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ORIGINAL ARTICLE

Managing fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae): Experience from smallholder farmers in central and western Africa

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Abstract

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is currently an important pest of maize crops worldwide not only because of its dispersal ability but also because of its polyphagous feeding behaviour. Lack of sufficient information on the management of the fall armyworm attacks remains a crucial problem for maize smallholder farmers in Africa. In this study, 420 farmers were surveyed in central and west Africa using individual interviews to assess farmers' knowledges and perceptions of the fall armyworm damages and the management practices used. Most farmers (99.4%) were shown to recognize the fall armyworm and 92.5% claimed to already have damages in their fields. The fall armyworm seems not to be a new pest as most farmers identified it in different countries from 2015 to 2019. Apart from maize as the preferred crop of *S. frugiperda*, several alternative host plants including Napier grass, sorghum, onion, and cabbage were identified by the farmers. Although cultural and mechanical control methods are used by several farmers, the synthetic pesticide market is still preferred by almost half of the farmers (44.28%) who still use them. To control fall armyworm, 96.4% in Burkina Faso, 85.3% in Gabon, 65.2% in Benin and 25% in DR Congo reported using insecticides, against 5.9% in Senegal. Semiochemical-based method and biological control by promoting natural enemies of the fall armyworm are new concepts for farmers in DR Congo, Gabon and Benin. To avoid additional problems regarding health and resilience of agricultural systems, alternative methods such as push–pull approach, the development of biopesticides and resistant cultivars should form the basis of training given to farmers and should be popularized for sustainable control of the fall armyworm in central and west Africa.

KEYWORDS

fall armyworm, farmer's perception, maize, pest management, pesticide

1 | INTRODUCTION

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), is a lepidopteran species in the Noctuidae family native to tropical and subtropical America (Cokola et al., 2020; Early et al., 2018). Since its arrival in West and Central Africa in early 2016 (Goergen et al., 2016), this pest has spread rapidly throughout sub-Saharan Africa (SSA) and is causing significant damages to a wide range of crop plants (Baudron et al., 2019). In almost 4 years, this devastating pest has invaded 3 continents, starting in Africa and extending to Oceania (CABI, 2021). With a preference for Poaceae, this caterpillar pest mainly attacks maize (Cokola et al., 2021a; Rwomushana et al., 2018). Nevertheless, in its native region, it can establish more than 350 plant species, of which 80 are commonly cultivated plants such as maize, sorghum, rice, or cotton (Montezano et al., 2018). Because of this polyphagous nature, FAW can establish and adapt well in a newly invaded area by attacking other crops, usually vegetable crops (Cokola et al., 2021b). Its rapid spread across the African continent is causing significant yield losses to maize crops for tens of millions of smallholder farmers who depend on this crop for their food security (Day et al., 2017). Estimates report annual yield losses to agriculture in Africa, especially maize, in monetary values of 9.4 billion USD (Eschen et al., 2021). Considering the rate of infestation, analyses by Tambo et al. (2021) indicate that households that reported severe FAW infestations experienced a significant 44% decline in income per capita.

Given the level of infestation, the presence of the FAW in Africa is irreversible, and therefore, the smallholder farmers must learn how to manage this insect pest (Hruska, 2019). In response to this threat, one of the first reactions of farmers is the use of neurotoxic insecticides that are often not efficient and pose environmental hazard (Togola et al., 2018). The increased incidence of FAW has potentially intensified smallholder reliance on pesticides (Kansiime et al., 2019; Tepa-Yotto et al., 2022). In the purely African context, there is no registered synthetic insecticide for FAW control, except for emergency label-authorized applications, suggesting an urgent need for synthetic insecticide screening (Sisay et al., 2019). To help farmers find sustainable solutions to limit the damage caused by this caterpillar, non-governmental organizations (NGOs) and producers' associations are implementing training through schemes such as demonstration fields or farmer field schools that allow farmers to share their experiences to control this pest (FAO, 2018; Prasanna et al., 2018).

Since its invasion in all tropical and subtropical regions of the world, the FAW has attracted increasing research interest to find sustainable management options through agroecological practices and the use of biopesticides (Bateman et al., 2018; Harrison et al., 2019; Midega et al., 2018). In the Americas, producers and researchers have long studied FAW and their experiences are being used to develop sustainable management options appropriate for large-scale farmer systems (Meagher et al., 2022; Sparks, 1986). For example, in the United States, Brazil and Argentina, FAW was commonly controlled by the application of effective pesticides and the use of genetically modified corn (Bt corn), which incorporated genes to produce lethal toxins against FAW (Hruska, 2019). Farming systems as well as agroecological and socio-economic conditions (such as farm size, yields and access to institutional support services) did not allow African farmers to explore these options (Tambo et al., 2019). In the African context, training programs through village meetings, farmer field schools and communication campaigns have been launched to teach farmers basic concepts on the biology and ecology of this pest and to allow them to exchange experiences and techniques for its management (Rwomushana et al., 2018). Unfortunately, these meetings are limited only in some regions and no action has yet been taken in other parts of Africa.

In parallel, a number of literatures explore the control strategies used by farmers in some parts of Africa and their perception towards such management practices against FAW (Ahissou et al., 2022; Ansah et al., 2021; Caniço et al., 2021; Chimweta et al., 2020; Houngbo et al., 2020; Hruska, 2019; Kansiime et al., 2019; Kasoma et al., 2021; Kassie et al., 2020; Kumela et al., 2019; Tambo et al., 2019, 2021, 2022; Tambo, Day et al., 2020; Tambo, Kansiime et al., 2020). Although research has already been undertaken in Africa, information on indigenous practices is lacking in some African countries, especially in French-speaking countries, such as DR Congo, Gabon, Senegal etc., yet farmers in these countries have been facing the FAW invasion since 2016 and indigenous knowledge, perceptions and management practices might be different depending on the situation in each country. Farmers in these countries undoubtedly have different farming practices in relation to soil and climate conditions. In addition, local data on FAW management methods used by farmers after the training programs remain poorly available. The objective of this study is to contribute to the data on farmers' local practices and their perception of the presence of FAW in 5 African countries: Democratic Republic of Congo, Gabon, Benin, Burkina Faso and Senegal. This study constitutes a source of information in the development of an integrated management strategy for FAW in Africa through the integration of indigenous methods of smallholder farmers.

2 | MATERIALS AND METHODS

2.1 | Study area

The survey was conducted in two countries in Central Africa and three in West Africa. First, the study focused on Gabon and the Democratic Republic of Congo (DRC). In Gabon, interviewed farmers were primarily from the Estuary province near the township of Ntoum (0°22′46″ N, 9°46′26″ E). In DRC, surveys were conducted in two provinces. In the southwest, in Kongo Central Province around the Luki Biosphere Reserve, specifically in the townships of Lukula (5°37′19″ S, 13°05′55″ E), Muanda (5°38′22″ S, 13°3′44″ E) and Banza Seke (5°29′55″ S, 13°17′28″ E). In eastern DRC, farmers interviewed were from South Kivu province in three territories: Kabare (2°18′56″ S, 28°47′40″ E), Walungu (2°37′51″ S, 28°45′41″ E) and Uvira (2°50′55″ S, 29°1′30″ E). Secondly, in West Africa, the survey was conducted in three countries: Benin, Burkina Faso and Senegal. In Benin, the surveys were distributed in the provinces of Ouémé and Zou, specifically in the townships of Djidja (7°23′20″ N, 2°4′31″ E), Bonou (6°54′25″ N, 2°27′19″ E) and Adjohoun (6°43′15″ N, 2°28′40″ E). In Burkina Faso, the farmers surveyed came from two agro-climatic zones (Sudanian and Sahelian). The Sudano-Sahelian zone included the township of Bama in Houet province, the towns of Tiéfora (10°39′4″ N, 4°38′42″ W) and Banfora (10°40′33″ N, 4°49′2″ W) in Comoé province, and the township of Léo (11°11′36″ N, 2°0′44″ W) in Sissili province. In the Sudan-Sahelian zone, farmers were from the township of Sapouy (11°40′34″ N, 1°39′13″ W) located in Ziro province. In Senegal, the farmers who were interviewed were located in the Kaffrine region around the Boulel township (14°17′10″ N, 15°32′7″ W) and Saint Louis (15°55′9″ N, 16°22′48″ W). An overview map of the study area with a repartition of the respondents in the regions where the study was conducted is presented (Figure 1).

2.2 | Survey design

The survey form was developed based on existing information and data sources on FAW in Africa (Rwomushana, 2018). This questionnaire was created to collect basic information about the respondent such as gender, age, education level, household characteristics, farm structure, farmers' knowledge and perception of FAW damage and management practices implemented. The questionnaire was sent in electronic format to the different partners involved in the study. To facilitate the survey, the questionnaire was encoded in the KoBoToolbox online data collection software (https://www.kobotoolbox.org/), and smartphones such as the Samsung Galaxy were used to conduct the survey, each time with the geographical coordinates of the locations and fields observed.

2.3 | Data collection

In the survey phase, a questionnaire was administered to farmers face-to-face with interviewers. In total, 420 farmers were randomly selected and interviewed, of which 172 were in the Democratic Republic of Congo, 89 in Benin, 55 in Burkina Faso, 34 in Gabon and 70 in Senegal (Figure 1). The sampling design of this study is appropriate to understand the actions taken by regional/local farmers from 5 distinct countries to control FAW 7 years after the first invasion in Africa. The surveys were conducted during the period from August to October 2020 in the fields and households of farmers. The period of the surveys coincided with different agricultural phases across countries: at the end of the growing season, into the dry season or the starting of the maize cultivation.

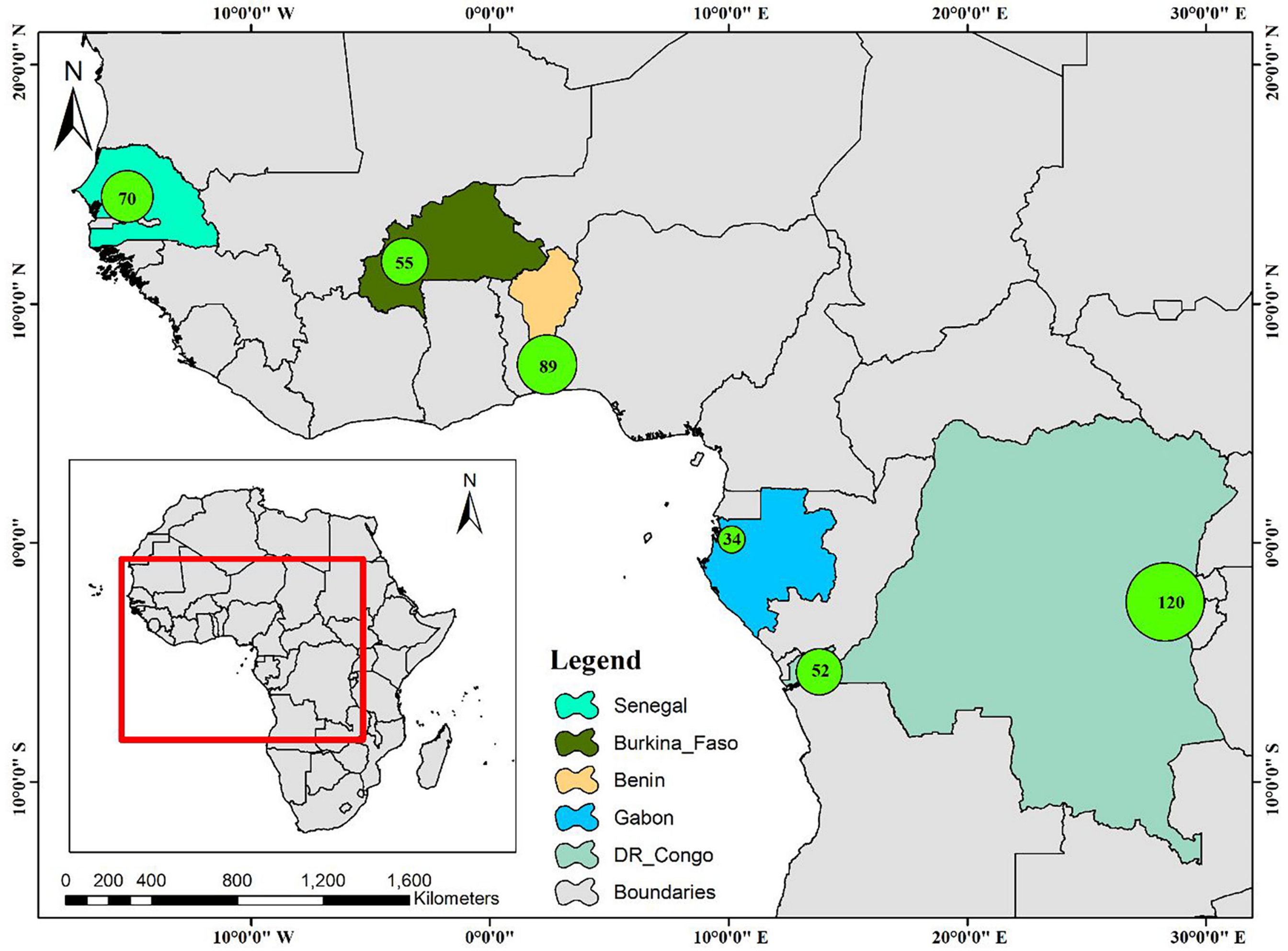

FIGURE 1 Map showing the study area with the countries and investigated zones in each country. The size of green circle corresponds to the number of survey respondent in the considered area. DR Congo is coloured in pale blue, Gabon is coloured in blue, Benin is coloured in light orange, Burkina-Faso is coloured in dark green and Senegal in turquoise. The map was generated by the author using ArcMap 10.8.1 (https://desktop.arcgis.com/en/arcmap/).

The concepts of knowledge, perceptions and management practices were used to analyse farmers' management decisions against FAW. These concepts have been widely used in previous studies (Ahissou et al., 2022; Caniço et al., 2021; Houngbo et al., 2020; Kansiime et al., 2019; Kasoma et al., 2021; Kumela et al., 2019; Tambo, Day et al., 2020) and were used as a basis in conducting this study. The knowledge referred to what the farmers know about the FAW: identification, year of observation of the pest and its damage on crops mainly maize. Questions related to trainings conducted by non-governmental organizations (NGOs), research institutions and international organizations such as International Institute of Tropical Agriculture (IITA), International Center for Tropical Agriculture (CIAT), food and agriculture organization (FAO) were asked to find out the level of knowledge of some farmers who received trainings on FAW and those who did not. To facilitate this, pictures of the FAW (different instars usually larval instar 4, 5 and 6) including damages/symptoms on the maize plant were printed on A4 size paper. Perceptions refer to how farmers assess the intensity of FAW damages on maize crop and the effectiveness of management practices (Kansiime et al., 2019). During the surveys, farmers were asked questions related to the year of FAW observation in own maize and other crop fields. Farmers gave a list of wild and cultivated plants. To confirm the presence of FAW, surveys were conducted on dry season crops (usually vegetables and fodder grasses) such as cabbage, onion, tomato, eggplant and grasses. The presence of FAW was confirmed in these crops by some experts participating in the survey.

Regarding management practices, farmers were given the possibility to provide more than one response to a proposed list of practices (Tambo et al., 2019; Tambo, Kansiime et al., 2020). To document pesticide usage, the trade names of the products were noted. Furthermore, in certain instances, additional details regarding the pesticides used, such as dosage, active ingredient, spraying regime and application method, were gathered from the product packaging discovered in or near the fields. The electronic survey form was improved during the data entry process in order to provide additional information's given by the farmers (e.g. crops not initially referenced or other reasons given by the farmers for not applying FAW management practices…).

2.4 | Data analysis

Data summary and descriptive statistics (frequencies, means and standard deviations) were performed using the data processing and statistical analysis software Rstudio 4.0.2 (R Core Team, 2021). Analysis of variance (ANOVA) was performed using the "rstatix" package (Kassambara, 2021) to estimate differences between countries not only on quantitative data of farmers' households such as their age, household size and labour force (number of assets in the household) but also on characteristics such as farm size and maize area cultivated in the year. In the case of rejecting the null hypothesis, a multiple comparison of means between each country was performed by a Tukey HSD (Honestly Significant Difference) test using the "multicompView" package (Graves et al., 2019). For the remaining questions, the frequency of response to the question was assessed and a chi-square test was performed to analyse relationships between countries and gender; between countries and farm size; between countries and variables related to the use of plant protection products; and between countries, kinds and sources of information received by farmers, and pest management practices. Excepting for the phytosanitary products where the percentages were calculated on the total number of farmers in the 5 countries, the other rates were calculated for each country. The significance level was set at 5% for all tests.

3 | RESULTS

3.1 | Socio-economic characteristics

Among all farmers surveyed in the five countries, 76.1% were men (Table 1). In Gabon, all smallholder farmers surveyed were men, while rates of 94.4%, 96.4% and 97.1% were found in Benin, Burkina Faso and Senegal, respectively. The female majority was only found in the Democratic Republic of Congo. Global average age of the survey population was 44.4 years. Farmers in Senegal were the oldest with an average age of ~50 years, while the ones in Benin were the youngest around 40 years. In Burkina Faso and Senegal, household size was found to be above average with ~9 and 10 persons, respectively. Smallest households were found in Gabon with approximately four persons. Senegal is the country with the largest number of active members by household, with an average of ~10 persons, unlike Gabon, where fewest active members were observed with an average of approximately two persons. Regarding the maize planted area during the year 2020, no significant difference between all countries was found as farmers planted an average of 1.99 ha of maize. There were differences between countries in the distribution of farm sizes. Then, farms of 1–5 ha were the most numerous in Benin, Burkina Faso and Gabon. In Senegal, most farmers had 5–10 ha, while it was mainly between 0.5 and 5 ha in DR Congo and larger than 10 ha in Burkina Faso.

3.2 | Farmers' knowledge and perception of FAW infestation

In general, farmers correctly identified the FAW (Table 2). Farmers reported recognizing the FAW caterpillar in 99.4% of the cases and 70.6% of them claimed to have already had damages to their crops due to this pest. Among farmers who received information's on all armyworm from NGO or other organizations, they were a majority in Burkina Faso (52.7%), while they represented only 2.3% in Benin, 4.3% in Senegal and 13.4% in DR Congo. In Gabon, no information was collected as farmers were concerned only by monitoring and control methods including the use of pesticides against FAW. The information sources came mainly from the FAO for farmers in Benin and from the farmers' field schools and demonstration fields set up by the farmers' communities in Burkina Faso. In DRC, fewer farmers received training, but it was more likely to come from several different sources. These included farmer associations that collaborate with NGOs and research institutions, university students, and the NGOs Mercy Corps and Food for the Hungry, or international institutions such as IITA and CIAT. In Senegal, the information was provided by the television and/or radio.

In total, 5 years (2015–2019) were listed by farmers as years of first observation of FAW in their fields (Figure 2). This information was collected in DRC and Gabon. In other countries such as Burkina Faso and Benin, 4 years were recorded (2016–2019). In Senegal, only 3 years were identified (2015–2017). In most cases and in every country except Gabon, farmers claimed to have seen the FAW for the first time in 2017. This represented 44.7% in DRC, 62.9% in Benin, 69% in Burkina Faso and 55% in Senegal. A very small minority of farmers claimed to have observed armyworm in 2015 (<0.05% in DRC, <0.05% in Senegal and <0.5% in Gabon) and 2019 (<0.05% in DRC, <0.05% in Gabon, <0.05% in Burkina Faso and <0.05% in Benin).

TABLE 1 Socio-economic profiles of surveyed farmers and associated data's of their farms.

Variable	Countries					Mean		
	Benin $n = 89$	Burkina Faso $n = 55$	Gabon $n = 34$	DR Congo $n = 172$	Senegal $n = 70$	$n = 420$	χ^2	F-test
Gender (%)								
Male	94.4	96.4	100.0	47.1	97.1	76.13	135.88***	
Female	5.6	3.6	0.0	52.9	2.9	23.87		
Age	39.5 ± 11.1c	44.8 ± 9.5ab	41.9 ± 10.3bc	46.6 ± 10.0ab	49.6 ± 11.7a	44.5 ± 10.5		11.29***
Household size	7.5 ± 4.2bc	8.9 ± 4.7b	3.5 ± 3.3d	6.8 ± 2.3c	14.1 ± 7.6a	8.2 ± 4.4		45.98***
Household active members	3.9 ± 2.6c	4.9 ± 2.8bc	1.7 ± 1.4d	5.6 ± 2.1b	9.7 ± 6.5a	5.2 ± 3.1		42.42***
Average maize area (ha)	2.19 ± 1.48a	1.63 ± 1.36a	1.85 ± 1.40a	1.23 ± 4.85a	3.05 ± 1.14a	1.99 ± 2.04		1.99^{ns}
Farm size (%)								
<0.5 ha	0.0	0.0	2.9	19.2	0.0	4.4	275.06***	
0.5-1 ha	12.4	1.8	20.6	39.0	0.0	14.7		
1-5 ha	65.2	63.6	58.8	39.5	23.1	54.4		
5-10 ha	21.4	30.9	14.7	1.7	36.9	21.1		
≥10 ha	1.1	3.6	2.9	0.6	40.0	9.6		

Note: Means ± standard deviations of countries followed by identical letters are not statistically different at the 5% significance level according to the HSD Tukey test. Statistically significant at ***$p < 0.001$; ns, not significant.

TABLE 2 Knowledge, types and sources of information on fall armyworm.

Variable	Countries						
	Benin $n = 89$	Burkina Faso $n = 55$	Gabon $n = 34$	DR Congo $n = 172$	Senegal $n = 70$	Mean $n = 420$	χ^2
Familiar with FAW (%Yes)	98.9	100.0	100.0	99.4	98.6	99.4	1.39 na
FAW infestation (%Yes)	100.0	100.0	100.0	91.8	70.6	92.5	56.62***
Informed about FAW (%Yes)	2.3	52.7	0.0	13.4	4.3	14.5	92.11***
Types of information							
Monitoring	0.0	1.8	0.0	5.3	3.5	2.7	49.36 na (a)
Monitoring & control methods	0.0	12.3	0.0	0.0	0.0	3.1	
Control methods	0.0	22.8	0.0	14.0	0.0	9.2	
Pesticides application	0.0	14.0	0.0	1.8	1.8	4.4	
Indigenous control methods	3.5	0.0	0.0	10.5	0.0	3.5	
Information sources							
FAO	50.0	0.0	0.0	19.0	0.0	17.3	67.04 na (a)
NGO, Mercy Corp & FH	50.0	4.2	0.0	14.3	0.0	17.1	
Farmer field school	0.0	50.0	0.0	33.3	0.0	20.8	
Demonstration fields	0.0	45.8	0.0	4.8	0.0	12.7	
Television and/or radio	0.0	0.0	0.0	0.0	66.7	16.7	
IITA	0.0	0.0	0.0	9.5	0.0	2.4	
CIAT	0.0	0.0	0.0	9.5	0.0	2.4	
Other sources	0.0	0.0	0.0	23.8	33.3	14.3	

Note: (a) Gabon was not included in the calculation of the χ^2. Statistically significant at $^{***}p < 0.001$; na, not applicable.

Abbreviations: CIAT, International Center for Tropical Agriculture; FAO, food and agriculture organization; FH, Food for the hungry; IITA, International Institute of Tropical Agriculture; IPM, integrated pest management; NGO, Non-governmental organization.

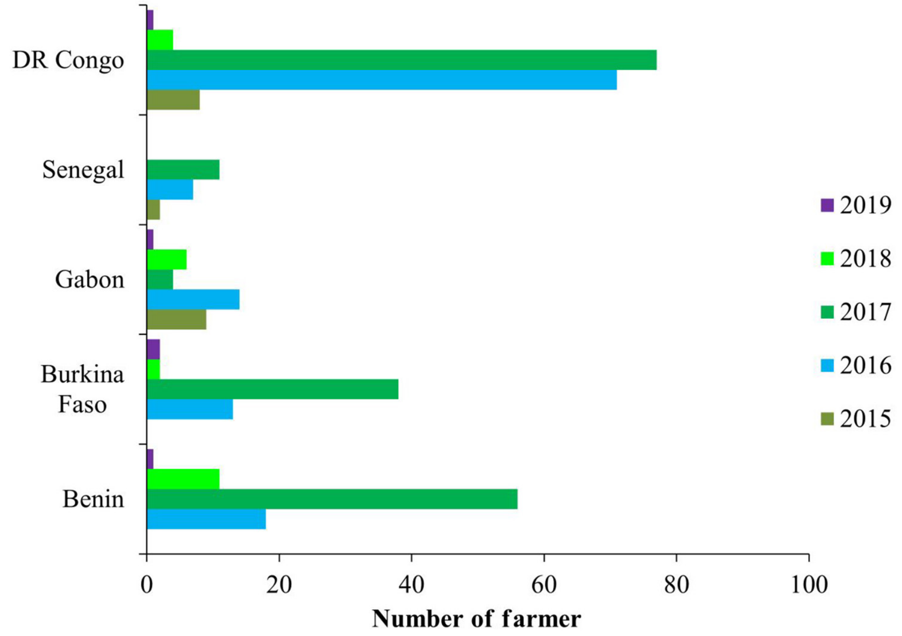

FIGURE 2 Observation years of fall armyworm by farmers in five central and west African countries.

TABLE 3 List of plants identified as alternate hosts for fall armyworm.

Scientific name	Common name	Familly	Observation country
Pennisetum purpureum Schumach	Napier grass	Poaceae	Burkina Faso, Gabon, DR Congo
Sorghum bicolor L.	Sorghum	Poaceae	DR Congo
Allium cepa L.	Onion	Amaryllidaceae	DR Congo
Brassica oleracea L.	Cabbage	Brassicaceae	DR Congo

Nevertheless, the year 2016 was listed by farmers in all 5 countries as the year of the first observation of FAW with considerable percentages.

From farmer observations and confirmations by some experts participating in the surveys in the concerned countries, four plant species constituting alternative hosts of the FAW were recorded (Table 3). These included a forage grass (*Pennisetum purpureum*), a cultivated grass (*Sorghum bicolor*) and two vegetable species, namely *Allium cepa* (onion) and *Brassica oleracea* (cabbage). These taxa are belonging to three botanical families. This information was collected in four of the five countries that participated in the survey. All alternative host plants of FAW were recorded in DRC. In Gabon and Burkina Faso, only one species (Napier grass) was recognized by farmers as an alternative host for FAW. No information on alternative hosts was collected in Senegal and Benin.

3.3 | Management methods to control FAW

A total of 14 methods were identified by farmers in West and Central Africa as indigenous management against FAW (Table 4), grouped into three categories including physical, cultural and chemical approaches. Chemical methods involve the use of synthetic pesticides and the application of certain plant extracts such as tobacco powder, *Tithonia diversifolia* extract, aqueous extract of garlic and Neem. All of them varied according to the reality of each country participating in the surveys. Farmers in Benin opted for cultural (frequent weeding, early planting) and physical methods (hand picking of larvae and egg masses). In Burkina Faso, cultural methods were dominant (early planting, use of resistant cultivars and crop rotation), with the addition of physical methods such as the application of ash. In DRC, cultural methods (frequent weeding) and physical methods were dominant (application of ash, hand picking of larvae and egg masses). In some cases, notably in Benin, hand picking contributed to feed livestock, while in DRC and Burkina Faso, caterpillars and eggs were destroyed on site without being recovered to feed livestock. In Gabon, no method was reported and farmers opted for no action. However, to manage FAW in this country, farmers have opted for chemical control. In general, during the surveys, *several* farmers responded that they were using no control methods, representing 14.6% in Benin, 10.9% in Burkina Faso and 16.3% in DRC. Two methods of FAW management were not recognized by farmers: the use

TABLE 4 Indigenous methods of managing fall armyworm in Central and West Africa.

Management methods	Countries						
	Benin $n = 89$	Burkina Faso $n = 55$	Gabon $n = 34$	DR Congo $n = 172$	Senegal $n = 70$	Mean $n = 420$	χ^2
Early planting	44.94	41.82	0.00	3.49	5.00	18.92	95.2***
Resistant/tolerant cultivars	1.12	41.82	0.00	1.16	5.00	7.30	114.3***
Crop rotation	5.62	41.82	0.00	1.16	10.00	8.65	93.0***
Regular weeding	48.31	16.36	0.00	48.84	20.00	37.84	47.1***
Fertilization	12.36	18.18	0.00	6.98	0.00	8.92	13.1***
Application of ash	2.25	38.18	0.00	37.21	0.00	23.51	63.5***
Use of plant extracts	7.87	16.36	0.00	4.65	10.00	7.03	11.76***
Intercropping with non-legumes crop	1.12	7.27	0.00	17.44	10.00	10.00	22.60***
Intercropping with legumes crop	2.20	0.00	0.00	30.20	0.00	14.60	63.25***
Trap cropping	Na	Na	Na	Na	Na	Na	Na
Push Pull	0.00	3.64	0.00	0.00	5.00	0.81	Na
Destruction of crop residues	0.00	0.00	0.00	16.3	35.0	9.50	43.17***
Uproot and burn infested plants	5.62	3.64	0.00	3.49	0.00	3.51	Na
Hand picking of larvae and egg masses	23.6O	0.00	0.00	48.30	0.00	28.10	78.06***
Replanting of attacked areas	3.37	7.27	0.00	0.00	0.00	1.89	Na
Biological control	Na	Na	Na	Na	Na	Na	Na
No action	14.61	10.91	100.00	16.28	0.00	23.14	125.74***

Note: Statistically significant at $^{***}p < 0.001$; Na, not applicable.

TABLE 5 Perception on the use of insecticides against fall armyworm.

Variable	Countries						
	Benin $N = 89$	Burkina Faso $N = 55$	Gabon $N = 34$	DR Congo $N = 172$	Senegal $N = 70$	Mean $N = 420$	χ^2
Application of pesticides (%Yes)	65.2	96.4	85.3	25.0	5.9	55.5	165.56***
Health problems related to pesticide use (%Yes)	42.7	41.8	29.4	28.5	75.0	43.5	9.95*
Uses PPE (%Yes)	93.1	30.2	90.6	31.4	80.0	65.1	90.66***
Types of PPE used							
Mask	36.6	51.7	24.5	34.1	30.8	35.5	51.25***
Glove	6.1	20.7	20.8	27.5	23.1	19.6	
Ruber boot	40.5	24.1	54.7	37.4	23.1	36.0	
Coveralls	16.8	3.5	0.0	1.1	23.1	8.9	
Perception of pesticide efficacy							
Low effective	10.3	7.5	0.0	9.3	0.0	6.8	13.68*(a)
Moderately effective	39.6	28.3	62.1	53.5	0.0	45.9	
Very effective	50.0	64.2	37.9	37.2	0.0	47.3	

Note: Senegal was not included in the calculation of the χ^2. Statistically significant at $*p > 0.05$, $***p < 0.001$.

Abbreviations: PPE, personal protective equipment.

of trap plants such as Napier grass or maize as a false seedling technique and biological control. The push–pull technology was only recognized in Burkina Faso and Senegal. Several other cultural methods were mentioned, including the application of both chemical and organic fertilizers, replanting areas attacked by FAW, destruction of crop residues, uproot and burn-infested plants and association of maize with both non-legume and legume crops.

To control FAW, 96.4% of farmers in Burkina Faso, 85.3% in Gabon, 65.2% in Benin and 25.0% in DRC reported the use of insecticides, compared to 5.9% of farmers in Senegal (Table 5). Paradoxically, farmers using mostly insecticides were also those who knew people having health problems due to pesticides with 42.7%, 41.8% and 29.4% for Benin, Burkina Faso and Gabon, respectively. This situation did not seem to discourage their use. Among farmers using pesticides, those wearing personal protective equipment (PPE) represented 93.1% of cases in Benin, 90.6% of cases in Gabon, 30.2% in Burkina Faso and 31.4% in DRC. Masks and Ruber boots were the most common PPE in all countries, with 35.5% of farmers using masks and 36.0% using Ruber boots. Coveralls were the least frequently encountered equipment, with 8.9% of farmers using them. Also, some farmers used equipment that did not provide effective protection against pesticides. For example, some farmers indicated that they used a hat or a motorcycle helmet when applying pesticides. Regarding their perception of the effectiveness of synthetic insecticides against FAW, the largest number of farmers perceived chemical treatments to be very (47.3%) or moderately effective (45.8%) on average in the five countries. Burkina Faso and Benin were the countries where farmers were most likely to use synthetic pesticides and to be convinced of their effectiveness against armyworm. Senegal was the country where insecticide treatment was reported by farmers with a small percentage.

In this survey, a good number of farmers representing 44.3% of the respondents used pesticides for FAW control (Table 6). A total of 18 commercial pesticides with 13 active molecules were recorded during the surveys. The most commonly used products were COTONIX 328 EC, EMACOT 050 WG, LAMBDA SUPER 2.5 EC and ROCKET. COTONIX 328 EC was used mainly in Benin and was generally supplied by the government. EMACOT 050 WG is a product that has been used mainly for maize

TABLE 6 Trade names, active molecules and frequencies of pesticides found in the community of farmers interviewed.

Trade products	Active molecules	Number of farmers	% of farmers[a]	WHO classes[b]
Insecticide treatments		186	44.28	
ACARIUS 018 EC	Abamectin 18 g/L	4	0.95	Ib
CAÏMA B19	Emamectin benzoate 19,2 g/L	1	0.23	II
COTONIX 328 EC	Deltamethrin 12 g/L + Chlorpyriphos-ethyl 300 g/L + Acetamiprid 16 g/L	10	2.38	II
CYPER LACER 5 EC	Cypermethrin 5%	1	0.23	II
DECIS 25 EC	Deltamethrin 25 g/L	3	0.71	II
DIMETHOATE 40 EC	Dimethoate 400 g/L	7	1.66	II
EMACOT 019 EC	Emamectin benzoate 19 g/L	9	2.14	II
EMACOT 050 WG	Emamectin benzoate 50 g/kg	49	11.66	II
K-OPTIMAL EC	Acetamiprid 20 g/L + Lambda-cyhalothrin 25 g/L)	3	0.71	II
LaraFORCE	Lambda-cyhalothrin 2,5%	6	1.42	II
LAMBDA SUPER 2,5 EC	Lambda-cyhalothrin 25 g/L	27	6.42	II
LAVA 100 EC	Dichlorvos 1000 g/L	8	1.90	Ib
PACHA 25 EC	Acetamiprid 10 g/L + Lambda-cyhalothrin 15 g/L	13	3.09	II
Pyro FTE 472 EC	Cypermethrin 72 g/L + Chlorpyriphos-ethyl 400 g/L	11	2.61	II
ROCKET	Chlorpyrifos 20% EC	24	5.71	II
TAFGOR 40 EC	Dimethoate 40%	3	0.71	II
THALIS 56 EC	Acetamiprid (32 g/L) + Emamectin benzoate (24 g/L)	6	1.42	II
THIODAN 50WP	Endosulfan 50%	1	0.23	II

[a]Percentage based on total number of farmers surveyed.

[b]Classification WHO (world health organization).

Ib, highly hazardous; II, moderately hazardous.

TABLE 7 Reasons for not applying fall armyworm management methods.

Management methods	Reasons for not applying: Expensive	Time required	Data not available	Inputs not accessible	Not understood the recommendation	Delayed rainfall	Do not know the method
Early planting						+	
Resistant/tolerant cultivars			+	+			
Fertilization	+			+			
Use of plant extracts					+		
Trapping crop			+				+
Push pull			+	+			+
Replanting of areas attacked		+		+			
Biological control			+		+		+
Application of pesticides	+			+			

Note: + Indicates the reason for not using fall armyworm management methods.

crops in Gabon and Burkina Faso. Generally, this product was supplied by traders in Burkina Faso and by the Gabonese chemical company. LAMBDA SUPER 2.5 EC is a product that was most often purchased on the market by Beninese farmers and was mainly used on maize crops. Finally, the insecticide ROCKET was used by Congolese farmers. Among the products used, the first family of insecticides found is highly toxic organophosphates. This is particularly the case for ROCKET, COTONIX 328 EC, Pyro FTE 472 EC, LAVA 100 EC and TAFGOR 40 EC. After organophosphates, the second most common pesticide family found is pyrethroids in slightly more than 10% of cases. Another very toxic product that was found is THIODAN composed of endosulfan which belongs to the organochlorine family.

Reasons for non-application of management methods against FAW are presented (Table 7). Also, a number of farmers generally used cultural, physical and chemical methods in managing FAW in the affected areas in Africa (Table 4). However, other farmers preferred not to deal with the observed damages or limited the use of a management method. Several reasons for non-application associated with the management methods are mentioned. For example, farmers in Benin, Burkina Faso and DRC often practised early planting as a preventive method, but this method was limited when there was a delay in rainfall due to climatic variability that favoured FAW outbreaks. Farmers would like to use resistant cultivars to FAW, but information on these was not available in some parts of Africa and in others, inputs were inaccessible. Methods such as fertilization and pesticide use appeared to be expensive and often not accessible. Information on the trap crop used in false seeding technique was not available and farmers were not aware of this method. The concepts of semiochemical based and biological control by promoting natural enemies of FAW were new to farmers in DRC, Gabon and Benin with respect to the push-pull method, and generally speaking to all respondents with respect to biological control. Replanting was not favoured by farmers because of the time required for that and input accessibility. The use of plant extracts should allow farmers to manage FAW at first sight but some of them did not understand how to apply the recommendation in the presence of several categories of plant extracts.

4 | DISCUSSION

The dominance of men in farms was reported in four of the five countries (Burkina Faso, Benin, Gabon and Senegal). The same trend was observed by Chimweta et al. (2020) in Zimbabwe; by Caniço et al. (2021) in Mozambique; and by Kasoma et al. (2021) in Zambia. In Africa, agricultural activities involved men and women differently (Palacios-Lopez et al., 2017). Men often dominate agricultural activities in Africa due to their status as household heads, landowners, and ultimate decision makers in resource use (Chuma et al., 2022; Kasoma et al., 2021). From another perspective, women are active in agricultural activities in Africa as in DRC where more than half of the farmers were women. According to Mugumaarhahama et al. (2021), the agriculture practised by women in most cases is of the "subsistence" type, unlike men ensure cash crops. In terms of maize area cultivated, no difference was reported between countries. This reflects the reality of agriculture in SSA, which is still practised in small areas (Hruska, 2019; Jayne et al., 2010) between 0.5 and 5 ha for this study.

Six years after its introduction on the African continent, several programs have been initiated in some countries invaded by the FAW to educate farmers on the pest and how to manage it (Chimweta et al., 2020; Tambo et al., 2019). Unfortunately, these programs are present in some African countries to the exclusion of others. This is the case, for example, in Gabon where NGOs and other organizations were not reported. According to Houngbo et al. (2020), belonging to a farmers' organization and being in contact with research or extension services is an advantage in the knowledge and perception of FAW damage. For effective deployment of control methods against a given pest, farmers must be able to morphologically identify the target pest and distinguish it from non-target ones (Caniço et al., 2021). Although methods and technologies are rapidly developing scientifically to find sustainable solutions against FAW, there is still human action that must be considered in the African context (Kansiime et al., 2019). FAW is not a new pest to farmers in Central and West Africa, who have observed it from the year 2015 for some and later in 2019 for others. Studies by Houngbo et al. (2020); Ahissou et al. (2022) also indicated that some farmers in Benin and Burkina Faso reported the presence of FAW in 2015. In this study, the vast majority of farmers reported 2016 and 2017 as the years they observed FAW in their fields. The year of introduction of FAW on the African continent remains an open question although first reported in 2016 (Goergen et al., 2016). Similar to the studies by Kumela et al. (2019); Houngbo et al. (2020); Caniço et al. (2021), this study indicated that farmers recognize FAW well and the majority of them already had damage in their maize crops. Furthermore, four plant species were recorded as alternative hosts of FAW including onion which was previously reported by Cokola et al. (2021b). The other crops reported, namely cabbage, sorghum and Napier grass, constitute new information that could help researchers and governments in the development of an integrated approach against FAW on the African continent.

Almost half of the farmers surveyed in this study used pesticides against FAW. Chimweta et al. (2020) and Tambo, Day et al. (2020) indicated higher values. Several molecules found in this survey were also found by Kansiime et al. (2019) and Tambo, Kansiime et al. (2020). Most of the active molecules found are not registered in Africa and are prohibited by Regulation (EC) 1107/2009. Most farmers perceived insecticide treatments to be very effective against FAW. This trend was very pronounced in Benin and Burkina Faso, where nearly two-thirds of farmers reported using insecticides. The same results were noted by Kumela et al. (2019). However, the use of PPE was far from widespread there. In Burkina Faso, half of the farmers who used insecticides did not wear PPE. Given the molecules used and the level of exposure, farmers in this part who did not wear PPE, while spraying products exposed themselves to high health risks for themselves and their relatives (Jepson et al., 2014; Togola et al., 2018). The progressive banning of molecules that are toxic to the environment and human health in industrialized countries continues to fuel the pesticide market in Africa. While farmers struggle to find organic fertilizer for their crops, pesticides are more accessible (e.g., at the market, at the corner shop, at the neighbour's house or provided by the state). In the global context of climate change and biodiversity loss, insects have important roles to play for ecosystems. However, pesticides are partly responsible for the disappearance of many species, which leads to the instability of agricultural ecosystems and makes them more vulnerable to the emergence of invasive species (Cardoso et al., 2020).

Despite the "farmer school field" programs undertaken in West Africa to find alternative methods, the pesticide use is not decreasing. Several factors may be responsible for the higher proportion of users. The land area is larger and the number of household members is smaller than the size of the household. The results of Tambo, Kansiime et al. (2020) indicated a positive relationship between maize area and pesticide use. In contrast, farmers in central Africa have smaller landholdings than in Benin and Burkina Faso. The ratio of assets in households is higher there, which makes it possible to favour mechanical methods such as hand picking, which are more labour intensive (Ansah et al., 2021; Tambo, Kansiime et al., 2020). Nevertheless, this method is still applicable at the farmer scale in SSA due to the relatively small areas of production (Hruska, 2019). In DRC and Benin, about one-third of the farmers interviewed used the hand-picking method, which showed their interest in finding alternatives to chemicals. Agroecological practices and the use of biopesticides as proposed by Midega et al. (2015, 2018); Bateman et al. (2018); Harrison et al. (2019) should form the basis of alternatives to be implemented in the training programs given to farmers and should not be limited in some countries as is the case for example in Ghana (Tambo, Kansiime et al., 2020) or Ethiopia (Gebreziher et al., 2020). As Yarou et al. (2017) pointed out, to encourage farmers to adopt new practices, we need to be able to convince them that the long-term benefits of agroecological practices will be more attractive than the immediate benefits provided by synthetic pesticides. Generally, farmers use a variety of inexpensive and locally available agroecological practices in pest management (Abate et al., 2000). Some farmers in this study opted for cultural methods such as frequent weeding, early planting and crop rotation. Similar results were noted by Tambo, Day et al. (2020); Tambo, Kansiime et al. (2020) in studies involving 5 other countries in Africa (Ghana, Rwanda, Uganda, Zambia, Zimbabwe). The push–pull method was only recognized in this study in Burkina Faso and Senegal with very low application frequencies. Similar results were obtained by Tambo, Day et al. (2020) in

Ghana and Zambia where only two households in a sample of 465 farm households applied the push–pull method. The concept of biological control appears to be new among the farmers interviewed in this study compared to Houngbo et al. (2020) who reported birds (francolin and the village weaver) and the common wasp as natural enemies of FAW identified by farmers in Benin.

Several reasons for not applying FAW management methods were mentioned by farmers. The early planting method is limited by climatic variability. At any given time, farmers do not know the ideal planting time in the presence or absence of rain (Ansah et al., 2021). The cost associated with pesticide application and fertilization has been cited for farmers who do not apply these methods. In Zimbabwe, for example, farmers reported a lack of financial resources as the main constraint (Chimweta et al., 2020). Availability and accessibility of resistant cultivars to FAW, etc. is also a major constraint. The use of Bt maize cultivars is discussed as an alternative in the sustainable management of FAW in Africa, but its use is not approved so far (Van den Berg et al., 2021). The availability of information and the lack of knowledge of certain methods by farmers (push pull, biological control…) constitute a real challenge in this study. Education campaigns on identification and the above-mentioned methods should be the priority in the control of FAW in countries where the level of knowledge of the pest remains low as proposed by Caniço et al. (2021).

5 | CONCLUSIONS

Currently, the training programs provided to African farmers for FAW control predominantly emphasize the utilization of synthetic insecticides. However, alternative methods employed by farmers were also mentioned, with their implementation based on the specific circumstances within each country. The limited adoption or absence of these alternative methods was attributed to several factors, including insufficient knowledge about certain techniques like push–pull and biological control, as well as limited availability of FAW-resistant crop varieties. This study identified four plants as alternative hosts of FAW, including fodder grass (*Pennisetum purpureum*), cultivated grass (*Sorghum bicolor*) and two plant species, namely *Allium cepa* (onion) and *Brassica oleracea* (cabbage). This information is one of the approaches to be used in the development of an integrated management strategy (IPM) for FAW in Africa.

In the future, the data collection system set up should make it possible to monitor the progress of FAW control programs and to target regions in SSA where farmers still need advice. This survey is a preliminary analysis of the management methods used by farmers against FAW in Central and West Africa. Continuation of the study and future analyses could provide a useful source of information for researchers and governments to monitor the evolution of farmers' practices and disseminate innovative methods of sustainable pest management that would have been implemented through farmers' organizations, research institutions and NGOs.

AUTHOR CONTRIBUTIONS

Marcellin C. Cokola: conceptualization, methodology, formal analysis, writing – original draft, writing – review and editing. Raphaël Van den Bussche: data curation, formal analysis, writing – original draft. Grégoire Noël: formal analysis, writing – original draft, writing – review and editing, Nongamanégré Kouanda: investigation, writing – review and editing. Rudy Caparros Megido: conceptualization, writing – review and editing. Boni B. Yarou: investigation, writing – review and editing. Sandrine Mariella Bayendi Loudit: investigation, writing – review and editing. Ernestine Lonpi Tipi: investigation, writing – review and editing. Fawrou Sèye: investigation, writing – review and editing. Baudouin Michel: conceptualization, writing – review and editing. Frédéric Francis: conceptualization, writing – original draft, writing – review and editing, supervision. All authors read and approved the final version of the manuscript.

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The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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