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Evaluation of maize germplasm for physio-morphological traits against fall armyworm

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Abstract

The fall armyworm (FAW), scientific name *Spodoptera frugiperda* (J.E. Smith), poses a significant challenge to farmers and agricultural systems due to its ability to adapt, reproduce rapidly, and develop resistance to pesticides. Hence, it is essential to adopt effective and feasible approaches to managing FAW. The present research aimed at identifying the physio-morphological traits in 22 diverse maize genotypes that influence resistance to FAW. Among the tested ones, moderately resistant genotypes had the highest trichome density (CML 71, CML 67, and CML 335), minimum leaf area, and leaf width (DMRE 63, CML 71, and CML 67). Moderately resistant genotypes, *viz.*, CML 67 (0.14 mm), CML 71 (0.14 mm), CML 561 (0.14 mm), and DMRE 63 (0.14 mm), exhibited significantly higher leaf toughness. Furthermore, the lowest relative water content was recorded in moderately resistant genotypes (DMRE 63, CML 71, and CML 67). The maximum cob length was observed in the moderately resistant genotype, CML 71 (18.56 cm), followed by CML 67 (18.26 cm), which was on par. Among moderately resistant genotypes, CML 71 had the greatest cob width of 4.97 cm, followed by CML 67 (4.88 cm), CML 561 (4.66 cm), CML 335 (4.66 cm), and DMRE 63 (4.62 cm), and these were statistically comparable. Of the genotypes evaluated, the moderately resistant genotypes CML 71, CML 67, and DMRE 63 registered significantly higher yields of 135.04 g/plant, 120.65 g/plant, and 117.92 g/plant, respectively. This information on physio-morphological traits is helpful in breeding programs focusing on maize resistance to FAW.

Keywords leaf area, leaf length, leaf width, leaf trichomes, resistant cultivars, relative water content

Introduction

Maize (*Zea mays* L.) is one of the most widely cultivated and economically significant cereal crops in the world [1]. It belongs to the grass family Poaceae. Originating in Central America thousands of years ago, maize has become a staple food crop in many parts of the world. India ranks 4th in area and 7th in production among nations cultivating maize. *Spodoptera frugiperda*, a new invasive and devastating polyphagous pest that feeds on more than 350 plant species, is responsible for as much as 33% of the reduction in yield in maize [2]. FAW causes damage from the seedling to the ear development stage [3]. Due to the excessive and indiscriminate application of synthetic insecticides, there is a problem with the development of pest resistance and pest outbreaks. The use of resistant cultivars is a cost-effective, safe, and sustainable strategy to lessen damage and the danger of pesticide-related issues.

Physio-morphological traits impart resistance/tolerance against feeding and oviposition by the FAW. Therefore, the present study aims to identify physio-morphological traits of maize genotypes that influence resistance to FAW incidence.

Methodology

Experimental area

During Kharif 2021, this research was carried out at the Winter Nursery Centre, ICAR-IIMR, Rajendranagar. The average annual rainfall ranges from 606 to 853 mm, with most of it falling during the South-West monsoon. A total of 22 diverse maize genotypes were grown with a 60 cm x 20 cm spacing. The physio-morphological traits were recorded for all the tested genotypes and the data was analyzed using one-way ANOVA (Randomized block design). The R-statistical program was used for comparing the differences using Duncan's Multiple Range Test. Furthermore, the infestation of FAW was correlated to various physiological and morphological traits to find out the relationship among the weather parameters.

Physio-morphological traits

All the leaf morphometric traits of maize genotypes were measured at the V_6-V_8 phenological stage. Leaf length (cm) and leaf width (cm) were measured using a 30 cm plastic measuring scale. For each genotype, five observations were recorded. The trichome density is counted from the first completely opened leaf, which was cut into 1 cm^2 leaf bits from three portions of the leaf, *i.e*., the top, middle, and bottom. A stereo-zoom microscope (ZEISS, Model-ISH 500) was used to count trichomes on the cut central leaf lamina. The average number of trichomes per square cm was computed. The leaf length was recorded from the base to the tip of the first completely opened leaf. The leaf width measurement was taken from the middle section of the leaf. Leaf thickness (mm) was recorded using a vernier caliper (PRECISION MEASURING-150mm/6″) and quantified in millimeters. The center area of the whorl of each genotype was taken, and the leaf area (cm^2) was measured with the help of a handheld leaf area-metre (CI-203, laser-based). Using a scale, the cob length (cm) was measured during the harvesting stage. Five plants were chosen at random from each genotype. During the harvesting stage, the width (cm) was measured from the middle portion of the cob using a scale. From each genotype, five plants were chosen randomly. Further, the grain yield per plant (g/plant) was weighed as total grains collected from five randomly selected plants from each genotype.

Relative water content (RWC)

The RWC of 22 maize genotypes was analyzed according to Barrs and Weatherley's [4] method. Physiologically functional leaves at the V_6-V_8 leaf stage of each genotype were chosen and cut into small pieces. These pieces were weighed to ascertain the fresh weight of the leaves. Later, it was allowed to float in 10 mL of water for 6 hours to acquire turgidity. The leaf fragments were then put on blotting paper to remove the moisture content. The leaf bits were then weighed and the turgid weight was recorded. Then the leaves were allowed to dry in a hot air oven (24 hours @70°C), and finally, the dry weight of the leaf pieces was measured. Five observations were recorded for each genotype. The obtained data were used to calibrate the RWC and the following formula was used to calculate the RWC:

$$\text{RWC (\%)} = \frac{(\text{Fresh weight} - \text{Dry weight})}{(\text{Turgid weight} - \text{Dry weight})} \text{ X } 100$$

Results and Discussion

The current research showed a significant difference in various physio-morphological traits among the tested genotypes. Earlier, the genotypes selected for the present study were screened against FAW under artificial infestation. The genotypes such as CML 71, CML 67, DMRE 63, CML 561, AEBY-1, CML 335, CML 345, and CML 337 were classified as moderately resistant since they had a mean leaf damage score of greater than 3.00 and less than 5.00 [5]. The higher damage scores were reported in the genotypes ENT 2-3, MIL-1-11, CML 334 (5.50), CML 336 (5.61), BML 7 (5.78), CML 139 (5.85), CML 338, CM 500, CML 144, BML 6, AEBY 5-34-1, CML 330, CM 400, and CM 501, which were grouped under susceptible, and their leaf damage score ranges from 5.00 to 7.00.

Physio-morphological traits of the maize genotypes

The results of the different physio-morphological traits are presented in Table 1.

Table 1. Physio-morphological traits of different maize genotypes

SN.	Genotypes	Trichome density per cm^2 of leaf area	Leaf width (cm)	Leaf thickness (mm)	Leaf length (cm)	Leaf area (cm)	Relative water content (%)	Grain yield per plant (g)	Cob length (cm)	Cob width (cm)
1	CML 335	207.20^{b}	4.63^{fg}	0.10^{bc}	47.48^{de}	144.26^{hi}	60.41^{ghij}	123.14^{b}	16.06^{bc}	4.66^{abc}
2	BML 6	73.13^{kl}	5.58^{bc}	0.08^{d}	43.44^{efg}	187.50^{d}	75.91^{ab}	44.94^{i}	12.55^{gh}	3.48^{fg}
3	CML 330	111.07^{ef}	5.54^{bc}	0.10^{bc}	51.40^{bcd}	180.23^{de}	71.37^{abcde}	48.93^{hi}	12.22^{gh}	3.47^{fg}
4	CML 337	90.27^{hij}	4.86^{ef}	0.11^{b}	47.84^{cde}	163.02^{f}	62.52^{fghi}	72.77^{d}	13.48^{fgh}	3.94^{de}
5	AEBYC5-34-1	96.33^{fghi}	5.44^{bcd}	0.10^{bc}	41.42^{fgh}	182.06^{de}	78.33^{a}	49.21^{ghi}	11.90^{h}	3.40^{g}
6	CML 334	115.13^{e}	4.92^{def}	0.11^{b}	53.06^{b}	176.92^{e}	62.31^{fghi}	50.10^{ghi}	14.20^{def}	3.85^{defg}
7	CML 561	190.40^{c}	4.47^{fgh}	0.14^{a}	69.62^{a}	159.00^{f}	58.91^{ghij}	120.02^{b}	17.44^{ab}	4.66^{abc}
8	CML 67	277.40^{a}	4.06^{h}	0.14^{a}	38.36^{h}	143.66^{hi}	55.95^{ij}	120.65^{b}	18.26^{a}	4.88^{ab}
9	ENT 2-3	110.00^{ef}	4.86^{ef}	0.10^{bc}	54.18^{b}	164.10^{f}	65.41^{defg}	62.66^{ef}	12.66^{fgh}	3.86^{def}
10	AEBY 1	185.00^{c}	4.50^{fgh}	0.11^{b}	46.40^{def}	149.76^{gh}	58.36^{hij}	117.17^{b}	15.88^{c}	4.49^{bc}
11	CM 500	99.00^{fghi}	5.77^{b}	0.09^{cd}	55.84^{b}	184.46^{de}	74.97^{abc}	52.74^{ghi}	13.40^{fgh}	3.47^{fg}
12	CML 345	77.53^{jk}	4.48^{fgh}	0.09^{cd}	39.34^{gh}	157.73^{fg}	61.81^{ghij}	86.98^{c}	15.26^{cd}	4.29^{cd}
13	CML 336	119.07^{e}	5.14^{cde}	0.11^{b}	53.36^{b}	160.10^{f}	68.65^{cdef}	54.46^{fghi}	13.64^{efg}	3.87^{def}
14	CML 71	211.40^{b}	4.13^{gh}	0.14^{a}	50.80^{bcd}	140.00^{i}	57.38^{ij}	135.04^{a}	18.56^{a}	4.97^{a}
15	BML 7	100.53^{fgh}	5.16^{cde}	0.10^{bc}	46.66^{de}	175.90^{e}	70.39^{bcde}	58.59^{fg}	13.46^{fgh}	3.68^{efg}
16	CM 400	99.27^{fghi}	5.66^{bc}	0.09^{cd}	55.86^{b}	215.06^{b}	75.95^{ab}	58.23^{fgh}	13.72^{efg}	3.49^{efg}
17	MIL-1-11	84.93^{ijk}	6.24^{a}	0.14^{a}	66.02^{b}	275.42^{a}	64.83^{efgh}	68.38^{de}	15.06^{cde}	4.23^{cd}
18	CM 501	96.80^{fghi}	5.42^{bcd}	0.10^{bc}	45.20^{ef}	177.70^{e}	76.42^{ab}	46.12^{i}	13.04^{fgh}	3.45^{fg}
19	CML 338	62.07^{l}	5.33^{bcde}	0.10^{bc}	44.70^{ef}	176.92^{e}	74.39^{abc}	53.43^{fghi}	13.84^{defg}	3.72^{efg}
20	CML 144	93.87^{ghi}	5.18^{cde}	0.09^{cd}	55.12^{b}	219.00^{b}	71.78^{abcd}	52.25^{ghi}	12.92^{fgh}	3.49^{efg}
21	DMRE 63	154.73^{d}	3.4^{i}	0.14^{a}	29.32^{i}	89.20^{j}	55.10^{j}	117.92^{b}	16.24^{bc}	4.62^{abc}
22	CML 139	106.20^{efg}	5.57^{bc}	0.10^{bc}	52.66^{bc}	198.82^{c}	72.01^{abcd}	48.17^{i}	12.92^{fgh}	3.56^{efg}
SE.m ±		4.43	0.15	0.004	1.57	5.27	2.06	2.84	0.47	0.13
CD @5%		13.12	0.46	0.01	4.65	15.60	6.11	8.43	1.39	0.39
CV (%)		4.99	4.43	4.59	4.49	4.29	4.36	5.39	4.64	4.72

Mean Values in each column followed by the same letter do not differ significantly by DMRT (p=0.05)

Leaf traits

There was a significant variation in different leaf traits among the tested genotypes at the V6-V8 phenological stage. The trichome density ranged from 62.07 (CML 338) to 277.40 (CML 67) among the tested genotypes. The density of trichomes was significantly greater in most of the moderately resistant genotypes, such as CML 67 (277.40), CML 71 (211.40), CML 335 (207.20), CML 561 (190.40), and DMRE 63 (154.73) (Table 1), while the susceptible genotypes, namely, AEBYC5-34-1 (96.33), BML 6 (73.13) and CM 400 (99.27), showed a significantly lower trichome density. In the present study, a strong negative correlation (r= -0.709***) was identified between the density of leaf trichomes and the FAW leaf damage score (Table 2). These findings align with prior research by Abdalla and Raguraman [6], who reported a noteworthy negative correlation (r= -0.684) between leaf trichomes and stem borer-induced damage in maize. Consistent with these results, Ali et al., [7] emphasized the significant role of trichome density in providing resistance to stem borer in maize, reporting a correlation value of (r= -0.866), thus supporting the present study's conclusions.

Table 2 Correlation between various physiological-morphological traits of maize genotypes and FAW leaf damage

SN.	Plant parameters	Correlation coefficient value (r)
1	Trichome density	-0.709***
2	Leaf thickness	-0.642***
3	Relative water content	0.955***
4	Leaf area	0.614***
5	Leaf width	0.829***
6	Leaf length	0.195
7	Cob length	-0.767***
8	Cob width	-0.848***
9	Grain yield per plant	-0.876***

*** Indicates correlation is significant at 1% (p= 0.01); N= 22; r = correlation coefficient; Table r value at 1% = 0.360

The outcome of the current work revealed that as the number of trichomes in a leaf increases, the leaf damage by FAW decreases and vice-versa. The mean leaf width (LW) varied from 3.40 cm (DMRE 63) to 6.24 cm (MIL-1-11) among the tested genotypes. Most of the moderately resistant genotypes, namely, DMRE 63 (3.40 cm), CML 71 (4.13 cm), CML 67 (4.06 cm), CML 561 (4.47 cm) and CML 345 (4.48 cm), had the lowest LW. However, in some of the moderately resistant genotypes, namely MIL-1-11 (6.24 cm), CM 500 (5.77 cm), CML 139 (5.57 cm), CML 330 (5.54 cm), CM 501 (5.42 cm) and CML 338 (5.33 cm), maximum LW was observed. Genotypes CM 400 (5.66 cm), BML 6 (5.58 cm), and AEBYC5-34-1 (5.44 cm) had maximum LW which were classified as susceptible based on LDR.

In the present study, there was a significant positive correlation between LW and FAW leaf feeding (r= 0.829***) (Table 2). Studies conducted by Kulkarni et al., [8] confirmed that LW and *C. partellus* infestation were significant and positively correlated (r= 0.790**) at 30 days after sowing. The present findings are in accordance with the outcomes of Rakesh et al., [9], where the correlation between LW and yellow stemborer was positive and significant (r= 0.194**). This could be due to increased LW, which might offer a greater surface area for FAW to oviposit and feed. Hence, the FAW larvae infestation was more on the genotypes with wider leaves. The leaf thickness (LT) varied from 0.08 mm (BML 6) to 0.14 mm (CML 67) among the tested genotypes. The moderately resistant genotypes, viz., CML 67 (0.14 mm), CML 71 (0.14 mm), CML 561 (0.14 mm), and DMRE 63 (0.14 mm), exhibited a significantly higher leaf. A considerable, lower thickness of the leaf was noticed in susceptible genotypes, viz., BML 6 (0.08 mm), CM 400 (0.09 mm), and AEBYC5-34-1 (0.10 mm).

The present investigation showed that there was a significant negative correlation between LT and leaf feeding by FAW (r= -0.642***) (Table 2). The present findings are in line with the results of Williams et al., [10], who observed that resistant genotypes (Mp 704 X Mp 707 and Mp 704 X Mp 708) exhibited significantly thicker leaves (5.5µm and 5.6µm) compared to susceptible genotypes when evaluated against the FAW. Bergvinson et al., [11] reported similar results, demonstrating a significant inverse correlation between LT and the damage inflicted by *O. nubilalis* at the mid-whorl stage. So, it can be inferred that an increase in LT minimizes FAW leaf damage by interfering with feeding. An increase in LT could damage the mandibles of the larvae. The leaf length (LL) of tested genotypes extended from 29.32 cm (DMRE 63) to 69.62 cm (CML 561). The shortest leaf length was observed in DMRE 63 (29.32 cm), followed by CML 67 (38.36 cm) and CML 345 (39.34 cm).

The highest LL was reported in CML 561 (69.62 cm), followed by MIL-1-11 (66.02 cm). In the other genotypes, the leaf length varies between 41.42 cm in AEBYC5-34-1 and 55.86 cm in CM 400. From the current results, it was observed that there was a slightly positive (r= 0.195) but non-significant correlation between the leaf damage caused by FAW and LL (Table 2). LL does not appear to play a significant role in conferring resistance to FAW, as the pest is predominantly observed in the whorl and foliar regions.

The leaf area (LA) among the tested genotypes ranged from 89.20 cm (DMRE 63) to 275.42 cm (MIL-1-11). Most of the moderately resistant genotypes, such as DMRE 63 (89.20 cm), CML 71 (140.00 cm), CML 67 (143.66 cm), CML 335 (144.26 cm), CML 345 (157.73 cm), and CML 561 (159.00 cm), recorded the significantly lowest LA except MIL-1-11 (275.42 cm), CML 144 (219.00 cm), CML 139 (198.82 cm), CM 500 (184.46 cm), CML 330 (180.23 cm), CML 338 (176.92 cm), BML 7 (175.90 cm) and CM 501 (177.70 cm). The susceptible genotypes namely, CM 400 (215.06 cm), BML 6 (187.50 cm), and AEBYC5-34-1 (182.06 cm), had greater LA except AEBY 1 (149.76 cm).

The correlation between LA and leaf damage was found to be significant and positive (r= 0.614***) (Table 2). Jinsa et al., [12] reported a positive correlation between *S. litura* larval density and the LA 60 days after sowing in soybean (r= 0.777). The current results are in line with the outcome of Jinsa et al., [12], who noticed that larval density of *T. orichalcea* and LA were positively correlated at 60 days after sowing in soyabean (r= 0.527). One of the possible reasons might be that increased LA provides a site for oviposition, colonization, and feeding.

Relative water content of leaves

The RWC among the tested genotypes ranged from 55.10% (DMRE 63) to 78.33% (AEBYC5-34-1). DMRE 63 had a significantly lower RWC of 55.10% in leaves, followed by CML 67 (55.95%), CML 71 (57.38%), AEBY 1 (58.36%), CML 561 (58.91%), CML 335 (60.41%), and CML 345 (61.81%). The maximum RWC was recorded in susceptible genotypes AEBYC5-34-1 (78.33%), followed by CM 501 (76.42%), CM 400 (75.95%), BML 6 (75.91%), CM 500 (74.97%), CML 338 (74.39%), CML 139 (72.01%), CML 144 (71.78%) and CML 330 (71.37%). As per the current research, the correlation between FAW leaf damage and the RWC of leaves was shown to be highly positively correlated (r= 0.955***) (Table 2). The current results are in line with Mohammad Saleem et al., [13], who recorded that the susceptible genotype, JL 24, (73.3%), had a significantly higher RWC. While the resistant genotype ICG 928 (54.2%) was found to have a lesser RWC. Experiments by Jinsa et al., [12] revealed that there was a strong positive correlation between leaf succulency and larval density of *S. litura* and *T. orichalcea* (r= 0.744 and 0.809). According to the information stated above, the increased RWC in leaves renders the plant succulent, making it susceptible to FAW damage. This could be attributed to the tenderness, softness, and juiciness of the leaves, which make the plant more palatable and tastier for feeding by the FAW.

Cob length (CL)

Cob length varied significantly between maize genotypes evaluated for resistance against FAW. The genotypes assessed showed CL ranging from 11.90 cm to 18.56 cm. The maximum CL was observed in the moderately resistant genotype, CML 71 (18.56 cm), followed by CML 67 (18.26 cm), which was on par. The next best genotypes with higher CL were CML 561 (17.44 cm), DMRE 63 (16.24 cm), CML 335 (16.06 cm), AEBY 1 (15.88 cm), and CML 345 (15.26 cm). The susceptible genotypes, namely, AEBYC5-34-1 (11.90 cm), CML 330 (12.22 cm), BML 6, (12.55 cm), ENT 2-3 (12.66 cm), CML 139 (12.92 cm), CML 144 (12.92 cm), CM 501 (13.04 cm), CM 500 (13.40 cm), and BML 7 (13.46 cm), had significantly shorter CL. As per the results, moderately resistant genotypes had a much greater CL than susceptible lines. From the current findings, CL was significantly and negatively correlated with the FAW leaf damage score (r= -0.655***) (Table 2). In accordance with the findings of Rasool et al., [14], the present study reveals a significant negative correlation (r= -0.767) between CL and the leaf damage caused by FAW. Shah et al., [15] also reported the negatively correlated significant association of CL with various insect pests of maize, which supports the current findings. They recorded the significantly lowest CL in a susceptible genotype, C-30M62 (24.81 cm). Resistant genotypes exhibit significantly longer CL compared to susceptible lines, attributed to the inherent mechanism of tolerance that enables plants to withstand pest attacks and promote normal growth. Resistant genotypes also demonstrate a higher rate of photosynthesis, contributing to an increased economic yield that shows a positive correlation with CL.

Cob width (CW)

There were significant differences among the maize genotypes in CW. The genotypes assessed showed CW ranging from 3.40 cm to 4.97 cm. CML 71, a moderately resistant genotype, had the greatest CW of 4.97 cm, followed by CML 67 (4.88 cm), CML 561 (4.66 cm), CML 335 (4.66 cm), and DMRE 63 (4.62 cm), and these were statistically comparable. The CW was much lower in susceptible genotypes, namely AEBYC5-34-1 (3.40 cm), CM 501 (3.45 cm), CM 500 (3.47 cm), CML 330 (3.47 cm), BML 6 (3.48 cm), CM 400 (3.49 cm), CML 144 (3.49 cm), CML 139 (3.56 cm), BML 7 (3.68 cm), CML 338 (3.72 cm), and CML 334 (3.85 cm), which were statistically on par. In the remaining genotypes, the CW varied between 3.86 cm (ENT 2-3) and 4.49 cm (AEBY 1).

According to the results presented above, susceptible genotypes had the least CW, whereas moderately resistant genotypes were found to have a significantly higher CW. The present study showed a highly significant and negative correlation between (r= -0.848***) CW and FAW leaf damage score (Table 2). An increased infestation might have led to a reduced development of kernels in the cob. A wider cob resulting from well-developed kernels and a thick rind could act as a deterrent for the FAW. Hence, robust cobs exhibited a lower susceptibility to FAW damage, indicating a negative correlation between FAW infestation and CW.

Grain yield

The yield data of the selected genotypes varied between 44.94 g/plant (BML 6) and 135.04 g/plant (CML 71) (Table 1). Of the genotypes evaluated, the moderately resistant genotype CML 71 had a significantly higher yield of 135.04 g/plant, followed by CML 67 (120.65 g/plant) and DMRE 63 (117.92 g/plant). Significantly, the lowest yield was reported in susceptible genotypes, *viz*., BML 6 (44.94 g/plant) and AEBYC5-34-1 (49.21 g/plant). Matova et al., [16] reported that there was a significant negative correlation between grain yield and leaf damage by FAW at 12 weeks after crop emergence. Hence, an increase in FAW infestation reduces the grain yield. The current results showed that the FAW leaf damage score had a significant negative correlation with the yield of a plant (r= -0.876***) (Table 2). In the study by Somashekar [17], the partially resistant maize cultivar, P 3405, exhibited the greatest test weight at 30.22 g. This contrasts with the lower yield observed in the highly susceptible cultivar NK 6240, which produced 17.33 g, aligning with the current findings. Ali et al., [7] reported a significant negative correlation (r = -0.677) between the weight of 100 maize grains and *C. partellus* infestation. Greater FAW larval infestation was the main factor behind the reduced yield in susceptible genotypes. These larvae hinder photosynthesis by devouring foliage and also target tassels, silk, and developing cobs.

Conclusion

Among the nine characteristics examined, the ones that had a significant negative effect on FAW infestation were trichome density, leaf thickness, cob length, cob width, and grain yield. In contrast, a significant positive impact was seen for relative water content, leaf area, and leaf breadth. On the other hand, leaf length showed a non-significant positive influence on FAW infestation. The extent of leaf damage caused by FAW was significantly influenced by both the morphological and physiological traits of the plant. Further study is required to find and integrate various mechanisms into new cultivars. These maize genotypes can be suggested as promising sources for FAW resistance breeding. Developing superior maize cultivars cuts pesticide consumption, resulting in a reduced cost of cultivation.

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