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Research article

Insights into fall armyworm (*Spodoptera frugiperda*) biology and resistance mechanisms in dual-purpose maize inbred lines

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Abstract

The biology of fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) was studied on fodder maize cultivar African Tall under room temperature in 2023. The average incubation period was 2.29 ± 0.16 days and the larval duration was 12.95 ± 1.03 days. The larvae underwent five molts, resulting in six instars, and exhibited a total feeding period of 12 days. The pupal period averaged 7.62 ± 0.17 days for males and 8.29 ± 0.57 days for females. Longevity studies revealed that males lived an average of 7.52 ± 0.23 days with food, while females lived 9.65 ± 1.30 days; survival was significantly reduced in the absence of food. The average fecundity per female was 942.8 ± 90.28 eggs, with total life cycle durations of 33.20 ± 2.47 days for females and 30.38 ± 2.66 days for males. Morphometric measurements were also taken. The field experiment was conducted at Dharwad during *kharif* 2023 to screen 15 dual-purpose maize inbreds along with the cultivar African Tall against FAW. Three inbreds, *viz.*, C 79, PML 36 and PML 46, were categorized as resistant; ten inbreds, CDM 1330, PDI 639, PML 96, PDI 649, PDI 12, PML 105, DDM 2309, CML 565, C 46, PML 85 and African tall, as partially resistant and two inbreds, DDM 2207 and PML 93-2, as susceptible. The resistant inbreds exhibited the lowest larval populations and minimal leaf damage, apparently due to high trichome density, low total soluble sugar and high phenol content. Conversely, susceptible inbreds displayed the opposite biochemical and physical profiles.

Keywords: Biology, Dual-purpose maize, Fall armyworm, Fodder, Inbreds, Resistance, Screening

Introduction

Maize (*Zea mays* L.) is a crucial crop celebrated for its high yield and nutritional value, serving as an essential source of high-energy feed. Nonetheless, maize cultivation faces significant challenges from pests, particularly the fall armyworm (*Spodoptera frugiperda* (J.E. Smith)), which has recently been reported for the first time in Karnataka (Sharanabasappa *et al*., 2018). Seasonal incidence of this insect pest at Dharwad conditions on fodder maize was reported by Kulkarni *et al.* (2023). The rapid proliferation of this pest, coupled with its resistance to pesticides, accentuates the urgent need to investigate its biology in relation to fodder maize to ensure food security and mitigate economic losses within the livestock sector. The Indian agricultural production system is based on mixed farming, which includes crops and livestock. To meet the ever-increasing needs of the livestock population, the production and also the fodder productivity have to be increased (Chaudhary *et al*., 2012). Maize is an ideal fodder crop grown throughout the country. Screening for resistant fodder maize inbreds is crucial to combat alien insect pests such as the FAW. By prioritizing hybrids with good plant vigor and genetic resistance, farmers can enhance maize resilience, ensuring sustainable production and improving fodder availability for livestock, which ultimately contributes to agricultural stability. While extensive research has focused on screening single-purpose grain maize or fodder maize against FAW damage (Darshan *et al.*, 2024), a critical gap remains in evaluating dual-purpose inbreds. In single-purpose maize, moderate foliar damage can be economically tolerated if grain yield is preserved; however, in dual-purpose varieties, the foliage itself is a primary economic output utilized for livestock feed. Earlier, some efforts were made to screen dual-purpose maize inbreds against FAW (Ganavi *et al.*, 2024), but

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studies were restricted only to screening. However, this study highlights the imperative of screening dual-purpose inbreds to identify genotypes that maintain both grain yield and stover integrity under FAW pressure and physical and biochemical factors responsible for resistance. This is of paramount importance in the mixed crop-livestock farming systems of southern India, where dairy farming serves as an economic lifeline for smallholders, and where year-round maize cultivation sustains unrelenting FAW populations. Developing FAW-resistant dual-purpose maize is therefore essential not only for mitigating chemical pesticide residues in animal feed but also for ensuring the intertwined food and nutritional security of both human and livestock populations in the region. Hence, in the present study, we screened dual-purpose inbred lines against FAW to identify resistant genotypes and dissect the biochemical and biophysical factors driving their defense.

Material and Methods

Location and experiment site: The biology of *Spodoptera frugiperda* was studied in the Entomology Laboratory, College of Agriculture, Dharwad, during 2023 on the fodder maize cultivar African Tall under room temperature. A nucleus culture was initiated using egg masses collected from fodder maize fields at ICAR-IGFRI and reared on fresh African Tall leaves. After pupation in sand, adults were allowed to mate in cages and fed with 10% honey solution, and eggs obtained were used for further studies (Plate 1).

Observations included incubation period (50 eggs), larval instars and duration (based on exuviae), pupal period (20 pupae), adult longevity (10 pairs), fecundity (10 females), and total life cycle. Morphometric measurements of different life stages were also recorded using a binocular microscope. Larvae were reared individually in vials and fed African Tall leaves throughout development.

Screening of dual-purpose maize inbreds: The experiment was conducted at ICAR-IARI, Regional Research Center, Dharwad, during kharif 2023 in a Randomized Complete Block Design (RCBD) with two replications. Fifteen dual-purpose maize inbreds were evaluated along with African Tall as the check. Each entry was sown in a 4 m row length with a spacing of 45 × 15 cm. Treatments were randomized within each replication and no plant protection measures were applied to allow natural FAW infestation.

Statistical analysis: Data were analyzed using ANOVA for RCBD using OPSTAT software (Sheoran *et al*., 2003). Treatment means were compared using Duncan's Multiple Range Test (DMRT) at a 5% level of significance ($p \leq 0.05$). SEM ± and CD values were calculated, and means followed by the same letter(s) are not significantly different as per DMRT (Duncan, 1955).

Larval population and foliar damage of *Spodoptera frugiperda* were recorded using the Davis and Williams (1992) scale modified by CIMMYT at 20, 30, 40, 50 and 60 days after sowing (DAS). Inbreds were categorized as resistant, partially resistant, susceptible and highly susceptible based on leaf damage at 40 DAS, which corresponds to the most suitable whorl stage for FAW assessment.

Fifteen dual-purpose maize inbreds, *viz*., CDM 1330, PDI 639, PML 93-2, PML 96, DDM 2207, PDI 649, PDI 12, C 79, PML 36, PML 105, DDM 2309, PML 46, CML 565, C 46, and PML 85, were used to screen against FAW and to study the mechanism of tolerance. African Tall was used as a check variety. The inbreds were obtained from ICAR-IARI, Regional Research Center, Dharwad. The check variety African Tall was sourced from IGFRI, Dharwad.

Parameters observed: Larval counts, leaf damage scores, and yield parameters were recorded to assess plant health and productivity. Observations were taken from five randomly selected plants per inbred at 10-day intervals starting from 20 DAS. Green fodder yield (GFY) and Dry fodder yield (DFY) were recorded in t/ha for each inbred line.

Leaf thickness: The leaf thickness was measured using a veneer caliper. Leaves from the top, middle and bottom canopies of two plants from each inbred in the field were selected. The sample leaf was placed between the two measuring jaws of the caliper by adjusting the screw and the resultant reading was recorded. The mean leaf thickness was calculated and expressed in millimeters (mm).

Trichome density: The leaves were collected from the top, middle and bottom canopies of two plants from each inbred in the field. In the laboratory, an incision of one square centimeter was made using fine sterilized scissors on the collected leaf sample. Macro hairs were counted by observing the cut area of the central lamina under a binocular microscope. The count was expressed as the mean number of trichomes per square centimeter.

Total phenol content estimation: Total phenolic content in leaf samples was estimated using the Folin–Ciocalteu method as described by Bray and Thorpe (1954). Plant samples were extracted in alcohol and the resulting extracts were used for analysis. The extract was reacted with Folin–Ciocalteu reagent under alkaline conditions using sodium carbonate solution, leading to the formation of a blue-coloured complex. The color intensity was measured using a spectrophotometer at 650 nm after appropriate dilution.

Quantification of phenols was performed using a standard calibration curve prepared with catechol. The phenolic content of each sample was calculated from the standard curve and expressed as mg catechol equivalents per gram of sample. All estimations were carried out in replicates and mean values were used for statistical analysis.

Total soluble sugars (TSS): The concentrations of total soluble sugars were measured using a hand refractometer (Somogyi, 1952). The instrument was calibrated initially by using distilled water, where it showed the TSS reading as zero. The plant samples collected were digested in a mortar with a pestle and the resulting plant extract was filtered through muslin cloth. A single drop of plant extract was kept on the optical disc area of the refractometer. After placing a cover on the disc area, the TSS readings were recorded by observing through the lens of a hand refractometer. The TSS was calculated and expressed in degree brix.

Results and Discussion

Biology of Spodoptera frugiperda: Biology of fall armyworm, *Spodoptera frugiperda,* reared on fodder maize leaves is given in Table 1 & Plate 1. Different life stages of the fall armyworm are shown in Plate 2. The incubation period of *S. frugiperda* on fodder maize ranged from 2.0–2.5 days with a mean of 2.29 ± 0.16 days, showing dome-shaped egg clusters consistent with Prasanna *et al*. (2018). The larval period ranged from 11.5 to 14.0 days with six instars, and developmental trends agreed with Igyuve *et al*. (2018), with progressive head capsule growth confirming normal development. The pupal period ranged from 6-9 days, with females showing a slightly longer duration than males, in agreement with Kalyan *et al*. (2020). Female pupae were also larger than male pupae. Adult longevity was higher in females than in males and increased with food availability, indicating its role in survival and reproduction. Fecundity ranged from 850 to 1064 eggs per female with a mean of 942.8 ± 90.28, consistent with Sharanabasappa *et al*. (2018). The total life cycle ranged from 28 to 38 days, being slightly longer in females. Overall, the biological parameters recorded were in close agreement with earlier reports on FAW in maize, confirming its typical developmental pattern.

Morphometric studies: Morphometric studies of different larval instars of *Spodoptera frugiperda* on fodder maize leaves are given in Table 2a. The first instar is small and pale green to yellow, with an average duration of 2.15 ± 0.35 days, measuring 1.45 ± 0.15 mm in length. The morphometric measurements of first to sixth instar head capsule length and head capsule width of all six instars were 0.33, 0.52, 0.79, 1.15, 1.89 and 2.29 mm, respectively and 0.35, 0.63, 0.84, 1.35, 2.04, and 2.64 mm, respectively (Table 2b & Plate 3). The present research findings corroborate those of Igyuve *et al.* (2018) and Prasanna *et al*. (2018), who noticed that the development times of FAW from I to VI larval instars were 3.3, 1.7, 1.5, 1.5, 2.0 and 3.7 days, respectively. The pupal length of fall armyworm of male varied from 14.98-16.33 mm with an average of 15.47 ± 0.37 mm, and the pupal length of the female fall armyworm varied from 17.35 to 17.95 mm with an average of 17.54 ± 0.25 mm. The pupillary width of males varied from 3.01 to 3.54 mm with an average of 3.22 ± 0.19 mm and the pupal width of females varied from 4.10 to 4.42 mm with an average of 4.21 ± 0.13 mm (Plate 4 & Table 2b). The present investigations are in support of the findings of Kalyan *et al.* (2020), who reported that the mean pupal duration of fall armyworm, *S. frugiperda,* on maize crop was found to be 8.96 days. The adult female lays eggs on the lower side of the leaf and even on the upper side of the leaf in the cluster. The eggs ranged from 850.00 to 1064.00 eggs by a single fall armyworm female adult moth, with an average of 942.8 ± 90.28 eggs (Table 2a).

Table 1. Biology of fall armyworm, *Spodoptera frugiperda* reared on fodder maize leaves

Insect stages	Duration (days)	
	Mean ± SD (Days)	**Range (Days)**
*Incubation period	2.29 ± 0.16	2.0-2.5
*Total Larval period	12.95 ± 1.03	11.5-14
Larval instars		
I	2.15 ± 0.35	2.00-2.50
II	1.98 ± 0.36	1.50-2.50
III	1.42 ± 0.41	1.00-2.00
IV	1.44 ± 0.41	1.00-2.00
V	2.67 ± 0.19	2.00-3.00
VI	3.28 ± 0.77	3.00 – 4.50
**Pupal period		
Male	7.62 ± 0.17	6.0 - 8.0
Female	8.29 ± 0.57	7.00 - 9.00
**Adult longevity with food		
Male	7.52 ± 0.23	7.00-9.00
Female	9.65 ± 1.30	8.00-11.00
**Adult longevity without food		
Male	3.20 ± 0.54	2.50-4.00
Female	4.45 ± 0.43	4.00-6.00
**Fecundity/female (number)	942.8 ± 90.28	850.00-1064.00
**Total life cycle		
Male	30.38 ± 2.66	28.00-36.00
Female	33.20 ± 2.47	30.00-38.00

Table 2a. Morphometrics of different larval instars of *Spodoptera frugiperda* on fodder maize leaves

Sl. No.	Stages	Head capsule length (mm)		Head capsule width (mm)	
		Mean ± SD	Range	Mean ± SD	Range
1	I instar	0.33 ± 0.12	0.20-0.56	0.35 ± 0.11	0.22-0.48
2	II instar	0.52 ± 0.14	0.45-0.69	0.63 ± 0.15	0.45-0.82
3	III instar	0.79 ± 0.11	0.62-0.95	0.84 ± 0.16	0.62-1.17
4	IV instar	1.15 ± 0.10	1.00-1.54	1.35 ± 0.22	1.10-1.67
5	V instar	1.89 ± 0.14	1.68-2.24	2.04 ± 0.32	1.67-2.39
6	VI instar	2.29 ± 0.14	2.07-2.45	2.64 ± 0.23	2.34-2.89

Mean of ten observations; SD: Standard deviation

Table 2b. Morphometrics of different stages of *Spodoptera frugiperda* on fodder maize

Sl. No.	Stages	Length (mm)		Width (mm)	
		Mean ± SD	Range	Mean ± SD	Range
1	I instar	1.45 ± 0.15	1.19 -1.74	0.27 ± 0.13	0.23-0.45
2	II instar	3.55 ± 0.12	3.49-3.82	0.43 ± 0.12	0.32-0.65
3	III instar	6.63 ± 0.18	6.47-6.91	0.58 ± 0.18	0.40-0.81
4	IV instar	15.24 ± 0.50	14.88-15.94	1.35 ± 0.22	1.09-1.66
5	V instar	20.12 ± 0.26	19.90-20.52	2.39 ± 0.14	2.23-2.65
6	VI instar	25.04 ± 0.58	24.50-25.75	4.25 ± 0.13	4.09-4.45
7	Pupa				
	Male	15.47 ± 0.37	14.98-16.33	3.22 ± 0.19	3.01-3.54
	Female	17.54 ± 0.25	17.35-17.95	4.21 ± 0.13	4.10-4.42
8	Adult				
	Male	13.19 ± 0.21	12.68-13.54	4.98 ± 0.20	4.65-5.21
	Female	15.32 ± 0.21	15.02-15.75	5.68 ± 0.22	5.43-6.01

Mean of ten observations; SD: Standard deviation

Screening of dual-purpose maize inbreds: The screening experiment was carried out at ICAR- IARI RRC, Dharwad, to evaluate the dual-purpose maize inbreds. Based on the extent of leaf damage caused by the fall armyworm, fodder maize inbreds grouping was done as described by Davis and Williams (1992), which was later modified by CIMMYT on the scale of 1 to 9 and was recorded at different intervals.

Fall armyworm larvae load: The dual-purpose maize inbred C-79 M was superior to other inbreds, recording the least larvae per plant (0.35) at 20 DAS. This was followed by PML 36 and PML 46, which had 0.45 and 0.55 larvae per plant, respectively and these were on par with each other. Next best entries were PDI 649, C 46, PML 85, PML 96, DDM 2309, PDI 12, PDI 639, CDM 1330, CML 565, PML 105 and African tall with 0.80, 0.80, 0.80, 0.80, 1.60, 0.80, 0.80, 0.90, 0.90, 1.40 and 1.40 larvae of FAW per plant, respectively. The highest larval load was observed in the dual-purpose maize inbred PML 93-2 (1.90) and DDM 2207(1.60) (Table 3).

After 30 DAS, the inbred C 79 was found superior to other dual-purpose maize inbreds, having the lowest count of 1.10 larvae of FAW per plant. The next best inbreds were PDI 649 (1.30 larvae per plant), PML 36 (1.30), C 46 (1.30), PML 46 (1.40). Whereas, the highest larval load was seen in fodder maize inbred PML 93-2, DDM 2207and African tall (2.90, 2.60 and 2.60 larvae per plant, respectively).

The results pertaining to larval load on different inbreds at 40 DAS had lowest larval population in C 79 (3.40) followed by PML 36 (3.50), PML 46 (3.50) and PDI 649(3.76), The next best entries were PDI 649, C 46, PML 85, PML 96, DDM 2309, PDI 12, PDI 639, CDM 1330, CML 565, PML 105 and African tall which are at par with each other. Whereas, the highest larval population was recorded in PML 93-2 (5.22) and followed by DDM 2207(5.23) at 40 DAS (Table 3).

Among the different dual-purpose maize inbreds, the lowest larval load per plant at 60 DAS was recorded in the inbred line, C 79 M (1.30), PML 36 (1.30), PML 46 (1.30), followed by PML 85 (1.40), PDI 649 (1.50), C 46 (1.50), PML 96 (1.60), PDI 12(1.70), DDM 2309 (1.80), PDI

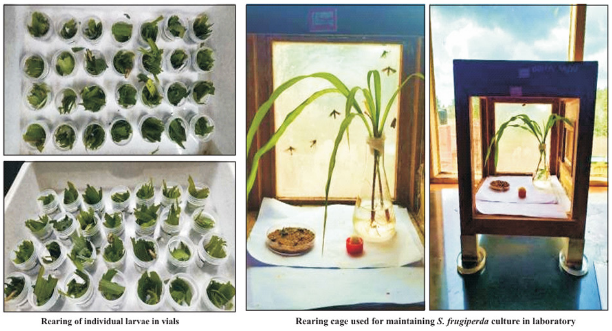
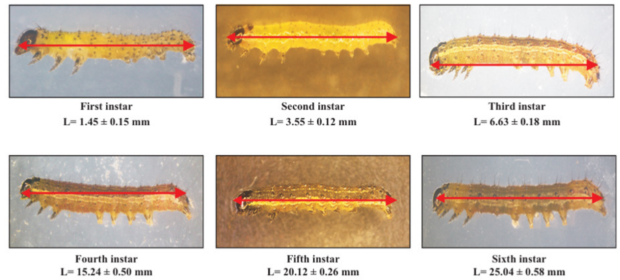


Plate 1. Experimental set up for biological studies on fall armyworm, *Spodoptera frugiperda*



L=Length

Plate 4: Morphometric measurements of *Spodoptera frugiperda* larval body length

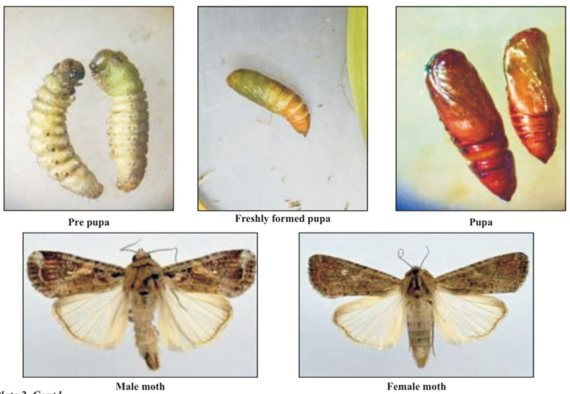


Plate 2. Contd...

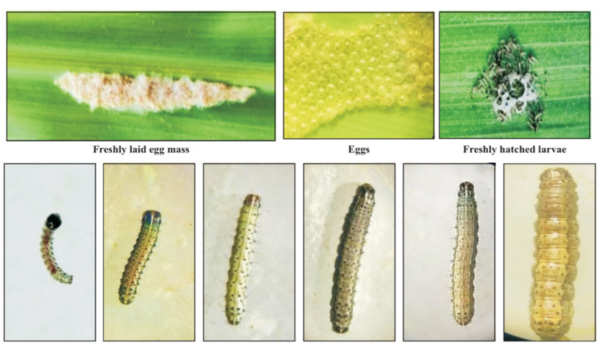
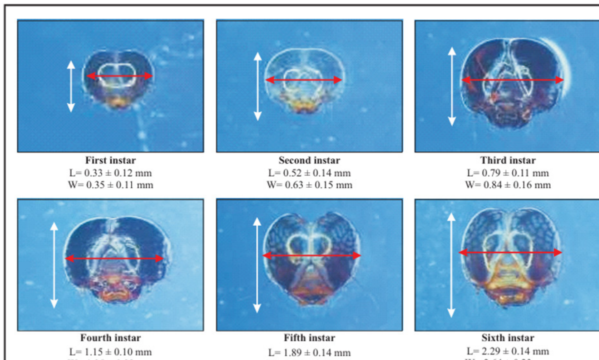


Plate 2. Life stages of fall armyworm, *Spodoptera frugiperda*



L= length W= Width

Plate 3. Morphometric measurements of *Spodoptera frugiperda* larval head capsule

639 (1.80), CDM 1330 (1.80), CML 565(1.80), PML 105 (1.90). Whereas, PML 93-2 inbred recorded the highest larval load (2.80), followed by DDM 2207(2.60) and African tall (2.30) compared to other inbreds at 60 DAS (Table 3). The current investigations are in support of that of Wiseman and Davis (1979), who recorded that more larvae were recovered at the 5 and 10 leaf stages and had a correlation of 0.84 and 0.96 between the leaf damage and the number of FAW larvae survived.

Leaf damage score: The results pertaining to leaf damage on different dual-purpose maize inbreds screened indicated the lowest leaf damage scores in C 79 (2.30), PML 36 (2.40) and PML 46 (2.60) compared to the rest of the inbreds. Next best entries were PDI 649, C 46, PML 85, PML 96, DDM 2309, PDI 12, PDI 639, CDM 1330, CML 565, PML 105, African tall (3.80, 4.10, 3.60, 3.90, 3.70, 3.90, 3.90, 4.10, 4.70, 4.80 and 5.01 each, respectively). Whereas, the highest leaf damage score was recorded in PML 93-2 (7.10) followed by DDM 2207(6.80) at 30 DAS (Table 4). At 40 DAS among the different inbred lines, the lowest leaf damage was scored in the inbred, C 79 (4.30), followed by PML 36 (4.40) and PML 46 (4.80), which were in agreement with each other. Whereas, PML 93-2(8.45) followed by DDM 2207(7.90) inbreds recorded the highest leaf damage score compared to other inbred lines at 40 DAS (Table 4). Similarly, among the different inbreds, C 79 (3.00) scored the least leaf damage score by fall armyworm compared to other dual-purpose maize inbreds at 60 DAS, followed by PML 36 (3.20) and PML 46 (3.30). In comparison, the highest leaf damage was registered in PML 93-2 (7.80) and DDM 2207 (7.30). Results pertaining to the mean of FAW leaf damage scoring indicated that C 79 recorded the least leaf damage (2.96), followed by PML 36 and PML 46 with leaf damage scores of 3.05 and 3.17, respectively. Whereas, the inbred line PML 93-2 observed the highest leaf damage score (6.93), followed by inbred DDM 2207(6.52) (Table 4). Similarly, Xinzhi *et al*. (2014) determined that Mp708 and Mp7061 had more resistance to fall armyworm to feeding, whereas EPM6 and Ab24E were highly susceptible cultivars.

Of the total 15 dual-purpose maize inbreds evaluated, three inbreds *viz.*, C 79, PML 36 and PML 46 were categorized as resistant; 10 inbreds, *viz.*, CDM 1330, PDI 639, PML 96, PDI 649, PDI 12, PML 105, DDM 2309, CML 565, C 46 and PML 85 and African tall (check) were categorized as partially resistant; two inbreds DDM 2207 and PML 93-2, were grouped as susceptible fodder maize inbreds. None of the above inbreds were classified in either the highly resistant or highly susceptible categories (Table 5).

Green fodder yield: Among the dual-purpose inbred lines evaluated, C 79 recorded the significantly highest green fodder yield (21.15 t/ha), followed by PML 36 (19.74 t/ha) and PML 46 (19.03 t/ha). Conversely, significantly lower green fodder yields were observed in PML 93-2 (11.03 t/ha) and DDM 2207 (12.40 t/ha; Table 6).

Dry fodder yield: The inbred line C 79 exhibited a superior dry fodder yield of 5.67 t/ha, significantly outperforming PML 36 (5.19 t/ha) and PML 46 (5.06 t/

Table 3. Larval population density of *Spodoptera frugiperda* across various dual-purpose maize inbred lines

Sl. No.	Dual-purpose maize inbreds	Larval population of fall armyworm per plant					
		20DAS	30DAS	40DAS	50DAS	60DAS	Mean
1	CDM 1330	0.90 (1.18)a	1.60 (1.45)ab	4.20 (2.17)bc	4.01 (2.12)ab	1.80 (1.52)abc	2.05 (1.73)bcd
2	PDI 639	0.80 (1.14)a	1.60 (1.45)ab	4.30 (2.19)bc	4.20 (2.17)ab	1.80 (1.52)abc	2.54 (1.74)abcd
3	PML 93-2	1.90 (1.55)d	2.90 (1.84)c	5.22 (2.39)c	5.01 (2.35)c	2.80 (1.82)d	3.57 (2.02)f
4	PML 96	0.80 (1.14)a	1.40 (1.38)ab	4.42 (2.22)ab	3.80 (2.07)ab	1.60 (1.45)ab	2.40 (1.70)abcd
5	DDM 2207	1.60 (1.45)cd	2.60 (1.76)c	5.23 (2.39)c	4.90 (2.32)c	2.60 (1.76)d	3.39 (1.97)ef
6	PDI 649	0.80 (1.14)a	1.30 (1.34)a	3.76 (2.06)a	3.41 (1.98)a	1.50 (1.41)ab	2.15 (1.63)ab
7	PDI 12	0.80 (1.14)a	1.50 (1.41)ab	4.11 (2.15)ab	4.01 (2.12)ab	1.70 (1.48)ab	2.42 (1.71)abcd
8	C 79	0.35 (0.92)a	1.10 (1.26)a	3.40 (1.97)a	3.01 (1.87)a	1.30 (1.34)a	1.83 (1.53)a
9	PML 36	0.45 (0.97)a	1.30 (1.34)ab	3.50 (2.00)a	3.12 (1.90)a	1.30 (1.34)a	1.93 (1.56)a
10	PML 105	1.40 (1.38)bc	1.90 (1.55)b	4.62 (2.26)bc	4.40 (2.21)bc	1.90 (1.55)bc	2.84 (1.83)de
11	DDM 2309	0.80 (1.14)a	1.50 (1.41)ab	4.22 (2.17)ab	3.80 (2.07)ab	1.80 (1.52)abc	2.42 (1.71)abcd
12	PML 46	0.55 (1.02)a	1.40 (1.38)ab	3.50 (2.00)a	3.36 (1.96)ab	1.30 (1.34)a	2.02 (1.59)a
13	CML 565	1.10 (1.26)ab	1.90 (1.55)b	4.63 (2.26)bc	4.40 (2.21)bc	1.80 (1.52)abc	2.77 (1.81)cde
14	C 46	0.80 (1.14)a	1.30 (1.34)a	3.70 (2.05)ab	3.52 (2.00)ab	1.50 (1.41)ab	2.16 (1.63)abc
15	PML 85	0.80 (1.14)a	1.40 (1.38)ab	4.22 (2.17)ab	3.70 (2.05)ab	1.40 (1.38)ab	2.30 (1.67)ab
16	African tall	1.40 (1.38)bc	2.60 (1.76)c	5.32 (2.41)c	4.90 (2.32)c	2.30 (1.67)cd	3.30 (1.95)ef
SEM (±)		0.06	0.07	0.09	0.09	0.07	0.07
C V (%)		8.45	9.90	8.80	9.08	8.28	9.19

DAS: Days after sowing; Figures in parenthesis are square root transformed values, means in the columns followed by same alphabet do not differ significantly by DMRT (P=0.05); *Mean of fifty observations; ** Mean of ten observations; SD: Standard deviation

Table 4. Leaf damage scores induced by fall armyworm (*Spodoptera frugiperda*) across various dual-purpose maize inbred lines

Sl. No.	Dual- purpose maize inbreds	Leaf damage score					
		20 DAS	**30 DAS**	**40 DAS**	**50 DAS**	**60 DAS**	**Mean**
1	CDM 1330	2.10^{abcd}	4.10^{defg}	6.50^{efgh}	6.1^{cde}	5.10^{cd}	4.78^{bcde}
2	PDI 639	2.10^{abcd}	3.90^{def}	6.30^{efgh}	6.20^{bcde}	4.80^{bcd}	4.66^{bcde}
3	PML 93-2	3.30^{e}	7.10^{h}	8.45^{i}	8.01^{f}	7.80^{e}	6.93^{f}
4	PML 96	1.80^{abc}	3.90^{def}	5.50^{cde}	5.10^{abcd}	4.70^{bcd}	4.20^{bc}
5	DDM 2207-E	3.20^{e}	6.80^{h}	7.90^{i}	7.40^{f}	7.30^{e}	6.52^{f}
6	PDI 649	1.80^{ab}	3.80^{bcd}	5.40^{bcd}	5.10^{abc}	4.50^{ab}	4.12^{ab}
7	PDI 12	1.90^{abc}	3.90^{def}	5.90^{defgh}	5.30^{abcd}	4.50^{bcd}	4.30^{bcd}
8	C 79	1.10^{a}	2.30^{a}	4.30^{a}	4.10^{a}	3.00^{a}	2.96^{a}
9	PML 36	1.14^{a}	2.40^{a}	4.40^{a}	4.10^{a}	3.20^{ab}	3.05^{a}
10	PML 105	2.80^{cd}	4.80^{fg}	6.70^{gh}	6.50^{e}	5.60^{d}	5.28^{de}
11	DDM 2309	2.30^{abcd}	3.70^{cde}	5.80^{defgh}	5.60^{abcd}	4.50^{bc}	4.38^{bcd}
12	PML 46	1.15^{a}	2.60^{ab}	4.80^{abc}	4.30^{ab}	3.30^{ab}	3.17^{a}
13	CML 565	2.60^{bcd}	4.70^{efg}	6.60^{fgh}	6.30^{e}	5.30^{cd}	5.10^{cde}
14	C 46	1.40^{a}	4.10^{abcd}	5.60^{cdef}	5.40^{abc}	4.10^{ab}	4.12^{ab}
15	PML 85	1.80^{abc}	3.60^{bcd}	5.70^{defg}	5.40^{abc}	4.20^{bcd}	4.14^{abc}
16	African tall	3.10^{d}	5.01^{g}	6.80^{h}	6.50^{de}	5.60^{d}	5.40^{e}
SEM (±)		0.36	0.31	0.30	0.29	0.31	0.29
C V (%)		10.61	9.17	8.34	8.09	8.83	8.37

DAS: Days after sowing; Means in the columns followed by same alphabet do not differ significantly by DMRT (P=0.05)

Table 5. Categorization of dual-purpose maize inbred lines into resistance classes based on leaf injury ratings (LIR)

Resistance category	Dual- purpose maize inbreds	Leaf damage score	Number
Highly resistant	-	1	-
Resistant	C 79, PML 36, PML 46	2-3	3
Partially resistant	CDM 1330, PDI 639, PML 96, PDI 649, PDI 12, PML 105, DDM 2309, CML 565, C 46, PML 85, African tall (Check)	4-5	11
Susceptible	DDM 2207, PML 93-2	6-7	2
Highly susceptible	-	8-9	-
Total			16

Note: As per Davis and Williams scale modified by CIMMYT (1-9)

ha). Conversely, PML 93-2 and DDM 2207 registered the minimum yields of 2.78 t/ha and 2.93 t/ha, respectively (Table 6).

Biophysical parameters: The FAW leaf damage score among the various inbreds ranged from 2.96 to 6.99.

Leaf thickness: The leaf thickness was maximum in resistant inbreds C 79 (0.20), PML 36 (0.19), PML 46 (0.18). In contrast, susceptible inbreds like PML 93-2 (0.08) and DDM 2207(0.09) recorded the minimum leaf thickness (Table 7). From the results, it can be concluded that the increase in leaf thickness reduces the damage from fall armyworm on the fodder maize leaves. The present study was in line with the outcome of Hedin *et al*. (1996) that resistant lines contained higher crude fibers, mostly of cellulose and hemicellulose, which play an important role in the leaf thickness/toughness and inhibit the feeding preferences of the fall armyworm on maize.

Trichome density: The resistant inbreds recorded the highest number of trichomes per cm^2 leaf area. The

Table 6. Fodder yield of dual-purpose maize inbreds

Sl. No.	Dual- purpose maize inbreds	Green fodder yield (t/ha)	Dry fodder yield (t/ha)
1	CDM 1330	13.94^{abc}	3.62^{ab}
2	PDI 639	15.30^{bcd}	3.83^{bcd}
3	PML 93-2	11.03^{a}	2.78^{a}
4	PML 96	17.05^{bcd}	4.33^{bc}
5	DDM 2207-E	12.39^{a}	2.93^{a}
6	PDI 649	18.77^{def}	4.93^{de}
7	PDI 12	16.15^{bcd}	4.04^{bc}
8	C 79	21.15^{g}	5.66^{g}
9	PML 36	19.74^{fg}	5.19^{fg}
10	PML 105	13.16^{ab}	3.16^{ab}
11	DDM 2309	16.77^{bcd}	4.16^{bc}
12	PML 46	19.02^{efg}	5.06^{efg}
13	CML 565	13.84^{abc}	3.39^{ab}
14	C 46	18.00^{cdef}	4.72^{cd}
15	PML 85	17.78^{bcde}	4.63^{bc}
16	African tall	12.93^{ab}	3.03^{abc}
SEM (±)		1.06	0.33
C V (%)		9.09	11.66

Means in the columns followed by same alphabet do not differ significantly by DMRT

resistant inbreds *viz*., C 79 (75.67), PML 36 (73.0) and PML 46 (69.75) recorded the highest number of trichomes per cm^2, followed by PDI 649 (67.67), C 46 (60.67), PML 85 (59.33), PML 96 (58.75), DDM 2309 (56.67), PDI 12 (56.25), PDI 639 (55.42), CDM 1330 (51.83), CML 565 (51) and PML 105 (46.67) (Table 7). The least number of trichomes was noticed on the susceptible inbreds of fodder maize, namely in PML 93-2 (38.42), followed by DDM 2207 (40.08). The different dual-purpose maize inbreds showed significant differences. C 79 (75.67), PML 36 (73.0) and PML 46 (69.75) inbreds had recorded the highest trichome density of dual-purpose maize that had the lowest leaf damage score and was grouped in the resistant category, whereas the susceptible and highly susceptible inbreds, *viz*., PML 93-2 (38.42), followed by DDM 2207(40.08), recorded the lowest trichome density. Therefore, from the pooled mean data, it can be inferred that as the trichome density increases considerably, the leaf damage score decreases and *vice versa*. Moya- Raygoza (2016) reported that the trichomes offered physical defense that minimizes the chewing damage of FAW associated with maize, which is in support of the present findings.

Total soluble sugar (TSS): The TSS was highest in the susceptible inbreds. The highest value of the total soluble sugar in ºBrix was recorded in susceptible inbred PML

Table 7. Biophysical and biochemical parameters of dual-purpose maize inbred lines screened for resistance to *Spodoptera frugiperda*

Sl. No.	Dual- purpose maize inbreds	Leaf thickness (mm)	Trichome density (no. of trichomes / cm^2)	Total soluble sugars (ºBrix)
1	CDM 1330	0.13^{de}	51.83^{abc}	15.75^{de}
2	PDI 639	0.14^{def}	55.42^{bcd}	15.2^{cde}
3	PML 93-2	0.08^{a}	38.42^{a}	23.5^{g}
4	PML 96	0.16^{fgh}	58.75^{bcde}	13.6^{abcd}
5	DDM 2207-E	0.09^{a}	40.08^{a}	22.5^{g}
6	PDI 649	0.18^{hij}	67.67^{defg}	12.6^{abc}
7	PDI 12	0.15^{efg}	56.25^{bcd}	14.25^{bcd}
8	C 79	0.2^{j}	75.67^{g}	11.15^{a}
9	PML 36	0.19^{ij}	73^{fg}	11.7^{ab}
10	PML 105	0.12^{bcd}	46.67^{ab}	17.75^{ef}
11	DDM 2309	0.12^{cd}	56.67^{bcde}	13.9^{abcd}
12	PML 46	0.18^{hij}	69.75^{efg}	12.25^{ab}
13	CML 565	0.12^{cd}	51^{abc}	17.15^{ef}
14	C 46	0.17^{ghi}	60.67^{cdef}	13^{abc}
15	PML 85	0.17^{ghi}	59.33^{bcde}	13.15^{abcd}
16	African tall	0.1^{abc}	41.92^{a}	18.8^{f}
SEM (±)		0.0065	3.9657	0.8032
C V (%)		6.2315	9.9363	7.3806

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

Table 8. Total phenol content of selected dual- purpose maize inbreds screened against fall armyworm

Sl. No.	Dual- purpose maize inbreds	Total phenol content (mg/g)
1	PML 93-2	2.89^{a}
2	DDM 2207-E	3.15^{a}
3	PDI 649	4.74^{b}
4	C 79	5.01^{b}
5	PML 36	4.66^{b}
6	PML 46	4.81^{b}
7	African tall	3.19^{a}
SEM (±)		0.24
C V (%)		8.48

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

Table 9. Correlation of bio-physical and bio-chemical parameters of different dual -purpose maize inbreds screened against fall armyworm

Insect pest	Correlation co-efficient (r)			
	Leaf damage score			
	Leaf thickness (X_1)	Trichome density (X_2)	Total soluble sugars (X_3)	Phenol content (X)
Fall armyworm	-0.943**	-0.918**	0.987**	-0.945**

**(P<0.01)

93-2 (23.5), followed by DDM 2207 (22.5). Conversely, the resistant inbreds recorded low soluble sugar in C 79 (11.15), PML 36 (11.7) and PML 46 (12.25). The findings are in agreement with those of Praveen *et al*. (2013), who reported that TSS content increased as the stage advanced and obtained low TSS in resistant inbred lines (Table 7).

Biochemical Parameters

Total free phenols: Phenols analysis was done only on the selected inbreds. Resistant inbreds such as C 79 (5.01 mg/g), PML 36 (4.66 mg/g) and PML 46 (4.81 mg/g) showed higher phenol content than that of the partially resistant inbreds and the susceptible inbreds, which showed the least phenol content. African tall (3.19 mg/g), which is partially resistant and PML 93-2 (2.89 mg/g) and DDM 2207 (3.15 mg/g), which are susceptible inbreds to fall armyworm (Table 10). It is strongly and negatively correlated with the leaf damage score (Table 8). Praveen *et al.* (2013) also reported that stem borer-resistant cultivars of maize recorded higher phenol content compared to susceptible inbreds.

Correlation of bio-physical and bio-chemical parameters of different dual-purpose maize inbreds screened against fall armyworm indicated that leaf thickness (-0.943**), trichome density (-0.918**), and phenol content (-0.945**) were negatively correlated, whereas total soluble sugars (0.987**) were positively correlated. (Table 9). Reddy *et al.* (2024) also reported that the leaf trichomes, phenols, tannins and sugars are associated with resistance to spotted stem borer, *Chilo partellus* in maize.

Conclusion

The study recorded an average incubation period of 2.29 ± 0.16 days and a larval duration of 12.95 ± 1.03 days under ambient conditions. Larvae completed five molts, leading to six instars with a total feeding period of about 12 days. The pupal period averaged 7.62 ± 0.17 days in males and 8.29 ± 0.57 days in females. Adult longevity was higher in females (9.65 ± 1.30 days) than in males (7.52 ± 0.23 days) when food was present, and it was reduced in the absence of food. Fecundity averaged 942.8 ± 90.28 eggs per female, indicating high reproductive potential. The total life cycle ranged from 30.38 ± 2.66 days in males to 33.20 ± 2.47 days in females. Through systematic field screening, three inbred lines- C 79, PML 36, and PML 46 consistently outperformed others, exhibiting superior resistance to *S. frugiperda*. This resistance resulted from a synergistic effect of physical barriers (enhanced leaf thickness and trichome density) and chemical defenses (increased phenols). Conversely, susceptible lines like PML 93-2 and DDM 2207 were marked by higher sugar content, likely making them more attractive to the pest. Ultimately, the positive relationship between structural traits and phenolic levels with lower damage scores highlights these parameters as reliable markers for breeding dual-purpose maize with robust fall armyworm resistance.

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