Seasonal activity of *Spodoptera frugiperda* (J. E. Smith) in maize agroecosystem of South India

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The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), was first detected in India in 2018 and seriously threatened the maize crop. In South India, we studied the population dynamics of FAW moths and the damage caused by the larvae in maize fields from 2019 to 2020. In the *kharif* season, the highest male moth catches occurred in July while in *rabi* season, the highest catches occurred in November. It was found that the early whorl stage (EV-V6) of maize crop was susceptible to FAW due to its high larval load, whereas the late whorl stage (V7-VT) of the crop showed greater leaf damage in both years.

Keywords: Damage rating, fall armyworm, maize crop, pheromone trap catches, population fluctuation.

THE fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), was first detected in Asia during 2018 (ref. 1). Since then, it has been established in different countries in Asia[2,3] and is highly polyphagous in nature[4–6]. FAW can cause a considerable loss of 80 million tonnes of maize worth US$ 18 billion annually, impacting approximately 600 million people in Africa, Asia-Pacific and the Near East countries[7]. The infestation rate of FAW in South India ranged from 6.00% to 100% (ref. 8). It was speculated that the incidence due to FAW would reduce maize production by 37,000–75,000 tonnes in India[9]. Prior to FAW invasion in the country, the cost of chemical pesticides used on maize crops amounted to US$ 5.56 per hectare in 2017. However, the cost of crop protection using pesticides in maize increased to US$ 71.23, US$ 64.48 and US$ 56.01 per hectare in 2018, 2019 and 2020 respectively[10].

Pest populations may be affected by abiotic factors such as weather conditions and biotic factors such as the number and composition of natural enemies, their intra- and interspecific competition, herbivore reproductive capacity of the host, and the availability of resources[11]. It is important to know how pest population fluctuations relate to meteorological variations for interpreting survey data, predicting pest outbreaks, developing forecasting systems and in rational pest management. Therefore, understanding the population dynamics of FAW and the abiotic factors that influence its abundance is essential. Pheromones are an excellent tool for monitoring pest populations and timing management procedures[12–14]. They also enhance the possibility of early pest detection, determining action threshold, mapping pest distribution, inspection of quarantine facilities, estimating population dynamics, its prevalence[13], for reconnaissance and exploration[15]. America and Africa have extensively studied the population dynamics of FAW. However, in India, only a few studies have been conducted over the years. We therefore undertook the present study to analyse FAW activity in South India during different seasons.

Materials and methods

Study site and crop establishment

Fixed plot experiment was carried out for four consecutive seasons of *kharif* 2019, 2020 and *rabi* 2019, 2020 at the Agricultural and Horticultural Research Station (AHRS), Kathalagere, Davanagere, Karnataka, India, which is located at an elevation of 596.47 m amsl, having geological coordinates of 14.226°N and 75.827°E. A bulk area of 1000 m^2 was sown during each season using maize hybrid CP818 with a spacing of 60 × 20 cm between the rows and plants. The crop was raised using all the recommended packages of practices, except for plant protection measures.

FAW population

Observations on pheromone trap catches, number of egg masses, larvae, damage rating and percentage of plant infestation were recorded starting from 8 to 9 days after planting, i.e. two ligulate leaves stage to maturity stage of the crop.

The maize developmental stages as given by Prasanna *et al.*[16] are:

VE-V_6 – Early whorl stage (July in *kharif* and November in *rabi*).

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V_7-VT – Late whorl stage (August in *kharif* and December in *rabi*).

R_1-R_3 – Tasseling to milk stage (September in *kharif* and January in *rabi*).

R_4-R_6 – Dough to maturity stage (October in *kharif* and February in *rabi*).

Four sleeve traps (Pheromone Chemicals, Hyderabad, India) along with a commercially available FAW pheromone lure were placed in the field on bunds at the time of sowing, and the distance between two traps was 20 m. Every week, the traps were emptied and the number of FAW males was recorded. The pheromone lure was replaced at an interval of 21 days. Maize plants were inspected by walking in a 'W' pattern in the field by avoiding borders[16].

The different growth stages of the crop served as the treatment, and ten blocks in an area of 1000 m^2 served as replications. In each block (100 m^2), 100 plants were observed at weekly intervals and observations on the number of egg masses and larvae were recorded visually, and all the observations recorded per replication were translated into per plant. Damage to the leaves was assessed visually using the scoring scale of 1 to 9 reported by Davis and Williams and modified by CIMMYT, Mexico. Weekly observations on leaf damage scores were recorded for all the 100 observed plants from each block. Percentage was calculated using the following formula[17,18].

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

Data analysis

The data infestation were subjected to analysis of variance (ANOVA), using SPSS Version 20.0 statistical packages. The correlation between trap catches, number of egg masses, number of larvae and leaf damage rating was done using weather parameters, viz. maximum and minimum temperature, relative humidity, rainfall and wind speed.

Results and discussion

Trap catches of FAW moths during kharif and rabi 2019 and 2020

Figure 1 depicts two-year pooled data of FAW trap catches in *kharif* and *rabi* season. Significantly higher trap catches in *kharif* season were noticed in July (23.00 ± 3.16 moths/trap/week) followed by August (9.75 ± 3.32 moths/trap/week) (one-way ANOVA, $F_{3,12}$ = 21.93, P < 0.01, Tukey's HSD) (Figure 1 *a*). Similarly, in the *rabi* season, significantly higher moth catches were recorded in November (14.97 ± 3.42 moths/trap/week) followed by December (7.85 ± 2.41 moths/trap/week) (one-way ANOVA, $F_{3,12}$ = 11.68, P = 0.001, Tukey's HSD) (Figure 1 *b*). In both seasons, trap catches declined during the reproductive stage of the crop, and no moths were trapped after the dough stage of the crop. Trap catches were found to have significant positive correlation with relative humidity (morning) (r = 0.279*), minimum temperature (r = 0.303*) and wind speed (r = 0.397**), whereas maximum temperature showed a negative correlation (r = –0.262*). Also, trap catches had a significant positive correlation with egg masses per plant (r = 0.855**) and leaf/cob damage score (r = 0.690**).

Egg-laying pattern of FAW during kharif and rabi 2019 and 2020

During *kharif* season, significantly higher egg mass/plants (0.23) was observed during July when the crop was at early whorl stage (VE-V_6) followed by August (0.12 ± 0.02) (one-way ANOVA, $F_{3,12}$ = 22.90, P < 0.01, Tukey's HSD) (Figure 1 *c*). Similarly, in the *rabi* season, differences in egg mass laid per plant were significant, being highest in November (0.25 ± 0.05) followed by December (0.09 ± 0.02) (one-way ANOVA, $F_{3,12}$ = 10.84, P = 0.001, Tukey's HSD) (Figure 1 *c*). The egg mass/plant had significant positive correlation with wind speed (r = 0.287*) and leaf/cob damage score (r = 0.585**).

FAW larvae/plant during kharif and rabi 2019 and 2020

FAW infestation appeared soon after the emergence (8–10 days after sowing) of the crop. The larval population was found to be higher in *kharif* than *rabi* season. During *kharif*, FAW larvae per plant ranged from 0.21 to 1.72. Maximum larvae per plant were noticed in the early whorl stage of the crop in July (1.72 ± 0.60), followed by August (0.70 ± 0.16). However, the infestation gradually declined there after, recording the lowest in September as the crop entered the reproductive stage. Similarly, during *rabi*, the peak of FAW larval population was noticed in November (1.57 ± 0.51), and it declined in December (0.59 ± 0.17) and January (0.17 ± 0.09). Whereas no infestation was noticed in February.

Leaf damage score and percentage of plant infestation during kharif and rabi 2019 and 2020

During the *kharif* season, leaf damage was found higher in August (4.53 ± 0.78) when the crop was in the late whorl stage (V_7-VT) than early whorl (VE-V_6) and during the reproductive stages of the crop. Leaf damage was significantly different among the months and stages of the crop (one-way ANOVA, $F_{3,12}$ = 14.36, P < 0.01, Tukey's HSD)

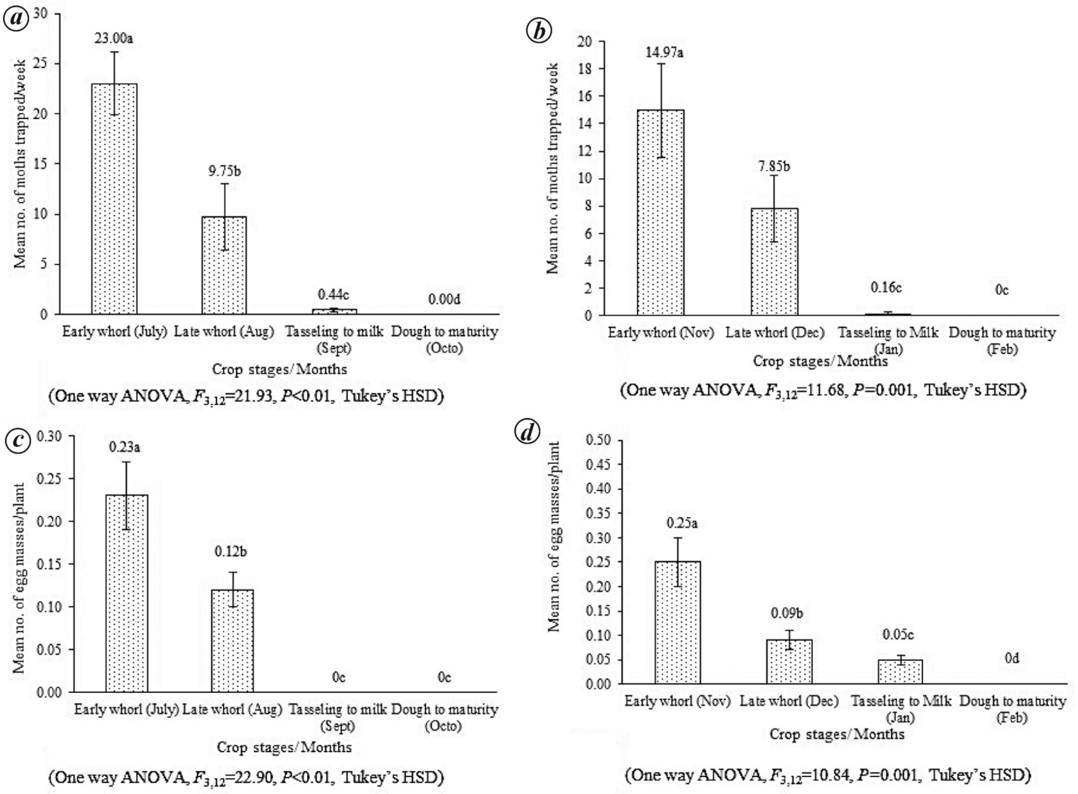

Figure 1. Mass trapping of adult moths and egg-laying pattern of fall armyworm (FAW) in *kharif* and *rabi* season during 2019 and 2020. ***a***, ***b***, Mean number of moths trapped per week during different months in (***a***) *kharif* maize and (***b***) *rabi* maize. ***c***, ***d***, Number of egg masses of FAW per plant during different months in (***c***) *kharif* maize and (***d***) *rabi* maize. Error bars represent standard error of means and mean values with same letters are not significantly different.

(Figure 2 *a*). Similar results were also obtained during *rabi* season, where leaf damage had significant differences in the other months (one-way ANOVA, $F_{3,12} = 14.42$, $P < 0.001$, Tukey's HSD) (Figure 2 *b*). Higher leaf damage was noticed in December (V_7-VT) (4.18 ± 0.57) than in the rest of the months. Leaf damage was significant and positively correlated with relative humidity (morning) ($r = 0.336$*) and wind speed ($r = 0.381$*), whereas it was significantly negatively correlated with maximum temperature ($r = –0.390$*).

The percentage of plants infested by FAW was more or less similar in the first two months of the crop in both *kharif* (July and August) and *rabi* (November and December) seasons; however, the differences were found to be non-significant, whereas significant differences were observed during rest of the months. In the *kharif* season, higher plant infestation was noticed in August (60.75 ± 10.92) while in the *rabi* season in November (58.00 ± 18.69). During the first two months after sowing, the crop was in the vegetative stage, indicating the most preferred stage by FAW. As the crop passed the vegetative stage and entered the reproductive stage, percentage of infested plants by FAW were reduced significantly in both *kharif* (September and October) (one-way ANOVA, $F_{3,12} = 7.77$, $P = 0.004$, Tukey's HSD) (Figure 2 *c*) and *rabi* seasons (January and February) (one-way ANOVA, $F_{3,12} = 7.49$, $P = 0.004$, Tukey's HSD) (Figure 2 *d*). Percentage of plant infestation was positively correlated with relative humidity ($r = 0.216$**) and wind speed ($r = 0.381$**), while it was negatively correlated with minimum ($r = –0.022$**) and maximum temperature ($r = –0.294$**).

We recorded higher trap catches of FAW moths during July and November. The trap catches increased gradually from the emergence of the crop in July and peaked in August during the reproductive stage of the crop[19]. However, in the present study, trap catches increased gradually from emergence, peaked in the third week of July and then gradually declined. Muturiki *et al.*[20] have also reported a rise in trap catches in August and November–December. During both seasons, the highest number of egg masses per plant was noticed in the early whorl stage (VE-V_6) of the crop, i.e. July in *kharif* and November in *rabi*. This might be due to the availability of uninfested plants for the female moths to lay eggs. The pheromone is the best method for settling on the number of pesticide applications[21]. In the present study, FAW infestation appeared soon after the emergence of the crop (8–10 days after sowing). In the *kharif* season, more larvae (0.18–2.76) per plant were recorded than in the *rabi* season (0.06–2.21). These results are similar to the findings of Anandhi *et al.*[22], who reported

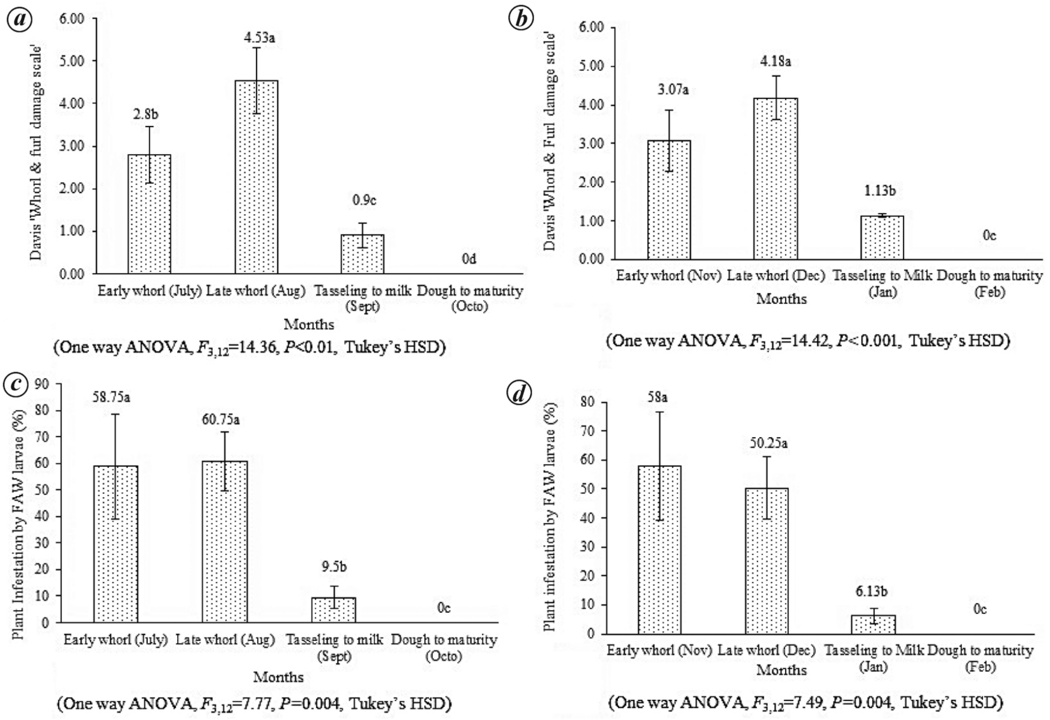

Figure 2. Damage scale and plant infestation (%) by FAW in *kharif* and *rabi* season during 2019 and 2020. ***a***, ***b***, Davis 'whorl and furl damage scale' during different months in (***a***) *kharif* maize and (***b***) *rabi* maize. ***c***, ***d***, Plant infestation (%) by FAW larvae during different months in (***c***) *kharif* maize and (***d***) *rabi* maize. Error bars represent standard error of means and mean values with same letters are not significantly different.

a higher FAW population in *kharif* (0.99–3.66 larvae/plant) and lower in *rabi* (0.66–2.60 larvae/plant). In both seasons, the early whorl stage (VE-V_6) was found to have the highest larval population compared to the late whorl and reproductive stage of the crop. The present findings are in accordance with those of Murua *et al.*[18], who reported that FAW larvae attack corn crops from V_1 to V_2 stage and recorded higher densities of FAW larvae during the vegetative stages from V_3 to V_6. Initially, when the crop is at the early stages, more number (>1) of larvae per plant was observed because of the soft leaves, absence of cannibalism in early instars, the ability of moths to lay eggs in groups and neonates feeding on the lower or upper surface of the leaf. When the crop stage advanced towards the late whorl stage, the number of larvae per plant declined and mostly 1 or 2 larvae were confined to the whorl, which could be due to cannibalism and dispersal of the larvae to adjacent plants and may be less preferred by the early instar larvae due to non-availability of tender/soft leaves. The present findings are in line with those of Deole and Paul[23], who reported that the FAW larvae mostly prefer the soft leaves of maize.

In the reproductive stage of the crop, the mean number of larvae per plant was recorded in *kharif* and *rabi* (0.21 ± 0.10 and 0.17 ± 0.09 respectively). More larvae were observed in the silking stage of the crop and a meagre population on the cob. A slight increase in the larval population was noticed in the silking stage compared to just the previous stage of the crop, containing 3–4 larvae per silk. However, we have noticed an early instar of FAW in silk. This might be due to the sudden availability of soft feed, i.e. silk, as by this time, all the leaves were mature, and the early instars could not feed on them. Similar results were obtained by Chimweta *et al.*[24], who recorded a higher number of larvae on silk (4.86 ± 0.44) than on/inside the cob (1.53 ± 0.44).

FAW usually acts as a defoliator and can kill young plants. Feeding on whorl can result in the loss of photosynthetic activity, and feeding on ears could affect the grain quality and yield reduction[25]. Maximum damage to the leaf was noticed in the late whorl stage (V_7-VT) in both *kharif* (August) and *rabi* (December) seasons compared to other stages. During the late whorl stage, whorls of the plants mostly contained the later instar larvae, which could cause severe damage as they are voracious feeders, resulting in a high leaf damage score. It was reported that 77% of the plant material is consumed in the last instar stage of FAW[26,27]. These results are in accordance with those of Sisay *et al.*[28], who reported leaf damage scores ranging from 1.8 to 7 across different locations surveyed. The reproductive stage of the crop recorded a cob damage score of 1.15 ± 0.07 and 1.13 ± 0.05 in *kharif* and *rabi* respectively, revealing meagre or negligible damage to the cob.

The percentage of plant infestation in *kharif* and *rabi* ranged from 7% to 87.50% and 3.50% to 86.50% respectively. In both seasons, the percentage of plant infestation was found to be higher in the vegetative stage of the crop than in the reproductive stage, and similar observations have been made in another study[29]. During *kharif* season, July and August had more or less similar plant infestations, whereas September recorded the least infestation. In the *rabi* season, November and December had more or less similar and higher infestation, while less infestation was observed in January. This indicates that FAW prefers the vegetative stage of corn. The present findings are in accordance with those of Shylesha *et al.*[30], who reported 9%–62.5% plant infestation from different locations surveyed. In a recent study from Karnataka, survey reports revealed that the FAW damage score ranged from 0 to 4.9 in maize and the larval count was 0.93–3.07/10 plants across locations[31]. However, from North Karnataka the incidence of FAW on maize ranged from 6% to 100% in *kharif* sown crop[8]. Sisay *et al.*[28] and Chimweta *et al.*[24] have reported 5%–100% and 94%–100% plant infestation by FAW respectively.

During the present study, the reproductive stage of the crop was less affected by FAW and there was a meagre incidence of larvae feeding on the cobs. However, Chimweta *et al.*[24] reported damage ranging between 25% and 50%, in silk and tasselling stages. Studies have reported 49.20% infestation by FAW during the reproductive stage of the crop[23]. The present study shows that the incidence and damage severity on maize crop by FAW varies with age of the plants[32].

Conclusion

This study conducted in South India uses data from *kharif* and *rabi* seasons for two years to demonstrate that changes in the abundance of FAW moth in maize are influenced by the growth stage of the crop, rainfall, precipitation and relative humidity. Since FAW damage is higher during vegetative growth stages (i.e. up to 9 weeks after emergence), pesticide applications after this period may be reduced or avoided.

Conflict of interest: The authors declare that they have no competing financial or other conflicts of interest.

Ethics approval and consent to participate: The authors agree to all concerned regulations.

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