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Influence of host plants on the biology of maize fall armyworm *Spodoptera frugiperda* (J.E. Smith)

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Abstract
Maize is an important cereal crop which has a three-fold use as food, feed and fodder in the Indian subcontinent, particularly with respect to farmers having small land holdings. Infestation by fall armyworm (FAW) results in substantial yield losses besides decrease in quality of the produce. Being an invasive species, the basic information on the study of biology and host survival on different hosts will provide a broader understanding of the pest's capability to survive on other hosts. An understanding on the pest's performance on alternate hosts in the absence of preferred host may help forecast the possibility of its attack on other crop plants and accordingly device effective pest management methods. Survival of FAW was highest in maize (90.3%), followed by sorghum (82.6%) and pearl millet (80.5%) among eleven hosts studied. Feeding preference by first instar larvae in four arm olfactometer showed that, maize was the most preferred host than sorghum and pearl millet. Similarly, ovipositional preference of female moths in cages and in Y tube olfactometer also revealed that moths were attracted more to maize plant. Nutritional indices studies revealed that maize registered the highest preference in terms of Consumption Index (CI) (1.8), Consumption Rate (CR) (8.9), Growth Rate (GR) (2) and Approximate Digestibility (AD) (75.8) of fall armyworm.

Keywords: Fall armyworm, feeding preference, maize, nutritional indices, ovipositional preference

1. Introduction
Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) is a noxious pest native to tropical and subtropical regions of Americas, originally identified [1]. It was recorded as a polyphagous invasive pest in Africa during 2016 [2]. In the Indian subcontinent, the pest was first reported in UAHS, Bengaluru, Karnataka during May 2018 [3]. In Tamil Nadu, fall armyworm was first noticed in Karur district in August, 2018 and was simultaneously recorded in Coimbatore. Till now, the pest has spread to many eastern and south Asian countries [4]. Over 350 species of plants are attacked by fall armyworm [5] including serious infestation in commercial crops like maize, cotton, rice [6]. It is being considered as a threat to an array of field crops because of continuous presence of maize and other hosts [7]. Due to continuous availability of host throughout the period, the FAW poses a serious threat to maize ecosystems. Host utilization by fall armyworm will provide an indirect measure of the host's relative susceptibility for growth and infestation [8]. Studies on the FAW survival on different hosts under laboratory conditions revealed that the pest showed a much high propensity only on three hosts *viz*., maize, sorghum and pearl millet though it is able to complete the life cycle in eleven economically important crops under laboratory conditions.

2. Materials and Methods
2.1 Survival of fall armyworm on different hosts
Experiment for the host range of *Spodoptera frugiperda* was performed at the Department of Agricultural Entomology TNAU, Coimbatore from 2020 to 2021. The culture maintained at the FAW lab of Dept. of Agriculture Entomology reared with artificial diet was used for the study. The culture was maintained at 28±5 °C, 70±10% rh. Egg masses were kept in a container until hatching. It was used as the base culture for further studies. Host range studies was conducted with 11 different hosts like maize (*Zea mays* L), sorghum (*Sorghum bicolor* L.) and pearl millet (*Pennisetum glaucum* L.R.Br*)*, minor millets like foxtail millet or thenai (*Setaria italica* L.P. Beauv), little millet or samai (*Panicum sumatrense* Roth.), kodo millet or varagu (*Paspalum scrobiculatum* L.), proso millet or panivaragu (*Panicum miliaceum* L.), finger millet or ragi (*Eleusine coracana* L.), fodder crop like cumbu napier (*Pennisetum glaucum* L. R.Br × *P. purpureum* Schumach.), variety Co 5 along with wheat (*Triticum aestivum* L.),

(castor *Ricinus communis* L.). Upon emergence of neonates from egg masses, 30 number of larvae were transferred to each hosts. Young larvae upto second instar were reared in the same container. From 3rd instar onwards larvae were separated and reared in individual containers due to cannibalistic behaviour. Fresh leaf bits were given to the larvae on daily basis. Larval duration, pre-pupal period, pupal period, adult longevity and per cent survival were observed for fall armyworm on different hosts.

$$\text{Per cent survival} = \frac{\text{No. of larvae entered pupation}}{\text{Total larva released}} \text{ X } 100$$

2.2 Feeding preference of FAW

For this experiment three hosts *viz*., maize, pearl millet and sorghum (which had a more than 50% per cent survival rate in host preference studies) were used and the study was performed under laboratory conditions. Three types of tests were performed *viz*., no choice, two choice and multi choice tests. Petri plate with 9 cm diameter were used with agar agar as a base to protect the leaves from dehydration. Leaf bits with 2cm diameter were cut and used for the experiments.

For no choice test, 15 petri plates were used and for two and multi choice tests 12 petriplate per host were used. For no choice test, one leaf bit of the respective host along with one neonate larvae were placed in the centre of the petriplate. Two leaf bits of respective hosts were taken for two choice test and three leaf bits were taken for multi choice tests and were placed at an equal distance on the edges of the petriplate and the larvae were placed on the centre. Position of the larva within the plates were observed after 24 and 48 hours for all the tests. Larvae that drifted from the leaf bits were also taken into account for analysis. At the end of 48 hours the larva which settled on different hosts were recorded which indicated the larval preference for that host.

2.3 Four arm olfactometer experiment

Feeding preference of *S. frugiperda* with three host species was evaluated using four arm olfactometer following the procedure of [9]. The olfactometer contained a centre chamber with four pointed ends. At the end of every point, glass vials were fitted from outside and leaf samples were kept in that vials. An extractor tube was fitted in the hole of the centre region and it can be disconnected during the introduction of the larvae. The tube was fitted with a pressure pump of capacity 10 l/m and the air flow can be adjusted. Experiment was conducted with first instar larvae (n=20). In 4 tubes of the olfactometer, three tubes were filled with young leaves of respected hosts. Through the central opening, the larvae were released one at a time and given 10 minutes for choosing the host. The larvae that failed to choose any of the tube within the time limit, was not included in the analysis. From this study the host preference of first instar larva according to olfactory stimuli can be ascertained.

2.4 Ovipositional preference of FAW

Host plants and the *Spodoptera* culture used in this experiment were similar to the previous studies. Here, no choice, two choice and multi choice tests were carried out for studying the ovipositional preference of FAW on different hosts.

Experiments were conducted by using cages made of mesh wires. Three hosts *viz.*, maize, sorghum and pearl millet were used for the experiments. No choice test was conducted with 15 day old seedlings of the respective hosts in a conical flask containing water and placed inside the cages. Six pairs of adults were released into the cage and permitted for mating and egg laying for three days. 50% honey solution was prepared and given for feeding on daily basis. After 3 days, the adult moths start laying eggs on the leaves of the respective hosts. Similarly two choice and multi choice tests were done. For each hosts 5 replications were maintained. By this study the female's preference for oviposition could be inferred.

2.5 Y-tube olfactometer experiment

This experiment was conducted for evaluating the ovipositional preference of female moths (n=20) with respective hosts by using y – tube olfactometer following the procedure by [10]. For this study 3-4 days old gravid female moths were selected. The Y-tube olfactometer consisted of a long central glass tube of 21cm and 3.5cm diameter fitted with two arms of 21cm and 3.5cm diameter and divided by 120°angle. The setup was connected to a vacuum pump which sucks the air and spread the volatile of the plant. Air pressure was adjusted to 8-10ml/min using air meter at end of the arms. The experiment was carried out under controlled laboratory conditions at 26±5°C and 75±10% rh. Female moths were released at the open end of the central tube in the olfactometer. Observation time of 10 minutes was given for each moths to choose one arm. Only moths that chose an arm within the time limit was taken into consideration for analysis. Each moth was used one time to avoid associative learning. In each treatment, sides of the arm were interchanged to avoid bias. Two replication with 20 moths per replication were used in this experiment. Odour sources used for the experiment were 1. maize vs clean air 2. pearl millet vs clean air 3. maize vs pearl millet 4. sorghum vs clean air 5. sorghum vs maize 6. sorghum vs pearl millet

2.6 Growth Indices of FAW

For this study, third instar larvae of *Spodoptera frugiperda* were selected and used to assess the growth parameters. This experiment was conducted under controlled conditions with 28± 5°C, 70 ±10% rh in the laboratory. Individual replications with 15 larvae were taken for each host and pre-starved for 6h before the experiments. Initial weight of the larvae were taken after starvation. The larvae were separated in rearing containers with respective host plants. The set up was kept as such upto 6th instar. Leaf bits were changed on a daily basis. At the end of the experiment, remaining leaf bits and fecal pellets were separated and weighed along with the individual larvae. Growth indices like growth rate, consumption index, consumption rate and approximate digestibility were calculated by using the formula proposed by [11]

$$\text{Consumption index} = \frac{\text{Weight of food consumed}}{\text{Duration of feeding period x larval weight}}$$

$$\text{Growth rate} = \frac{\text{Final weight of larva} - \text{Initial weight of larva}}{\text{Initial weight of larva x Duration of feeding period}}$$

$$\text{Approximate digestibility} = \frac{\text{Weight of food consumed} - \text{weight of dry excreta}}{\text{Weight of food consumed}}$$

$$\text{Consumption rate} = \frac{\text{Weight of food consumed}}{\text{Duration of feeding period}}$$

2.7 Statistical analysis
Mean value, Standard deviation, Analysis of variance of all the data were calculated by using online software WASP 2.0. Significant means were separated by the Least Significant Difference (LSD) at the 0.05 significance level ($P \leq 0.05$).

3. Results and Discussion
3.1 Survival of FAW on different hosts
Insect development is mostly influenced by quality of the larval food. The growth and development is heavily influenced by the host plant [12]. In our studies the results revealed that, the larval duration was shortest in sorghum (14.8 d), followed by maize (15.8 d) and pearl millet (17.6 d). Larva that fed on hosts like varagu (24.2 d), cumbu napier grass (24.6 d) had the longest larval period among other hosts (Figure 1). Longer larval period suggest the relative unsuitability of hosts for survival and development [7]. Prepupal period was shortest in maize (1.5 d), ragi (18.2 d) and castor (1.7 d). The pupal period was minimum with maize (7.3 d), ragi (7 d), castor (7 d) and pearl millet (7.4 d) (Figure 2). Longest pupal period was observed in hosts like wheat (9.3 d), cumbu napier grass (9.2 d) and varagu (9.1 d) (Figure 3). Male and female longevity was highest in sorghum (7.7, 7.4 d), maize (6.5d, 7.6 d) followed by pearl millet (6.5d, 7.4 d) (Figure 4). Larval survival was highest in maize (90.3%) and castor (85.5%) followed by sorghum (82.6%) and pearl millet (80.5%). Lowest larval survival was recorded in varagu (14.4%) and wheat (20.3%) (Figure 5). *S. frugiperda* favoured C4 plants like maize, sorghum, and Bermuda grass over C3 plants like cotton or soybeans [13]. The larval period in sorghum is shorter than in maize [14]. Larval period for wheat and napier grass was more similar to our study. Similar observations were reported by [15] in which the larval period of maize lies between 14 and 19 days. Pupal period was similar to results of [16]. Our results were similar with the research conducted by [17] that, fall armyworm fed on maize showed better performance than sorghum and wheat. Fall armyworm larvae prefers more cereal crops than other plants [7].

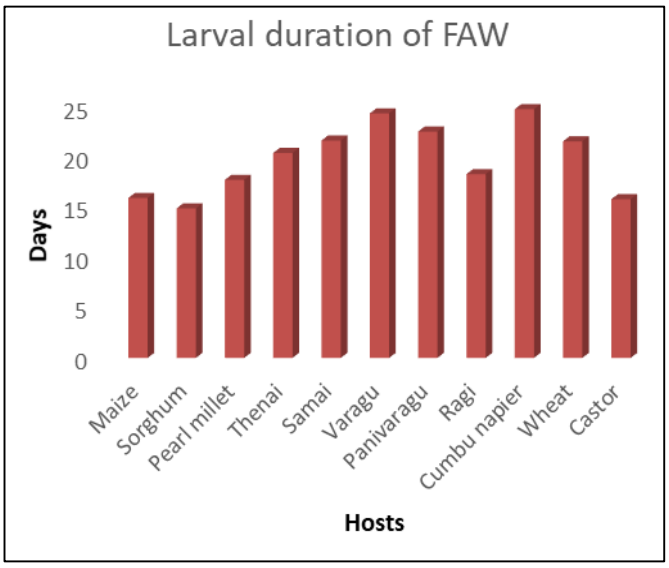

Fig 1: Larval period of fall armyworm in different hosts

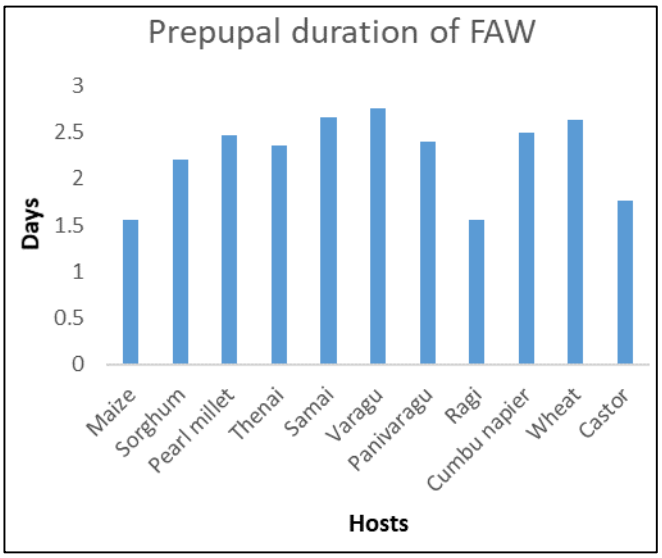

Fig 2: Prepupal period of fall armyworm in different hosts

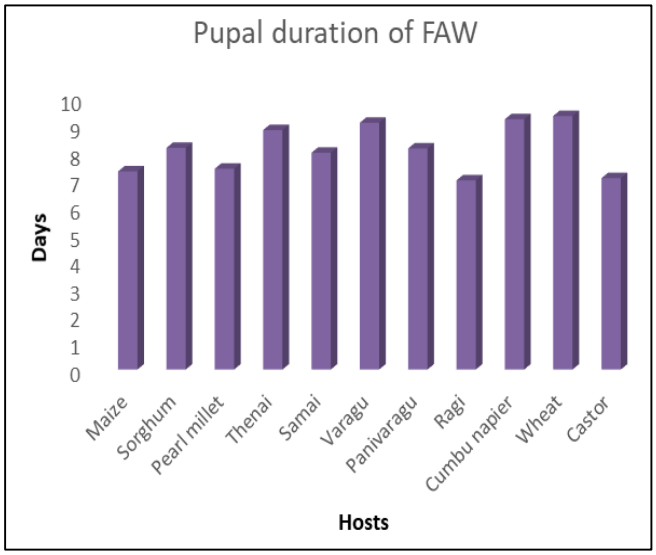

Fig 3: Pupal period of fall armyworm in different hosts

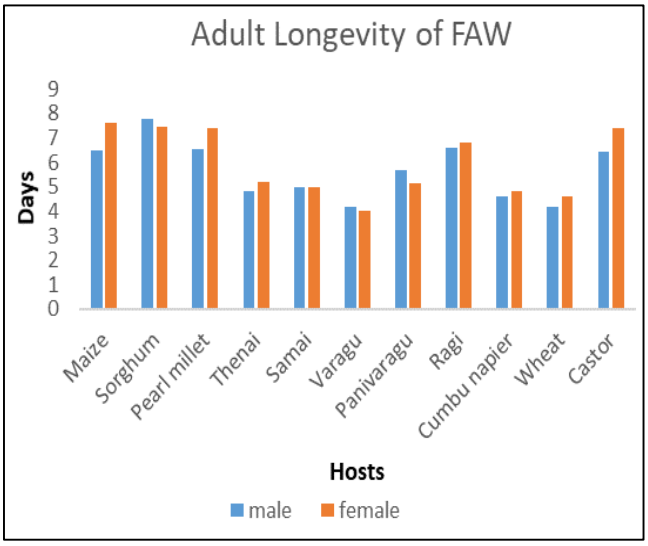

Fig 4: Adult longevity of fall armyworm in different hosts

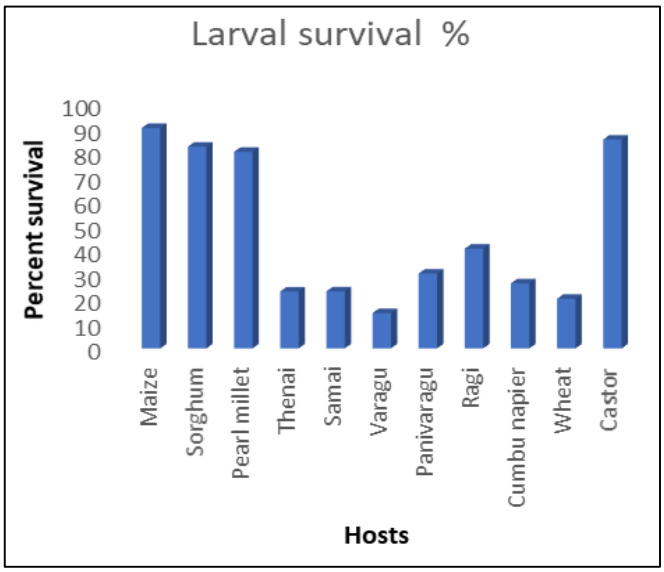

Fig 5: Survival % of fall armyworm in different hosts

3.2 Feeding preference of FAW

In no choice test more number of larva settled on pearl millet than maize after 24 hours observation. At 48 hours observation, equal number of larvae were present in maize and pearl millet followed by sorghum (Figure 6). In two choice tests, maize was the most preferred host than sorghum and pearl millet in two combinations after 24 and 48 hours. In sorghum and pearl millet combination pearl millet was most preferred than sorghum in both 24 and 48 hours observation (Table 1). In both no choice and two choice tests all the larvae settled on hosts. In multi choice tests at 24 hours and 48 hours observation, maize was the most preferred host followed by pearl millet and sorghum (Figure 7). The initial choice of the larvae towards a particular host is decided by the presence of plant compounds, plant's physical traits, or inadequate nutrient quality [18]. In relation to the studies [19] maize was mostly preferred by first instar larvae than other crops like sorghum, napier and Bermuda grass. In our personal observations, one isolated and heavy infestation of pearl millet was observed in which more than 60 per cent infestation was recorded during December 2020. This was attributed at that time to the non-availability of maize in the vicinity and maize being the previous crop in the fields (Srinivasan (2020), personal communication).

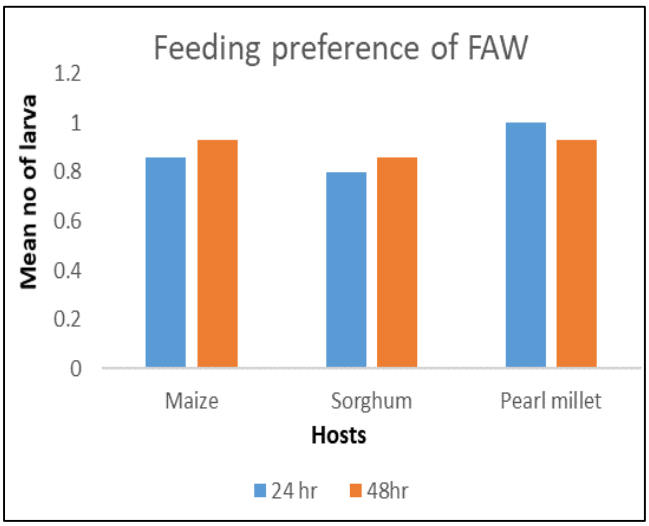

Fig 6: No choice test for feeding preference of fall armyworm in different hosts

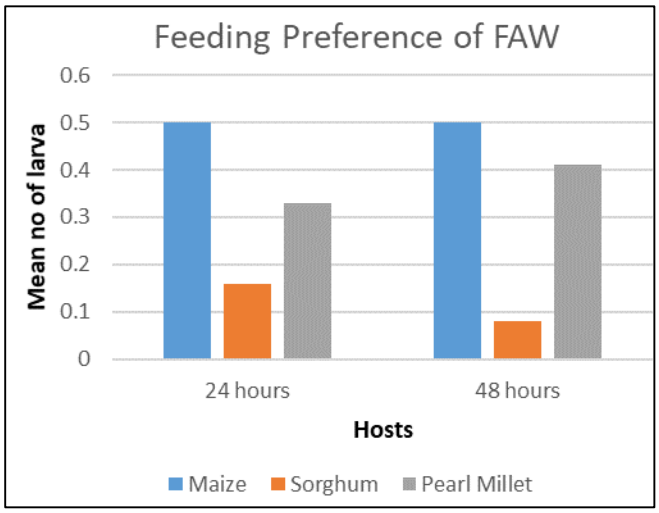

Fig 7: Multi choice test for feeding preference of fall armyworm in different hosts

Table 1: Two choice test for feeding preference of fall armyworm in different hosts

Treatment	Two choice test			
	24 hours		48 hours	
	Maize	Pearl Millet	Maize	Pearl Millet
Maize+Pearl millet	0.58±0.32	0.41±0.23	0.66±0.33	0.33±0.34
	Maize	Sorghum	Maize	Sorghum
Maize+Sorghum	0.75±0.38	0.25±0.44	0.75±0.66	0.25±0.59
	Sorghum	Pearl Millet	Sorghum	Pearl Millet
Sorghum+Pearl millet	0.33±0.45	0.66±0.57	0.25±0.75	0.75±0.33

All values are represented as Mean ± Standard deviation

3.3 Four arm olfactometer experiment

First instar larva showed significant difference between three hosts by spending more time in the arm which had maize leaf (P=0.025) (Table 2). Gravid females showed more attraction to maize volatiles in the four arm olfactometer experiment conducted by [20]. Female moths preferred odors from herbivore damaged over undamaged maize plants [21]. Herbivore-induced plant volatiles are used by neonate FAW as host plant locating and recognition signals in cowpea seedlings [22].

Table 2: Four arm olfactometer experiment with first instar larvae of *Spodoptera frugiperda*

No of insects	Treatment	Time (m)	P value
20	Maize	1.916	0.025*
20	Sorghum	0.706	
20	Pearl millet	0.563	

P value < 0.05 are significant (*) @ 0.05 probability level

3.4 Ovipositional preference

No choice tests for ovipositional preference revealed that

gravid females oviposit more on maize followed by pearl millet. In case of sorghum more number of eggs were laid in cages than on hosts (Figure 8). In two choice tests, maize was the most preferred host than sorghum and pearl millet in both combinations (Figure 9). Where maize plants were present in cages, egg laying by females in the cage walls were reduced. In multi choice tests more number of eggs were laid on maize followed by pearl millet and sorghum (Figure 10). Maize was the most preferred host for egg laying by gravid female moths with more than 670 eggs per female than sorghum and pearl millet. Other oviposition studies reveal that FAW females do not have a specific ovipositional preference for hosts and non-host plants [23]. Fecundity of female moths was more in maize compared to sorghum and cotton [17]. Female moths preferred more grassy hosts than dicot plants [14]. More gravid females of fall armyworm laid eggs on paper and cages than on non-preferred host plants [24]. Maize was much more preferred host for oviposition than potato and tobacco crops for fall armyworm moths [25].

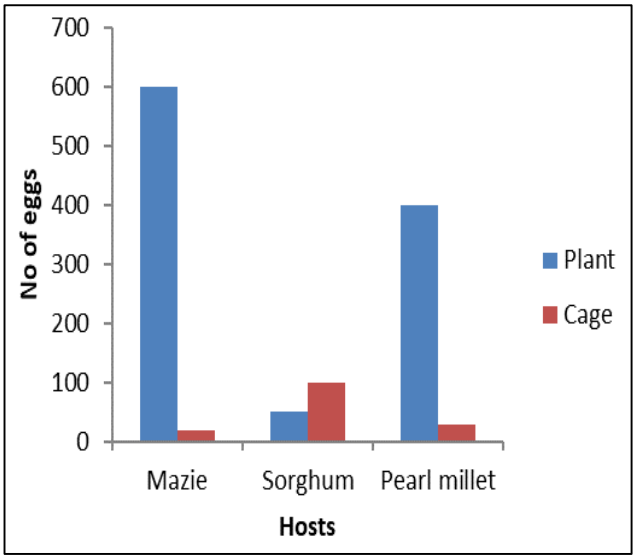

Fig 8: No of eggs laid by *Spodoptera frugiperda* gravid female in no choice tests

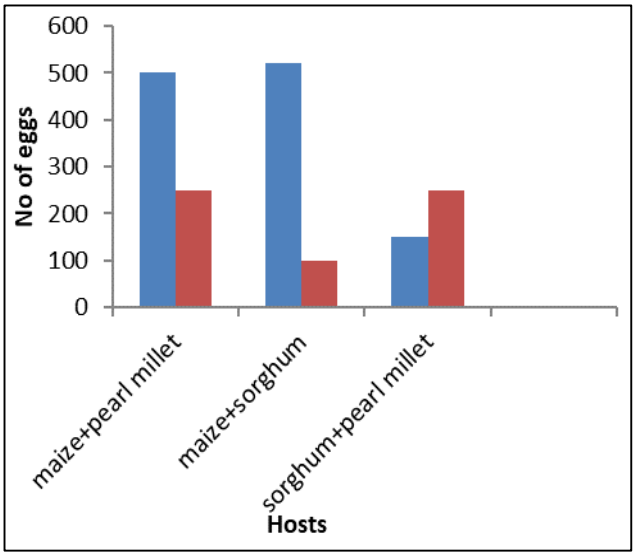

Fig 9: No of eggs laid by *Spodoptera frugiperda* gravid female in two choice tests

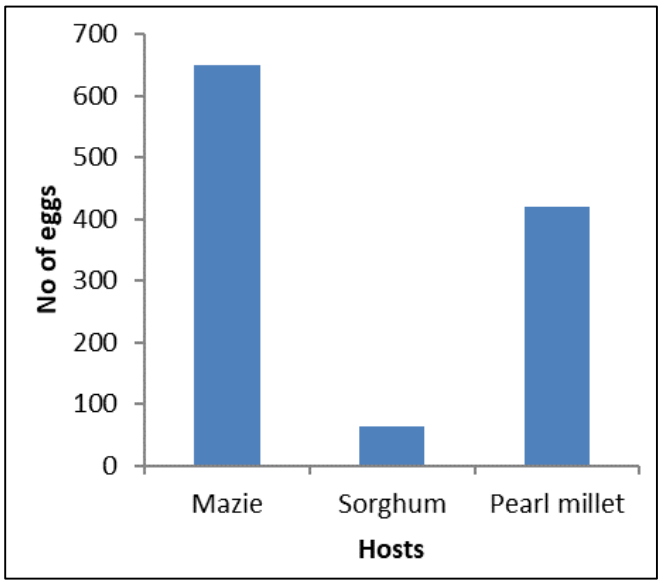

Fig 10: No of eggs laid by *Spodoptera frugiperda* gravid female in free choice tests

3.5 Y tube olfactometer experiment

Female moths of fall armyworm showed significant difference with three treatments *viz*., maize vs clean air, maize vs sorghum and maize vs pearl millet. From this combination female moths preferred maize (Arm A) the most, than other (Arms B). There was no significant difference between sorghum and pearl millet treatment (Table 3). Ovipositional preference experiment with *Spodoptera exigua* female moths in Y tube olfactometer and observed that maize volatile was most preferred by the moths than cabbage and cucumber [10].

Table 3: Y tube olfactometer experiment with *Spodoptera frugiperda* female moths

Treatments (Arm A vs Arm B)	No. of. Moths	Insects responded		P Value
		Arm A	Arm B	
maize vs clean air	20	14	4	0.022*
sorghum vs clean air	20	12	6	0.157
pearl millet vs clean air	20	10	6	0.205
maize vs sorghum	20	13	4	0.033*
maize vs pearl millet	20	14	4	0.022*
sorghum vs pearl millet	20	10	8	0.527

P value < 0.05 are significant (*) @ 0.05 probability level of chi square test.

3.6 Growth indices

Among the three hosts, sorghum showed low values for all the indices measured. it was due to reduced consumption and assimilation of food [26]. Consumption index (CI) denotes the relationship between larval intake and weight gain throughout the feeding period. From the table CI value was more in maize (1.83) followed by pearl millet (1.15) and sorghum (1.12). Consumption rate (CR) indicates the preference of the host by the pest. CR value was also high in maize (8.95). Growth rate (GR) relates to increase in fecal matter per day per gram with the insect body weight [27]. The value was significantly high in maize plant (2.09). Approximate digestibility (AD) denotes the amount of food digested from the intake of the feed by the larva. Maize has the highest value with 75.8% than other crops (Table 4). From the overall studies on *Spodoptera frugiperda* larva with different

nutritional indices, maize was the most preferred host. Next to maize, pearl millet was suited for the development of fall armyworm. Our results were similar with [17] that corn was the most preferred crop in accordance with growth indices than sorghum, soyabean, wheat and cotton. Maize has the highest nutritional balance of carbohydrates, vitamins, amino acid than other hosts, hence it was preferred the most by the larvae [28].

Table 4: Growth indices parameter with larvae of *Spodoptera frugiperda*

Treatment	Consumption Index (CI)	Consumption Rate (CR)	Growth Rate (GR)	Approximate Digestibility (AD) %
Maize	1.83 (2.87)a	8.95 (79.8)a	2.09 (3.87)a	75.8 (94)a
Sorghum	1.12 (0.76)b	6.72 (44.9)c	1.21 (0.96)c	49.6 (58)c
Pearl millet	1.15 (0.83)b	7.44 (54.8)b	1.30 (1.2)b	64.1 (81)b
SEd	0.019	0.15	0.08	0.05
CD(5%)	0.039	0.32	0.17	0.37
CV%	3.90	5.66	6.99	3.85

All data are calculated in g dry weight. Means in the same column followed by different letters are significantly different.

Conclusion

The study depicts that three hosts *viz*., maize, sorghum, pearl millet much favoured the growth and development of the *Spodoptera frugiperda* among eleven hosts tested. Based on host survival, feeding preference, ovipositional preference and nutritional indices of fall armyworm studies, maize was the most preferred host among all other hosts. Crops like varagu and wheat though infested, the population build-up on these crops was minimal. Furthermore, in the absence of the major hosts, coupled with coexistence of multiple crops in the agro-ecosystem, particularly millet complex, feeding preference of fall armyworm may exhibit diverse reactions.

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Conflict of Interests

The authors declare that there is no competing interest

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