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Screening of Tropical Maize Inbred Lines by Artificial Infestation for Resistance against Invasive Fall Armyworm in India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: This study was aimed to find resistance sources against FAW.
Study Design: Randomised Block Design.
Place and Duration of Study: The Present study was conducted at Maize Research Centre, Hyderabad with promising germplasm during *Kharif*-2021, *Rabi*-2021-22 and *Kharif*-2022.
Methodology: Field-collected FAW egg masses were reared using maize leaf- and stalk-based diet at 27 ± 1 °C, 60 ± 5% relative humidity and 12 h day length. The resulting neonates were used to infest the seedlings of 34 diverse tropical maize inbred genotypes.
Results: A total of 15 genotypes were found to have recorded a leaf damage score of less than 5 with the least score recorded in BML 2 (3.24), followed by BML 11 (3.34), BML 7(3.37), BML 5 (3.37), BML 8 (3.49), CM 201 (3.60), BML 32-2 (3.91), CM 132 (3.97), BML 10 (4.01), BML 6

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(4.02), BML 13 (4.34), CM202 (4.34), CM 131 (4.68), BML 90 (4.82), BML 45 (4.95) and displayed moderate resistance.
Conclusion: Out of 34 inbred lines studied 15 were found to be moderately resistant to fall armyworm based on LIR and cob damage score under artificial infestation.

Keywords: Fall army worm; rearing; artificial infestation; controlled screening; genotypes.

1. INTRODUCTION

"The fall armyworm (*Spodoptera frugiperda* J.E. Smith) is a polyphagous pest and inflicting huge crop losses in maize and other major cereal crops" [1,2]. "Fall army worm (FAW) is India's recent invasive polyphagous pest, reported in 2018. The spread of FAW to different countries of Africa and Asia with existing abiotic and biotic production constraints threatening the maize production and productivity" [3,4]. "In Africa, FAW causes 21 to 53% yield losses in maize production" [5]. "Severe FAW infestation coupled with abiotic or biotic stresses causes yield loss of 80% or complete crop failures in maize and sweet corn production" [6,7]. "The yield losses caused by the fall armyworm have risked food security and the livelihoods of over 500 million people who depend on maize production and products" [8,9].

"In India, the fall armyworm was confirmed in May 2018 by the University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka. Later, it moved within the country and to the surrounding countries, *viz*., Bangladesh (December 2018), Myanmar (December 2018), Sri Lanka (January 2019), China (January 2019), Nepal, Thailand (December 2018), South Korea and Japan (July 2019). The temporal spread of FAW within India has been reported since its first report from Karnataka in May 2018" [10]. "FAW spread from peninsular India to the North and North East during 2018 and early 2019, respectively; from the 2019 monsoon season, FAW incidence has been reported from the northern and northwestern parts of the country. FAW has adversely affected the maize and other major cereal crop production, food systems and value chains. Hence, there is an urgent need for dedicated FAW-resistance breeding programs in India to develop new-generation open-pollinated and hybrid maize varieties. Globally, various FAW management strategies include using of biological agents, cultural practices, crop protection chemicals, landscape management practices, transgenic crop varieties, host plant resistance and integrated pest management (IPM). IPM involves a curated combination of more than one of the above methods and is a very effective, sustainable and environmentally friendly. Resistance breeding is a core component of IPM for cost-effective and easily implementable technology for the farmers who are the end users of the advanced technologies" [11,12]. FAW-resistance breeding requires the artificial screening of locally adapted, market-preferred maize genotypes. Screening will enable gene introgression and the development of high-yielding varieties with resistance in the IPM strategy. FAW is a highly gregarious and unpredictable insect pest, and control screening facilities are required for reliably assessing pest development and infestation levels and rating the reaction types of the host to select resistant individuals for breeding. A customized insectary is necessary for the mass production of the FAW larvae, while a controlled-environment facility is needed for pest development, infestation, host screening and host selection process.

Screening for FAW resistance can be undertaken in controlled screening under greenhouse or screen house conditions with optimal combinations of temperature, relative humidity and day length to enhance the host–pest activity. Artificial controlled screening data ensure effective comparisons of the host genotypes under moderate pest pressure. Controlled screening with insect populations from the same larval generation allows for detailed observations of pest progress, host reactions and resistance, ensuring higher selection efficiency.

"Earlier studies documented that insect feeding patterns and the ease of assessing host reactions under controlled screening conditions allow for an improved understanding of the pest–host reaction and pest management conditions" [13,14,15]. "Ideal abiotic conditions reported to be temperatures of 24 to 31°C, relative humidity of 52 to 88% and a day length of 12 to 14 h for the controlled rearing of FAW from egg or larval samples collected from maize plants" [16-20].

"FAW was recently reported in India; there is a lack of information on pest initiation and development under local crop production conditions. Further, there is an urgency for resistance breeding programs in the region. FAW resistance breeding programs depend on the availability of inexpensive, reproducible methods for pest rearing, infestation and host screening" [21,22]. The selected lines and hybrids should be rigorously evaluated under controlled environmental conditions and pest pressure for precision phenotyping and recommendation. Knowledge of the rearing, infestation and development of the pest and high-throughput screening protocols are preconditions for successful cultivar recommendation and the introgression of FAW-resistant genes into farmer-preferred and locally adapted maize genotypes. Therefore, this study aimed to screen maize lines, and select resistant lines under controlled environment.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The study was conducted at IV-block of research farm, Maize Research Centre (MRC), Rajendranagar, Hyderabad, situated at 17°32'N latitude and 78°40'E longitude. This research area falls under the Southern Agro-Climatic Zone of Telangana under a semi-arid tropical climate. Soils are Sandy loam with assured irrigation facilities with an average temperature of 22°C. These agroecological conditions make the experimental site suitable for screening maize germplasm for insect pest resistance, including FAW. Since the report of FAW in Telangana in 2018, Maize Research Centre has consistent FAW populations and crop damage scorings during the seasons.

2.2 Mass Production of FAW

2.2.1 Sampling of eggs and larvae

Representative samples of FAW constituting 40 egg masses were collected from unsprayed maize fields of Maize Research Centre, Rajendranagar, Hyderabad. Samples were collected using perforated plastic containers from field-grown maize hybrid DHM 117. Larvae were carefully picked from the leaf whorls of the plants, while fresh eggs were carefully scraped off from the leaf blades and collected into plastic containers. FAW eggs were identified following the description procedure of Deole and Paul, [23] as small, circular masses of mostly white eggs. Sampled FAW eggs and larvae were grown in rearing jars, as detailed below.

2.3 Laboratory Rearing Procedure

The field-collected egg masses were allowed to hatch in plastic containers containing maize leaves as a diet for newly hatched neonates. Then the larvae were reared in plastic jars containing tender baby corn pieces and tender leaves. The baby corn was washed with 5% sodium hypochlorite and rinsed twice or thrice with water to prevent contamination before being used as feed. The larvae from the third instar were transferred to individual jars covered with the muslin cloth to avoid cannibalism. The eggs and larvae were grown at temperatures of approximately 27 ± 1°C, relative humidity of 60 ± 5%, an average day length of 12 h. and the natural diet replaced for every two days, plastic jars were cleaned with a 5% hypochlorite solution to prevent microbial growth between each successive diet change. The pupae developed were distinguished as loose, oval cocoons that preceded the mature stage of the FAW. The temperatures and relative humidity during the pupal stage were adjusted to 26°C and 70 ± 5% using an internal heating system and humidifier, respectively. These conditions were conducive to pupal development. Male and female FAW pupas were transferred into separate jars for adult emergence. The adult moths in the cage were allowed to mate for subsequent oviposition. FAW moths were supplied with a 5% sugar solution by soaking cotton wool balls in a sugar solution and placing these inside the jars. After mating, the eggs were laid on the muslin cloth. The eggs were collected by using a camel brush. The fresh eggs of the FAW were carefully scraped off from the surface of the muslin cloth using a clean spatula and transferred into new plastic jars possessing tender maize leaves for hatching. New larval neonates that hatched from the eggs were used for further rearing.

2.4 Screening of Maize Genotypes for FAW Resistance

2.4.1 Genetic materials

The present study used 34 elite inbred lines selected from promising tropical maize genotypes acquired from MRC (Table 1). All the 34 MRC inbred lines were previously selected through rigorous field evaluations at Hyderabad for their resistance against other stem borers like *Chilo partellus* and *Sesamia inferens*. Further, the 34 lines also have desirable agronomic traits, including grain yield and medium maturity.

Table 1. List of genotypes used in this study

S. No.	Type of Inbred	S. No.	Type of Inbred
1	BML 2	18	BML 90
2	BML 5	19	CM 104
3	BML 6	20	CM 105
4	BML 7	21	CM 114
5	BML 8	22	CM 115
6	BML 10	23	CM 131
7	BML 11	24	CM 132
8	BML 13	25	CM 201
9	BML 14	26	CM 202
10	BML 15	27	CM 209
11	BML 20	28	V6 32-154
12	BML 30 F	29	3070
13	BML 32-2	30	Z63-45
14	BML 41	31	5125
15	BML 45	32	5063
16	BML 51	33	1235-1
17	BML 80	34	3122

2.4.2 Experimental design and trial establishment

The field experiment was carried out in a standard screen house (Fig. 1, Fig. 2) at IV block of the research farm at Maize Research Centre, Rajendranagar, Hyderabad situated at 17°31'N latitude and 78°39' E longitude.

2.4.3 Preparatory cultivation

The field was vigorously upturned with spades by applying recommended dosage of Farm yard manure (FYM) @ 5 t ha^{-1}. After removing all the stubbles and weeds, it was pulverized with a power weeder then levelled. Furrows of 15 cm broad and 20 cm depth were formed with a spacing of 0.6 m. An irrigation channel with a spacing of 0.75 m was formed in between the replications.

2.4.4 Layout of the field experiment

The experiment was laid out in a completely randomized block design with an individual row lengths of 2 m replicated twice with a spacing of 60 cm between the rows and 20 cm between the plants. Three seeds were sown at a depth of 2.5 cm and later thinned to one plant per hill. The field was watered twice a week to ensure sustained moisture for germination. Emerging seedlings were kept free of weeds.

2.4.5 Seedling infestation with FAW larvae

Larvae from the laboratory were used to screen maize genotypes. The infestation of the maize genotypes with FAW neonates when the plants were at the five-leaf stage (V5). Ten to twelve FAW neonate larvae were deposited per plant under artificial infestation (Fig. 3, Fig. 4). A camel hair brush was used to transfer the larvae from the plastic jars to the whorl of the maize plants.

2.5 Data Collection

2.5.1 Reaction of Maize Genotypes to FAW

Maize genotypes were rated for FAW resistance. Resistance was assessed based on FAW damage scores obtained after the infestation. FAW leaf-damage (LIR) rating was recorded after 7 days, 14 days, 21 days, 28 days and ear damage at harvest (Fig. 5, Fig. 6), for Leaf Injury Rating (LIR) and ear damage 1 to 9 scale was adapted from Modified Davis and Williams, 1992 where a score of 1 denotes a healthy plant with no damage symptoms and a score 9 denoting a completely damaged plant with no possibility of recovery (Table 2, Table 3).

Fig. 1. Screen houses for screening of genotypes

Fig. 2. Genotypes in screen house

Fig. 3. V5 stage of maize genotypes

Fig. 4. Artificial release of FAW neonates at V5 stage of the maize genotypes with the help of camel hairbrush

Table 2. Scale for screening of maize genotypes based on foliar damage

Score	Damage symptoms/ Description	Response
1	No visible leaf feeding damage	Highly resistant
2	Few pinholes on 1-2 older leaves	Resistant
3	Several shot-hole injuries on a few leaves	Resistant
4	Several shot-hole injuries on several leaves (6–8 leaves) or small lesions/pinholes, small circular lesions, and a few small elongated (rectangular-shaped) lesions of up to 1.3 cm in length present on whorl and furl leaves	Moderately Resistant
5	Elongated lesions (>2.5 cm long) on 8-10 leaves, plus a few small- to midsized uniform to irregular-shaped holes (basement membrane consumed) eaten from the whorl and/or furl leaves	Moderately Resistant
6	Several large elongated lesions present on several whorl and furl leaves and/or several large uniform to irregular-shaped holes eaten from furl and whorl leaves	Susceptible
7	Many elongated lesions of all sizes present on several whorl and furl leaves plus several large uniform to irregular-shaped holes eaten from the whorl and furl leaves	Susceptible
8	Many elongated lesions of all sizes present on most whorl and furl leaves plus many mid- to large-sized uniform to irregular-shaped holes eaten from the whorl and furl leaves	Highly Susceptible
9	Whorl and furl leaves almost totally destroyed and plant dying as a result of extensive foliar damage	Highly Susceptible

[30]

Fig. 5. Leaf Injury Rating (LIR) at V7 stage

Fig. 6. Ear damage

Table 3. Scale for ear damage caused by FAW where FAW is already present on plants

Score	Damage symptoms/ Description	Response
1	No damage to the ear	Resistant
2	Damage to a few kernels (<5) or less than 5% damage to an ear	Resistant
3	Damage to a few kernels (6-15) or less than 10% damage to an ear	Resistant
4	Damage to 16-30 kernels or less than 15% damage to an ear	Moderately Resistant
5	Damage to 31-50 kernels or less than 25% damage to an ear	Moderately Resistant
6	Damage to 51-75 kernels or more than 35% but less than 50% damage to an ear	Susceptible
7	Damage to 76-100 kernels or more than 50% but less than 60% damage to an ear	Susceptible
8	Damage to >100 kernels or more than 60% but less than 100% damage to an ear	Highly Susceptible
9	Almost 100% damage to an ear	Highly Susceptible

[30]

3. RESULTS AND DISCUSSION

3.1 Selection of Maize Genotypes with FAW Resistance under Controlled Screening

3.1.1 Mean performance of test genotypes

During *Kharif* 2021, the genotypes recorded the most variable FAW damage scores at different days of infestation (Table 4a). Most of the tested inbred lines had leaf damage score ratings below the score of 7.33. Only 15% of the genotypes had a leaf damage score of 3, while 15% had a score of 4 at Seven Days after infestation. At 14 days after infestation, 6% of the genotypes had a leaf damage score of 3, while 29% of the genotypes had a leaf damage score of 4. At 21days after infestation, 41% of the genotypes had a leaf damage score of 1, *i.e*., indicating a healthy plant with no damage symptoms, while 15% had a score of 4. Whereas at 28 days after infestation, 29% of the genotypes had a leaf damage score of 1 i.e., indicating a healthy plant with no damage symptoms, while 3% had a leaf damage score of 3 and 21% had a score of 4. At harvest, ear damage rating score of test genotypes had below the score of 7.75. Only 9% of the genotypes had an ear damage score of 3, while 18% had a score of 4 at harvest. The mean performance values for all the genotypes in the study are recorded in (Table 4b) The mean leaf damage score of the maize genotypes ranged between 3.06 to 6.78 with the lowest LIR in BML 2 and BML 8 (3.06) and followed by BML 5 (3.11), BML 11 (3.13), BML 7 (3.35), CM 201 (3.59), BML 6 (3.66), BML 32-2 (3.81) and BML 10(3.91). The best genotypes were CM 132 (4.03), CM202 (4.41), BML 13 (4.45), CM 131 (4.80), BML 90 (4.90), BML 45 (4.93), BML 20 (4.94) were recorded more than 3.00 and less than 5.00 hence they were categorized as moderately resistant. The highest leaf injury rating score was recorded in the genotypes BML 14 (5.65), BML15 (5.38), BML 30F (5.30), BML 41 (5.15), BML 51 (5.51), BML 80 (5.81), CM 104 (5.25), CM 105 (5.82), CM 114 (5.78), CM 115 (5.40), CM 209 (5.84), V6 32-154 (5.21), 3070 (6.78), Z63-45 (6.21), 5125 (5.86), 5063 (5.90), 1235-1 (5.52), 3122 (5.99) with more than 5.00 and less than 7.00 and was categorized as susceptible genotypes.

3.1.2 *Rabi* 2021-22

FAW damage scores were the most variable at different days of infestation (Table 5a). Most of the test genotypes had leaf injury rating score below 7.67. Only 6% of the genotypes had a leaf damage score of 3, while 15% had a score of 4 at Seven Days after infestation. At 14 days after infestation 21% of the genotypes had a leaf damage score of 4. At twenty-one days after infestation, 9% of the genotypes had a leaf damage score of 1, *i.e*., indicating a healthy plant with no damage symptoms, while 33% had a score of 3 and 6% of the genotypes had a leaf damage score of 4. Whereas at twenty-eight days after infestation, 12% of the genotypes had a leaf damage score of 1, *i.e*., indicating a healthy plant with no damage symptoms, while 18% had a leaf damage score of 3 and 18% had a score of 4. Most test genotypes harvest ear damage rating score was below 7.75. Only 30% of the genotypes had an ear damage score of 3, while 12% had a score of 4 at harvest. The mean performance values for the all genotypes in the study are recorded in Table 5b. Categorization of genotypes based on damage score during *Rabi* 2021-22 The mean leaf injury rating score of the maize genotypes ranged between 3.57 to 7.01, with the lowest LIR in BML 2 (3.49) and followed by BML 7 (3.57), BML 5 (3.59), BML 11 (3.75), BML 8 (3.83) and the next best genotypes followed were CM 201 (4.01), BML 32-2 (4.15), BML 10 (4.39), CM 132 (4.40), BML 6 (4.47), BML 13 (4.75), CM202 (4.85) were recorded more than 3.00 and less than 5.00 LIR and were categorized as moderately resistant. Further, the test genotypes BML 14 (5.87), BML15 (5.53), BML 20 (5.42), BML 30F (5.54), BML 41 (5.35), BML 45 (5.25), BML 51 (5.81), BML 80 (6.00), BML 90 (5,28), CM 104 (5.63), CM 105 (6.25), CM 114 (6.15), CM 115 (5.83), CM 131 (5.18), CM 209 (6.09), V6 32-154 (5.55), Z63-45 (6.47), 5125 (6.07), 5063 (6.20), 1235-1 (5.79), 3122 (6.21) were recorded more than 5.00 and less than 7.00 LIR and were categorized as susceptible genotypes. The maximum leaf damage score was recorded in genotype 3070 (7.01) and was categorized as a highly susceptible genotype.

3.1.3 *Kharif* 2022

FAW damage scores for the genotypes were most variable at different days of infestation (Table 6a). Most of the test genotypes had leaf damage score ratings below the score of 7.36. Only 12% of the genotypes had a leaf damage score of 3, while 15% had a score of 4 at Seven Days after infestation. At 14 days after infestation, 12% of the genotypes had a leaf damage score of 3; at 14 days after infestation, 12% of the genotypes had a leaf damage score of 4. At twenty-one days after infestation, 12% of the genotypes had a leaf damage score of 1, *i.e*., denoted a healthy plant with no damage symptoms, while 18% had a score of 2 and 6% of the genotypes had a leaf damage score of 3, 15% of the genotypes had a leaf damage score 4. Whereas at twenty-eight days after infestation, 9% of the genotypes had a leaf damage score of 1, *i.e*., denoted a healthy plant with no damage symptoms, while 24% had a leaf damage score of 2, 27% had a leaf damage score of 3 and 21% had a score of 4. At harvest, ear damage rating score of most of the test genotypes had below the score of 7.00. Only 15% of the genotypes had an ear damage score of 2, 27% of the genotypes had an ear damage score of 3 and 24% had a score of 4 at harvest. The mean performance values for all the genotypes in the study are recorded in Table 6b. Categorization of genotypes based on damage score during *kharif* 2022 The mean LIR score of the maize genotypes ranged between 3.16 to 5.95, with the lowest in BML 11 (3.16) and was followed by BML 7 (3.20), CM 201 (3.20), BML 2 (3.28), BML 5 (3.42), CM 132 (3.48), BML 8 (3.58) BML 10 (3.72), CM 202 (3.76), BML 32-2 (3.78), BML 13 (3.83), BML 6 (3.93) and the following best genotypes were CM 131 (4.05), BML 90 (4.27), BML 45 (4.67), CM 115 (4.77), 5125 (4.92), V6 32-154 (4.96), CM 104 (4.98) were more than 3.00 and less than 5.00 and were categorized as moderately resistant. The test genotypes BML 14 (5.25), BML15 (5.80), BML 20 (5.30), BML 30F (5.17), BML 41 (5.12), BML 51 (5.24), BML 80 (5.35),CM 105 (5.04), CM 114 (5.30), CM 209 (5.29), 3070 (5.95), Z63-45 (5.40), 5063 (5.32), 1235-1 (5.12), 3122 (5.42) were more than 5.00 and less than 7.00 and were categorized as susceptible genotypes.

3.1.4 Pooled analysis

The mean FAW damage scores for the genotypes were most variable at different days of infestation (Table 7a). Most test genotypes had leaf damage score ratings below the score of 7.50. Only 12% of the genotypes had a leaf damage score of 3, while 15% had a score of 4 at Seven Days after infestation. At 14 days after infestation, 6% of the genotypes had a leaf damage score of 3, while 21% of the genotypes had a leaf damage score of 4. At twenty-one days after infestation, 9% of the genotypes had a leaf damage score of 1, *i.e*., denoted a healthy plant with no damage symptoms, while 21% had a score of 1 to 2, 12% had a leaf damage score of 2 and 9% had a score of 4. Whereas at twenty-eight days after infestation, 9% of the genotypes had a leaf damage score of 1, *i.e*., exemplified a healthy plant with no damage symptoms, while 15% had a leaf damage score of 1 to 2, 6% had a leaf damage score of 2 and 9% had a score of 3 and 21% had a leaf damage score of 4. At harvest ear damage rating score of most test genotypes had below the score of 7.43. Only 3% of the genotypes had an ear damage score of 2, 21% of the genotypes had an ear damage score of 3, while 24% had a score of 4 at harvest.

The mean performance values for the genotypes in the study were recorded in Table 7b. Categorization of genotypes based on damage score. The mean leaf damage score of the maize genotypes ranged between 3.24 to 6.58, with the lowest LIR recorded in BML 2 (3.24). It was followed by BML 11 (3.34), BML 7(3.37), BML 5 (3.37), BML 8 (3.49), CM 201 (3.60), BML 32-2

Table 4a. Performance of genotypes during *Kharif* 2021

S. No.	Name of the inbred	7 DAI	14 DAI	21 DAI	28 DAI	Ear damage	Mean Injury rating
1	BML 2	4.40	5.38	1.00	1.00	3.50	3.06
2	BML 5	4.70	6.33	1.00	1.00	2.50	3.11
3	BML 6	5.40	7.38	1.00	1.00	3.50	3.66
4	BML 7	3.86	3.88	4.50	1.00	3.50	3.35
5	BML 8	6.67	4.13	1.00	1.00	2.50	3.06
6	BML 10	6.67	4.38	4.50	1.00	3.00	3.91
7	BML 11	4.00	4.63	1.00	1.00	5.00	3.13
8	BML 13	6.50	4.75	1.00	4.00	6.00	4.45
9	BML 14	7.00	5.50	5.50	4.25	6.00	5.65
10	BML 15	6.43	6.13	1.00	6.17	7.20	5.38
11	BML 20	7.33	4.75	1.00	5.63	6.00	4.94
12	BML 30 F	6.83	5.64	1.00	5.50	7.50	5.30
13	BML 32-2	5.75	5.30	1.00	1.00	6.00	3.81
14	BML 41	6.89	4.88	1.00	6.50	6.50	5.15
15	BML 45	3.65	6.07	4.75	5.17	5.00	4.93
16	BML 51	5.82	5.13	5.42	5.21	6.00	5.51
17	BML 80	6.95	4.90	5.42	6.30	5.50	5.81
18	BML 90	7.27	4.75	1.00	6.00	5.50	4.90
19	CM 104	6.44	3.75	4.88	6.42	4.75	5.25
20	CM 105	6.79	3.17	5.17	6.50	7.50	5.82
21	CM 114	5.00	5.00	6.50	5.90	6.50	5.78
22	CM 115	7.50	4.75	5.75	4.50	4.50	5.40
23	CM 131	6.13	5.38	6.50	1.00	5.00	4.80
24	CM 132	7.38	6.75	1.00	1.00	4.00	4.03
25	CM 201	3.83	6.38	1.00	3.75	3.00	3.59
26	CM 202	3.50	4.13	5.75	4.17	4.50	4.41
27	CM 209	6.39	5.00	6.08	4.75	7.00	5.84
28	V6 32-154	4.88	6.00	4.83	5.83	4.50	5.21
29	3070	7.00	6.50	5.70	7.00	7.71	6.78
30	Z63-45	5.69	6.38	5.83	6.67	6.50	6.21
31	5125	6.30	5.50	6.50	4.50	6.50	5.86
32	5063	6.67	5.33	6.13	4.75	6.60	5.90
33	1235-1	4.29	6.75	6.17	5.92	4.50	5.52
34	3122	4.29	5.80	6.33	6.20	7.33	5.99
	SEd	0.238	0.316	0.298	0.271	0.254	0.132
	CD at 5%	0.485	0.646	0.608	0.555	0.519	0.270
	CV%	4.076	5.956	8.018	6.519	4.772	2.719

(3.91), CM 132 (3.97) and the following best genotypes were BML 10 (4.01), BML 6 (4.02), BML 13 (4.34), CM202 (4.34), CM 131 (4.68), BML 90 (4.82), BML 45 (4.95) were more than 3.00 and less than 5.00 and were categorized as moderately resistant. The other test genotypes BML 14 (5.59), BML 15 (5.57), BML 20 (5.22), BML 30F (5.34), BML 41 (5.21), BML 51 (5.52), BML 80 (5.72), CM 104 (5.33), CM 105 (5.71), CM 114 (5.74), CM 115 (5.33), CM 209 (5.74), V6 32-154 (5.27), 3070 (6.58), Z63-45 (6.03), 5125 (5.66), 5063 (5.81), 1235-1 (5.48), 3122 (5.87) were more than 5.00 and less than 7.00 and were categorized as susceptible genotypes.

3.2 Artificial Infestation and Screening of Maize Genotypes

The leaf injury rating began to increase from 7 days after infestation, and the highest LIR was reported at 14 days after infestation (V7 leaf stage) when plants were more succulent, and the larval stage progresses, then gradually it declined at the V9 stage. This suggested that there might be a significant relationship between the number of larvae surviving on plants and the amount of leaf damage caused. The present findings were in accordance with Wiseman *et al.*, 1981 who reported that more larvae survived during the V5 and V10 Stages. The less damage in moderately resistant genotypes might be attributable to either antixenosis or antibiosis. The leaf damage caused by fall armyworm was evaluated based on a modified Davis scale of 1 to 9, and it revealed a vast range of differences among the genotypes screened in the present study.

A total of 15 were found to have recorded a leaf damage score of less than 5, with least score recorded in BML 2 (3.24) followed by BML 11 (3.34), BML 7(3.37), BML 5 (3.37), BML 8 (3.49), CM 201 (3.60), BML 32-2 (3.91), CM 132 (3.97), BML 10 (4.01), BML 6 (4.02), BML 13 (4.34), CM202 (4.34), CM 131 (4.68), BML 90 (4.82), BML 45 (4.95) which were classified as moderately resistant genotypes (Table 8, Fig. 7). Further, a total of 19 genotypes were found to have recorded a leaf damage score of above 5.00, namely BML 14 (5.59), BML 15 (5.57), BML 20 (5.22), BML 30F (5.34), BML 41 (5.21), BML 51 (5.52), BML 80 (5.72), CM 104 (5.33), CM 105 (5.71), CM 114 (5.74), CM 115 (5.33), CM 209 (5.74), V6 32-154 (5.27), 3070 (6.58), Z63-45 (6.03), 5125 (5.66), 5063 (5.81), 1235-1 (5.48), 3122 (5.87) which were classified as susceptible genotypes. The resistance might be due to a lack of growth inhabiting mechanisms or favourable biochemical parameters could be the reason for the higher leaf injury score.

Similarly, earlier studies on screening for FAW-resistant maize germplasm has been carried out comprehensively by Ni et al. [24], Smith [25], Wiseman et al., [22], Widstrom et al., [26] in Florida reported that fall armyworm resistance at the seedling stage was examined in 6 corn inbred lines, including 4 CIMMYT maize inbred lines (CML333, CML335, CML 336, and CML338) and fall armyworm-resistant Mp708 and susceptible AB24E. Similarly, Xinzhi et al. [27] in Florida reported that based on cluster analysis of *S. frugiperda* injury rating, 'Mp708' and 'FAW7061' were the most resistant one, whereas 'Ab24E' and 'EPM6' were most susceptible to fall armyworm feeding. Ni et al., [28] in Florida evaluated 2 newly-developed partial corn germplasm inbred lines, namely "FAW7061" and "FAW7111," derived from a previously released population, "GTFAWCC (C5)", were resistant to the feeding by *S. frugiperda* as to compared with the resistant Mp708 and the susceptible control "Ab24E" while "FAW7061", they had lower *S. frugiperda* lesion than "FAW7111". As per Paul and Deole [29], out of 25 maize genotypes, DKC-9190 (2.36), genotype recorded minimum leaf damage whereas genotype NK-30 (8.21) recorded maximum leaf damage. Heera-1122 (1.91) genotype recorded minimum ear damage. Whereas NMH-707 (5.91) genotype was recorded with maximum ear damage on the crop at Raipur (Chhattisgadh). Among the twenty-five cultivars NMH-707 (1.59) genotype recorded minimum kernel damage, while, LG34.06 (4.31) genotype recorded with maximum kernel.

Further, a more detailed investigation of the profiled genotypes is required to enhance our understanding of maize responses to FAW feeding. Morphological characteristics and biochemical parameters will be studied for further confirmation of the resistance. Therefore, the selected maize genotypes are recommended as sources of FAW resistance and should be evaluated under representative growing environments for breeding. The information presented in this paper will allow for reliable FAW infestation, genotype screening and the integration of candidate FAW resistance genes into market-preferred maize lines in related agro ecologies.

Table 4b. Categorization of genotypes based on damage score during *kharif* 2021

S. No.	Injury rating	Categorization	Name of inbreds	No. of inbreds
1	1.0-3.0	Resistant	-	Nil
2	3.1 – 5.0	Moderately Resistant	BML 2, BML 5, BML 6, BML 7, BML 8, BML 10, BML 11, BML 13, BML 20, BML 32-2, BML 45, BML 90, CM 131, CM 132, CM 201, CM202,	16
3	5.1 – 7.0	Susceptible	BML 14, BML15, BML 30F, BML 41, BML 51, BML 80, CM 104, CM 105, CM 114, CM 115, CM 209, V6 32-154, 3070, Z63-45, 5125, 5063, 1235-1, 3122	18
4	7.1 – 9.0	Highly susceptible	-	Nil

Table 5a. Performance of genotypes during *Rabi* 2021-22

S. No.	Name of the inbred	7 DAI	14 DAI	21 DAI	28 DAI	Ear Damage	Mean Injury rating
1	BML 2	5.20	5.50	1.25	2.00	3.50	3.49
2	BML 5	5.05	6.42	2.00	1.00	3.50	3.59
3	BML 6	5.35	7.50	2.00	3.00	4.50	4.47
4	BML 7	3.71	4.13	5.00	2.00	3.00	3.57
5	BML 8	6.75	4.38	2.50	2.00	3.50	3.83
6	BML 10	6.83	4.63	4.50	2.00	4.00	4.39
7	BML 11	4.36	4.88	1.50	3.00	5.00	3.75
8	BML 13	6.50	5.25	1.50	4.50	6.00	4.75
9	BML 14	7.19	5.60	5.50	4.75	6.33	5.87
10	BML 15	6.57	6.19	1.50	6.17	7.20	5.53
11	BML 20	7.50	5.00	2.50	5.75	6.33	5.42
12	BML 30 F	7.00	5.71	1.50	6.00	7.50	5.54
13	BML 32-2	6.13	5.40	2.00	1.00	6.20	4.15
14	BML 41	7.00	5.00	2.00	6.00	6.75	5.35
15	BML 45	4.05	6.21	5.00	5.50	5.50	5.25
16	BML 51	6.09	5.63	5.50	5.50	6.33	5.81
17	BML 80	7.15	5.30	5.50	6.30	5.75	6.00
18	BML 90	7.41	5.50	1.00	6.50	6.00	5.28
19	CM 104	6.81	4.50	5.13	6.58	5.13	5.63
20	CM 105	7.00	4.17	5.67	6.67	7.75	6.25
21	CM 114	5.28	6.00	6.70	6.00	6.75	6.15
22	CM 115	7.67	5.25	6.25	5.00	5.00	5.83
23	CM 131	6.63	5.75	7.50	1.00	5.00	5.18
24	CM 132	7.63	7.38	1.00	1.00	5.00	4.40
25	CM 201	4.17	6.88	1.00	4.00	4.00	4.01
26	CM 202	3.93	4.88	6.25	4.33	4.88	4.85
27	CM 209	6.78	5.75	6.25	5.00	6.67	6.09
28	V6 32-154	5.31	6.33	5.33	6.00	4.75	5.55
29	3070	7.30	6.75	6.10	7.33	7.57	7.01
30	Z63-45	6.13	6.63	6.17	6.67	6.75	6.47
31	5125	6.50	6.00	6.83	5.00	6.00	6.07
32	5063	6.92	5.67	6.38	5.25	6.80	6.20
33	1235-1	4.71	7.00	6.50	6.00	4.75	5.79
34	3122	5.00	6.10	6.67	6.30	7.00	6.21
	SEd	0.214	0.273	0.531	0.470	0.490	0.182
	CD at 5%	0.437	0.558	1.086	0.960	1.002	0.372
	CV%	3.499	4.807	12.727	10.294	8.743	3.48

Table 5b. Categorization of genotypes based on damage score during *Rabi* 2021-22

S. No.	Injury rating	Categorization	Name of inbreds	No. of inbreds
1	1-3.0	Resistant	-	Nil
2	3.1 – 5.0	Moderately Resistant	BML 2, BML 5, BML 6, BML 7, BML 8, BML 10, BML 11, BML 13, BML 32-2, CM 132, CM 201, CM202	12
3	5.1 – 7.0	Susceptible	BML 14, BML15, BML 20, BML 30F, BML 41, BML 45, BML 51, BML 80, BML 90, CM 104, CM 105, CM 114, CM 115, CM 131, CM 209, V6 32-154, Z63-45, 5125, 5063, 1235-1, 3122	21
4	7.1 – 9.0	Highly susceptible	3070	1

Table 6a. Performance of genotypes during *Kharif* 2022

S. No.	Name of the inbred	7 DAI	14 DAI	21 DAI	28 DAI	Ear Damage	Mean Injury rating
1	BML 2	4.25	5.13	1.00	2.00	3.50	3.28
2	BML 5	4.50	6.08	2.00	2.00	2.50	3.42
3	BML 6	5.15	7.00	2.00	2.00	3.50	3.93
4	BML 7	3.50	3.50	3.50	2.50	3.00	3.20
5	BML 8	6.17	3.75	2.00	2.50	3.50	3.58
6	BML 10	6.08	4.00	4.00	2.00	2.50	3.72
7	BML 11	3.68	4.13	2.50	2.50	3.00	3.16
8	BML 13	5.90	3.75	2.00	3.00	4.50	3.83
9	BML 14	7.13	5.60	5.50	3.00	5.00	5.25
10	BML 15	6.64	6.31	4.50	4.83	6.70	5.80
11	BML 20	7.33	5.00	5.00	4.50	4.67	5.30
12	BML 30 F	6.78	5.71	3.50	3.00	6.88	5.17
13	BML 32-2	5.19	5.00	2.50	1.00	5.20	3.78
14	BML 41	6.72	5.13	4.50	4.00	5.25	5.12
15	BML 45	4.15	6.07	4.75	4.00	4.38	4.67
16	BML 51	6.14	5.25	5.42	4.71	4.67	5.24
17	BML 80	7.10	5.00	5.17	5.00	4.50	5.35
18	BML 90	7.36	6.00	1.00	3.00	4.00	4.27
19	CM 104	6.50	4.00	5.38	5.67	4.00	4.98
20	CM 105	6.71	3.67	4.50	5.33	5.00	5.04
21	CM 114	5.17	5.00	6.10	5.00	5.25	5.30
22	CM 115	7.33	5.00	5.25	3.00	3.25	4.77
23	CM 131	6.13	5.63	5.00	1.00	2.50	4.05
24	CM 132	6.38	6.50	1.00	1.00	2.50	3.48
25	CM 201	3.61	6.38	1.00	3.00	2.00	3.20
26	CM 202	3.14	4.25	4.50	3.17	3.75	3.76
27	CM 209	6.44	5.25	5.92	3.50	5.33	5.29
28	V6 32-154	5.06	6.67	5.33	4.50	3.75	4.96
29	3070	6.10	6.00	5.30	5.33	7.00	5.95
30	Z63-45	5.81	6.63	5.33	4.00	5.25	5.40
31	5125	6.60	5.67	6.50	2.50	4.00	4.92
32	5063	6.58	5.17	5.75	3.50	5.60	5.32
33	1235-1	4.43	7.00	5.33	5.08	3.75	5.12
34	3122	4.71	6.00	5.50	5.20	5.67	5.42
	SEd	0.252	0.322	0.515	0.487	0.373	0.148
	CD at 5%	0.516	0.659	1.052	0.996	0.763	0.302
	CV%	4.695	6.588	14.987	14.242	8.701	3.452

Table 6b. Categorization of genotypes based on damage score during *kharif* 2022

S. No.	Injury rating	Categorization	Name of inbreds	No. of inbreds
1	1-3.0	Resistant	-	Nil
2	3.1 – 5.0	Moderately Resistant	BML 2, BML 5, BML 6, BML 7, BML 8, BML 10, BML 11, BML 13, BML 32-2, BML 45, BML 90, CM 104, CM 115, CM 131, CM 132, CM 201, CM202,V6 32-154, 5125	19
3	5.1 – 7.0	Susceptible	BML 14, BML15, BML 20, BML 30F, BML 41, BML 51,BML 80,CM 105, CM 114, CM 209, 3070, Z63-45, 5063, 1235-1, 3122	15
4	7.1 – 9.0	Highly susceptible	-	NIl

Table 7a. Pooled mean performance of genotypes

S. No.	Name of the inbred	7 DAI	14 DAI	21 DAI	28 DAI	Ear Damage	Mean Injury rating
1	BML 2	4.62	5.33	1.08	1.67	3.50	3.24
2	BML 5	4.75	6.28	1.67	1.33	2.83	3.37
3	BML 6	5.30	7.29	1.67	2.00	3.83	4.02
4	BML 7	3.69	3.83	4.33	1.83	3.17	3.37
5	BML 8	6.53	4.08	1.83	1.83	3.17	3.49
6	BML 10	6.53	4.33	4.33	1.67	3.17	4.01
7	BML 11	4.02	4.54	1.67	2.17	4.33	3.34
8	BML 13	6.30	4.58	1.50	3.83	5.50	4.34
9	BML 14	7.10	5.57	5.50	4.00	5.78	5.59
10	BML 15	6.55	6.21	2.33	5.72	7.03	5.57
11	BML 20	7.39	4.92	2.83	5.29	5.67	5.22
12	BML 30 F	6.87	5.69	2.00	4.83	7.29	5.34
13	BML 32-2	5.69	5.23	1.83	1.00	5.80	3.91
14	BML 41	6.87	5.00	2.50	5.50	6.17	5.21
15	BML 45	3.95	6.12	4.83	4.89	4.96	4.95
16	BML 51	6.02	5.33	5.44	5.14	5.67	5.52
17	BML 80	7.07	5.07	5.36	5.87	5.25	5.72
18	BML 90	7.35	5.42	1.00	5.17	5.17	4.82
19	CM 104	6.58	4.08	5.13	6.22	4.63	5.33
20	CM 105	6.83	3.67	5.11	6.17	6.75	5.71
21	CM 114	5.15	5.33	6.43	5.63	6.17	5.74
22	CM 115	7.50	5.00	5.75	4.17	4.25	5.33
23	CM 131	6.29	5.58	6.33	1.00	4.17	4.68
24	CM 132	7.13	6.88	1.00	1.00	3.83	3.97
25	CM 201	3.87	6.54	1.00	3.58	3.00	3.60
26	CM 202	3.52	4.42	5.50	3.89	4.38	4.34
27	CM 209	6.54	5.33	6.08	4.42	6.33	5.74
28	V6 32-154	5.08	6.33	5.17	5.44	4.33	5.27
29	3070	6.80	6.42	5.70	6.56	7.43	6.58
30	Z63-45	5.88	6.54	5.78	5.78	6.17	6.03
31	5125	6.47	5.72	6.61	4.00	5.50	5.66
32	5063	6.72	5.39	6.08	4.50	6.33	5.81
33	1235-1	4.48	6.92	6.00	5.67	4.33	5.48
34	3122	4.67	5.97	6.17	5.90	6.67	5.87
	SEd	0.220	0.216	0.539	0.239	0.247	0.170
	CD at 5%	0.449	0.441	1.102	0.489	0.504	0.348
	CV%	3.737	3.970	13.530	5.907	4.858	3.488

Table 7b. Categorization of genotypes based on damage score b (mean of three years)

S. No.	Injury rating	Categorization	Name of inbreds	No. of inbreds
1	1-3.0	Resistant	-	Nil
2	3.1 – 5.0	Moderately Resistant	BML 2, BML 5, BML 6, BML 7, BML 8, BML 10, BML 11, BML 13, BML 32-2, BML 45, BML 90, CM 131, CM 132, CM 201, CM202	15
3	5.1 – 7.0	Susceptible	BML 14, BML15, BML 20, BML 30F, BML 41, BML 51, BML 80,CM 104, CM 105, CM 114, CM 115, CM 209, V6 32-154, 3070, Z63-45, 5125,5063, 1235-1, 3122	19
4	7.1 – 9.0	Highly susceptible	-	NIl

Table 8. FAW reaction against promising genotypes

S. No	Name of the inbred	2021 *Kharif*		2021-22 *Rabi*		2022 *Kharif*		Mean of three seasons	
1	BML 2	3.06	MR	3.49	MR	3.28	MR	3.24	MR
2	BML 5	3.11	MR	3.59	MR	3.42	MR	3.37	MR
3	BML 6	3.66	MR	4.47	MR	3.93	MR	4.02	MR
4	BML 7	3.35	MR	3.57	MR	3.20	MR	3.37	MR
5	BML 8	3.06	MR	3.83	MR	3.58	MR	3.49	MR
6	BML 10	3.91	MR	4.39	MR	3.72	MR	4.01	MR
7	BML 11	3.13	MR	3.75	MR	3.16	MR	3.34	MR
8	BML 13	4.45	MR	4.75	MR	3.83	MR	4.34	MR
9	BML 14	5.65	S	5.87	S	5.25	S	5.59	S
10	BML 15	5.38	S	5.53	S	5.80	S	5.57	S
11	BML 20	4.94	MR	5.42	S	5.30	S	5.22	S
12	BML 30 F	5.30	S	5.54	S	5.17	S	5.34	S
13	BML 32-2	3.81	MR	4.15	MR	3.78	MR	3.91	MR
14	BML 41	5.15	S	5.35	S	5.12	S	5.21	S
15	BML 45	4.93	MR	5.25	S	4.67	MR	4.95	MR
16	BML 51	5.51	S	5.81	S	5.24	S	5.52	S
17	BML 80	5.81	S	6.00	S	5.35	S	5.72	S
18	BML 90	4.90	MR	5.28	S	4.27	MR	4.82	MR
19	CM 104	5.25	S	5.63	S	4.98	MR	5.33	S
20	CM 105	5.82	S	6.25	S	5.04	S	5.71	S
21	CM 114	5.78	S	6.15	S	5.30	S	5.74	S
22	CM 115	5.40	S	5.83	S	4.77	MR	5.33	S
23	CM 131	4.80	MR	5.18	S	4.05	MR	4.68	MR
24	CM 132	4.03	MR	4.40	MR	3.48	MR	3.97	MR
25	CM 201	3.59	MR	4.01	MR	3.20	MR	3.60	MR
26	CM 202	4.41	MR	4.85	MR	3.76	MR	4.34	MR
27	CM 209	5.84	S	6.09	S	5.29	S	5.74	S
28	V6 32-154	5.21	S	5.55	S	4.96	MR	5.27	S
29	3070	6.78	S	7.01	S	5.95	S	6.58	S
30	Z63-45	6.21	S	6.47	S	5.40	S	6.03	S
31	5125	5.86	S	6.07	S	4.92	MR	5.66	S
32	5063	5.90	S	6.20	S	5.32	S	5.81	S
33	1235-1	5.52	S	5.79	S	5.12	S	5.48	S
34	3122	5.99	S	6.21	S	5.42	S	5.87	S
	SEd	0.132		0.182		0.148		0.170	
	CD at 5%	0.270		0.372		0.302		0.348	
	CV%	2.719		3.48		3.452		3.488	

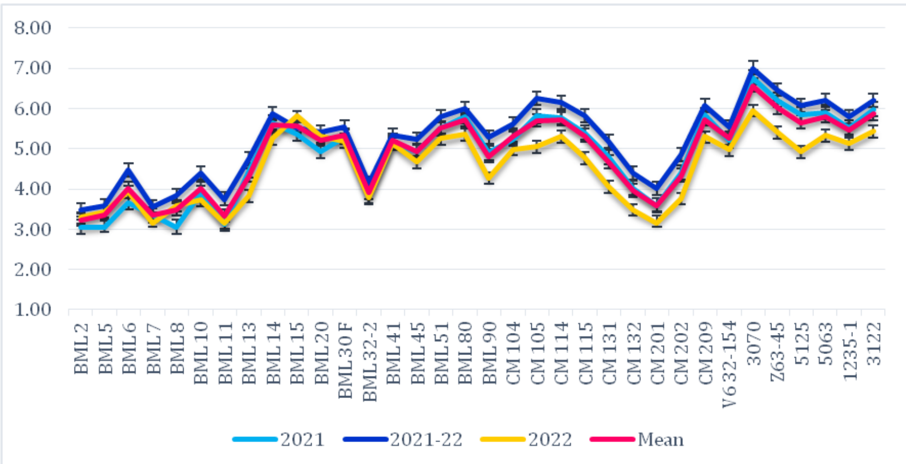

Fig. 7. FAW reaction against promising genotypes

4. CONCLUSION

15 genotypes that recorded moderate resistant will assist plant breeders in undertaking controlled resistance screening and enhance breeding efforts. The study also identified candidate maize genotypes to validate of FAW resistance and other farmer-preferred traits under field conditions of FAW infestation. Subsequently, these genotypes can be used to develop suitable germplasm to be incorporated in the development of a coherent IPM program for FAW management in India and similar tropical agro ecologies.

DATA AVAILABILITY STATEMENT

The data sets generated during and/or analysed during the current study are available with the corresponding author on reasonable request.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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