

Pest management practices, preference criteria for biopesticides, and determinants of their adoption by smallholder maize farmers in the Republic of Benin

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ABSTRACT

Maize is the primary food source for many Beninese people. Unfortunately, insect pests, particularly *Spodoptera frugiperda* (J.E. Smith), have a heavy impact on its production. Farmers commonly rely on synthetic pesticides, which pose risks to human health and the environment. Biopesticides offer a safer alternative, yet their adoption remains low among smallholder farmers. An ethnobotanical survey was conducted among 437 farmers across 60 villages to document pest management practices, perceptions, preference criteria, and willingness to pay for biopesticides. The results showed that most farmers rely heavily on synthetic pesticides (81.7%), with 42 different pesticides recorded. A small majority (50.3%) of farmers used plant-based pesticides. Few farmers (48.1%) are knowledgeable about formulated and commercialized biopesticides for pest control. Surveyed farmers identified 8 constraints to biopesticide use, primarily high product costs (37.3%), perceived ineffectiveness (18.2%), and slow action (16.9%). The farmers' criteria for an appropriate botanical biopesticide were documented, and they were willing to pay up to 3,000 FCFA (\$5.33) per litre. Land ownership increased producers' willingness to pay, whereas livestock farming and larger household size reduced it. Increasing biopesticide adoption among Beninese farmers requires awareness campaigns, economic incentives, and a national strategy addressing socio-economic factors affecting perceptions and willingness to pay.

Key words: Pesticides, willingness to pay, pest control, maize, determinants.

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INTRODUCTION

Maize (*Zea mays* L.) is the main cereal grown and the staple food for millions of Beninese (Miassi *et al.*, 2024). Maize production has been increasing over the years, with an estimated production of 2,059,254 tons per hectare in 2023 due to increased cultivated land (FAO, 2023). Indeed, the maize yield has declined over the years, from 1,421.6 kg/ha in 2011 to 991.9 kg/ha in 2023 (FAO, 2023). This decline in yield is due to numerous constraints, including the attack of

insect pests with *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), which has caused enormous economic damage (Houngbo *et al.*, 2020). Since 2016 when it was introduced in Benin, this pest has been present in maize fields all year round, with its peak being during the rainy season (Zanzana *et al.*, 2025). It causes annual maize yield losses estimated between 295.6 and 735.8 thousand tons, with an economic loss of between 86.6 and 215.6 million

dollars (Day *et al.*, 2017). Beninese producers commonly use the application of synthetic chemical pesticides for its management although it does not always satisfy them in the management of *S. frugiperda* (Houngbo *et al.*, 2020). In fact, *S. frugiperda* has developed resistance to many pesticides, and smallholder farmers who use pesticides are exposed to sanitary risks and environmental pollution (Day *et al.*, 2017). It is therefore urgent to find an eco-friendly alternative solution that is adapted to the needs of producers and respects both human health and the environment.

Biopesticides are proving to be a viable alternative because they can substitute for chemical pesticides while maintaining the same level of agricultural productivity (Fenibo *et al.*, 2023). Biopesticides can be either natural organisms or bio-based formulations that control pests through various mechanisms of action (Rajamani and Negi, 2021). Due to their environmental benefits, they are becoming popular over chemical pesticides. Biopesticides cause less harm to humans, the environment, and ecosystems (Bateman *et al.*, 2018). Biopesticides have the advantage of combining several modes of action against target pests, making it difficult for the pest to develop resistance, as is often the case with synthetic pesticides (Khurshed *et al.*, 2022). Widely used in the worldwide, there are very few commercial biopesticides in Africa with a low adoption rate due to various limiting factors (Fenibo *et al.*, 2023). The limited financial resources of smallholder farmers in developing countries such as Benin play an important role in the adoption of environmentally friendly pest control approaches (Fiaboe *et al.*, 2024). It is therefore crucial to identify the characteristics sought in a biopesticide by smallholder Beninese farmers (application dose, physical form of the product, type of packaging, quantity per unit, price, etc.) in order to boost their adoption in rural areas. Furthermore, it is well known that biopesticides, just like any new technology in agriculture, should be adopted and promoted by farmers themselves (Kontogeorgos and Tsiamis, 2025). Thus, the first step in any initiative to promote biopesticide products is to understand farmers' intentions to use them (Istriningsih *et al.*, 2024).

Therefore, it is crucial to examine farmers' perceptions of biopesticides, their preference criteria, and determine approaches for their large-scale vulgarization (Huang *et al.*, 2022). Studies on the perception and willingness of Beninese producers to pay for biopesticides have focused mainly on vegetable crops (Coulibaly *et al.*, 2008; Adétonah *et al.*, 2011). Therefore, there is a lack of information on maize producers' perception, preference criteria, and willingness to pay for biopesticides. Moreover, the factors that influence the adoption of biopesticides, which should guide the implementation of a national agricultural extension policy, are not well documented. It has been shown that the use of biopesticides in an integrated pest management strategy against fall armyworm permits the attainment of good yields (Fiaboe *et al.*, 2024; Zhang and Wang, 2024). The aim of this study is to fill the observed gaps to better orient researchers toward the development of biopesticides that correspond to the needs of maize producers. It also aims to better define national policies to promote them.

MATERIALS AND METHODS

Study area

The study was conducted in the major maize-growing regions of the Republic of Benin (Figure 1).

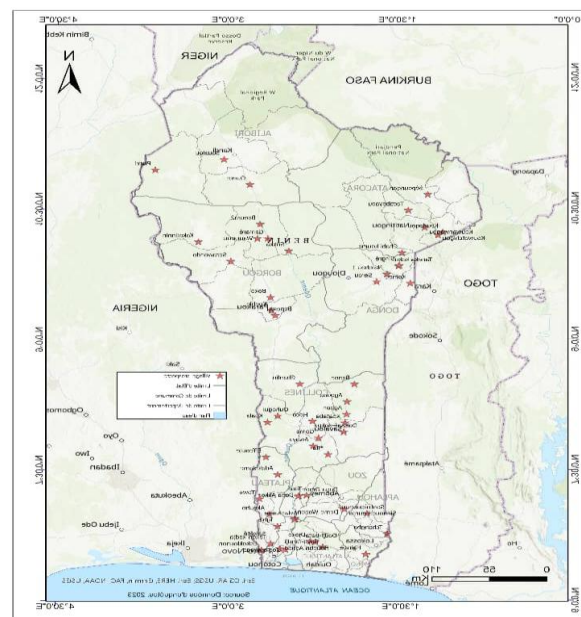


Figure 1. Map of Benin showing the distribution of study areas of the surveyed producers.

With an estimated area of approximately 114,869 km², Benin comprises three climate zones. The Guinean zone (6°25' - 7°30' N) is characterized by a sub-equatorial climate, vegetation consisting of dense or gallery forests, bimodal rainfall averaging 1200 mm/year and temperatures between 25 and 29 °C. The Sudano-Guinean zone (7°30' - 9°45' N) has two rainy seasons that tend to merge into one, with an average rainfall of 1110 mm/year (Djaboutou *et al.*, 2025). In this region, vegetation consists of wooded savannahs and woodlands with dense or gallery forests, and temperatures between 25 and 29 °C. The Sudanian zone (9°45' - 12°30' N) has a tropical climate with a single rainy season, with an average rainfall of less than 1000 mm/year. The vegetation comprises wooded and shrubby savannahs, and the temperature ranges from 24 to 31 °C. Throughout the country, there is a variety of soil types, with the main ones being mineral, hydromorphic, vertisols, and ferruginous soils. Benin is an agricultural-based country, with agriculture accounting for 30% of GDP and employing 70% of the labour force (Kinkpe *et al.*, 2024). Maize is the first cereal and the third food crop produced in Benin after cassava and yam (FAO, 2023).

The study area covers sixty villages (23 in the south, 14 in the centre and 23 in the north) surveyed in the maize production areas (Figure 1). The selection of these villages was done with the assistance of local agricultural extension agents based on maize production statistics of 2022 and the potential exposure to biopesticide use.

Sampling methods

The sample size was obtained using the normal approximation to the binomial distribution proposed by Dagnelie (1998):

$$N = \frac{U_{1-\alpha/2}^2 \times p(1 - p)}{d^2}$$

The value of the normal random variable ($U_{1-\alpha/2}$) corresponding to the probability value of $1-\alpha/2$, α being the risk of error. For $\alpha = 5\%$, the probability $1-\alpha/2 = 0.975$ and we have $U_{1-\alpha/2} = 1.96$. p is the proportion of people engaged in maize production in the study area, and the margin of estimation error was retained at 8% in this study (Gavoedo *et al.*, 2025). By analyzing the total population of agricultural households in

Benin (1,371,062) and those engaged in maize production (1,089,233), it was possible to determine the proportion of maize producers ($p = 0.79$) (DSA, 2024). It was determined that the minimum number of households needed to be surveyed was 102.03.

Surveys

The surveys were conducted from October 2023 to February 2024 using participatory methods such as individual household surveys and field observations. In each village, interviewers targeted every fifth household using the systematic random sampling method to select households (Constantine *et al.*, 2020). A total of 437 maize producers were surveyed in the study area. Interviews were conducted with a local extension agent who was recruited for language translation and two pre-trained interviewers using a structured questionnaire. The questionnaire was validated by an initial test with ten farmers. At the beginning of each interview, the interviewer was asked to give oral consent to participate after being informed of the purpose of the study and their right to terminate the interview at any time (Mulugeta *et al.*, 2024). The data collected concern the various methods of managing maize pests, the desired qualities, and the willingness of producers to pay for biopesticides. Willingness to pay for a biopesticide was assessed first by documenting producers' knowledge and perception of biopesticides used or not, with a hypothetical evaluation in terms of cost, application, efficacy, and impact on pests (Nyangau *et al.*, 2020; Kontogeorgos and Tsiamis, 2025).

Data analysis

Descriptive and multivariate statistics were used to analyze the collected data. The significance of gender ratios in maize production was determined using the chi-square test. A logistic regression was used to determine factors that influenced the use of a specific insect pest management method and the farmer's willingness to pay for a biopesticide (Constantine *et al.*, 2023). SPSS version 23 software was employed to analyze the data. The amounts are indicated in the West African Financial Community franc (FCFA) and were converted from US dollars (\$) using a rate of

\$1=560 FCFA.

RESULTS

Sociodemographic characteristics of surveyed farmers

The majority of the surveyed farmers were male

(86%), had an average age of 43.40 ± 12.86 years, and worked mainly in agriculture (91%) (Table 1).

Table 1. Socio-demographic characteristics of surveyed households

Variables descriptions		Surveyed farmers (N = 437)			
		Mean	SD	Min	Max
Dependant variables					
Use of biopesticides (0 = No; 1 = Yes)		0.06	0.24	0	1
Willingness to pay a biopesticide (0 = No; 1 = Yes)		0.81	0.39	0	1
Independent variables					
Gender of household head (0 = Female; 1 = Male)		0.86	0.34	0	1
Age of household head (years)		43.40	12.86	18	85
Household size (number)		7.67	4.25	1	28
Experience (years)		23.21	13.04	1	60
Member of farmers' associations (0 = No; 1 = Yes)		0.12	0.33	0	1
Religion	Animism (0 = No; 1 = Yes)	0.16	0.37	0	1
	Christian (0 = No; 1 = Yes)	0.60	0.49	0	1
	Muslim (0 = No; 1 = Yes)	0.24	0.43	0	1
	Other (0 = No; 1 = Yes)	0.00	0.00	0	0
Education level	Illiterate (0 = No; 1 = Yes)	0.53	0.50	0	1
	Primary (0 = No; 1 = Yes)	0.27	0.45	0	1
	Secondary (0 = No; 1 = Yes)	0.19	0.39	0	1
	University (0 = No; 1 = Yes)	0.01	0.10	0	1
Marital status	Single (0 = No; 1 = Yes)	0.05	0.22	0	1
	Divorced (0 = No; 1 = Yes)	0.00	0.07	0	1
	Married (0 = No; 1 = Yes)	0.93	0.25	0	1
	Widower (0 = No; 1 = Yes)	0.01	0.12	0	1
Livestock practice (0 = No; 1 = Yes)		0.57	0.50	0	1
Agricultural training (0 = No; 1 = Yes)		0.16	0.36	0	1
Extension agent visit (0 = No; 1 = Yes)		0.15	0.36	0	1
Principal activity (1 = Agriculture; 0 = other)		0.99	0.08	0	1
Land owner (0 = Rental; 1 = Personal)		0.90	0.30	0	1
Land area sown (ha)		5.67	8.64	0.03	90

SD: Standard deviation; Min: Minimum; Max: Maximum

The average size of the surveyed households was 7.67 ± 4.25 people. The agricultural experience of the surveyed farmers was on average 23.21 ± 13.04 years, with an average sown area of 5.67 ± 8.64 ha. The majority of the surveyed producers practised Christianity (60%), were illiterate (53%), were married (93%), and practised livestock farming (57%). The majority of them (90%) owned property. Very few surveyed household heads were members of a farmers' association (12%) or received agricultural training or a visit from extension agents.

Chemical pesticides used by maize producers

The surveyed farmers used different methods to

protect their crops against pest attacks. A majority of them (81.7%) used synthetic chemical pesticides to protect their crops. Herbicides were used by the majority (56.9%) of the surveyed farmers, mainly in maize (56.9% of responses), soybean and peanut fields (Figure 2a). Herbicides such as Tallis 240 EC (32.8% of responses), Kalach 360 SL and Paraforce were the most widely used in the study area (Table 2). In addition to maize (44.2% of responses),

Table 2. Herbicides used by the surveyed maize producers in the study area (N = 368)**91**

Commercial name	Active ingredient	Chemical class	Toxicological class	Percentage of responses (%)			Study area (%)
				South	Centre	North	
Tallis 240 EC	Clodinafop propargyl (240 g/l) + Cloquintocet-mexyl (60 g/l)	Aryloxyphenoxy-propionate	III	16.4	47.7	34.3	32.8
Kalach 360 SL	Glyphosate 360 g/l	Glycine derivative	II	2.1	9.5	28.7	13.3
Paraforce	Paraquat Dichloride 24% SL	Bipyridyl	II	22.6	3.4	0.7	8.9
Herbicide total	Glyphosate 36 %	Glycine derivative	II	17.1	1.2	2.8	7.0
Force up	Glyphosate 480 % SL + Isopropylamine salt	Glycine derivative	II	17.8	2.3	0.7	6.9
Herbextra 720 EC	2.4 D amine salt 720 g/l	Glycine derivative	II	0.7	1.2	13.3	5.0
Sofa 40 SC	Nicosulfuron 40 g/l	Sulfonylurea	III	6.8	3.4	0.7	3.7
Rapide 750 WG	Tribenuron-Methyl	Sulfonylurea	III	1.4	8.1	-	3.2
Altrazine	Atrazine 80% WP	Triazines	III	4.1	2.3	2.7	3.1
Nico Star	Nicosulfuron 40 g/l	Sulfonylurea	III	2.1	1.2	4.2	2.5
Sunphosate 360 SL	Glyphosate 360 g/l	Glycine derivative	II	2.1	3.4	0.7	2.1
Buron 600 100GM	Bensulfuron-methyl 60% (w/w)	Sulfonylurea	III	2.7	2.3	-	1.7
Gramazol	Paraquat 24% SL	Bipyridyle	II	-	4.7	-	1.6
Soja plus 100SL	Imazetapyr 100 g/L	Imidazolinone	III	-	3.4	-	1.2
Fast	Glyphosate 80% SG	Glycine derivative	II	-	1.2	2.1	1.1
Imma soja	Imazetapyr 100 g/L	Imidazolinone	III	-	2.3	0.7	1.0
Faba soja	Imazetapyr 100 g/L	Imidazolinone	III	-	-	2.8	0.9
Nwurawura	Glyphosate 360 g/l	Glycine derivative	II	2.7	-	-	0.9
Killer 480 SL	Glyphosate 480g/L SL	Glycine derivative	II	-	1.2	0.7	0.6
Cotochem 560 SC	Prometryn (250 g/l) + Fluometuron (250 g/l)	Methylthiotriazine + Phenylurea	III	-	-	1.4	0.5
Gramoquat Super	Paraquat Chloride 276 g/l	Bipyridyle	II	-	-	1.4	0.5
Deal 11 OD	Glyphosate 510g/L SL	Glycine derivative	II	0.7	-	0.7	0.5
Glyking 480 SL	Glyphosate 480g/L SL	Glycine derivative	II	-	1.2	-	0.4
Cotoran 4L	Fluometuron	Phenylurea	II	-	-	0.7	0.2
Kalifor-G	Clomazone	Isoxazolidinones	III et IV	-	-	0.7	0.2
Cool Power	MCPA 56.14%, Triclopyr 5.0%, Dicamba 3.6%	Phenoxy, Pyridine, Benzoic Acid	II	0.7	-	-	0.2

Table 3. Insecticides used by the surveyed maize producers in the study area (N = 265)

Commercial name	Active ingredient	Chemical class ^a	Toxicological class	Percentage of responses (%)			Study area (%)
				South	Centre	North	
Lambda Super 2.5 EC	Lambda-Cyhalothrin	Pyr	II	3.7	12.5	45.1	20.4
Magic force	Lambda-Cyhalothrin 15g/+ Dimethoate 300g/L	Pyr + OP	II	16.9	20.0	13.6	16.9
Agro	Cypermethrin 5 EC	Pyr	II	3.6	42.5	-	15.4
Pacha 25 EC	Acetamiprid + Lambda-Cyhalothrin	OC + Pyr	II	34.9	2.5	-	12.5
Pyro 672 EC	Cypermethrin (72 g/l)	Pyr	II	14.5	10.0	11.8	12.1
Sniper 1000EC							
DDVP	Dichlorvos	OP	Ib	4.8	7.5	-	4.1
Emacot 050 WG	Emamectin benzoate 50 g/kg	Ave	II	3.6	-	5.9	3.1
Power Force	Cyfluthrin 0,75%	Pyr	II	2.4	2.5	3.9	2.9
Bella FTE 424 EC	Deltamethrin 24g/l + Chlorpyrifos-ethyl 400g/l	Pyr + OP	II	-	-	5.9	2.0
Polytrine C 44 EC	Profenofos 400g/L + Cypermethrin 40g/L	Pyr + OP	II	-	-	5.9	2.0
Calife 500 EC	Profenofos 500 g/l	OP	II	1.2	-	3.9	1.7
Endrine 2.4 EC	Endrin aldehyde (2,4 g/l)	OC	III	4.8	-	-	1.6
Insecticide balistique	Deltamethrin 27,5 g/l + Liquid hydrocarbons (811 g/l)	Pyr	III	4.8	-	-	1.6
Sunpyrifos 48% CE	Chlorpyrifos-ethyl	OP	II	4.8	-	-	1.6
Cotonix 328 EC	Deltametrin 12 g/l +. Chlorpyrifos-ethyl 300 g/l +. Acetamiprid 16 g/l	Pyr +. OP + Neo	II	-	2.5	2.0	1.5
DDT	Dichlorodiphenyltrichloroethane	OC	II	-	-	2.0	0.6

^a Pyr = Pyrethroid; OC = Organochlorine; Neo: Neonicotinoid; Ave: Avermectin, OP = Organophosphate. Ib = very dangerous; II = moderately dangerous, III: slightly dangerous.

synthetic insecticides were mainly used by farmers to protect beans (40.4%) against crop pests (Figure 2b). The most commonly used insecticides in the study area were synthetic insecticides based on pyrethroids and/or organophosphates (Table 3). The main insecticides used were those marketed under the names Lambda Super 2.5 EC (20.4% of responses), Magic Force (16.9%) and Agro (15.4%). All of the insecticides were employed for curative purposes, with the exception of Sunpyrifos 48% EC.

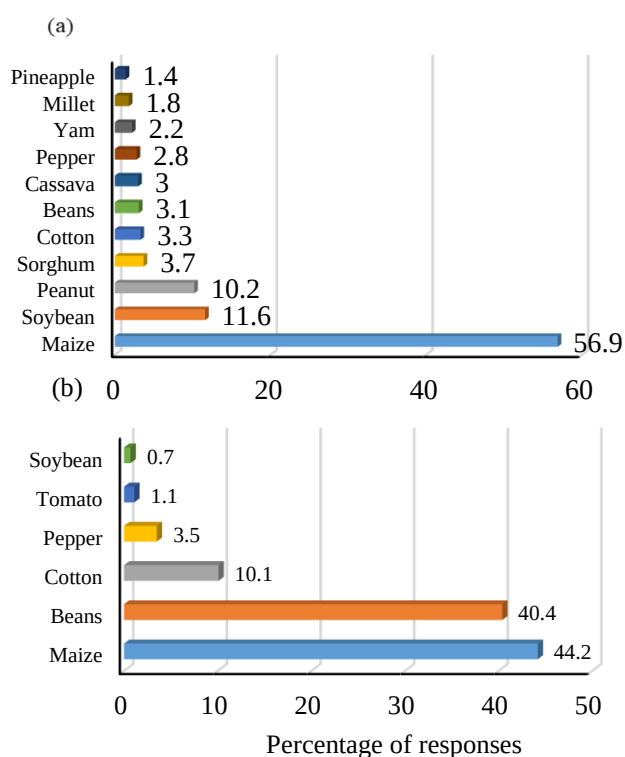


Figure 2. Use of (a) herbicides and (b) insecticides by the surveyed maize producers in the study area

To control rodents in crop fields, very few farmers (8.2%) used rodenticides such as Push Out (5 producers) with zinc phosphide as active ingredient and insecticides such as Sniper DDVP (7 producers), Fumigan Dichlorvos 76 EC DDVP (2 producers), and Momtaz 45% WS (2 producers). The rodenticides, which are mostly purchased in markets under the local names 'Gamalé' or 'Adjakatin', are in the form of sachets without indication of the active ingredient (20 producers). These rodenticides were mainly used for the protection of maize fields (61.3% of responses), beans (16.1%), soybeans (12.9%) and peanuts (9.7%). To protect plant against fungi and bacteria, 14.15 % of farmers used seven chemical insecticides (Agro (4 farmers), Ballistic 10 EC, Gamaler, Pacha 25 EC, Pyro 672 EC, Sniper 1000 EC DDVP, and Thalys FTE 112 EC).

Alternative pest control used by maize producers

The majority of farmers (72.31%) reported using other pest management techniques alongside chemical pesticides. Only 27.68 maize producers use only non-chemical control methods to protect maize against insect pests. Some producers (50.3%) used various insecticidal plants for maize protection (Table 4).

Neem (71.1% of responses), chili pepper, African mahogany (4.7%), African locust bean (2.9%) and pignut or chan were the main pesticide plants used in the study area. Few surveyed farmers (7.09%) used cultural practices such as the removal and destruction of diseased or infested plants (Table 4).

Table 4 . Non-chemical methods used by the surveyed maize producers in the study area

Alternative pest control methods	Number of farmers			X^2	P-value
	Overall	Female	Male		
Plant extracts	220	80	140	15.820	0.000
Removal and destruction of diseased or infested plants	31	3	28	12.800	0.000
Crop's association (trap crop or repellent)	8	4	4	0.190	0.665
Crop rotation	7	3	4	0.020	0.877
Varietal resistance	5	2	3	0.300	0.855
Commercial biopesticides	11	5	6	0.380	0.540

Few maize producers practised crop association (trap crop or repellent) of maize with companion plants to control insect pests. Some farmers in the study area (Table 4) used three commercially available biopesticides, namely Topbio (active ingredient Azadirachtin), Bioneem (active ingredient Azadirachtin), and Thymox

(active ingredient Thymol).

Determinants of the use of specific pest control methods

The estimation of factors that affect producers' behaviour towards using a particular control method to combat crop pests is presented in Table 5.

Table 5. Factors influencing the use of a specific pest control method for the protection of maize fields in the study area

Variables	Chemical control		Insecticidal plants		Integrated control	
	Coefficient	P value	Coefficient	P value	Coefficient	P value
Sociolinguistic groups	0.108	0.315	0.167	0.414	0.0143	0.895
Sex	0.470	0.360	0.313	0.805	0.014	0.895
Age	0.007	0.738	0.026	0.604	0.012	0.590
Household size	0.013	0.806	0.155	0.129	0.039	0.453
Marital status	0.424	0.611	0.607	0.772	1.072	0.203
Agricultural experience	0.031	0.165	0.054	0.910	0.008	0.697
Religion	0.115	0.665	0.009	0.999	0.330	0.215
Sown area	0.036	0.097**	0.011	0.786	0.017	0.333
Land ownership	0.491	0.092**	0.898	0.150	0.414	0.161
Membership of farmers association	0.615	0.318	1.071	0.345	0.229	0.736
Other sources of income	0.275	0.456	0.910	0.250	0.587	0.119
Livestock practice	0.560	0.146	1.487	0.066**	0.316	0.422
Training in agriculture	0.002	1.000***	1.459	0.263	0.401	0.537
Extension agent visit	0.518	0.415	0.170	0.899	0.382	0.587
Education level	0.019	0.932	1.603	0.002***	0.536	0.028**
Practice of cultural association	1.170	0.002***	1.293	0.096**	0.182	0.617
Constant	0.989	0.588	22.471	0.994	19.490	0.995

Significant at *** 1% and ** 5%. "No control" used as base category.

The model used was statistically significant (Prob > Chi-square = 0.0000) at 1% significance. The pseudo-R-squared (Pseudo-R²) of the regression model indicated that 31.82% of the variation in the use of a specific control method by farmers is explained by the variables introduced in the model. The use of chemical control methods by producers was positively influenced by sown area, land ownership, agricultural training, and cultural association (Table 5). Livestock farming, cultural association, and education level had a positive impact on producers' use of insecticidal plants. The level of education of producers positively influenced the use of an integrated pest management method.

Farmer awareness and perceptions of biopesticides

While pesticide plants are used by 50.3% of surveyed farmers to protect their crops, only 48.1% are knowledgeable about formulated and commercialized biopesticides for pest control. The main reasons given by maize producers for using botanical biopesticides were environmental protection (11 producers), preservation of stored food (6 producers), protection of human health (5 producers), and their effectiveness (1 producer) (Figure 1). All these producers used biopesticides for preventive purposes against crop pests. Maize producers who reported using biopesticides said they were satisfied with their effectiveness in protecting crops. However, they all stated that these biopesticides were not able to substitute for synthetic pesticides. The three biopesticides used by the producers were obtained either from the NEO LIFE company (9 producers), the Songhai

Center (1 producer) and the Prosol project (1 producer).

Constraints and farmers' proposals to promote the use of biopesticides

The majority (91%) of surveyed producers were unaware of the constraints associated with the use of biopesticides. A few surveyed producers (9%) listed eight constraints associated with the use of biopesticides (Figure 3a).

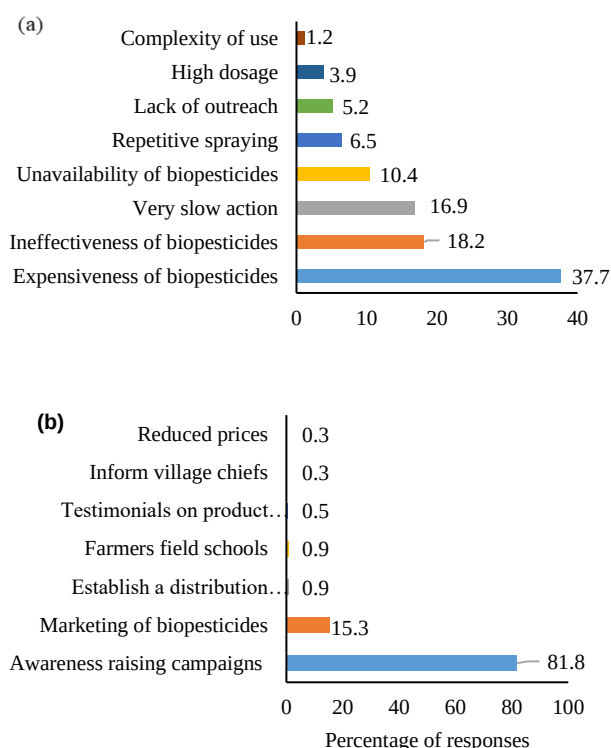


Figure 3. Farmers' perceptions of the constraints (a) related to the use of biopesticides and their suggestions (b) of strategies to promote their use.

The high cost of biopesticides (37.7% of responses), their ineffectiveness (18.2%), and slow action (16.9%) were the main constraints to their use reported by the surveyed producers (Figure 3a). To promote the use of biopesticides in the study area, the vast majority of surveyed producers (99.5%) suggested eight proposals. Most frequently suggested strategies were to raise awareness among producers (81.8%), followed by marketing biopesticides (13.4%). The creation of a distribution structure for biopesticides (0.9%) and the training of producers in the use of biopesticides through farmers' field schools were among the suggestions made by the surveyed producers (Figure 3b).

Farmers' criteria for the adoption of biopesticides

The first criterion listed by the surveyed producers for the adoption of a biopesticide was the recommendation made by other producers (67.2% of responses) followed by the toxicity of the biopesticide (25.3% of responses). The availability (4%) and the price (3.5%) of the biopesticide were the least cited criteria. In the development of new biopesticides, producers were given a list of criteria to take into account. The liquid form was the most popular form (81.2% of responses), followed by the powder form (15.9%) and the granular form (2.9%). In terms of biopesticide packaging, the plastic container (87.7% of responses) was the most popular compared to the sachet form (12.3%). For the majority of producers who suggested a liquid form of the biopesticide, the proposed dosage was between 0.5 L/ha and 5 L/ha, with a strong preference for an active biopesticide at 1 or 2 L/ha (Figure 4a).

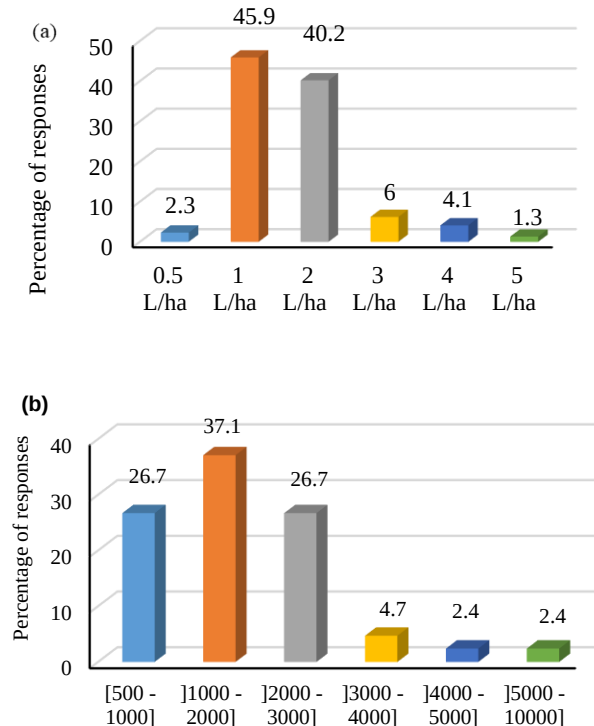


Figure 4. Dosage proposed by farmers for the formulation of a new biopesticide and amounts proposed by farmers for the purchase of a biopesticide

Table 6. Determinants of the use of biopesticides by maize producers surveyed in the study area

Variables	Coefficient	Standard error	z	P>z	[95% of confidence interval]	
Use of an integrated method	0.116	1.128	0.10	0.918	2.327	2.095
Use of botanical pesticides	0.355	1.020	0.35	0.727	1.643	2.355
Use pesticides	0.120	0.744	0.16	0.871	1.581	1.339
Practice of crop association	0.492	0.549	0.90	0.371	0.585	1.569
Education level	0.095	0.293	0.33	0.744	0.670	0.478
Extension agent visit	1.588	0.537	2.96	0.003***	0.535	2.641
Agricultural training	1.142	0.574	1.99	0.047**	0.16	2.267
Livestock practice	0.059	0.485	0.12	0.902	1.012	0.892
Membership in a farmers' association	0.157	0.604	0.26	0.795	1.027	1.342
Land ownership	0.231	0.187	1.24	0.215	0.134	0.598
Religion	0.620	0.410	1.51	0.130	1.424	0.183
Agricultural experience	0.018	0.027	0.68	0.495	0.035	0.073
Marital status	1.022	0.387	2.64	0.008***	1.780	0.263
Household size	0.124	0.080	1.55	0.121	0.282	0.032
Age	0.014	0.026	0.55	0.579	0.376	0.067
Sex	0.323	0.716	0.45	0.651	1.727	1.079
Sown area	0.014	0.033	0.44	0.663	0.050	0.079
Constant	0.015	1.777	0.01	0.993	0.3468	3.498

Significant at *** 1% and ** 5%.

Table 7. Determinants of the willingness to pay for a biopesticide by the surveyed maize producers in the study area

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Variables	Coefficient	Standard error	z	P>z	[95% of confidence interval]	
Use of an integrated method	0.767	0.627	1.22	0.221	0.462	1.996
Use of botanical pesticides	0.706	0.556	1.27	0.205	1.797	0.384
Use pesticides	0.290	0.419	0.69	0.488	0.531	1.112
Practice of crop association	0.063	0.287	0.22	0.825	0.499	0.627
Education level	0.148	0.172	0.86	0.388	0.189	0.487
Extension agent visit	0.512	0.439	1.17	0.243	0.347	1.373
Agricultural training	0.343	0.417	0.82	0.411	1.161	0.475
Livestock practice	0.645	0.283	2.28	0.023**	1.200	0.090
Other sources of income	1.960	1.31	1.50	0.134	4.546	0.607
Membership in a farmers' association	0.497	0.354	1.40	0.161	1.192	0.197
Land ownership	0.373	0.157	2.37	0.018**	0.650	0.681
Religion	0.234	0.211	1.11	0.267	0.179	0.648
Agricultural experience	0.007	0.015	0.48	0.628	0.036	0.022
Marital status	0.196	0.290	0.68	0.498	0.372	0.766
Household size	0.065	0.033	1.98	0.048**	0.130	0.0005
Age	0.023	0.015	1.57	0.117	0.005	0.053
Sex	0.699	0.458	1.53	0.127	0.596	0.198
Sown area	0.007	0.015	0.49	0.627	0.037	0.0224
Constant	0.150	1.210	0.12	0.901	0.222	2.523

** Significant at 5%.

All the surveyed producers suggested the free sale of future biopesticides in the markets. Some producers suggested that the formulated biopesticide should target all insects (58.4%). Others suggested specific targets such as caterpillars (33.5%), weevils (5.8%), locusts (1.5%), whiteflies (0.6%), and ants (0.2%) for the development of future biopesticides.

Farmers' willingness to pay for a biopesticide and its determinants

The majority of the surveyed producers (95.4%) expressed their willingness to pay between 500 (\$0.89) and 10000 FCFA (\$17.78) to acquire a liter of biopesticide. The producer should expect to pay an average of 2171 FCFA (\$3.86) for a liter of biopesticide. The vast majority (90.5%) of producers are willing to pay no more than 3000 FCFA (\$5.33) per liter of biopesticide (Figure 4b). Factors that may affect producers' willingness to pay for a new biopesticide and therefore to adopt it were estimated by probit analysis (Table 5). The model used was statistically significant (Prob > Chi-square = 0.025) at a 0.05% significance level. The predictive power (pseudo-R²) of the regression model indicated that only 7.37% of the variation in producers' willingness to pay for a biopesticide is explained by the variables introduced in the model. Producers' willingness to pay for a biopesticide was negatively influenced by livestock farming and household size. Producers' willingness to pay for a biopesticide was positively influenced by land ownership.

DISCUSSION

The great majority of surveyed farmers use herbicides to protect maize, with a predominance of use of Tallis 240 EC, a selective herbicide based on Aryloxyphenoxypropionate. Unfortunately, this active ingredient has a negative impact on the environment and the aquatic ecosystem and has been proven harmful to humans through ingestion (Diao *et al.*, 2010; Lim *et al.*, 2016). In addition, the frequent utilization of synthetic insecticides that incorporate pyrethroids and/or organophosphates leads to high levels of contamination of maize grains (Tonato *et al.*, 2025). Their concentration in Beninese agricultural land sediments exceeds

environmental standards (Pazou *et al.*, 2006; Bokossa *et al.*, 2024), leading to an accumulation of residues in fish and seafood (Douny *et al.*, 2021). The negative impact of farmers' chemical control methods is amplified by the lack of or inadequate knowledge of pesticides for rodent, fungi, and bacteria control. Indeed, the use of prohibited pesticides such as those based on zinc phosphide and the purchase of pesticides in sachets without indication of the active ingredient imply the urgency of raising awareness and offering alternative control methods to farmers.

Some surveyed farmers demonstrated a good knowledge of insecticidal plants to use for maize protection. Indeed, neem, chilli pepper, African mahogany, African locust bean, and pignut (or chan) are widely used by African producers to protect various crops against insect pests (Sola *et al.*, 2014; Stevenson *et al.*, 2014). These plants possess some biochemicals that they use for defence against insect pests, which can act as growth regulators, antifeedant, and anti-oviposition (Ojo *et al.*, 2024). Currently, there are several formulations of neem-based biopesticides, making them a promising biological control option against insect pests and weeds (Ojo, *et al.*, 2024, Jat *et al.*, 2025). Furthermore, the use of the three commercial biopesticides (Topbio, Bioneem, and Thymox), although limited to a few producers, reveals awareness of the need to safeguard the environment and human health. Promoting and popularising these biopesticides among small producers is crucial by introducing simplified legislative procedures (Bugiani and Bariselli, 2021), awareness campaigns, and economic incentives (Fusar Poli *et al.*, 2025). It is crucial to consider livestock farming practices, cultural associations, and farmers' educational levels, as these factors positively influence producers' use of insecticidal plants in the study area.

The practice of intercropping for pest management by 1.8% of the surveyed farmers needs to be promoted. Indeed, various maize-based intercropping combinations have been shown to negatively impact insect pest populations (Yousefi *et al.*, 2024). Intercropping maize with legumes such as beans or cowpeas is

widely recommended for effective pest management by increasing natural enemy populations (Pierre *et al.*, 2022; Rao *et al.*, 2025; Emana *et al.*, 2025). Innovative pest management methods that involve the judicious association of companion plants like the push-pull technology must be developed and popularized. However, it is important to consider that cultural associations positively influence producers' use of chemical control methods in the study area. Therefore, it is necessary to promote integrated pest management through farmer field schools and the enforcement of national IPM policies.

Compared to Indian producers (Kumar *et al.*, 2025), who have good knowledge of commercial biopesticides and similarly to Chinese producers (Guo *et al.*, 2021), in our study area, only 48.1% are knowledgeable about formulated and commercialised biopesticides for pest control. This could be explained by the fact that very few surveyed farmers are members of a farmers' association, have received agricultural training, or have received visits from extension agents. Indeed, farmers who are involved in farmers' cooperatives are generally knowledgeable about modern agricultural production and therefore are aware of the advantages of environmentally friendly agricultural technologies (Guo *et al.*, 2021). Furthermore, farmers' involvement in technical training can significantly increase the likelihood of utilizing biopesticides (Liu *et al.*, 2022). It is therefore important to implement a national program that integrates training and outreach on biopesticides for farmers in rural areas through the Territorial Agencies for Agricultural Development (ATDA). Furthermore, it is necessary to establish farmer field schools to remove the misconception among producers that biopesticides are not a substitute for synthetic pesticides.

The constraints related to the use of biopesticides listed by the surveyed producers are similar to those encountered by other producers worldwide (Marrone, 2023; Constantine *et al.*, 2023; Mweke *et al.*, 2025; Fusar Poli *et al.*, 2025). Farmers in India (Kumar *et al.*, 2025), North America (Marrone, 2023), and the Mediterranean region (Fusar Poli *et al.*, 2025) also share the perception of the high price of

biopesticides and scepticism about their effectiveness. Indeed, the high cost and short shelf life of biopesticides are often linked, respectively, to the cost of obtaining regulatory approvals and their sensitivity to climatic variations (Kumar *et al.*, 2021). The slow-acting nature of biopesticides was also a limitation for their use by Kenyan farmers (Constantine *et al.*, 2020). The unavailability of biopesticides in markets had already been identified as a major constraint to their use for managing insect pests in vegetable crops in urban and peri-urban areas of Benin (Adétonah *et al.*, 2011). It is therefore important to simplify the biopesticide registration procedures while ensuring health and environmental safety and integrating those already registered into existing distribution networks.

Our results revealed that the primary criterion listed by the surveyed producers for adopting a biopesticide was a recommendation from other producers. In fact, like the Kenyan producers (Constantine *et al.*, 2020) and farmers in the Mediterranean region (Fusar Poli *et al.*, 2025), the willingness of the surveyed producers to adopt a biopesticide was based on demonstrated efficacy and affordability. Given that the toxicity of the biopesticide to pests is the second most important criterion for its adoption, developing highly effective products with fewer risks represents a significant challenge for researchers (Constantine *et al.*, 2020). Researchers must take farmers' preference criteria into account when developing new biopesticides. The liquid form in a plastic container with an active biopesticide at 1 or 2 L/ha of broad-spectrum action was more preferred.

According to the survey, most producers are willing to pay no more than 3000 FCFA (\$5.33) to get one liter of biopesticide. This price is relatively low compared to the purchase prices of commonly used pesticides such as Tallis 240 EC (10000 FCFA $\approx$ \$17.87 per liter) and Lambda Super 2.5 EC (4000 FCFA $\approx$ \$7.14 per liter). Given that the total cost of the biopesticide approval system is quite high (Kumar *et al.*, 2021), it is important to implement lighter legislation to reduce costs. It is also important to prioritise the development of phytochemical

biopesticides, as they offer low production costs (Danesh *et al.*, 2025). The willingness of producers to pay for a biopesticide was negatively influenced by household size. These results are consistent with those reported by Nyang'au *et al.* (2021) in Uganda, which found that those who had a big family size reduced willingness to pay for biopesticides. Indeed, this could be explained by the fact that large farming households face higher financial constraints in acquiring environmentally friendly means of production, such as biopesticides (Liu *et al.*, 2022). The negative influence of livestock farming on producers' willingness to pay for biopesticides may be due to its emphasis on inputs and perceived fewer direct benefits from biopesticides. Our results also showed that, the willingness of producers to pay for a biopesticide was positively influenced by land ownership. Landowners may have a more positive attitude towards the environment and be more inclined to invest in technologies that promote ecosystem services (Sorice *et al.*, 2014). It is therefore important to take into account these parameters that influence the adoption of biopesticides by farmers and integrate them into a national strategy for the promotion of biopesticides in the Republic of Benin.

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Disclosure statement

The authors report there are no competing interests to declare.

Data availability statement

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

Ethical approval

Interviews were conducted in accordance with the guidelines of the Declaration of Helsinki. Oral consent was obtained from all participants prior to the interviews because most of the producers are illiterate.

Credit authorship contribution statement

All authors: Funding acquisition. Alexandre Akouègnon Fassinou: Investigation, Writing - original draft. Loko Yêyinou Laura Estelle: Project administration, Conceptualization,

Methodology, Writing - original draft. Dassou Anicet, Toffa Joelle, Dieudonné Gavoedo, Fidèle Mahoudo Assogba, Yadouleton Anges: Writing - review & editing.

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