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Identification of Resistant Genotypes against Stem Fly, *Melanagromyza sojae* (Zehntner) in Soybean

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Abstract

Background: Soybean, *Glycine max* has gained paramount importance in the agriculture of this country. Contribution of soybean in the oilseed basket of the world has been maximum. In India, of late, the cultivation and utilization of soybean has picked up rapidly. Insect infestation is considered to be the single largest impediment among several abiotic and biotic factors. Among them, stem fly, *Melanagromyza sojae* (Zehnter) is the number one pest of soybean in southern India causing infestation up to a level of 75 to 90 per cent. Hence, the study was carried out to identify the potential donar of resistance in soybean to stem fly.

Methods: The trial was carried out at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka in randomized block design (RBD) with two replications during *kharif* 2022 and 2023. Twenty-one soybean genotypes were screened against stem fly, *M. sojae* with one check variety JS 335 under *in-vivo* condition. Observation on seedling mortality was recorded at weekly intervals up to 30 days after germination. Stem fly incidence and stem tunneling due to stem fly at flowering and harvesting stage were recorded and percentage was worked out.

Result: The pooled data of two years concluded that, the soybean genotypes DSb 34, DLSb 1, KDS 1096 and NRC 197 could be found under resistant genotype, while DLSb 3, JS 23-09, MAUS 795, NRC 195, NRC 196 and MAUS 791 as moderately resistant. JS 23-03, JS 335, VLS 102, DSb 21, RSC 11-42 and RVS 13-20 were categorized as low resistant genotypes as against SL 1282, RSC 11-35 and PS 1682 as susceptible and CAUMS-2 and AS 24 genotypes as highly susceptible irrespective of the crop growth stages.

Key words: Genotypes, Resistance, Soybean, Stem fly.

Introduction

Soybean [*Glycine max* (L.) Merrill], a vital leguminous crop native to East Asia, plays a pivotal role in global agriculture and food production. Its economic significance derived from its multifaceted uses, particularly as a source of protein (40%) and oil (20%) for human and livestock consumption and as a versatile raw material in various industries. In addition, it contains good amount of minerals, salts and vitamins hence it is known as a 'Wonder crop'. In India, it plays a crucial role for small and marginal farmers and ranks fifth globally with 11.85 million hectares area, 11.87 million tonnes of production and 1002 kg/ha productivity (Anonymous, 2023).

However, soybean was susceptible to a wide range of insect pests that have the potential to cause substantial damage. Insect infestation is considered to be the single largest impediment among several abiotic and biotic factors in decreasing the productivity of soybean (Arangba Mangang *et al*., 2017). Various insect feeds on soybean crop from germination to harvesting stage with an average yield loss of 20 to 25 per cent due to insect pests (Ramesh Babu *et al*., 2017). Among them, Stem fly, *Melanagromyza sojae* (Zehntner) (Diptera: Agromyzidae) has emerged as a major pest in the soybean cultivating regions of India. The stem fly lays its eggs on underside of young leaves. Once hatched, the maggot mines through the leaf, moves down the petiole and enters the stem, creating upward and downward tunnels by consuming the pith and forming reddish-colored tunnel that shows the affected plant's appearance. Before transitioning to the pupal stage within the stem, the maggot creates an exit hole for the adult emergence through the stem's vascular tissues, disrupting growth and diminishing crop yield (Nayaka, 2013). Host plant resistance plays a key role in formulating integrated pest management systems, especially in low input farming conditions. It is the least expensive and easily adoptable by small, marginal and illiterate farmers. The availability of reliable and promising donors of resistance is fundamental to any breeding programme aimed at evolving high yielding cultivars endowed with resistance to key insect pests. Though, considerable efforts have been made to identify potential donors of resistance in soybean to stem fly, information regarding promising resistant sources of

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germplasm is inadequate. Parallel to the activities of screening and breeding programme, efforts to identify the mechanisms of resistance against insect pests are essential (Kogan and Turnipseed, 1987; Singh *et al*., 1990; Sagar and Dhal, 2018).

Promoting the use of pest-resistant varieties is a critical step in sustainable agriculture as it reduces the reliance on harmful chemicals and contributes to a healthier environment. Additionally, these resistant varieties can help to mitigate yield losses caused by insect pests, ensuring a more stable and productive soybean crop (Purwantoro *et al*., 2023). A perusal of existing literature in this direction revealed that in India very little work has been done so far on these aspects particularly the basis of resistance to major pests of soybean. Hence, field screening efforts were undertaken to identify potential resistant genotypes against *M. Sojae* under *in-vivo* conditions.

MATERIALS AND METHODS

The field experiment was carried out at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka during *kharif* 2022 and 2023. Dharwad is located at 15°17′ North latitude and 70°05′ East longitude with an altitude of 678 m above the mean sea level (MSL). It is located at Zone-8 *i.e.* Northern transitional zone and receives an annual rainfall of 800 to 1000 mm distributed throughout the growing season.

Twenty-one soybean genotypes obtained from Indian Institute of Soybean Research (IISR), Indore and All India Co-ordinated Research Project on Soybean, UAS, Dharwad centre were evaluated in the field to find out the genotype resistant to stem fly, *M. sojae*. Each of the soybean genotype by sowing in three rows of 5 m length with a spacing of 30 cm × 10 cm and JS 335 (Susceptible check) was sown after every five entries. The trial was conducted in randomized block design (RBD) with three replications. The crop was raised as per the package of practices, except for plant protection measures against stem fly.

Observations on seedling mortality were recorded at weekly intervals up to 30 days after germination by enumerating the number of plants dead to total number of sampling plants. Stem fly incidence and stem tunneling due to stem fly at the flowering and harvesting stage was calculated by recording the number of plants showing stem fly infestation to the total number of plants to arrive per cent stem fly infestation. Randomly selected five plants in each genotype were uprooted and split opened the stem vertically to measure the actual length of the tunnel caused by the maggot to compute per cent stem tunneling.

The genotypes were categorized into different groups *viz*., highly resistant, resistant, moderately resistant, low resistant, susceptible and highly susceptible based on All India Co-ordinated Research Project on Soybean, AICRP method of classification by considering the mean and critical difference (C.D.) of per cent seedling mortality, stem fly infestation and stem tunneling (Anonymous, 2017).

Seedling mortality, Stem fly infestation and stem tunneling were arrived by using following formula.

Seedling mortality (%) =

$$\frac{\text{Number of plants dead}}{\text{Total number of observed plants}} \times 100$$

Stem fly infestation (%) =

$$\frac{\text{Number of plants infested}}{\text{Total number of observed plants}} \times 100$$

$$\text{Stem tunneling (\%)} = \frac{\text{Length of the tunnel}}{\text{Total length of the stem}} \times 100$$

Biophysical parameters

Randomly selected five plants in each genotype were taken for studying the morphological factors governing resistance like stem thickness (mm), internodal length (mm), leaf thickness (mm), leaf trichome density (No. per 0.25 cm^2) and trichome colour during flowering stage (45 DAS) of the crop.

Scales of measurement of resistance in soybean against stem fly (Anonymous, 2017)

Highly resistant (HR)	:	Values < mean - CD at 1%.
Resistant (R)	:	Value between mean - CD at 1% and mean - CD at 5%.
Moderately resistant (MR)	:	Value between mean - CD at 5% and mean.
Low resistant (LR):		Value between mean and mean + CD at 5%.
Susceptible (S):		Value between mean + CD at 5% and mean + CD at 1%.
Highly susceptible (HS)	:	Values > mean + CD at 1%.

RESULTS AND DISCUSSION

Seedling mortality due to stem fly

Seedling mortality refers to the abrupt withering and death of the plant due to severe attack of stem fly at the seedling stages of the crop whereas, infestation is the condition where the crop is invaded by pest, which does not lead to an immediate drying or wilting of the plants. Instead, the infestation persists, affecting all branches and manifesting as marginal leaf drying in the latter phases of crop development. After the infestation, stem fly maggot enters the main stem through the petiole and bores the stem downwards by feeding the cortical region of the stem damaging the vascular system of the plant where tunneling was noticed.

Of the seedling mortality was recorded at 7, 15, 21 and 30 days after germination (DAG) interestingly, no incidence of stem fly damage was observed at 7 DAG. These findings align with the results reported by Kundu and Srivastava (1991), who noted that stem fly infestation typically begins between the 3^{rd} and 10^{th} week after sowing. However, there was a significant difference found among different genotypes concerning seedling mortality at both 15 and 30

DAG. The mean seedling mortality of different genotypes screened for their relative resistance against stem fly recorded from 15 DAG to 30 DAG ranged from 2.53 and 8.89 per cent. DSb 34 (2.53%) and DLSb 1 (2.57%) had significantly the lowest mean seedling mortality as compared to other genotypes up to 30 DAG and found to be resistant. The genotypes DLSb 3, JS 23-09, MAUS 795, NRC 195, NRC 196 and MAUS 791 possessing the least mean seedling mortality being statistically on par with each other fell under moderately resistant category. The check entry, JS-335 suffered 5.62 mean per cent seedling mortality which was on par with VLS 102, DSb 21, RSC 11-42 and RVS 13-20. However, the maximum mean per cent seedling mortality of 8.45 and 8.89 per cent observed in CAUMS-2 and AS 24, respectively were naturally grouped as highly susceptible to stem fly attack (Table 1). The findings are in line with the findings of Kavita (2006) who identified NRC-55, NRC-51, NRC-52 and DSb-101 as having the lowest seedling mortality.

Flowering stage

Stem fly infestation at the flowering stage varied between 10.64 and 31.39 per cent. The genotypes DSb 34 (10.64%), DLSb 1 (10.65%), KDS 1096 (11.12%) and NRC 197 (11.26%) exhibited the lowest infestation and were significantly better than the other genotypes. Conversely, genotypes CAUMS-2 (30.95%) and AS 24 (31.39%) had the highest infestation and were comparable to each other (Table 2). The genotypes DLSb 3 (14.44%), JS 23-09 (15.00%), MAUS 795 (15.48%), NRC 195 (15.57%), NRC 196 (16.05%) and MAUS 791 (16.11%) displayed relatively lower percentage of stem fly infestation, indicating moderate resistance to *M. sojae*. The check entry JS 335 had 19.25 per cent stem fly infestation, comparable to JS 23-03 (19.35%), VLS 102 (21.18%), DSb 21 (21.35%), RSC 11-42 (21.46%) and RVS 13-20 (21.73%) which were statistically on par with each other.

The stem tunneling caused by stem fly during flowering stage varied among the screened genotypes, ranging from 7.86 to 26.43 per cent. DSb 34 suffered the lowest stem tunneling of 7.86 per cent, which was statistically comparable to DLSb 1 (7.86%), KDS 1096 (8.05%) and NRC 197 (8.52%). The genotypes SL 1282 (21.29 %), RSC 11-35 (22.70%) and PS 1682 (26.33%) had statistically similar stem tunneling rates and making them inferior to other genotypes in terms of resistance. The highest stem tunneling was observed in CAUMS-2 (25.83%) and AS 24 (26.43%) which was statistically on par with each other (Table 2).

Pod formation stage

The stem fly infestation ranged from 17.52 to 36.84 per cent. The least stem fly infestation of 17.52 per cent

Table 1: Reaction of soybean genotypes on seedling mortality due to stem fly (Mean of two years).

Genotypes	15 DAG	21 DAG	30 DAG	Mean	Reaction
AS 24	6.58 (14.82)^{e}	8.59 (17.04)^{f}	11.49 (19.81)^{ef}	8.89^{ef}	HS
CAUMS-2	5.58 (13.54)^{de}	8.49 (16.84)^{f}	11.27 (19.57)^{ef}	8.45^{def}	HS
DLSb 1	1.35 (6.67)^{a}	2.56 (9.19)^{a}	3.81 (11.25)^{a}	2.57^{a}	R
DLSb 3	2.15 (8.43)^{b}	3.56 (10.88)^{bc}	5.60 (13.69)^{bc}	3.77^{bc}	MR
DSb 21	3.62 (10.81)^{bc}	5.56 (13.60)^{cd}	8.34 (16.73)^{cd}	5.84^{cd}	LR
DSb 34	1.30 (6.55)^{a}	2.54 (9.17)^{a}	3.76 (11.16)^{a}	2.53^{a}	R
JS 23-03	3.65 (11.01)^{bc}	5.33 (13.34)^{cd}	7.80 (16.11)^{cd}	5.59^{cd}	LR
JS 23-09	2.15 (8.42)^{b}	3.61 (10.91)^{bc}	5.89 (14.05)^{bc}	3.88^{bc}	MR
JS 335 (SC)	3.40 (10.62)^{bc}	5.35 (13.36)^{cd}	8.12 (16.55)^{cd}	5.62^{cd}	LR
KDS 1096	1.55 (7.15)^{a}	2.79 (9.62)^{ab}	4.06 (11.58)^{ab}	2.80^{ab}	R
MAUS 791	2.56 (9.19)^{b}	4.56 (12.31)^{bcd}	6.67 (14.96)^{bcd}	4.59^{bcd}	MR
MAUS 795	2.35 (8.82)^{b}	3.75 (11.15)^{bc}	6.29 (14.50)^{bc}	4.13^{bc}	MR
NRC 195	2.38 (8.87)^{b}	4.08 (11.65)^{bc}	6.33 (14.57)^{bc}	4.26^{bc}	MR
NRC 196	2.50 (9.08)^{b}	4.40 (11.98)^{bcd}	6.58 (14.84)^{bc}	4.50^{bc}	MR
NRC 197	1.57 (7.18)^{a}	2.83 (9.68)^{ab}	4.40 (12.10)^{ab}	2.93^{ab}	R
PS 1682	4.49 (12.23)^{cd}	7.43 (15.67)^{de}	10.56 (18.96)^{def}	7.49^{def}	S
RSC 11-35	4.89 (12.78)^{cd}	7.33 (15.71)^{de}	10.29 (18.71)^{de}	7.50^{de}	S
RSC 11-42	3.71 (11.08)^{bc}	5.59 (13.66)^{cde}	8.40 (16.83)^{cd}	5.90^{cde}	LR
RVS 13-20	3.80 (11.23)^{bc}	5.72 (13.84)^{cde}	8.52 (16.87)^{cd}	6.01^{cde}	LR
SL 1282	4.66 (12.28)^{cd}	7.26 (15.63)^{de}	10.32 (18.45)^{de}	7.41^{de}	S
VLS 102	3.45 (10.69)^{bc}	5.55 (13.56)^{cd}	8.24 (16.68)^{cd}	5.75^{bcd}	LR
S.Em. ±	0.724	0.93	1.18	-	-
C V (%)	10.34	10.46	10.89	-	-

DAG - Days after germination, SC- Susceptible check, HR- Highly resistant, R- Resistant, MR- Moderately resistant, LR- Low resistant, S- Susceptible, HS- Highly susceptible, Figures in parentheses are arc sine transformed values, Means in the columns followed by the same alphabet do not differ significantly by DMRT (P=0.05).

observed in the entry DSb 34 was similar to DLSb 1, KDS 1096 and NRC 197 with 18.25, 18.27 and 18.70 per cent stem fly infestation respectively; JS 335 (28.57%), JS 23-03 (28.56%), VLS 102 (28.76 %), DSb 21 (28.91%), RSC 11-42 (29.09%) and RVS 13-20 (29.53%) falling under less resistance. The maximum per cent stem fly infestation of 36.45 and 36.84 per cent were observed in the entries CAUMS-2 and AS 24, respectively (Table 2).

At the pod formation stage, the stem tunneling percentages in soybean genotypes ranged from 11.55 to 31.55 per cent. The genotype DSb 34 had the lowest stem tunneling at 11.55 per cent and was statistically on par with DLSb 1 (12.45%), KDS 1096 (12.74%) and NRC 197 (12.88%). In contrast, CAUMS-2 (30.17%) and AS 24 (31.55%) exhibiting higher stem tunneling rates indicated their susceptibility to stem fly infestation during this stage.

The present investigation findings on different genotypes reaction to stem fly incidence are consistent with earlier researcher reports. Three decades earlier, Singh *et al.* (1990) by their investigation at Ludhiana observed stem fly infestation at flowering stage (12.25 to 32.50%) and pod formation (19.00 to 49.50%) and classified DSb 23, DSb 1, DSb 12, DSb 15 and DSb 24 as resistant genotypes against stem fly. Recent findings of Nagendra (2019) and Bala Muralidhar Naik *et al* (2021) confirmed the stem tunneling was in the range 6.45 to 21.00 per cent at 30 DAG and in the range of 9.94 to 24.51 per cent at maturity. The check variety JS 335 recorded medium stem tunneling of 13.18 per cent at 30 DAG and 18.43 per cent at maturity stage. Taware *et al.* (2008) reported stem tunneling in the range of 6.55 to 35.53 per cent, with the check variety JS-335 showing 22.15 per cent. Jadhav (2012) observed lower stem tunneling in NRC-55 (13.31%), DSb-101 (14.36%), NRC-51 (14.57%) and NRC-52 (14.93%). Kanjarla *et al.* (2020) evaluated eight germplasms and identified Basara, JS-335, JS 93-05, DSb-2803 and KDS-756 as highly resistant, while KDS-869, MACS-1460 and RSC-1046 were highly susceptible to stem fly. Khandare *et al.* (2021) found that MACS-1340 and NRC-127 followed by RSC-1046 exhibited the minimum stem tunneling. Conversely, genotypes VLS-89, SL-1104 and PS-1572 comparatively were inferior in minimizing stem tunneling due to stem fly at harvest. These findings are in line with our findings.

Morphological characters

Studies on morphological characters of soybean genotypes showed significant negative correlation between stem fly

Table 2: Screening of soybean genotypes for stem fly resistance during different crop growth stages (Mean of two years).

Entries	Flowering stage		Pod formation stage		Reaction
	Stem fly infestation (%)	Stem tunneling (%)	Stem fly infestation (%)	Stem tunneling (%)	
AS 24	31.39 (34.05)^{e}	26.43 (30.92)^{f}	36.84 (37.37)^{fg}	31.55 (34.17)^{ef}	HS
CAUMS-2	30.95 (33.58)^{e}	25.83 (30.54)^{f}	36.45 (37.14)^{fg}	30.17 (33.32)^{ef}	HS
DLSb 1	10.65 (19.05)^{a}	7.86 (16.29)^{a}	18.25 (25.29)^{ab}	12.45 (20.65)^{ab}	R
DLSb 3	14.44 (22.33)^{b}	12.38 (20.60)^{b}	22.50 (28.30)^{bc}	16.19 (23.69)^{bc}	MR
DSb 21	21.35 (27.47)^{cd}	18.22 (25.24)^{cd}	28.91 (32.52)^{cde}	24.52 (29.68)^{d}	LR
DSb 34	10.64 (19.03)^{a}	7.86 (16.28)^{a}	17.52 (24.69)^{a}	11.55 (19.86)^{a}	R
JS 23-03	19.35 (26.02)^{cd}	16.68 (24.11)^{cd}	28.56 (32.30)^{cd}	23.28 (28.84)^{cd}	LR
JS 23-09	15.00 (22.79)^{b}	13.60 (21.60)^{b}	23.26 (28.83)^{bc}	16.60 (24.03)^{bc}	MR
JS 335 (SC)	19.25 (26.03)^{cd}	17.42 (24.66)^{cd}	28.57 (32.30)^{cd}	23.77 (28.96)^{cd}	LR
KDS 1096	11.12 (19.47)^{a}	8.05 (16.49)^{a}	18.27 (25.30)^{ab}	12.74 (20.91)^{ab}	R
MAUS 791	16.11 (23.65)^{bc}	14.76 (22.59)^{bc}	24.38 (29.59)^{c}	18.95 (25.80)^{bc}	MR
MAUS 795	15.48 (23.17)^{bc}	13.66 (21.69)^{b}	23.32 (28.86)^{bc}	17.16 (24.47)^{bc}	MR
NRC 195	15.57 (23.24)^{bc}	14.10 (22.06)^{bc}	23.38 (28.91)^{bc}	17.52 (24.74)^{bc}	MR
NRC 196	16.05 (23.60)^{bc}	14.76 (22.58)^{bc}	24.12 (29.41)^{c}	18.62 (25.56)^{bc}	MR
NRC 197	11.26 (19.61)^{a}	8.52 (16.93)^{ab}	18.70 (25.62)^{ab}	12.88 (21.01)^{ab}	R
PS 1682	26.33 (30.87)^{de}	23.57 (28.76)^{ef}	33.26 (35.22)^{ef}	27.86 (31.86)^{de}	S
RSC 11-35	25.87 (30.48)^{de}	22.70 (28.33)^{ef}	32.41 (34.70)^{ef}	27.76 (31.79)^{de}	S
RSC 11-42	21.46 (27.56)^{cd}	18.41 (25.39)^{cd}	29.09 (32.64)^{cde}	24.65 (29.75)^{d}	LR
RVS 13-20	21.73 (27.78)^{cd}	18.89 (25.73)^{cd}	29.53 (32.92)^{cde}	24.88 (29.92)^{d}	LR
SL 1282	25.51 (30.29)^{de}	21.29 (27.43)^{def}	32.66 (34.85)^{def}	27.11 (31.37)^{de}	S
VLS 102	21.18 (27.40)^{cd}	18.07 (25.15)^{cd}	28.76 (32.43)^{cd}	24.47 (29.64)^{cd}	LR
S.Em. ±	1.04	1.25	0.75	0.89	
C V (%)	9.74	10.06	10.17	10.43	

SC- Susceptible check, HR- Highly Resistant, R- Resistant, MR- Moderately resistant, LR- Low resistant, S- Susceptible, HS- Highly susceptible; Figures in parentheses are arc sine transformed values; Means in the columns followed by the same alphabet do not differ significantly by DMRT (P=0.05).

infestation and leaf thickness and stem fly infestation and stem thickness. However, a significant positive correlation existed with internodal length (Table 3).

Leaf thickness

A significant negative correlation was observed between stem fly (- 0.984) and leaf thickness. The leaf thickness of soybean genotypes ranged from 0.15 to 0.25 mm. Among the 21 assessed genotypes, DSb 34 (0.25 mm) and DLSb 1 (0.25 mm) exhibiting the maximum leaf thickness were found to be resistant to stem fly. On the other hand, the genotypes AS 24 (0.15 mm) and CAUMS-2 (0.16 mm) with minimum leaf thickness were found to be susceptible to stem fly.

Stem thickness

Soybean genotypes exhibited stem thickness ranging from 10.80 to 17.21 mm. Genotype DSb 34 had the highest stem thickness of 17.21 mm followed by DLSb 1 (17.00 mm), KDS 1096 (16.85 mm) and NRC 197 (16.54 mm) which were significantly superior to other entries. Conversely, genotype CAUMS-2 (11.20 mm) and AS 24 (10.80 mm) possessing lower stem thickness were significantly inferior to the rest of the genotypes indicating a significant negative correlation between stem thickness and stem fly infestation (-0.986).

Internodal length

Significant positive relationship was noted between internodal length and stem fly infestation (+ 0.996). The internodal length of various genotypes ranged from 15.52 to 19.60 mm. Among 21 genotypes assessed, AS 24 having higher intermodal length of 19.60 mm followed by PS 1682 (19.00 mm), RSC 11-35 (18.75 mm) and SL 1282 (18.60 mm) were found to be susceptible with the higher stem fly infestation as against DSb 34 (15.52 mm) with a lower internodal length compared to the rest of the genotypes was found to be resistant.

Trichome density

Leaf trichome density in different soybean genotypes ranged from 23 to 117 trichomes per 5 mm^2. The highest leaf trichome density was observed in DSb 34 and DLSb 1 genotypes (117 and 115 trichomes per 5 mm^2), whereas, the least trichome density was observed in CAUMS-2 and AS 24 (26 and 23 trichomes per 5 mm^2) exhibiting a significant negative correlation with the stem fly infestation (-0.953).

Table 3: Morphological characters of genotypes influencing stem fly infestation.

Entries	Stem fly infestation (%)	Leaf thickness (mm)	Stem thickness (mm)	Internodal length (mm)	Leaf trichome density (No. per 5 mm^2)	Trichome colour
AS24	8.89^{ef}	0.15	10.80	19.60	23	Grey
CAUMS-2	8.45^{def}	0.16	11.20	19.54	26	Tawny
DLSb1	2.57^{a}	0.25	17.00	15.54	115	Tawny
DLSb3	3.77^{bc}	0.22	15.83	16.50	97	Tawny
DSb 21	5.84^{cd}	0.19	13.30	17.62	55	Grey
DSb34	2.53^{a}	0.25	17.21	15.52	117	Grey
JS23-03	5.59^{cd}	0.20	13.60	17.32	76	Grey
JS23-09	3.88^{bc}	0.22	15.80	16.50	93	Grey
JS335(SC)	5.62^{cd}	0.20	13.50	17.50	74	Tawny
KDS1096	2.80^{ab}	0.23	16.85	15.60	114	Tawny
MAUS791	4.59^{bcd}	0.21	14.70	16.86	94	Tawny
MAUS795	4.13^{bc}	0.22	15.20	16.75	94	Grey
NRC195	4.26^{bc}	0.21	15.00	16.78	96	Tawny
NRC196	4.50^{bc}	0.21	14.85	16.85	93	Tawny
NRC197	2.93^{ab}	0.23	16.54	15.60	112	Tawny
PS 1682	7.49^{def}	0.17	12.60	19.00	42	Grey
RSC11-35	7.50^{de}	0.17	12.65	18.75	72	Grey
RSC11-42	5.90^{cde}	0.19	13.32	17.65	46	Grey
RVS13-20	6.01^{cde}	0.19	13.25	17.80	77	Grey
SL1282	7.41^{de}	0.18	12.80	18.60	48	Tawny
VLS102	5.75^{bcd}	0.20	13.35	17.52	75	Grey
S.Em. ±	0.80	-	-	-	-	-
C V (%)	10.65	-	-	-	-	-
Correlation coefficient (r)		-0.984**	-0.986**	+0.996**	-0.953**	

**Significance at 0.01 level, SC- Susceptible check.

Means in the columns followed by the same alphabet do not differ significantly by DMRT (P=0.05).

Table 4: Categorization of soybean genotypes for their relative resistance against stem fly (Mean of two years).

Category	Genotypes
Highly resistant (HR)	-
Resistant (R)	DSb 34, DLSb 1, KDS1096, NRC197
Moderately resistant (MR)	DLSb 3, JS23-09, MAUS 795, NRC 195, NRC 196, MAUS 791
Lower resistant (LR)	JS 23-03, JS 335, DSb 21, VLS 102, RSC 11-42, RVS 13-20
Susceptible (S)	SL 1282, RSC 11-35, PS 1682
Highly susceptible (HS)	CAUMS-2, AS 24

Trichome colour

Genotypes are classified based on trichome colour into two classes: grey and tawny. Tawny coloured trichomes are found in NRC 197, NRC 196, NRC 195, SL 1282, CAUMS-2, MAUS 791, KDS 1096, DLSb 3, DLSb 1 and JS 335; while grey coloured trichomes in JS 23-03, MAUS 795, PS 1682, RVS 13-20, RSC 11-42, AS 24, DSb 21, VLS 102, JS 23-09, DSb 34 and RSC 11-35.

The present investigation focuses on various morphological aspects related to leaf thickness, leaf trichome density, stem thickness and internodal length in soybean varieties playing a crucial role in offering resistance. Wherein a significant negative correlation between stem fly infestation and stem thickness (r=-0.986) and leaf thickness (r = -0.984) was evident. While a significant positive correlation with internodal length (r = 0.996). These findings corroborate with Jadhav (2012), who also reported a significant positive correlation with internodal length (r = 0.76) and a significant negative correlation with stem thickness (r = -0.53). Similarly, Singh *et al.* (1990) found a significant positive correlation with internodal length (r = 0.90) and a significant negative correlation with stem thickness (r = -0.89) supporting the present investigation's results.

The soybean with high leaf thickness and trichome offering resistance to stem fly may be through mechanical hindrance in imparting resistance for oviposition by the stem fly as well as it makes difficult for the maggot to enter the stem through mining the leaves and petiole as proposed by Chiang and Norris (1983) and Shete *et al.* (2019). These trichomes play a role in minimizing insect damage by limiting contact with the plant's surface and inhibiting either oviposition and/or larval growth. (Jayappa, 2000; Sridhar, 2000; Gupta *et al.* 2004).

Additionally, the internodal length was shorter in stem fly-resistant soybean varieties due to earlier differentiation of sclerenchyma (gelatinous fibres) in their stems. This physical hindrance is associated with reducing the stem fly's feeding area and resistant varieties have a narrower pith cavity enclosed by lignified xylem fibres, making it difficult for the larvae to feed and pupate. These findings are consistent with previous studies conducted by Jadhav (2012). As early as 1990, the role of stem anatomy playing role in soybean resistance was emphasized by Singh *et al.* (1990).

Levels of resistance to stem fly

The present study has indicated that, among different genotypes, DSb 34, DLSb 1, KDS 1096 and NRC 197 was found to be resistant to stem fly, whereas CAUMS-2 and AS 24 genotypes were found highly susceptible to the target insect (Table 4). However, further more correlation studies are required for resistant genotypes with biochemical constituents like phenols, tannins, anti-nutritional factors and phytohormone etc. which are present in the plant and are most important which impart resistance against stem fly attack by deterring the feeding of cortical region of the pith cavity of stem and protecting the vascular system of plant. In general, overall incidence was more and the majority of genotypes tested had shown moderately resistant and low resistant reaction against stem fly.

CONCLUSION

Among the 21 soybean genotypes screened for field resistance against stem fly, DSb 34, DLSb 1, KDS 1096 and NRC 197 had statistically lower stem fly infestation and stem tunneling compared to the other genotypes and found to be resistant. DLSb 3, JS 23-09, MAUS 795, NRC 195, NRC 196 and MAUS 791 exhibited a moderate level of resistance. On the other hand, JS 23-03, JS 335, VLS 102, DSb 21, RSC 11-42 and RVS 13-20 were categorized as having low resistance. SL 1282, RSC 11-35 and PS 1682 were found to be susceptible, CAUMS-2 and AS-24 experienced higher stem fly infestation and tunneling, making them significantly inferior and highly susceptible among all genotypes. Genotypes that exhibited resistance or moderate resistance showed thicker stems and shorter internodal lengths, whereas susceptible genotypes showed the opposite characteristics. The promising genotypes disrupted the oviposition behavior of the stem fly, *M. sojae,* attributed to their high trichome density.

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Conflict of interest

I hereby declared that there will be no conflict of interest on behalf of all authors of the manuscript.

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