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Investigating the efficacy of common agricultural practices for the management of fall armyworm (*Spodoptera frugiperda* (J.E. Smith)) on cereal crops

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Abstract

In Benin, the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is the most important polyphagous noctuid pest. This study aimed to assess the impact of agricultural practices on the abundance of this pest and determine whether its feeding preference and larval development differ among four cereal types. First, we conducted a descriptive survey of 80 farmers randomly selected for farm visits and oral interviews using a structured questionnaire to ascertain their preferred agricultural practices for managing *S. frugiperda*. Secondly, rearing methods in the laboratory were used to assess the development of the *S. frugiperda* maize strain feeding on maize, millet, rice, and sorghum. Data were collected on the number of larval instars, pupae, and adults as well as their developmental times. Agricultural practices were found to influence the abundance of *S. frugiperda* in the farmers' fields. The number of larvae was higher in sampling fields treated with herbicides alone. *S. frugiperda* larvae were reported to be more abundant on young vegetative plants, while the highest mortality rate was obtained on rice. In addition, the development level of *S. frugiperda* was fastest in maize, followed by sorghum, millet, and rice. The Structural Equation Models (SEM) showed significant relationships between the crop types and the abundance of development stages. Conversely, these relationships were significantly negative across the different stages of insect development. This study allowed us to understand the development level of the pest according to the different farmer's agricultural practices and its feeding preference to its potential cereal host plants.

Keywords: FAW larvae, feeding preference, maize, sorghum, rice, millet, Benin

1 Introduction

The Fall Armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith), is a polyphagous pest of many important crops (Day *et al.*, 2017). This pest was first reported in West Africa in 2016 (Goergen *et al.*, 2016). By the end of 2017, it had spread to over 30 countries in sub-Saharan Africa, Madagascar, Seychelles, and Cabo Verde. It has already reached Asia and has the potential to spread to parts of the Mediterranean region (Day *et al.*, 2017; FAO 2018; Nagoshi *et al.*, 2018). Since *S. frugiperda* was first reported on maize in Africa (Goergen *et al*, 2016), it has not only caused significant damage to cultivated grasses of economic importance, such as maize, sorghum, and sugarcane (Altaf *et al.*, 2022), but also to other legumes and cotton (Bundy & McPherson, 2007). Other economically important crops in Africa that have suffered major *S. frugiperda* damage include rice, beets, tomatoes, potatoes, and pasture grasses (Abrahams *et al.*, 2017; Day *et al.*, 2017; Ganiger *et al.*, 2018).

Understanding the evolution of pest abundance in cropping systems and the factors favoring their development on

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different host plants is an important step in designing diagnostic tools and appropriate control measures. Better knowledge of pest abundance at different stages of host plant development will contribute to appropriate decisions to improve farmers' management practices and phytosanitary interventions. Few African farmers have received training in agricultural practices and many still use endogenous practices, which often have limitations. Even then, the use of agricultural practices may vary according to farmers' sociodemographic characteristics, including their level of education.

The abundance of *S. frugiperda* and its damage may vary depending on host plant and agricultural practices (Dassou *et al.*, 2021). Several factors such as agricultural practices, food preferences, living environment, and food quality may explain the variation in the abundance of *S. frugiperda* on host plants (Dassou *et al.*, 2023). These environmental factors would also modify the pest feeding behavior, depending on its ease of digesting the host plant. Other mechanisms can also explain the feeding behavior of *S. frugiperda* on cereals. This could be due to the cereal plant's chemical resistance, after the damage caused by the feeding of the pest over a long period. This resistance can be induced by decreasing water and nutrient concentrations and increasing the production of secondary defence compounds, such as phenols, tannins, and alkaloids (Clay & Cheplick, 1989; Heidel-Fischer & Vogel, 2015).

For growth, development, and reproduction, FAW larvae prefer to feed on maize leaves rather than on other host plants (Davis & Williams 1995; Meagher *et al.*, 2004). However, Barros *et al.* (2010) found that larvae reared on maize and millet leaves showed a high survival rate, with values higher than those obtained with other diets under laboratory conditions. Juarez & Schofl (2012) also showed that, in Columbia, the *S. frugiperda* maize strain was more abundant on maize and cotton while the rice strain damaged maize and rice more, demonstrating that maize strain specificity is superior to rice strain. In Benin, no study has shown how the *S. frugiperda* maize strain, which is the most widespread, behaves on other host plants. This study provides a better understanding of the evolution of this pest on maize and other cereals as influenced by agricultural management practices, as a crucial first step in the establishment of viable monitoring systems. We hypothesized that farmers' choice of agricultural practices could contribute to reducing the abundance of *S. frugiperda* in cereal fields.

This study aimed to determine the abundance of the *S. frugiperda* maize strain on four kinds of cereal crops i.e., maize, millet, rice, and sorghum. Specifically, we: i) assessed the abundance of *S. frugiperda* in cereal cropping fields and variations according to farmers' sociodemographic characteristics; ii) determined agricultural practices and pesticide use patterns in cereal cropping systems; and iii) determined the development of the *S. frugiperda* maize strain on maize, millet, rice and sorghum.

2 Materials and methods

2.1 Study site

The study was conducted in the department of Collines (8°25′0" N and 1°52′60" E) in the region of central Benin between August and November 2019. The department of Collines belongs to the subequatorial climatic zone and has two seasons: the dry season (November – March) and the rainy season (April –October). The average annual rainfall is approximately 1,100 mm. The distribution of rains is fairly regular, with the maximum rainfall usually recorded in July. Temperature variations are relatively high, ranging from 25 to 38 °C (Adomou *et al.*, 2006). The soils are usually of the tropical ferruginous, hydromorphic, and vertisol types (Junge & Skowronek, 2007).

2.2 Farmer's sociodemographic characteristics and agricultural practices

A structured questionnaire was designed and administered to 80 farmers in 8 villages (Dassa Center, Tré, Kèrè, Mudji, Muja, Pira, Lulè, and Okouta-Ossé) of Collines in the Republic of Benin, who were actively involved in cultivating maize, sorghum, millet or rice for more than three years. In total, 10 cereal farmers per village were selected for the study based on their experiences. The fields were selected using a farmer's participatory approach according to the method of Dassou *et al.*, (2021) who worked with farmers in the study area based on the farmer's knowledge of FAW management. A discussion was conducted beforehand with the village chiefs, who helped identify the 10 cereal farmers according to their field size, years of experience, and willingness to make their fields available for observation. The selected fields were at least 10 km apart and within agricultural landscapes with a diversity of trees and crops. Data were collected on age, household size, sex, level of education, type of fertilizer used by farmers, weed management, farming practices used to control pests, and the mode and frequency of use of selected agricultural practices such as crop rotation, fallow, use of pesticides, resistant plant varieties or trap plants, and the variety and production cycle of each crop. The level of education (out of school, primary, secondary, or university) of the farmers and their experiences acquired during their years of agricultural production were documented to understand their influence on agricultural practices (Table 1).

2.3 Assessment of S. frugiperda abundance in farmers' fields

FAW larvae were collected from 80 cereal crop fields, including 20 maize fields, 20 sorghum fields, 20 millet fields, and 20 rice fields, in the Department of Collines from July to September 2019. The fields were chosen according to agricultural practices (fertilizer, herbicide, etc.). In each selected farmer's field, an experimental plot of 10 × 10 m was delimited, in which all developmental stages of *S. frugiperda* were collected on the leaves and stems of all plants infested by *S. frugiperda* and then counted. During the collection of *S. frugiperda* larvae, the phenology of the cereal plants was recorded. The three stages of development, i.e., the vegetative or young, flowering, and fruiting stages, were recorded on every data collection date. This description of the plant developmental stages made it possible to identify at which plant stage the damage of *S. frugiperda* becomes important.

2.4 Mass rearing of S. frugiperda in laboratory

Mass rearing of *S. frugiperda* was carried out in the Laboratory of Biotechnology, Genetic Resources, and Plant and Animal Breeding (BIORAVE – ENSBBA) under natural tropical lighting conditions (mean temperature of 25 °C and 75 – 90 % RH) in Central Benin. The temperature and relative humidity of the laboratory were measured daily using a HTC-1 wall-mounted hygrothermometer. Mass rearing allowed obtaining a large number of *S. frugiperda* larvae for pest development experiments on host plants. Two pairs (male and female) of *S. frugiperda* adults (1 day old) kept in the rearing box were transferred to oviposition jars (10 × 10 × 15 cm). The oviposition jars had a 2.5 cm layer of moist sterilized sand at their bottoms already covered with a circular cut piece of ordinary paper and then with cotton swabs for relative humidity and with each exactly fitting the rearing box. An ordinary paper was placed to avoid direct contact between the wax paper and the moist sand. After the release of the moths, each jar opening was covered with a thin fillet cloth tied with a rubber band to prevent the adults from escaping. The experimental jars were observed daily for egg laying. Wax paper containing egg masses was removed from the respective rearing boxes, cut to the desired size along with the egg mass, and kept separately in a Petri dish provided with moist cotton swabs. These freshly laid egg masses served as the initial cultures of *S. frugiperda* for further mass rearing for subsequent laboratory experiments (Murúa & Virla, 2004).

2.5 Laboratory experiment on the development of S. frugiperda

The development of *S. frugiperda* was evaluated on four host plants: maize, rice millet, and sorghum. Germinated plants were used as substrates for breeding *S. frugiperda*. First, 30 *S. frugiperda* larvae of first instar were introduced into each rearing box containing 0.3 Kg of germinated plants measured with a HUAJIE brand electronic scale instrument (Model HJ-300, Specification 300 g : 0.001, Power: DC-9V). Four plastic boxes (10 × 10 × 10 cm) containing germinated seeds from the host plant were used. The boxes were doubly closed with a paper cloth and perforated lid, which was covered with a wire mesh to allow ventilation. Thereafter, the rearing boxes containing the larvae and host plants were placed on plates containing water to prevent attacks by ants, which are predators of the larvae of *S. frugiperda*, from entering the setup. The food source, including the host plants, was changed every two days. When the larvae reached the adult stage, the moths were fed on cotton wick soaked in 4 % honey and water solutions daily (Bird *et al.*, 2022). Data were collected once every two days on larval survival and duration, the number of pupae, and adults that emerged or died on each host plant for the entire duration of the experiment. The percentage of live larvae (including all larval stages) and that of pupae and adults that emerged or died on each host plant were then determined.

3 Data analysis

We determined FAW abundance by calculating the number of larvae collected per unit area for each farmer's field. Generalized Linear Models (GLMs) with the Poisson family were used to determine the variation in FAW abundance, effect of agricultural practices (fertilisation and pest management), plant development stages on *S. frugiperda* abundance, and feeding preference of *S. frugiperda* on cereal crops (maize, millet, rice, and sorghum). The GLMs were tested against a null model using the Likelihood Ratio Test (Bolker *et al.*, 2009). Estimates of GLMs were done using the 'lme4' package (Bates *et al.*, 2011), in which the maximum likelihood of parameters is approximated by the Laplace method (Bolker *et al.*, 2009). To test the direct and indirect interactions between the crop types and the abundances of insect development stages, we used structural equation modeling (SEM) with the 'lavaan' package (Rosseel, 2012). All data analyses were conducted using the software R version 3.4.2 (R Core Team, 2017).

4 Results

4.1 *Influence of socio-demographic parameters on the number of S. frugiperda collected in farmer's fields*

FAW number varied significantly from one farmer's field to another ($p < 0.05$; Df = 79; LRT = 565.23). A significant correlation was found between the number of larvae collected and the farmers' educational level ($p < 0.05$; Df = 2; LRT = 25.95). The higher the educational level of respondent farmers, the lower was the number of larvae in their fields ($p < 0.05$; Df = 2; LRT = 232.84). More specifically, farmers who had up to secondary education had the least infested fields, followed by those who had only primary education. Higher numbers of *S. frugiperda* larvae were recorded in the fields of non-educated farmers. The mean larval abundance per field per village is as follows: Dassa center (19.0 ± 6.38); Okouta-Ossé (6.66 ± 1.03); Tré (6.16 ± 1.32); Muja (4.50 ± 2.50); Pira (4.16 ± 3.10); Lulè (3.00 ± 1.89); Kèrè (2.00 ± 0.80); Moudji (2.00 ± 0.50). In addition, the number of *S. frugiperda* larvae recorded differed significantly with the cereal type (Table 1).

Table 1: *Socio-demographic parameters of farmers surveyed.*

	in percentages				
parameters	*Overall*	*Maize*	*Millet*	*Sorghum*	*Rice*
Sex					
Male	76	76	68	76	84
Female	24	24	32	24	16
Education					
Never study	45	32	56	56	36
Primary school	41	52	32	32	48
Secondary school	14	16	12	12	16
Household size					
1 to 3	28	32	28	20	32
4 to 6	48	48	48	52	44
> 6	24	20	24	28	24
Age of respondents					
18 - 49	67	68	64	75	72
Above 49	33	32	36	25	28

4.2 *Influence of agricultural practices on the number of S. frugiperda collected in farmer's fields*

In total, 562 *S. frugiperda* larvae were collected from 80 fields, of which 396 were found on maize, 91 on sorghum, 52 on millet, and 23 ,on rice. All surveyed millet and sorghum farmers (100 % response) practiced intercropping and crop rotation and their fields had low numbers of *S. frugiperda*. Fertilization influenced the number of S. frugiperda larvae in the sampled fields ($p < 0.05$; Df = 2). The surveyed farmers used two types of fertilizers: urea and NPK.

The number of *S. frugiperda* varied according to the flowering, fructification, and vegetative/young stages (Table 2). Fruiting plants had a high number of *S. frugiperda*, followed by the vegetative plants. The flowering plants had a low number of *S. frugiperda*. Regarding pest management, some farmers (60 %) used herbicides and insecticides to control weeds and insect pests, respectively. *S. frugiperda* number varied according to pest management methods (Fig. 1).

Table 2: *Effect of the village, farmer's education level, host crop type and agricultural practices on S. frugiperda number collected in farmer's fields*

Variables	*Df*	*δ AIC*	*Deviance*	*LRT*	*P-Value*
Village	79	-584.5	976.72	660.48	< 0.0001
Education	2	-22	976.72	25.95	< 0.0001
Main host crops	3	-509.23	976.72	565.23	< 0.0001
Fertilisation	2	-70.7	976.72	74.696	< 0.0001
Pest management	2	-27.9	976.72	131.86	<0.0001
Plant phenology	2	-233.3	976.72	60.729	<0.0001

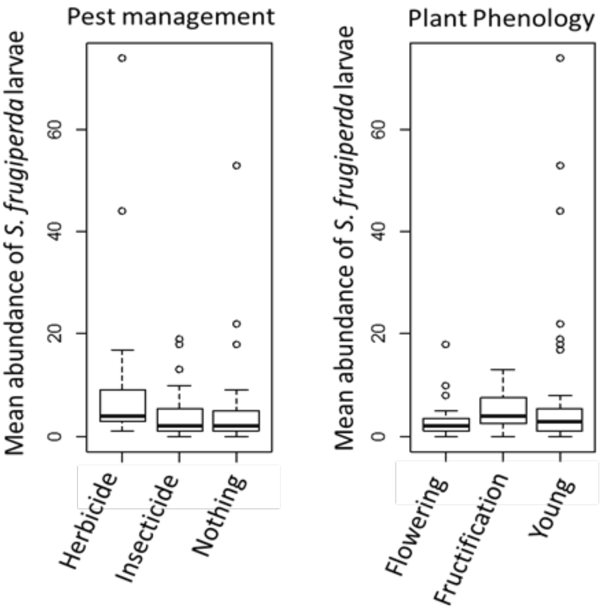

Fig. 1: *The abundance of S. frugiperda according to pest management (use of herbicide/insecticide or not) and plant phenology*

4.3 *Abundances of fall armyworm on different cereal crops during rearing in the laboratory*

The abundance of live *S. frugiperda* larvae varied among the crops tested (Table 3). The percentage of live larvae (including all larval stages) was higher on maize (80 % success rate) than on sorghum (53 %), millet (51 %), and rice (51 %). The number of dead larvae was higher on rice than on other crops. The lowest number of dead larvae was observed on maize. The number of emerged adults was higher on millet and maize than on rice and sorghum (Fig. 2). Chi-squared analysis revealed significant negative correlations between the numbers of live and dead larvae, living larvae and pupae emerged, living larvae and emerged adults, and living pupae and emerged adults (Fig. 3).

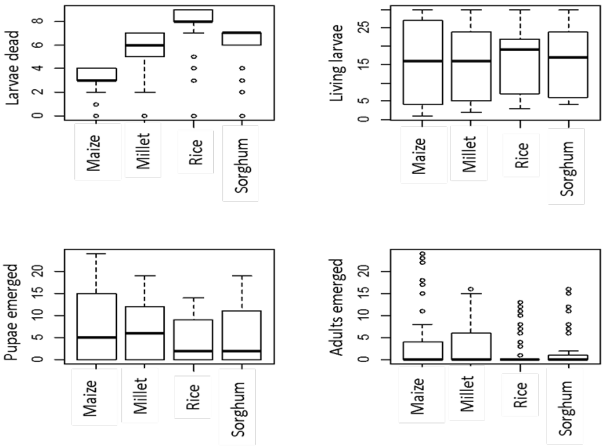

Fig. 2: *Evolution of different development stages of S. frugiperda in different leaves of cereal crops .*

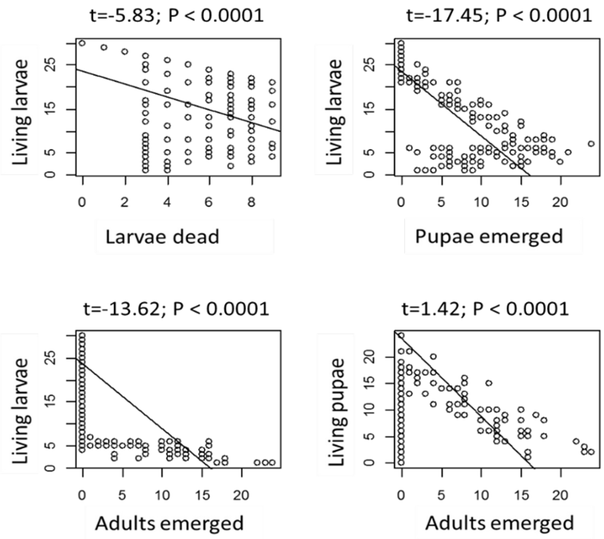

Fig. 3: *Relationship between living larvae number and numbers of other development stages of Fall Armyworm (FAW, S. frugiperda) grown on cereal crops*

The Structural Equation Models (SEM) showed significant positive interactions between the different types of crops and the number of live larvae, dead larvae, pupae, and adults. Conversely, the interactions were significantly negative between the number of larvae (live and dead) and pupae, showing that an increase in pupae led to a decrease in larvae. The interactions between the number of adults and pupae were also significantly negative (Fig. 4; Table 3).

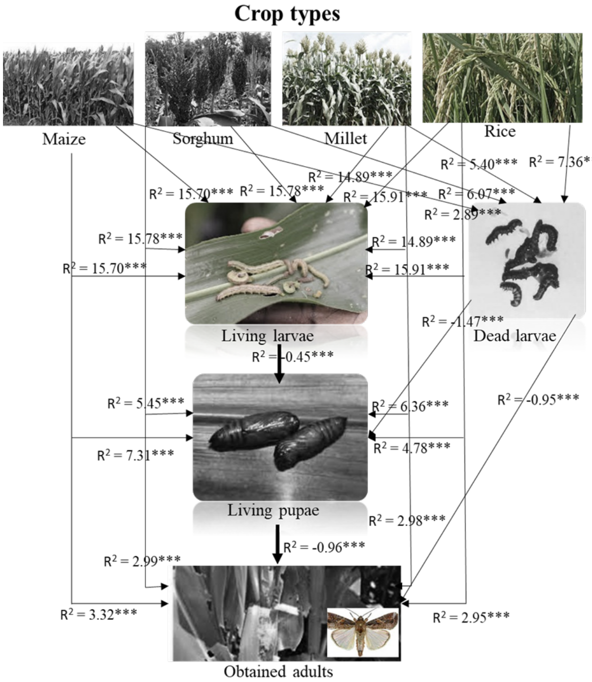

Fig. 4: *Structural Equation Models showing the interactions across the different stages of development (larvae, pupae, and adults) of S. frugiperda according to the crop types during rearing in the laboratory. With the function psem several linear models were tested simultaneously. As models, there were: living_larvae ~ crop_ypes; dead_larvae ~ crop_types; living_pupae ~ crop_types; adults_obtained ~ crop_types, living_pupae ~ living_larvae; obtained_adults_living_pupae; obtained_adults ~ living_larvae; obtained_adults ~ dead_larvae; living_pupae ~ dead_larvae and living_larvae ~ dead_larvae.*

5 Discussion

his study presents a concise analysis of the impact of farmers' agricultural management practices on the infestation and development of *S. frugiperda* (Fall Armyworm, FAW) on cereal crops. Our findings showed that the educational level and farming experience significantly influenced the severity of FAW infestations in cereal fields. Farmers who had up to secondary educational level had the least infested fields than those with the primary level. This relationship between FAW abundance in the fields and farmers' education could be explained by the influence of education on their knowledge level, as well as on the adoption and adequate deployment of efficacious agricultural practices (Alonge & Martin, 1995). Farming experience has a significantly positive effect on

Table 3: *Effect of crop types on the different stages of development (larvae, pupae, and adults) of S. frugiperda and their interactions during rearing in the laboratory.*

Response variables	*Predictor variables*	*DF*	*Estimate*	*Std.Error*	*P-Value*
Obtained adults	Living larvae	221	-0.9724	0.0086	0.0001
	Living pupae	221	-0.9667	0.0119	0.0001
	Dead larvae	221	-0.9552	0.0329	0.0001
	Crop type/rice	221	2.9526	0.1172	0.0001
	Crop type/millet	221	2.9809	0.0979	0.0001
	Crop type/sorghum	221	2.9919	0.1002	0.0001
	Crop type/maize	221	3.3202	0.1284	0.0001
Living larvae	Crop type/millet	224	14.8947	1.2888	0.0001
	Crop type/maize	224	15.7018	1.2889	0.0001
	Crop type/sorghum	224	15.7895	1.2890	0.0001
	Crop type/rice	224	15.9123	1.2891	0.0001
	Dead larvae	226	-1.47	0.25	0.0001
Living pupae	Crop type/rice	224	4.7895	0.8523	0.0001
	Crop type/sorghum	224	5.4561	0.8523	0.0001
	Crop type/millet	224	6.3684	0.8523	0.0001
	Crop type/maize	224	7.3158	0.8523	0.0001
	Living larvae	226	-0.50	0.02	0.0001
Dead larvae	Crop type/maize	224	2.8947	0.2315	0.0001
	Crop type/millet	224	5.4035	0.2315	0.0001
	Crop type/sorghum	224	6.0702	0.2315	0.0001
	Crop type/rice	224	7.3684	0.2315	0.0001

FAW management, indicating that more-experienced farmers were more technically efficient in their cereal production than new farmers, who might be new to implementing new agronomic practices (Onumah *et al.*, 2010). Knight *et al.*, (2003) argued that illiterate farmers can understand modern production technology as well as their educated counterparts when they are trained and the technology is communicated properly.nana production.

The high number of *S. frugiperda* recorded in the fields treated with herbicides may be explained by the fact that herbicide application also has indirect negative effects on beneficial insects. The number of larvae collected from fields treated with herbicides and insecticides was higher than that of untreated fields, which had the lowest number of larvae. This could be due to the misuse of chemical insecticides by farmers or the resistance of FAW to pesticides, leading to difficulties in its control (Kriticos *et al.*, 2015). In fact, in several regions of the world, insecticide overuse has resulted in the development of populations that are highly resistant to common synthetic chemicals (Yainna *et al.*, 2021). Consequently, collateral effects such as negative impacts on biological control organisms are often observed (Romeis *et al.*, 2006) through a reduction of biological control services and the degree of mitigation of pesticide effects on natural enemies. Insects have demonstrated great genetic plasticity, with more than 500 species now resistant to one or more insecticides (Mc-Gaughey *et al.*, 2002; Yu *et al.*, 2003). Insecticides can disrupt natural enemies by lethal and sublethal means causing pest resurgence or secondary pest outbreaks. At the field scale, non-compliance with good practices such as the use of selective insecticides, low doses, special formulations, creation of refuges, special application methods and targeted applications (temporal or spatial) (Roubos *et al.*, 2014) could also explain the high number of *S. frugiperda* observed in the treated fields.

FAW larvae were more abundant on young and fruiting maize plants than on flowering maize plants. This could be explained by the fact that the first two larval stages feed gregariously on the underside of young leaves for their growth in a very short time (Guo *et al.*, 2021). The pest actively feeds on the leaves, leaving only the leaf blades in place. Despite the attacks by this pest on the plants, many grew until flowering. During the fruiting stage, new colonies often appear for a second time, causing enormous damage to the fruits. However, little information has been published regarding the levels of infestation and yield losses. The damage caused by FAW larvae at the early stages of plant development was primarily caused by feeding on leaves and tender tissues. In addition, most infestations occurred at the mi-whorl, the most susceptible growth stage of maize (Baudron *et al.*, 2019).

The Structural Equation Models of the feeding interactions of the developmental stages showed that larval abundance varied according to crop type. This difference in the abundance of larvae confirmed the feeding preference of *S. frugiperda* through its host cereal plants. The high number of *S. frugiperda* was collected from the maize fields, followed by sorghum, millet, and rice. Indeed, *S. frugiperda* is reported to be a very polyphagous pest that can feed on plants from more than 20 families but prefers plants of the family Poaceae (CABI, 2016). The highest number of larvae recorded, particularly from maize, has already been observed by several authors (Casmuz *et al.*, 2010). Davis *et al.*, (1999) and Meagher *et al.*, (2004), reported that *S. frugiperda* larvae prefer to feed on maize leaves rather than some other host plants. Although FAW prefers maize, it is also common on sorghum, rice, and millets, and is sporadically important on a vast array of additional crops and plants, including cotton and vegetables. Conversely, the negative feeding interactions between the different developmental stages were justified by the rapid development of the insect from larvae to pupae and then to adults. During the experiment, we did not count the different larval stages to avoid generating multiple feeding interactions that were difficult to establish. This could constitute a bias that could be corrected in future studies.

6 Conclusion

Farmers' socio-demographic characteristics, particularly educationally level and farming experience, and their agricultural practices strongly can influence the abundance, level of infestation and the development of *S. frugiperda* on cereal crops. Then, higher numbers of pupal and adult emergence were recorded on maize, than on the other cereals. *S. frugiperda* preferred maize as its main host because its developmental period was shortest and the lifespan longer on the crop relative to sorghum, rice, and millet, which are considered its alternative host plants. The vegetative and fruiting plants had a high abundance of *S. frugiperda*.

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Authors' contributions

WA, DGA, FP, LYEL, JT, CA, EI, and AD participated in the study design; they analyzed and interpreted the data and drafted the manuscript. WA, AGD, JT, and LYEL carried out the field surveys. WA, DGA, FP, LYEL, JT, CA, EI, and AD corrected the manuscript. All authors approved the final manuscript.

Declarations

No ethical approval was needed for this study. Before data collection, participants gave oral consent to participate in the study.

Conflict of interest

The authors declare that they have no conflict of interest.

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