	4.42 ± 0.11 bcde	31.00 ± 0.20 mn	36.83±0.20 lmn
G26	55.18 ± 0.88 jk	19.16 ± 0.48 abcdef	198.67 ± 4.85 ef	50.50 ± 1.15 gh	0.00 ± 0.00	3.90 ± 0.07 efg	32.00 ± 0.06 m	34.67±0.06 o
G27	55.47 ± 0.38 jk	20.50 ± 0.87 abc	189.67 ± 4.56 fg	51.25 ± 0.43 gh	0.00 ± 0.00	4.36 ± 0.18 bcde	32.16 ± 0.12 m	34.66±0.12 o
G28	77.62 ± 3.72 efg	16.00 ± 0.77 fghij	122.00 ± 1.10 jkl	56.25 ± 1.30 efg	0.00 ± 0.00	3.49 ± 0.21 ghi	28.00 ± 0.29 o	32.50 ±0.29 p

In columns, each mean is the average of three replications and means followed by the same letter (s) indicate the statistically similar with each other at 5% level of significance with Tukey's HSD. ± SE: Standard Error

G14 (122.94 mm), G12 (112.41 mm), G2 (99.01 mm), and G17 (81.29 mm). Conversely, G24 demonstrated the lowest fruit length (38.00 mm), statistically similar to G1 but differing from G26 (Table 6). Correlation analysis revealed a weak negative correlation (r = -0.072) between fruit infestation by BSFB and fruit length (Fig. 1).

Fruit diameter: Significant variation was observed in fruit diameter among the brinjal mutant lines ($F_{27,54}$ = 189.47; P<0.01). G4 exhibited the highest fruit diameter (73.58 mm), similar to G13 (71.99 mm), G7 (69.91 mm), G21 (69.29 mm), G6 (68.56 mm), and G20 (67.89 mm) but differing from other lines. Conversely, G24 had the lowest fruit diameter (27.69 mm), similar to G18 (28.23 mm), G1 (29.43 mm), G23 (30.74 mm), G28 (31.01 mm), and G22 (32.53 mm). G4, with the highest fruit diameter, showed relatively higher fruit infestation (48.00%), whereas G24, with the lowest fruit diameter, exhibited lower fruit infestation (Table 6). Correlation analysis indicated a significant positive correlation (r = 0.631) between fruit infestation and fruit diameter (Fig. 1).

Fruit weight: Among the twenty-eight brinjal mutant lines, G6 displayed the maximum fruit weight (145.78 g), similar to G4 (141.17 g) but differing from G7 (122.22 g), G12 (114.67 g), G2 (112.78 g), G8 (112.78 g), G11 (109.72 g), and G13 (109.50 g). The minimum fruit weight was recorded

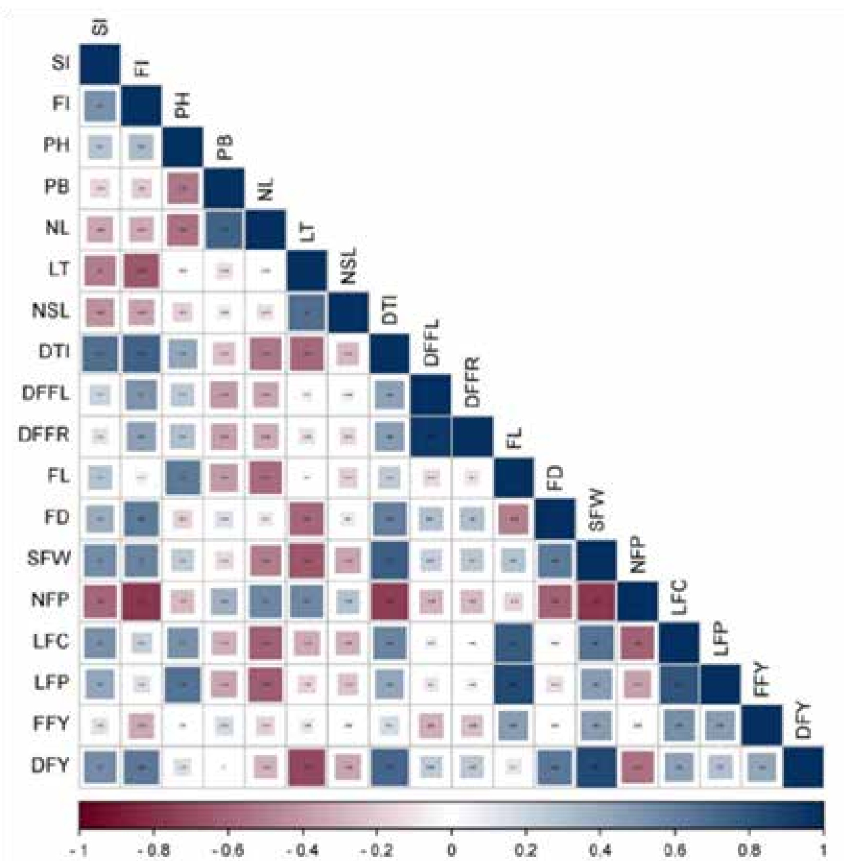

Fig. 1. Correlation matrix among the different variables of brinjal mutant lines. Correlation plots represent the order wise relationship corresponding to the color gradient between different variables. SI- Shoot infestation; FI- Fruit infestation; PH- Plant height; PB- Numbers of primary branch per plant; NL- Numbers of leaves per plant; LT- Leaf trichomes density; NSL- Number of spine per leaf; DTI- Diameter of top internode; DFFL- Days to first flowering; DFFR- Days to first fruiting; FL-Fruit length, FD- Fruit diameter; SFW- Single fruit weight; NFP- Numbers of fruits per plant; LFC- Length of fruit calyx; LFP- Length of fruit pedicel; FFY-Fresh Fruit yield; DFY-Damage fruit yield

in G24 (13.06 g), differing from G18 (19.50 g), G1 (21.56 g), G15 (43.50 g), and G9 (57.33 g). G6, with maximum fruit weight, showed relatively higher fruit infestation (36.31%), while G24, with minimum fruit weight, exhibited lower fruit infestation (Table 6). Correlation analysis revealed a significant positive correlation (r = 0.598) between fruit infestation and fruit weight (Fig. 1).

Number of fruits per plant: The number of fruits per plant exhibited significant variation among the brinjal mutant lines ($F_{27,54}$ = 26.37; P<0.01). G1 had the maximum number of fruits per plant (28.33), similar to G24 (27.33), G9 (24.00), and G18 (22.83) but differing from G3 (18.50), G19 (18.00), G22 (17.33), G15 (16.66), and G6 (16.33). Conversely, G2 displayed the minimum number of fruits per plant (8.00), similar to G21 (8.33), G12 (9.00), G13 (9.66), G7 (10.15), and G17 (10.50). G1, with the maximum number of fruits per plant, demonstrated lower fruit infestation (21.90%), whereas G2, with the minimum number of fruits per plant, exhibited higher fruit infestation (61.97%) (Table 6). Correlation analysis indicated a strong negative correlation (r = -0.766) between fruit infestation and the number of fruits per plant (Fig. 2).

Length of fruit calyx: Regarding the length of fruit calyx, G22 displayed the highest (40.55 mm), similar to G3 (39.31 mm), G12 (39.06 mm), G14 (38.00 mm), and G28 (37.13 mm), whereas G1 exhibited the lowest (13.45 mm), similar to G24 (13.76 mm) but differing from G9 (21.41 mm), G18 (21.50 mm), G15 (23.79 mm), and G17 (27.26 mm) (Table 6). The length of fruit calyx exhibited a positive but non-significant correlation (r = 0.227) with percent fruit infestation of brinjal mutant lines (Fig. 1).

Length of fruit pedicel: G3 had the highest length of fruit pedicel (64.84 mm), similar to G28 (55.50 mm) and G19 (54.79 mm) but differing significantly from G22 (49.29 mm), G12 (48.88 mm), G14 (48.53 mm), G21 (48.29 mm), and G23 (48.13 mm). Conversely, G18 displayed the lowest length of fruit pedicel (30.96 mm), similar to G24 (31.87 mm), G1 (32.62 mm), and G15 (35.90 mm) (Table 6). The length of fruit pedicel exhibited a positive correlation (r = 0.147) with percent fruit infestation of brinjal mutant lines (Fig. 1).

Qualitative traits: The evaluation of qualitative traits in 28 brinjal mutant lines, showed significant variation in fruit color, shape, curvature, and calyx spines (Fig. 2 and Table 7). Five distinct color groups were identified: white (six lines), green (five lines), purple (eleven lines), dark purple (two lines), and greenish purple (four lines). White fruits had the least BSFB damage(25.14%) while green fruits had the highest (53.94%), followed by greenish purple (29.2%), purple (34.9%), and dark purple (38.2%) (Fig. 3a). Six different fruit shapes were observed: oval (three lines), obovate (two lines), long (six lines), oblong (one line), round (five lines), and flattened (eleven lines). Oval fruits showed the least damage (22.28%) while obovate fruits displayed the highest susceptibility (56.14%), followed by round (39.9%), flattened (37.5%), oblong (35.4%), and long shapes (28.5%) (Fig. 1b).Only six lines (G3, G14, G19, G22, G23, and G28) exhibited curved fruits, which generally showed lower infestation compared to non-curved fruits. Additionally, two lines (G9 and G15) had spines on the calyx, which negatively affected the percentage of fruit infestation (Table 7).

Yield production

Significant variations were observed in fresh fruit yield, infested fruit yield, and total yield among mutant lines (Table 8). Notably, mutant line G6 exhibited The highest healthy fruit yield was recorded in line G6 at 15.21 t/ha, significantly higher than other lines. Conversely, the lowest healthy fruit yield was recorded from G24 line at 2.92 t/ha, which was statistically similar to G18, G21, G2, G1, and G17, but significantly lower than others ($F_{27,54}$ = 44.43; P<0.01). Regarding infested fruit yield, G6 also produced the highest yield at 8.84 t/ha, significantly different from other lines except for G4 at 7.40 t/ha. Conversely, the lowest infested fruit yield was observed in G24 at 0.67 t/ha, statistically similar to G18, G1, and G15, but significantly different from other lines ($F_{27,54}$ = 48.90; P<0.01). The total fruit yield was

Table 6. Quantitative morphological traits in brinjal fruits across mutant lines

Mutant line	Fruit length (mm)	Fruit diameter (mm)	Single fruit weight (g)	No. of fruits per plant	Length of fruit calyx (mm)	Length of fruit pedicel (mm)
G1	39.95 ± 0.96 n	29.42 ± 2.90 lm	21.56 ± 0.24 k	28.33 ± 0.19 a	13.45 ± 0.14 j	32.62 ± 0.42 jk
G2	99.01 ± 0.45 f	52.49 ± 1.59 gh	112.78 ± 1.85 c	8.00±0.28 j	30.67 ± 0.29 efgh	44.76 ± 0.20 cdef
G3	150.16 ± 0.32 a	38.15 ± 0.47 jk	89.61 ± 1.79 fg	18.50 ± 0.57 bcd	39.31 ± 0.85 ab	64.84 ± 0.52 a
G4	64.63 ± 0.59 ij	73.58 ± 1.57 a	141.17 ± 0.67 a	10.68 ± 0.94 ghij	28.44 ± 0.38 gh	43.09 ± 0.64 defg
G5	55.99 ± 1.14 klm	63.95 ± 0.85 cde	94.83 ± 0.35 f	13.00 ± 0.86 defghij	29.87 ± 0.57 efgh	38.10 ± 0.28 hi
G6	62.57 ± 0.22 ijk	68.56 ± 0.52 abc	145.78 ± 0.39 a	16.33 ± 1.55 defg	31.32 ± 0.32 efg	40.81 ± 0.47 fgh
G7	64.57 ± 1.87 ij	69.91 ± 1.05 abc	122.22 ± 0.97 b	10.15 ± 0.07 hij	28.55 ± 0.20 fgh	45.93 ± 0.23 cde
G8	60.86 ± 0.19 ijkl	66.44 ± 0.27 bcde	112.78 ± 0.49 c	11.83 ± 0.63 efghij	28.54 ± 0.26 gh	39.23 ± 0.99 ghi
G9	58.69 ± 2.81 jklm	50.81 ± 1.37 gh	57.33 ±0.25i	24.00 ± 0.57 ab	21.41 ± 0.57 i	38.73 ± 0.43 ghi
G10	58.24 ± 3.40 jklm	64.89 ± 1.36 cde	106.72 ± 1.15 de	13.33 ± 0.19 defghij	30.05 ± 0.47 efgh	41.39 ± 0.41 efgh
G11	73.95 ± 1.98 gh	61.11 ± 0.61 ef	109.72 ± 0.78 cd	14.83 ± 2.19 defgh	31.60 ± 0.92 efg	42.84 ± 0.92 defg
G12	112.41±0.40 e	47.02 ± 0.55 hi	114.67 ± 1.25 c	9.00 ± 1.44 ij	39.06 ± 0.79 ab	48.88 ± 1.79 c
G13	53.80±0.09 lm	71.99 ± 0.16 ab	109.50 ± 0.19 cd	9.66 ± 0.80 hij	32.79 ± 0.20 de	41.66 ± 0.43 efgh
G14	122.94 ± 1.43 d	35.07 ± 0.60 kl	85.33 ± 0.50 gh	13.00 ± 0.57 defghij	38.00 ± 0.13 a-c	48.53 ± 1.14 c
G15	51.68 ± 0.99 m	44.22 ± 1.94 ij	43.50 ± 0.25 j	16.66 ± 0.34 def	23.79 ± 0.30 i	35.90 ± 1.54 ij
G16	54.10 ± 1.17 lm	64.63 ± 0.45 cde	91.78 ± 0.89 f	11.50 ± 0.86 fghij	28.91± 0.29 fgh	39.25 ± 0.36 ghi
G17	81.29 ± 2.25 g	55.79 ± 0.95 fg	93.67 ± 0.59 f	10.50 ± 0.28 hij	27.26 ± 0.59 h	47.15±0.84 cd
G18	51.52 ± 0.99 m	28.23 ± 0.49 m	19.50 ± 0.79 k	22.83 ± 2.36 abc	21.50 ± 0.85 i	30.96 ± 0.59 k
G19	125.98 ± 1.34 cd	41.91 ± 1.93 ij	94.56 ± 2.04 f	18.00 ± 1.15 cd	35.25 ± 0.81 cd	54.79 ± 0.22 b
G20	56.35 ± 0.29 klm	67.89 ± 0.29 abcd	103.50 ± 0.33 e	14.86 ± 0.51 defgh	30.43 ± 1.10 efgh	41.04 ± 1.71 fgh
G21	66.73 ± 0.81 hi	69.29 ± 0.25 abc	90.89 ± 2.02 f	8.33 ± 0.19 j	31.98 ± 0.21 def	48.29 ± 0.63 c
G22	138.79 ± 0.86 b	32.53 ± 1.01 klm	102.17 ± 0.10 e	17.33 ± 0.71cde	40.55± 0.97 a	49.29 ± 1.46 c
G23	133.37 ± 1.47 bc	30.73 ± 1.43 lm	91.94 ± 1.40 f	15.16 ± 2.82 defgh	36.40 ± 0.93 bc	48.13 ± 0.67 c
G24	38.00 ± 0.98 n	27.69 ± 0.49 m	13.06 ± 0.97 l	27.33 ± 0.11a	13.76 ± 1.04 j	31.87 ±1.29 jk
G25	51.73 ± 0.93 m	61.88 ± 1.46 def	82.50 ±0.58 h	13.33 ± 0.17 defghij	30.31 ± 0.10 efgh	39.49 ± 0.18 ghi
G26	51.29 ± 0.34 m	64.68 ± 0.82 cde	94.61 ± 0.06 f	12.83 ± 1.15 defghij	29.01 ± 0.23 fgh	40.41 ± 0.05 fghi
G27	51.87 ± 0.73 m	66.34 ± 0.26 bcde	92.44 ± 0.24 f	14.66 ± 0.75 defghi	27.41 ± 0.84 h	40.43 ± 0.42 fghi
G28	131.12 ± 1.08 c	31.01 ± 1.46 lm	103.78 ± 0.40 e	12.00 ± 1.15 efghij	37.13 ± 0.08 abc	55.50 ± 0.61 b

In columns, means followed by the same letter (s) indicate that they are statistically similar to each other at the 5% level of significance with Tukey's HSD. ± SE: Standard Error highest in G6 at 24.05 t/ha, significantly different from other lines, followed by G22, G19, G3, G11, and G20 ($F_{27,54}$ = 19.21; P<0.01). Conversely, the lowest total fruit yield was recorded in G24 at 3.60 t/ha, statistically similar to G18, G1, G15, and G21. Correlation analysis revealed fresh fruit yield was positively correlated with fruit length, single fruit weight, length of fruit calyx, and length of fruit pedicel, but negatively correlated with fruit infestation. Damaged fruit yield exhibited a strong positive relationship with shoot and fruit infestation, diameter of the shoot and fruit, single fruit weight, and calyx length, but a negative correlation with leaf trichome density and spines per leaf (Fig 1).

Discussion

The study explored the screening of various brinjal mutant lines against the brinjal shoot and fruit borer (BSFB) across multiple morphological characteristics. Among the 28 evaluated mutant lines, none showed complete resistance to BSFB infestation in either shoots or fruits. However, two lines (G9 and G24) demonstrated notable tolerance to shoot infestation, while three were categorized as susceptible and 22 as highly susceptible. Regarding fruit infestation, ten lines (G1, G3, G9, G14, G15, G18, G19, G23, G24, and G28) exhibited moderate tolerance, 12 were susceptible, and six were highly susceptible. Infestation levels for shoots followed the sequence: mid-fruiting stage > late fruiting stage > early fruiting stage > vegetative stage, whereas fruit infestation consistently increased from the early to the late fruiting stage. These patterns align with previous studies showing higher BSFB infestation during periods of vigorous vegetative growth and fruiting (Mannan et al., 2015; Naik et al., 2008; Sultana et al., 2018).

In case of quantitative plant traits, a positive correlation was observed between shoot infestation and both plant height and top shoot diameter, while negative correlations were noted with the number of primary branches, leaf count, leaf trichome density, and spine

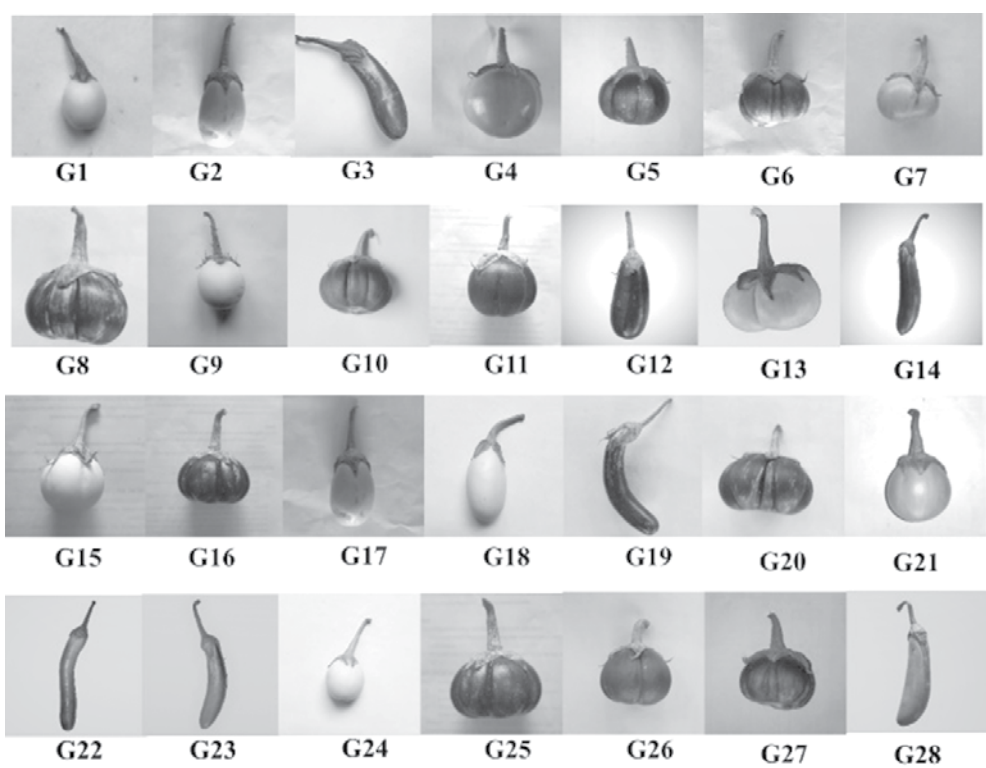

Fig. 2. Qualitative morphological traits of brinjal fruit among the different mutant line

Table 7. Qualitative morphological traits in brinjal fruits across mutant lines

Mutant line	Fruit color	Fruit Shape	Fruit curvature	Calyx spine
G1	White	Oval	No	No
G2	Green	Obovate	No	No
G3	Purple	Long	Curved	No
G4	Green	Round	No	No
G5	Purple	Flattened	No	No
G6	Purple	Flattened	No	No
G7	Green	Round	No	No
G8	Purple	Flattened	No	No
G9	White	Round	No	Yes
G10	Purple	Flattened	No	No
G11	Dark Purple	Flattened	No	No
G12	Dark Purple	Oblong	No	No
G13	White	Flattened	No	No
G14	Greenish purple	Long	Curved	No
G15	White	Round	No	Yes
G16	Purple	Flattened	No	No
G17	Green	Obovate	No	No
G18	White	Oval	No	No
G19	Purple	Long	Curved	No
G20	Purple	Flattened	No	No
G21	Green	Round	No	No
G22	Greenish purple	Long	Curved	No
G23	Greenish purple	Long	Curved	No
G24	White	Oval	No	No
G25	Purple	Flattened	No	No
G26	Purple	Flattened	No	No
G27	Purple	Flattened	No	No
G28	Greenish purple	Long	Curved	No

density. These findings are consistent with previous studies suggesting that thicker shoots facilitate larval movement and growth, making them more susceptible to BSFB attacks (Javed et al., 2011; Niranjana et al., 2016; Shubham et al., 2017). Leaf trichomes and spines seem to act as physical barriers, deterring newly hatched larvae from reaching boring sites, a defensive mechanism supported by other studies (Wagh et al., 2012; Niranjana et al., 2016; Mitchell et al., 2016; Shubham et al., 2017).Fruit infestation showed strong positive correlations with plant height, fruit diameter, weight, and the number of days to first flowering and fruiting, while negatively correlating with the number of primary branches, fruit count, fruit length, leaf count, and leaf trichome density. These observations align with previous findings (Wagh et al., 2012; Begum et al., 2013; Amin et al., 2014; Devi et al., 2016; Shubham et al., 2017; Sowmya and Pradeep, 2020).

Qualitative fruit characteristics also play a crucial role in breeding for resistance. The study found significant variation among the brinjal mutant lines in terms of fruit color, shape, curvature, and calyx spines. Green fruit color showed the highest infestation rate, followed

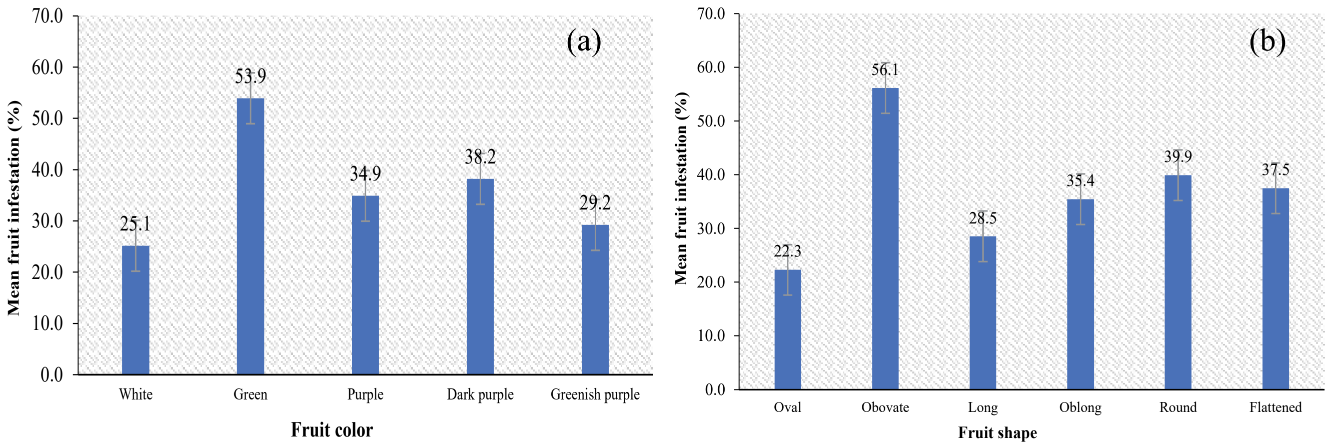

Fig. 3. Effect of (a) fruit color and (b) fruit shape on mean fruit infestation (%) of brinjal mutant lines

by dark purple, purple, greenish purple, and white. This finding contrasts with some previous studies that associated green fruit color with resistance and purple with susceptibility to BSFB (Jat and Parrek, 2003; Wagh et al., 2012; Dar et al., 2014; Prasad et al., 2014; Nagappan and Vethamoni, 2016), suggesting other morphological and biochemical traits may also influence susceptibility. Regarding fruit shape, oval-shaped fruits were least preferred by borers, while obovate fruits showed the highest susceptibility, followed by round, flattened, oblong, and long shapes. This supports findings from other studies indicating oval, thin, and elongated fruits are more resistant to BSFB, whereas round fruits are more susceptible (Payal et al., 2015; Shaukat et al., 2020). Curved fruits generally exhibited lower infestation compared to non-curved fruits, and spines on the calyx had a negative effect on fruit infestation rates. Yield varied significantly among the mutant lines, with G6 exhibiting the highest yield and G24 the lowest. Fresh fruit yield showed positive correlations with fruit length, single fruit weight, length of the fruit calyx, and length of the fruit pedicel, while a negative correlation was observed with fruit infestation. Damaged fruit yield had strong positive correlations with shoot and fruit infestation and negative correlations with leaf trichome density and spine density per leaf.

Based on these findings, the brinjal mutant lines G1, G3, G9, G14, G15, G18, G19, G23, G24, and G28, which exhibit moderate tolerance to shoot and fruit borer, are recommended for further breeding evaluation. This evaluation will focus on elucidating their tolerance mechanisms, considering both morphological traits and biochemical processes, despite their relatively lower yields.

Conclusion

The study evaluated 28 brinjal mutant lines for resistance to the Brinjal Shoot and Fruit Borer (BSFB), focusing on morphological traits. None of the lines exhibited complete resistance, but G9 and G24 demonstrated significant tolerance to shoot infestation, while lines G1, G3, G9, G14, G15, G18, G19, G23, G24, and G28 exhibited moderate tolerance to fruit infestation. The study identified key morphological traits associated with BSFB tolernace included shorter plant height, more branches and leaves, higher trichome density, leaf spines, and shorter flowering and fruiting periods. Resistant fruit traits as also included smaller size, lighter weight, and specific color and shape. These findings are crucial for breeding BSFB-resistant varieties to improve yield and reduce pest damage. Future research should focus on understanding the genetic basis of these traits..

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Table 8. The yield of brinjal mutant lines during November 2020 to May 2021

Mutant line	Fruit yield (ton/ha) ± SE		
	Healthy fruit	Infested fruit	Total
G1	4.82 ± 0.23 jklm	1.34 ± 0.21 lm	6.16 ± 0.07 ijk
G2	3.42 ± 0.36 klm	5.69 ± 0.09 cdef	9.11 ± 0.43 ghij
G3	12.54 ± 0.77 b	4.22 ± 0.08 fghij	16.76 ± 0.86 bc
G4	7.84 ± 0.41defghi	7.40 ± 1.75 ab	15.24 ± 1.35 bcdef
G5	7.61 ± 0.66 efghi	4.78 ± 0.16 fghi	12.45 ± 0.82 bcdefgh
G6	15.2 ± 0.31 a	8.84 ± 2.03 a	24.05 ± 2.34 a
G7	5.99 ±0.64 ghijk	6.53 ± 0.63 bcd	12.52 ± 0.01 bcdefgh
G8	9.68 ± 0.35 cdef	3.79 ± 0.40 hijk	13.48 ± 0.75 bcdefg
G9	11.37 ± 1.29 bc	2.51 ± 0.23 kl	13.90 ± 0.39 bcdefg
G10	8.08 ± 0.61 defghi	6.28 ± 0.44 bcde	14.37 ± 0.23 bcdefg
G11	9.61 ±1.33 cdef	6.83 ± 0.17 bc	16.41 ± 2.33 bcd
G12	8.11 ± 0.34 defghi	3.47 ± 0.10 ijk	10.45 ± 1.76 efghi
G13	6.45 ± 0.20 ghij	4.24 ± 0.71 fghij	10.69 ± 0.90 efghi
G14	7.76 ± 0.59 efghi	3.44 ± 0.03 ijk	11.20 ± 0.55 defghi
G15	5.71 ± 0.25 hijkl	1.61 ± 0.41 lm	7.32 ± 0.17 hijk
G16	5.56 ± 0.36 ijkl	5.09 ± 0.48 defgh	10.65 ± 0.81 efghi
G17	4.88 ± 0.08 jklm	5.07 ± 0.27 defgh	9.93 ± 0.22 fghij
G18	3.33 ± 0.46 lm	1.14 ± 0.06 lm	4.50 ± 0.53 jk
G19	12.24 ± 0.55 bc	5.00 ± 0.78 efgh	17.21 ± 1.38 bc
G20	10.45 ± 0.09 bcd	5.08 ± 0.58 defgh	15.53 ± 0.49 bcde
G21	3.36 ± 0.11 klm	4.28 ± 0.18 fghij	7.65 ± 0.29 hijk
G22	12.55 ± 0.11 b	5.33 ± 0.64 defg	17.88 ± 0.74 b
G23	10.04 ± 0.34 bcde	4.14 ± 0.09 ghij	14.02 ± 2.44 bcdefg
G24	2.92 ± 0.24 m	0.67 ± 0.06 m	3.60 ± 0.26 k
G25	7.22 ± 0.24 fghij	3.99 ± 0.07 ghijk	11.11 ± 0.19 defghi
G26	8.28 ± 0.37 defgh	3.98 ± 0.74 ghijk	12.26 ± 1.11 cdefgh
G27	8.56 ± 0.56 defg	5.13 ± 0.18 defgh	13.69 ± 0.74 bcdefg
G28	10.48 ± 0.96 bcd	3.14 ± 0.37 jk	12.57 ± 1.20 bcdefgh

In columns, means followed by the same letter (s) indicate the statistically similar with each other at 5% level of significance with Tukey's HSD. SE: Standard Error

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Conflict of interest

The authors declare no competing interests.

Author contributions

MAH and MH developed the experimental design and conceptual framework. PD carried out the experimental procedures and collected the resulting data. MMR, MAH, and AH performed the data analysis and interpreted the results. MMR was responsible for drafting the original manuscript. MGR and AH provided oversight, technical guidance, and editorial support throughout the study. All authors reviewed and approved the final manuscript.

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