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Emergency response to the *Spodoptera frugiperda* invasion in Africa: What do maize producers in Burkina Faso think and do?

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***Spodoptera frugiperda*, the fall armyworm (FAW), has become a major pest of maize since its appearance in Burkina Faso in 2017 requiring appropriate emergency response. A survey was conducted with 161 maize farmers from 9 regions and 48 villages in the Sudano-Sahelian and Sudanese agro-climatic zones, the main maize-growing areas in Burkina Faso to collect their perceptions. For this purpose, a questionnaire designed on the Open Data Kit (ODK) mobile platform was administered to them individually. 96% of the farmers considered FAW the main current biotic constraint to maize cultivation. Most of them (98%) declared they could recognize the pest even though 60% had not received any training on the pest identification. Production losses caused by FAW range from 25 to 50% each year for 91% of the respondents. More farmers (90%) systematically use chemicals, notably Emacot 50WG (Emamectin benzoate 50 g/kg) against the pest. Unfortunately, 96% of users do not take any appropriate personal protective measures, while more than half (59%) have experienced adverse health effects. These results contribute to the implementation of a better FAW control strategy. It is also recommended that an effective national surveillance and early warning system be set up to better manage other such pests.**

Key words: *Spodoptera frugiperda*, perception survey, maize farmers, pest control, chemicals, health, environmental risks.

INTRODUCTION

Maize (*Zea mays* L) is one of the world's most important grains beside wheat and rice (Shiferaw et al., 2011). It is a food crop in sub-Saharan Africa where 70% of the production is used for human consumption (Shiferaw et al., 2011). In Burkina Faso, maize has the highest production rate estimated at 1,920,101 tons, or 37.07% of total cereal production (MAAHM, 2021). In addition to being the staple food of populations, maize is an

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important source of income for rural households (MAAHM, 2021). It is also one of the main cereals used in poultry farming.

However, since 2017, maize production has been compromised following the invasion of the fall armyworm (FAW), *S. frugiperda* J. E. Smith (Lepidoptera: Noctuidae) (Day et al., 2017; Prasanna et al., 2018). Indeed, discovered for the first time in West Africa in 2016 (Goergen et al., 2016), then in Burkina Faso in 2017 (Day et al., 2017), originating from the American continent (Nagoshi et al., 2012), this caterpillar has since posed a serious threat to maize crop (Prasanna et al., 2018). Its spread was so rapid in Burkina Faso that within a few months, all regions were invaded (MAAHM, 2021). *S. frugiperda* is a polyphagous pest (Goergen et al., 2016; Prasanna et al., 2018) with a marked preference for maize on which major damage is caused. Damage is caused by the larvae feeding on the young tender leaves, horn and reproductive organs. This leads to significant production losses reported in recent years in various African countries (Bhusal and Bhattarai, 2019). For example, losses are estimated at 22 to 67% in Ghana, 25 to 50% in Zambia (Day et al., 2017), and 32 to 47% in Ethiopia and Kenya (Kumela et al., 2019). In addition, FAW infestations can also lead to a reduction in production quality (Prasanna et al., 2018). In view of these various negative consequences, FAW poses a threat to the food and nutrition security of more than 200 million farmers in sub-Saharan Africa (Day et al., 2017; Prasanna et al., 2018).

In response, chemical control through the use of synthetic insecticides has been the main urgent measure taken by governments of affected countries to combat the pest (FAO, 2018). In addition to the risks to human health and the environment, the uncontrolled and inappropriate use of chemical pesticides, including unregistered ones, increases the risks of rapid development of pest resistance to the molecules used (Gountan, 2013; Kolia, 2015; Lehmann, 2017; Son et al., 2018; Ahmad and Arif, 2010; Hong et al., 2013; Muraro et al., 2021). Moreover, chemical control is not suitable for small-scale farmers because of the financial costs involved (Rwomushana et al., 2018; Grzywacz et al., 2014; Wyckhuys and O'Neil, 2010; Abate et al., 2000). In the more or less medium term, effective alternative methods should be offered to farmers for sustainable pest management. Currently, and, a few years after the appearance of FAW in Burkina Faso, it is important to assess the knowledge and practices of maize farmers in order to better define the actions to be taken for their benefit (Abate et al., 2000; Wyckhuys and O'Neil, 2010).

The present study, conducted in the main maize production areas of Burkina Faso, is part of this framework and aims to gather the perceptions of producers regarding their knowledge of the pest and its impact, as well as their management practices. The results will contribute to the implementation of an adapted FAW control strategy in Burkina Faso and in West Africa.

MATERIALS AND METHODS

Study area

The study was carried out in 9 regions (Cascades, Centre, Centre-Est, Centre-Ouest, Centre-Sud, Plateau Central, Sud-Ouest, Hauts-Bassins, and Boucle du Mouhoun) located in the Sudano-Sahelian and Sudanese agro-climatic zones of Burkina Faso (Figure 1). The choice of these regions is based, on the one hand, on the importance of the maize crop and, on the other hand, on the high pressure of FAW (MAAH, 2021). The study area belongs to the Sahelian climate with two seasons, a dry and a rainy season during which the main production of maize takes place. In the Sudano-Sahelian zone, the rainy season runs from June to October, the dry season from November to May, the average annual temperature is 28.2°C and rainfall averages 788 mm (Kabore et al., 2017). The Sudanian zone has a rainy season from April to October with an annual rainfall of 1,150 mm and average annual temperatures 2° lower than those in the Sudano-Sahelian zone (Kabore et al., 2017).

Surveyed farmers and data collection

The survey concerned farmers selected in forty-eight (48) villages spread over twenty-nine (29) municipalities in the described study area. In each village, 2 to 3 participants were randomly selected among the cereal growers registered with the regional services of the department in charge of agriculture. A total of 161 farmers (Table 1) were enrolled in the survey, which took place from May to June 2021. The survey consisted of an individual questionnaire designed on the Open Data Kit (ODK) mobile platform. The questions asked included some socio-demographic characteristics of the respondents, the crops they grow, the level of knowledge of *S. frugiperda*, the perception of damage and losses due to the pest, the control methods used, the chemicals used, the effectiveness of the control methods used, the use of personal protective equipment, the management of pesticides' packages and the constraints encountered in the control of the pest. Some questions were close-ended and others were multiple choice where respondents could have several answers at the same time.

Data processing

The collected data was first entered in the ODK mobile application, and then extracted and processed with Excel 2016 software for the determination of descriptive statistics in terms of percentages and means. Graphs were produced using Excel 2016 and GraphPad Prism 6.

RESULTS AND DISCUSSION

Socio-demographic characteristics of producers

Most of the farmers surveyed (89%) in this study were men (Table 2). They were in average 46 years old, the youngest being 20 and the oldest 79 years old. The main socio-economic activity of the respondents is agriculture (100%). Maize is produced by almost all (97%) of the farmers (Figure 2), but some of them also or exclusively

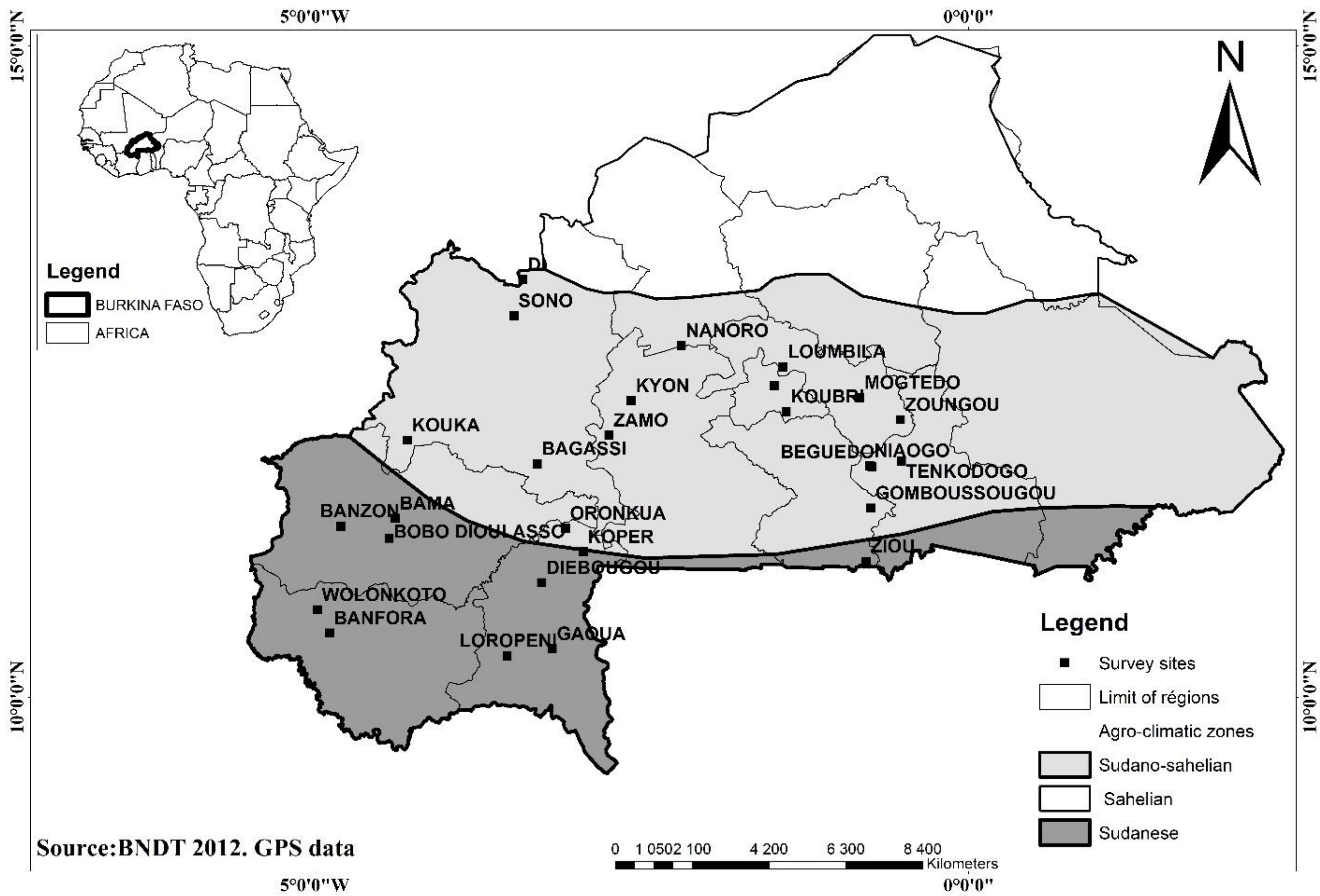

Figure 1. Geographical location of the study sites.
Source: Authors

Table 1. Distribution of farmers interviewed among study municipalities and villages.

Agro-climatic zone	Regions	Number of municipalities	Number of villages	Number of farmers
	Hauts-Bassins	3	8	26
Sudanian zone	Sud-ouest	5	6	22
	Cascades	3	5	7
Subtotal 1		11	19	55
	Boucle du Mouhoun	6	9	30
	Centre	1	2	9
Sudano-Sahelian zone	Centre-Est	3	4	28
	Centre Ouest	3	5	24
	Centre Sud	2	5	8
	Plateau Central	3	4	7
Subtotal 2		18	29	106
Total		29	48	161

Source: Author

produce rice (51%) sorghum (34%), millet (25%), vegetable gardening (20%) and cotton (10%). 42% of responding farmers had received no education and only 1% had reached higher education, which reflects a

Table 2. Socio-demographic characteristics of the farmers surveyed.

Characteristics	Sub-characteristics	% Respondents
Gender consideration	Male	89
	Female	11
Level of education	No level of education	42
	Primary school	30
	Secondary school	12
	French-Arabic school	10
	Non-formal literacy	6
	University	1
Training on *S. frugiperda* and methods of control	None	60
	Yes	40

Source: Author

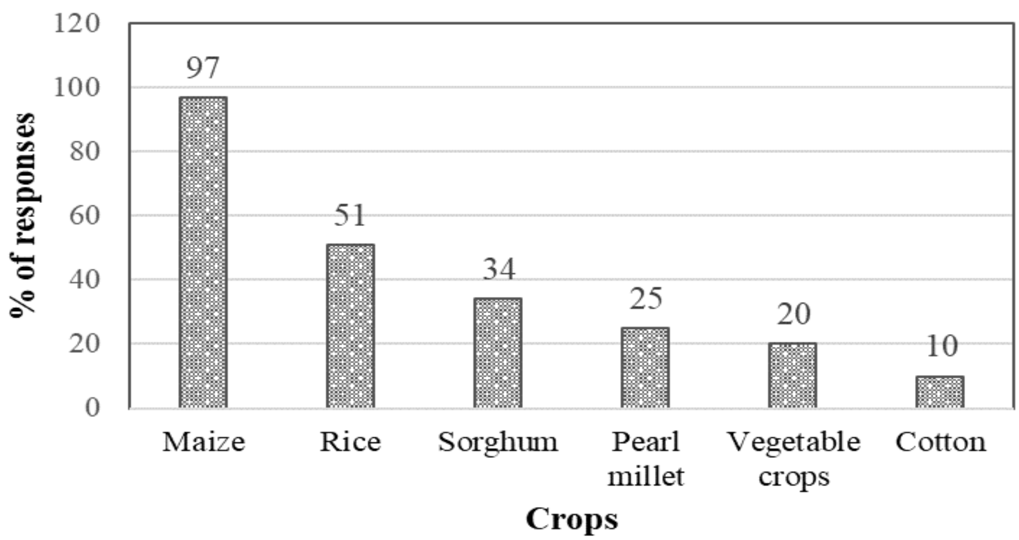

Figure 2. Distribution of respondents' answers* in relation to the crops they grow. *Multiple choices per respondent are possible.
Source: Author

general low level of education as reported in previous similar studies in Benin (Baco et al., 2011) and Burkina Faso (Son et al., 2017; Tarnagda et al., 2017; Sawadogo et al., 2020). This situation can limit the adoption of good plant protection practices, and especially favors the misuse of synthetic pesticides whose labels are often written in French (Ahouangninou et al., 2011; Naré et al., 2015).

Farmers' awareness of FAW

Although most of the farmers surveyed stated that they had not received any training on *S. frugiperda*, 98% of the surveyed population knew about the pest (Figure 3A). In addition, 86% said they could formally identify it using criteria such as droppings (75%), color (40%) and size (34%) of caterpillars (Figure 3B). Furthermore, 37% of the farmers responded that they know the life cycle of the pest. These results which show a relatively good knowledge of FAW by producers are similar to those of Kumela et al. (2019) in Ethiopia and Kenya highlighting the knowledge of the pest by all producers surveyed. This is due, on the one hand, to the drastic effects caused by the larvae on infested plants, making it easier to identify the pest, and on the other hand, to the interventions of

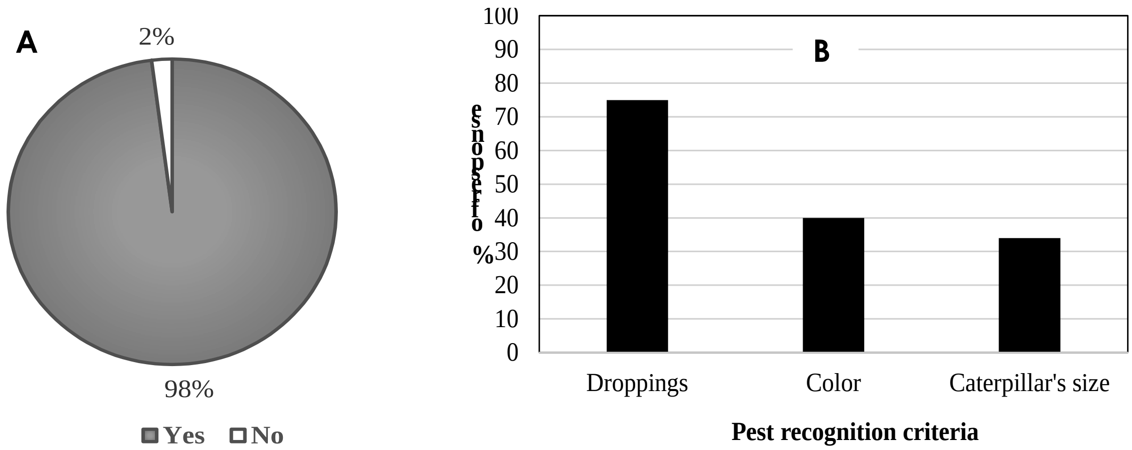

Figure 3. Respondents' perception of their knowledge of the pest (A) and their recognition criteria* (B). *Multiple choices per respondent are possible.
Source: Author

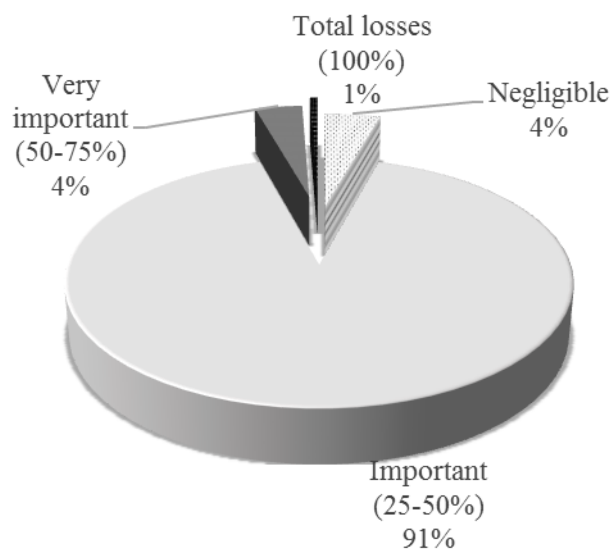

Figure 4. Perception of production losses due to *S. frugiperda* among surveyed farmers.
Source: Author

the government and some projects and programs since the appearance of the pest, which have made it possible to train and raise the awareness of many producers in different regions of the country (FAO, 2018; Bateman et al., 2018). However, these interventions remain late, reflecting the failure of the phyto-sanitary surveillance system in Burkina Faso in particular and in the West African sub-region in general. Indeed, the existence of a functioning national pest surveillance and early warning system should allow for an appropriate response to the appearance of new pests. This situation is unfortunately observed in most African countries affected by FAW (Fan et al., 2020; Rwomushana et al., 2018).

Perception of losses caused by *S. frugiperda*

Most of the farmers surveyed said that *S. frugiperda* was the current main biotic constraint to maize cultivation. Estimates of production losses due to this pest vary among farmers. Thus, 91% of them consider that losses caused by FAW are important ranging 25 to 50%, whereas for 4% of farmers, these losses are negligible, that is, less than 25% (Figure 4). These perceptions seem to be consistent with the significant yield losses reported in several African countries such as Ghana, Zambia, Ethiopia and Kenya (Day et al., 2017; Kumela et al., 2019) and in Latin America (Blanco et al., 2016). The

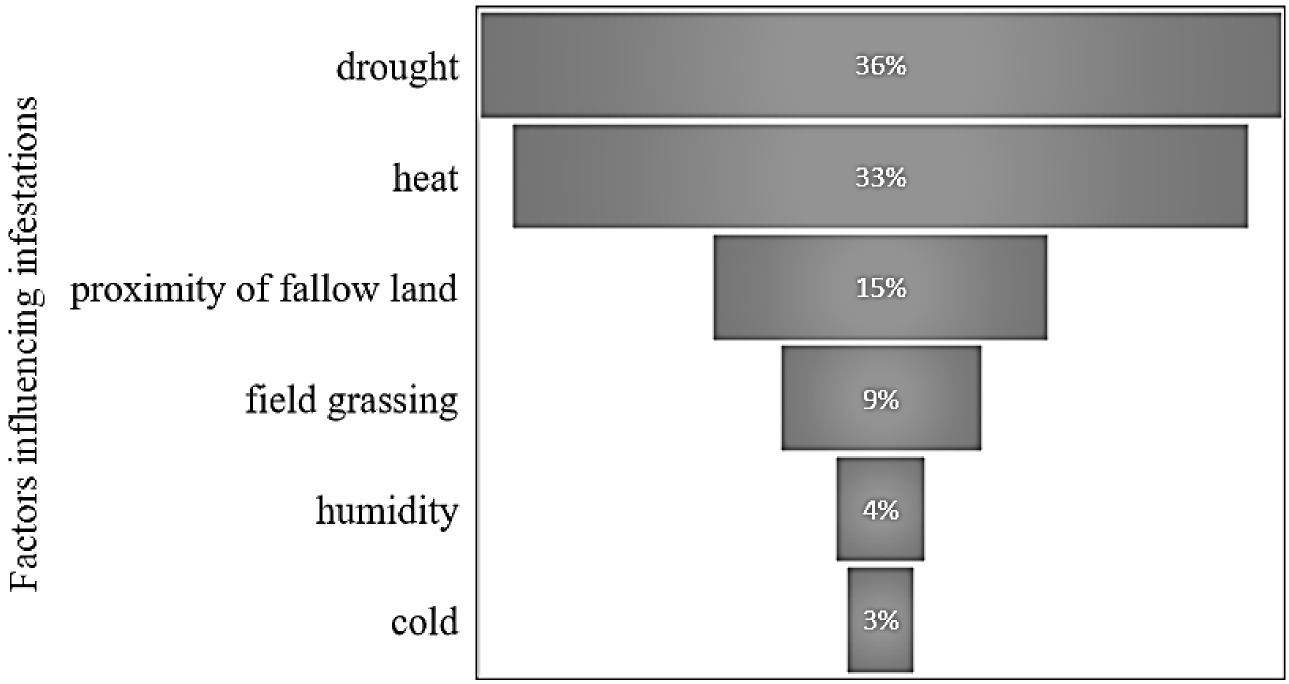

Figure 5. Farmers' perception on factors influencing maize infestations by FAW.
Source: Author

extent of losses is correlated with the level of farmers' knowledge of the pest and the financial means that would impact the adoption of effective control means (Rwomushana et al., 2018). From this point of view, small-scale, generally low-income African farmers suffer the greatest losses (Rwomushana et al., 2018).

Factors determining FAW infestations

Climatic factors such as drought and heat were perceived as favourable conditions for *S. frugiperda* infestations by 36 and 33% of the farmers, respectively, as opposed to humidity (4%) and cold (3%) (Figure 5). This perception of the farmers surveyed is not wrong when one considers that FAW is a typical tropical species adapted to life in hot climates (Ramirez Garcia et al., 1987; He et al., 2019). The proximity of fallow land to maize fields (15%) and the grassing of crops (9%) were also perceived as favouring factors. Regarding farmers' knowledge of FAW host plants, only 20% felt that weeds (of the genera *Andropogon* and *Pennisetum*) and some vegetable crops (eggplant, cabbage, and tomato) could serve as refuge plants for the pest (Figure 6). However, 80% of the respondents felt that they did not have a good knowledge of the alternative host plants of this pest whereas this information could help to limit the sources of primarily infestation. Indeed, the polyphagy of *S. frugiperda* offers it more chances of survival in a diverse natural environment and explains, at least in part, its maintenance and rapid spread in Africa (Fan et al., 2020).

Management practices and control methods for *S. frugiperda*

Overall, 90% of respondents declared they systematically use synthetic insecticides (Figure 7) with 5% carrying out more than 6 treatments, 48% between 3 and 6 treatments and 30% only 2 treatments during maize growing season (Table 3). For 80% of farmers, the average frequency of insecticide application is between 1 and 3 weeks but the number of insecticide applications could depend on the cropping season. Thus, 80% of farmers declared that insecticides were applied 1 to 4 times during the rainy season (from June to October) but 4 to 6 times during the dry season (from November to May) probably in response to greater pest pressure in this season. However, the frequency of insecticide application does not, however, correspond to technical recommendations but to the producers' assessment of the damage suffered.

The extensive use of synthetic insecticides reported here can be broadly linked to the fact that chemical control was the recommended emergency response to the dramatic invasion of the pest in most African countries (Ahissou et al., 2021). The increased use of insecticide treatments would respond to the importance and recurrence of FAW infestations. In addition to synthetic insecticides, the use of sand, ash, locally

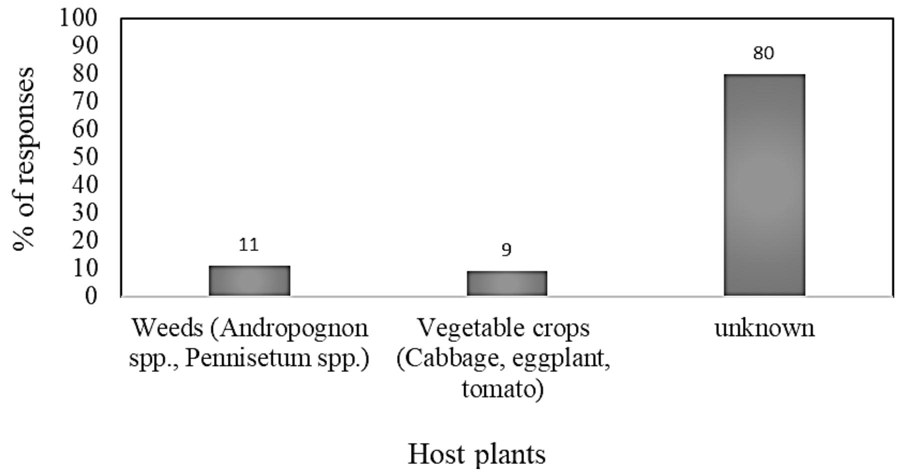

Figure 6. Farmers' perception of *S. frugiperda* alternative host plants.
Source: Author

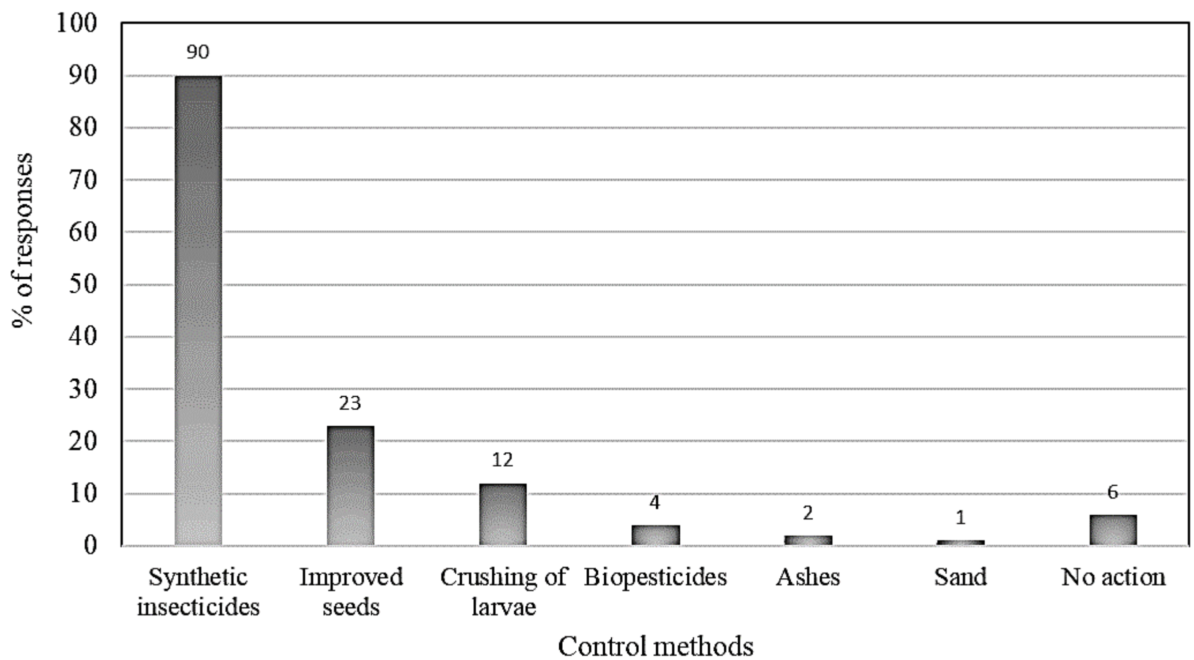

Figure 7. Farmers' perception on control methods they use against FAW. Multiple choices per respondent are possible.
Source: Author

produced biopesticides and crushing of larvae were also mentioned to a lesser extent as methods of controlling the pest (Figure 7). Seeds and varieties are also seen as a means of pest control. Thus, 23% of farmers reported using improved seed, including mainly the varieties SR21, Barka, Bondofa and FBC6, while the use of local varieties was insignificant. However, any effective control method should aim to eliminate the young larvae before they cause significant damage. It should be also noted that 6% of respondents did not refer to any of the afore-mentioned control methods. The actual effectiveness of the non-chemical methods reported by farmers needs to be assessed and if necessary improved for their effective contribution to FAW integrated management and reduced use of chemicals.

Thirteen main synthetic insecticides were identified by farmers, of which Emacot 50WG was mentioned as being used by 56% of respondents (Table 4). The analysis of

Table 3. Respondents' perception on the number and frequency of insecticide application during maize growing cycle.

Insecticide application criteria	Crop types	Range	% of responses
Number of applications during maize growing cycle	General	1	17
		2	30
		3-6	48
		>6	5
	Rainy season	1-4	80
		>4	20
	Dry season	1-4	10
		4-6	80
		>6	10
Treatment Frequency (weeks)	General	1-3	80
		>3	20

Source: Author

the active ingredients in the listed insecticides shows that Emamectin benzoate, lamda-cyhalotrin and acetamiprid are the most widely used, either alone or in combination with other active ingredients. Moreover, none of the insecticides listed are registered/authorized for use against FAW in Burkina Faso. In Sahelian West Africa, the first list of pesticides registered/authorized against FAW was only released in 2020 (CSP, 2020) and probably that such products are poorly or not at all available on the market or still unknown to maize producers (Ahouangninou et al., 2011; Son et al., 2017). In addition, this overuse of synthetic pesticides can lead to the emergence of resistant strains of insects. Indeed, FAW is known to develop resistance rapidly and some cases of resistance to pyrethroids (deltamethrin, permethrin, cypermethrin, cyhalothrin, tetramethrin), organophosphates (chlorpyrifos, dichlorvos, malathion) and carbamates (methomyl, carbaryl and thiodicarb) have already been reported (Yu, 1991; Prassana, 2018; Gutiérrez-Moreno et al., 2019). Fortunately, no cases of FAW resistance to Emamectin benzoate, the most widely used active ingredient in Burkina Faso, have yet been reported (Muraro et al., 2021) but this is feared because resistance to this active ingredient in various species of the genus *Spodoptera* (that is, *Spodoptera exigua* and *Spodoptera litura*) has been observed in Pakistan and China (Su et al., 2014; Wang et al., 2019). Overall, the misuse of insecticides is probably related to the aforementioned low level of training and education of farmers.

Other problems related to chemical control were also highlighted during this study. Farmers said that when applying pesticides, dosages are approximated by the caps of the packages. As a result, dosages can vary from one producer to another, from one treatment to another, and are therefore higher than the recommended dose. Such overuse of pesticides not only contributes to the development of pest resistance (Muraro et al., 2021) but also increases maize production costs (Son et al., 2017; Kassie et al., 2018). Exclusive chemical control therefore does not appear to be a viable option in the long term, highlighting the need to develop and encourage adoption of effective FAW integrated management options (Prassana et al., 2018).

Risks related to plant protection practices

As is well known, poor insecticide use practices lead to health risks for users, consumers and the environment. Thus, during insecticide treatments, only 2% of producers have reported using recommended personal protective equipment (PPE) probably due to the relatively high cost of this equipment (Sougnabe et al., 2010; Diop, 2013; Congo, 2013). This may explain why 71% of producers limit themselves to wearing ordinary clothes (trousers, breeches, long or short-sleeved shirt) (Table 5).

Regarding intoxication risks, the respondents said they had already experienced, after treatments, skin irritation (31%), headaches (25%), coughing (15%), respiratory problems (11%), eye problems (9%) or vomiting (9%) (Figure 8A), which are common symptoms of exposure to synthetic pesticides (Toe et al., 2013; Naré et al., 2015; Lehmann, 2017; Son et al., 2018; Doumbia and Kwadjo, 2009; Diop, 2013; Son et al., 2017). Then, empty pesticide packaging is left in the wild by 44% of respondents while 31% incinerate and 24% bury it in the ground. A very small proportion of respondents (1%) said

Table 4. Respondents' perception of the insecticides used and their frequencies.

Insecticide	Active ingredient	Authorization status	Frequency (%)
Emacot 50WG	Emamectin benzoate (50 g/kg)	Authorized against phyllophagous and carpophagous caterpillars on cotton	56
Emacot 19 EC	Emamectin benzoate (19g/l)	Authorized against phyllophagous, carpophagous and sucking insects on cotton	4
K-Optimal	Lambda Cyhalothrin (15 g/l) + Acetamiprid (20g/l)	Authorized against insect pests of cabbage and cotton	6.7
Décis 25EC	Deltametrin (25g/l)	Authorized against *Helicoverpa armigera* larvae on tomato	5.3
Pacha 25EC	Lamda-cyhalotrin (15g/l) + Acetamiprid (10g/l)	Authorized against caterpillars and sucking insects on tomato	4
Caiman B19	Emamectin benzoate (19,2 g/l)	Authorized against phyllophagous, carpophagous and sucking insects on cotton	2
Sunpyrifos 48% EC	Chlorpyriphos-ethyl (480 g/l)	Authorized against *Helicoverpa armigera* larvae, aphids and thrips on tomato	1.3
Savahaler	Methomyl (250g/kg)	Authorized for use against defoliator moths, sucking insects of cabbage	1.3
Thalis 56EC	Emmamectin benzoate (24g/l) + Acetamiprid (32 g/l)	Authorized for control of phyllophagous, carpophagous and cotton sucking insects	1.3
Cypercal 50EC	Cypermethrin (50 g/l)	Authorized against insect pests of tomato	1.3
Bomec 18EC	Abamectin (18 g/l)	Acaricide/insecticide authorized in tomato crops	0.7
Acarius	Abamectin (18 g/l)	Authorized against red mite (*Tetranychus urticae*)	0.7
Titan 25EC	Acetamiprid (25 g/l)	Authorized against sucking insects of tomato	0.7
All types	Lambda-cyhalothrin + Emamectin benzoate	Not authorized	14.7
Total	-		100

Source: Author

Table 5. Farmers' perception on their use of protective equipment during insecticide application.

Personal protective equipment	Respondents	
	Number	Frequency (%)
Ordinary clothing	115	71
Ordinary clothing + nose cover	15	9
Ordinary clothing + boots	13	8
Ordinary clothing + gloves	10	6
Ordinary clothing + glasses	5	3
Recommended Personal Protective Equipment	3	2
Total	161	100

Source: Author

they would reuse these containers to package various products including food beverages (Figure 8B). Poor management of empty packaging leads to environmental pollution in its various components as reported by several authors (Congo, 2013; Lehmann, 2017; Tarnagda et al., 2017; Son et al., 2017) and may increase pesticide toxicity to humans. These results highlight the need for greater support from government

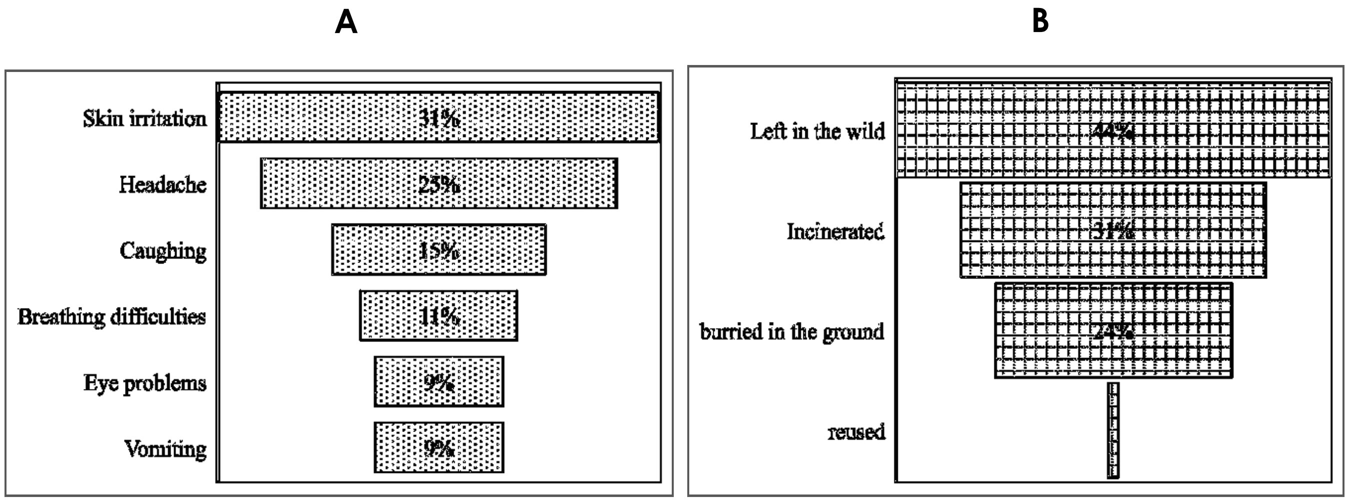

Figure 8. Farmers' perception on insecticide intoxication symptoms (A) and their management of empty pesticide packaging (B).
Source: Author

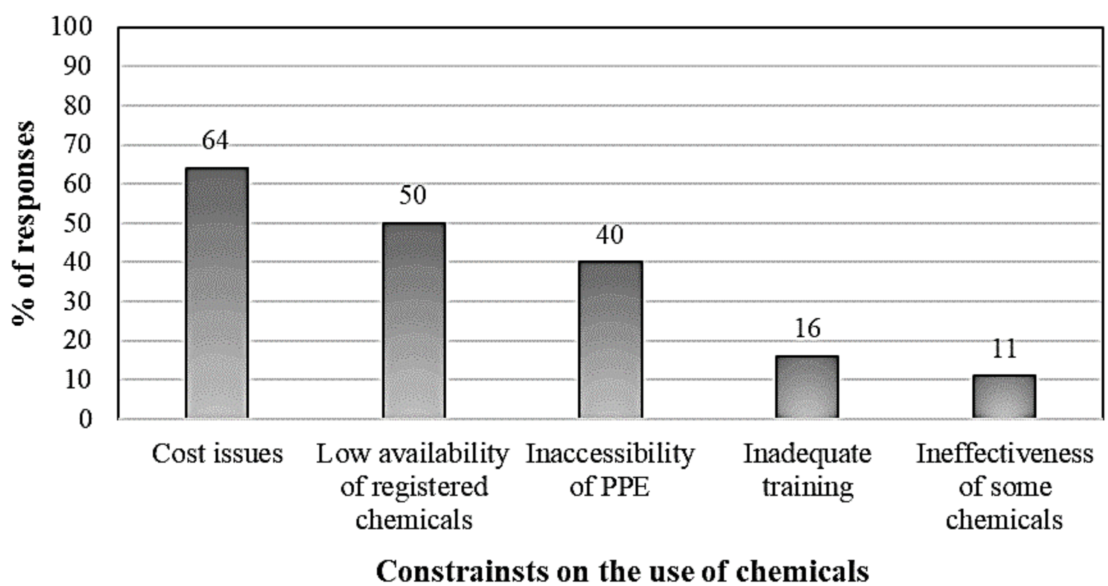

Figure 9. Perceived constraints on the use of chemicals among respondents*. PPE, Personal Protective Equipment; *Multiple choices per respondent are possible.
Source: Author

technical services and NGOs in terms of training and awareness-raising on good pesticide use practices and the risks associated with their misuse.

Perceived constraints in the control of *S. frugiperda*

As the main constraints to FAW control, the participants cited the high cost of chemicals (64%), the non-availability of registered pesticides (50%), the inaccessibility of personal protective equipment (40%), insufficient training (16%) and the ineffectiveness of some pesticides (11%) (Figure 9).

Understanding these different farmer perceptions should help to better guide the control of *S. frugiperda*, a key maize pest that should be managed in a sustainable way.

CONCLUSIONS

As could be expected, the fall armyworm is perceived as a major constraint for maize producers in Burkina Faso. Pest pressure seems to be higher in the dry season than in the rainy season which can impact pest management practices. Faced with the threat of large infestations of this relatively new pest, poorly trained and educated farmers resort to unregistered synthetic pesticides in not recommended conditions of use. This increases the risk of resistance development in FAW, higher production costs, human intoxication and environmental pollution. To reduce these negative consequences of chemicals, more support and training is needed for farmers in terms of pest knowledge and good pesticide use practices. The agricultural authorities should also strictly apply the relevant regulations, support research to develop and disseminate alternative methods that are effective, profitable and available to producers. To this end, future research could focus on the identification and/or development of maize varieties tolerant to *S. frugiperda*, the promotion of effective biopesticides, and biological control in an integrated pest management perspective. Finally, in line with IPPC recommendations, the department in charge of agriculture should set up a functional monitoring and early warning system to better manage the possible invasion of the country by other invasive pests.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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