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Approved pesticide compliance, productivity enhancement, and sustainable cocoa production among smallholder farmers in Nigeria

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This study assessed the effect of compliance with approved pesticide use on cocoa productivity and sustainable cocoa production in Osun State, Nigeria. Primary data were collected from 240 cocoa farmers selected through a multistage sampling procedure across four major cocoa-producing Local Government Areas. Data were analyzed using descriptive statistics, double hurdle regression, and endogenous switching regression models. Findings revealed that all sampled farmers used approved pesticides, although 94.58% were fully compliant by exclusively using approved products, while 5.42% combined approved and banned pesticides. The most commonly used fungicides were Red Force and Ultimax Plus, whereas Force Up dominated herbicide application. Major constraints to compliance included weather fluctuations, labor shortages, and high input costs. Results from the double hurdle model showed that age, education, and farming experience significantly increased the likelihood of compliance with approved pesticide use, while age, farming experience, farm size, and cocoa yield significantly influenced the intensity of pesticide application. The endogenous switching regression results indicated that compliance with approved pesticide use significantly enhanced cocoa productivity. Compliant farmers achieved a mean yield of 0.482 tons/ha compared to 0.430 tons/ha among non-compliant farmers. Treatment effect estimates further revealed that compliance generated an 11% productivity gain for compliant farmers, while non-compliant farmers could potentially increase productivity by 12.8% through full compliance. The study concludes that compliance with approved pesticide use contributes significantly to productivity enhancement, food safety, and sustainable cocoa production. Therefore, strengthening extension services, farmer education, and enforcement of approved pesticide regulations is essential for achieving sustainable cocoa sector transformation in Nigeria.

KEYWORDS

approved pesticides, cocoa yield, compliant farmers, farm productivity, Nigeria

Introduction

Cocoa (*Theobroma cacao*) is a cash crop cultivated in the humid regions of Africa, South America, Asia, and the Caribbean (International Cocoa Organization, 2025; Otekunrin, 2025; Reddy et al., 2024, 2026; Adegunsoye et al., 2024). More than 85% of the cocoa beans consumed by European countries are imported from Africa, including Nigeria. Cocoa products contain proteins, carbohydrates, vitamins, fats, and minerals that exhibit health benefits (Paparella et al., 2025; Tušek et al., 2024). The distribution of cocoa beans from producers to food processing industries generates substantial income for more than five million different actors along the cocoa supply chain, including exporters, marketers, warehouse agents, transporters, and farmers (International Cocoa Organization, 2025) in Nigeria.

Nigeria is the fourth-largest cocoa producer in the world, supplying about 350,000 metric tons annually, which accounts for 7.2% of global production. Smallholder cocoa farmers account for about 95% of total cocoa production in the country while cultivating 1–3 hectares of farmland on average (International Cocoa Organization, 2025; Ogunleye et al., 2020; Kolapo et al., 2025a). Cocoa is grown in eighteen states, with the Southwestern states of Ondo, Osun, Oyo, Ogun, and Ekiti accounting for about 60% of the country's total production. Cocoa beans are the fifth most exported commodity from Nigeria, generating an export value of \$907 million (TradeInt, 2025). However, cocoa output and exports have experienced significant fluctuations over the years. According to Food Agriculture Organization of the United Nations (2025), cocoa production declined from 357,610 metric tons in 2020 to 280,000 metric tons in 2021, before recovering to 284,230 metric tons in 2023.

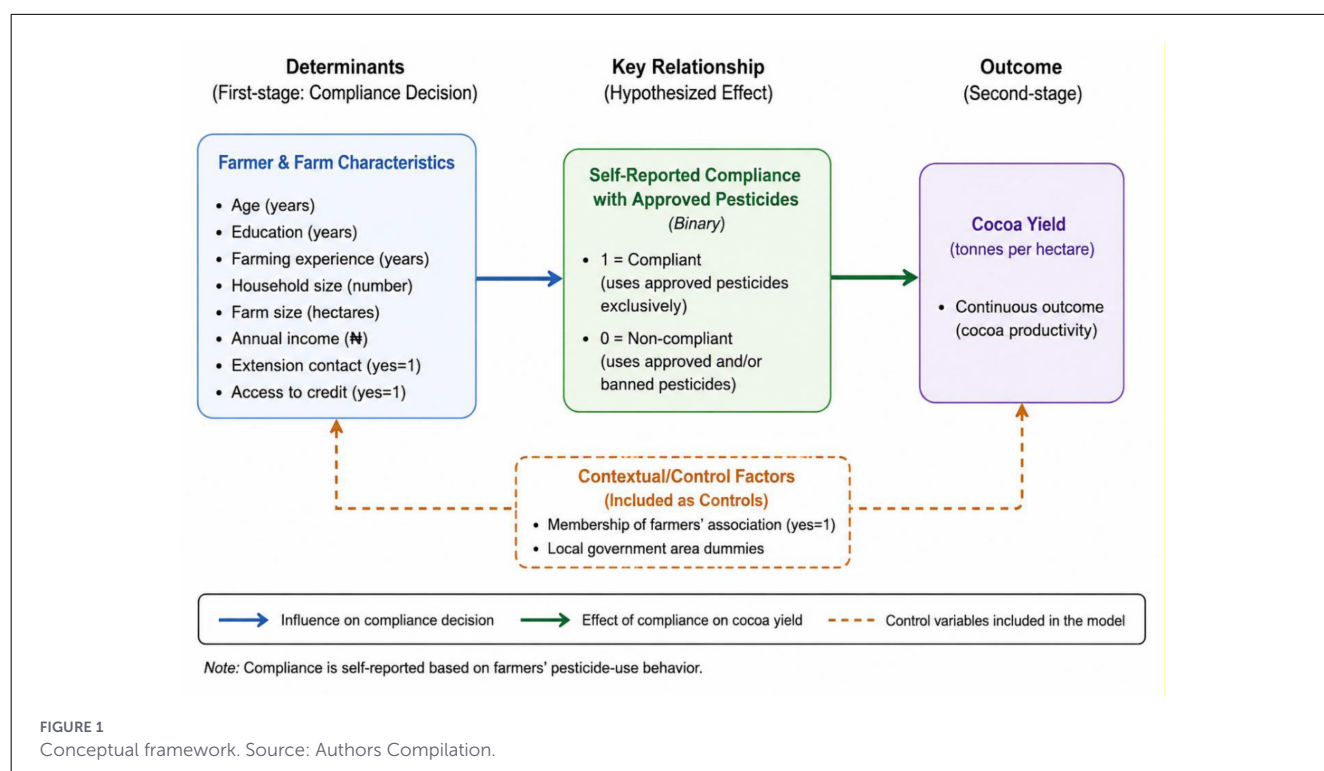
In states like Osun, approximately 80% of the population relies on cocoa farming for their primary income (Ademola et al., 2024). Cocoa production provides both direct and indirect employment to producers, processors, retailers, and other stakeholders in the cocoa value chain. It also provides a market for various agrochemicals, including herbicides, insecticides, fungicides, and fertilizers. Despite its economic potential, cocoa production is characterized by low productivity in Nigeria, and faces challenges including: high pest and disease incidence, low soil fertility, limited access to finance, inadequate adoption of improved farming practices, and insufficient extension services (Kongor and Dimas, 2024). Pest and disease infestations have been identified as major contributors to reduced cocoa quality and productivity.

In Nigeria, pesticide regulation is overseen by the Cocoa Research Institute of Nigeria (CRIN), in collaboration with the Federal Ministry of Agriculture and Food Security. Approved pesticides are those officially registered and recommended for cocoa production based on efficacy and safety, whereas banned pesticides are prohibited due to risks to human health, the environment, or non-compliance with international residue standards. The use of approved pesticides serves to mitigate high insect and disease incidence, as well as high chemical residue levels in cocoa beans, resulting in higher yields (Tham-Agyekum and Owusu, 2025). Unlike banned or

unregulated chemicals, the approved pesticides are specifically developed to be effective against pests, diseases, and weeds while posing minimal risks to farmers, consumers, and the environment (Kolapo et al., 2025b; Kamara et al., 2025; Kolapo et al., 2024). However, many cocoa farmers in Nigeria do not comply with the use of approved pesticides. For instance, in Osun State, several farmers combine approved pesticides with banned or unregulated ones, either due to lack of consistent access to the right products or attraction to cheaper, readily available but prohibited chemicals. Ademola et al. (2024) found that many smallholder cocoa farmers in Osun State were unable to distinguish between approved and banned pesticides, with some deliberately mixing both in the belief that it would provide stronger pest control.

The economic repercussions of this poor practice are substantial. Poor pest control and excessive residue result in lower yields and reduced income, making it difficult for farmers to sustain their operations. Hyde-Cooper et al. (2024) noted that farmers who relied on unapproved or mixed pesticides lost up to 30% of their potential harvests, affecting their household welfare and their ability to reinvest in farming activities. In some instances, produce contaminated with banned chemicals was rejected by buyers, thereby cutting off access to premium markets and diminishing export earnings. Boateng et al. (2023) revealed that without effective monitoring and regulation, many farmers still resort to banned or counterfeit alternatives, sometimes mixing them with approved ones. This not only undermines farm productivity but also endangers farmer health, consumer safety, and long-term soil sustainability.

The problem is compounded by limited extension services and weak regulatory enforcement. As highlighted by Samed et al. (2024), inadequate monitoring and poor follow-up have left many cocoa farmers dependent on guesswork, informal networks, or outdated practices, further entrenching the misuse of pesticides in the cocoa sector. Existing studies have examined the effects of approved pesticide use on cocoa production in Osun State (Ademola et al., 2024; Adetomiwa et al., 2022; Faloni et al., 2022; Oyenpemi et al., 2023). However, a research gap remains on how compliance with the use of approved pesticides influences the productivity of cocoa farmers in the study area. Although previous studies have examined pesticide adoption, compliance with EU regulations, and the economic effects of approved pesticide use among Nigerian cocoa farmers, they largely focused on adoption behavior or welfare outcomes. Few studies have explicitly quantified the productivity effects of compliance while correcting for selection bias and examining both the determinants and intensity of compliance. This study addresses these gaps using a double hurdle and endogenous switching regression framework to provide robust productivity-enhancing association on how compliance with approved pesticide use influences cocoa productivity. This study therefore assessed the impact of compliance with approved pesticide use on the productivity of cocoa farmers in Osun State, Nigeria. The specific objectives were to: identify the types of approved pesticides used by cocoa farmers in Osun State, determine the factors influencing compliance level with approved pesticides in the study area, and assess the impact of compliance with the use of approved pesticides on the productivity of cocoa farmers in the study area.



Conceptual framework

Figure 1 illustrates the conceptual pathway through which farmers' socioeconomic and institutional characteristics influence self-reported compliance with approved pesticide use, which is subsequently associated with cocoa yield. The framework is intentionally simplified to correspond directly with the empirical models estimated in this study. It is anchored in the Theory of Planned Behavior and Rational Choice Theory, which suggest that farmers' compliance decisions are shaped by their knowledge, experience, access to information, and perceived economic benefits (Opoku et al., 2020; Akin-Olagunju et al., 2022). The first component comprises farmer and farm characteristics, including age, education, farming experience, household size, farm size, income, extension contact, and access to credit. These variables represent the socioeconomic and institutional factors that influence farmers' decisions to comply with approved pesticide recommendations. Previous studies have shown that education improves farmers' ability to understand pesticide labels and recommended application practices (Danso-Abbeam and Baiyegunhi, 2018), while farming experience enhances knowledge of pest management and compliance with approved pesticide regulations (Kehinde and Tijani, 2021). Similarly, extension services improve farmers' access to technical information and promote the adoption of recommended agricultural practices (Aminu et al., 2019). The central construct of the framework is self-reported compliance behavior, measured as whether farmers exclusively used approved pesticides or combined approved and banned products. Because compliance is based on farmers' self-reports, the framework recognizes that the variable reflects reported behavior rather than independently verified pesticide use. This distinction is important because self-reported

compliance may be influenced by social desirability or recall bias, although confidentiality procedures were adopted to minimize such reporting errors. The framework hypothesizes that self-reported compliance is positively associated with cocoa yield because approved pesticides provide more effective pest and disease control while reducing crop losses and maintaining crop health. This proposition is consistent with evidence reported by Faloni et al. (2022), Oyenpemi et al. (2023), and Tham-Agyekum and Owusu (2025), who found that compliance with approved pesticide recommendations improves farm performance and supports sustainable cocoa production. By aligning the conceptual framework closely with the estimated double hurdle and endogenous switching regression models, the study provides a clear theoretical basis for examining the relationship between self-reported compliance behavior and cocoa productivity while acknowledging that the observed relationship should be interpreted as an association rather than definitive causation.

The framework follows a temporal sequence in which socioeconomic and institutional characteristics influence compliance decisions, compliance affects pesticide use intensity, and both subsequently determine cocoa productivity, thereby avoiding circular relationships between explanatory and outcome variables.

Methodology

Study area

This study was conducted in Osun State, located in the southwestern region of Nigeria. The state covers an area of approximately 14,875 square kilometers and lies between

longitudes 04°E and 05°E, and latitudes 07°N and 08°N. Osun is bordered by Ogun, Oyo, Ondo, Ekiti, and Kwara States. Administratively, it is divided into 30 Local Government Areas (LGAs). As of 2022, Osun State's estimated population was approximately 4,435,800 people (Adetomiwa et al., 2022). The climate is characterized by two distinct seasons: the rainy season and the dry season. The average annual rainfall is about 1,570 mm, while the mean annual temperature is approximately 27 °C. The state falls within the tropical rainforest zone of Nigeria's western uplands, which, combined with its fertile soils, creates an ideal environment for cocoa cultivation. Cocoa is the leading cash crop and principal agricultural export of the state, with an estimated annual production of 70,000 tons. Approximately 70% of households in the state are involved in cocoa farming and depend on it for their livelihood. Osun State experiences high incidences of cocoa black pod disease (*Phytophthora* spp.), cocoa mirids (*Sahlbergella singularis* and *Distantiella theobroma*), and capsid infestations, which substantially reduce yields and bean quality. These persistent pest and disease pressures justify the study's focus on compliance with approved pesticide use for sustainable cocoa production (Adetomiwa et al., 2022).

Sampling technique and method of data collection

A multistage sampling procedure was employed in selecting respondents for this study. In the first stage, four Local Government Areas (LGAs): Ife South, Atakunmosa West, Ayedaade, and Ife East were purposively selected based on their high concentration of cocoa farmers and their substantial contribution to the state's overall cocoa production. In the second stage, a major cocoa-producing village was selected from each of the chosen LGAs. Finally, in the third stage, cocoa farmers in each of the villages were randomly selected proportionate to size. A total of 240 respondents were selected: 80 farmers from Ife South, 65 from Atakunmosa West, 45 from Ayedaade, and 50 from Ife East. Primary data was obtained through the administration of a semi-structured questionnaire designed for cocoa farmers in Osun State. The questionnaire was used to gather information on the farmers' socio-economic characteristics such as age, level of education, and farming experience, as well as institutional factors including access to extension services and credit facilities. Additional questions on application rate, constraints, and awareness level were also included to capture other relevant factors that might influence compliance with approved pesticides. To minimize selection bias, the selected LGAs were chosen because they represent the principal cocoa-producing areas in Osun State and exhibit characteristics common to other major cocoa-producing LGAs, including similar agroecological conditions, farming systems, extension service coverage, and market access. Random sampling was subsequently employed to select respondents within each LGA, thereby improving the representativeness of the sample. The questionnaire was developed from relevant literature and reviewed by agricultural economics and extension experts to ensure content validity. A pilot survey was conducted among cocoa farmers outside the study communities to refine question clarity and consistency.

The main survey was conducted between May–July 2024. Of the 250 questionnaires administered, 240 were successfully completed, representing a response rate of 90%.

Data analysis

The data collected for this study was analyzed using a combination of descriptive statistics, the double hurdle model, and the endogenous switching regression model. Descriptive statistics such as mean, standard deviation, percentages, and frequency were used to profile the various pesticides used by cocoa farmers and describe their socioeconomic characteristics.

Double hurdle model

The double hurdle model was selected because compliance with approved pesticide recommendations involves two distinct behavioral decisions. Unlike the conventional application of the model, where the first hurdle represents the decision to adopt a technology, all farmers in this study already used approved pesticides to some extent. Therefore, the first hurdle models the decision to comply exclusively with approved pesticide recommendations (exclusive use of approved pesticides vs. combined use of approved and banned pesticides), rather than technology adoption. Conditional on exclusive compliance, the second hurdle models the intensity of approved pesticide application, measured by the frequency of pesticide use. These two decisions are conceptually distinct because a farmer may decide to comply with approved pesticide recommendations but still differ in the intensity with which approved pesticides are applied. The double hurdle framework therefore provides a flexible approach for jointly analyzing the determinants of compliance behavior and application intensity, allowing each decision to be influenced by different socioeconomic and institutional factors.

The double hurdle model was used to identify factors influencing farmers' compliance level with approved pesticides. This model assumes that individuals pass through two stages. The first stage is the decision to use approved pesticides exclusively or not, while the second stage determines how many times pesticides are applied. In the first stage, probit regression was used, where 0 represents the decision not to apply approved pesticides exclusively and 1 represents the decision to use approved pesticides exclusively.

The selection equation, which indicates whether farmers use approved pesticides exclusively or not, is specified as:

$$A_i = \Pr(A_i/A_i^* > 0) = \beta^1 X_i + \varepsilon_i \quad (1)$$

where $A_i = 1$ for approved pesticide compliant farmers and $A_i = 0$ for non-compliant farmers, A_i^* is the latent variable for adoption probability, β^1 represents the estimated coefficients of the independent variables, X_i are the set of covariates, and ε_i is the error term.

The second stage explains the intensity of use; the truncated regression model is specified as:

$$Y_i^* = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_{10} X_{10i} + \varepsilon_i \quad (2)$$

Y_i^* = is the latent unobserved variable (frequency of approved pesticide application). $Y_i = Y_i^*$ only if $Y_i^* > 0$; Y_i is unobserved due to truncation. X_1 to X_{10} are explanatory variables influencing frequency of application, and β_0 to β_{10} = are parameters to be estimated.

ε = error term.

Prior to estimation, the dataset was screened for completeness and consistency. Observations with incomplete information on variables included in the econometric models were excluded using listwise deletion. Consequently, the estimation sample decreased from 240 respondents to 231 observations in the first-stage compliance model. The second-stage truncated regression was estimated only for observations satisfying the model's truncation condition, resulting in a final estimation sample of 227 farmers.

Endogenous switching regression model (ESRM)

ESRM was used to analyse the impact of approved pesticide use on cocoa yield. In estimating the impact of approved pesticides use on productivity, there are two problems: heterogeneity between user and non-user, and endogeneity between the adoption and productivity equations. When measuring the impact of the programme, the endogenous switching regression model considers both observed and unobserved characteristics. This justifies the use of ESRM, which involves a joint estimation of the probability of using approved pesticides and productivity level.

A decision equation (probit model) was constructed in the first stage to assess the factors that influence approved pesticides exclusive use behavior:

$$P_i^* = Z_i \alpha + \mu_i \quad P_i = \begin{cases} 1 & \text{if } P^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

where P_i is the observed approved pesticides exclusive use behavior for household i ; $P_i = 1$ represents using approved pesticides exclusively, and $P_i = 0$ represents not using approved pesticides exclusively. Z_i represents the vector of explanatory variables, α is the estimated coefficient, and μ_i is the error term.

An outcome equation was used in the second stage to analyse factors influencing productivity level:

$$\begin{aligned} Y_{1i} &= \beta_{1i} X_{1i} + \varepsilon_1 & \text{if } P_i = 1 \\ Y_{0i} &= \beta_{0i} X_{0i} + \varepsilon_0 & \text{if } P_i = 0 \end{aligned} \quad (4)$$

where Y_{1i} and Y_{0i} are defined as the farmers' productivity for those that use, and did not use approved pesticides exclusively, respectively.

The Average Treatment Effect on the Treated (ATT) and Average Treatment Effect on the Untreated (ATU) were computed to estimate the effect of approved pesticides use on productivity.

The explanatory variables included age of cocoa farmer (years), education (years), farm experience (years), household size (number

of members), farm size (hectares), farm income (Naira), extension contact (1 if contact, 0 otherwise), access to credit (1 if access, 0 otherwise), awareness of approved pesticides (1 if aware, 0 otherwise), and cocoa yield (tons per hectare).

Approved pesticide use is treated both in terms of compliance (whether a farmer uses approved pesticides exclusively) and non-compliance (whether a farmer uses both approved and banned pesticides). These patterns are influenced by farmers' access to agricultural information and support systems, including extension services and awareness campaigns. The proper use of approved pesticides is expected to reduce pest and disease damage, thereby increasing cocoa yield per hectare and total output.

The productivity of cocoa farmers, measured by cocoa yield (tons per hectare), serves as the dependent variable in this study. By examining the relationship between compliance with approved pesticide use and cocoa productivity, the framework seeks to assess the impact of approved pesticide application while factoring in the roles of socioeconomic and institutional variables. These include variables such as access to credit (which affects ability to purchase approved pesticides), extension visits (which affect knowledge of correct usage), and farmer awareness (which determines understanding of approved vs. banned products).

The endogenous switching regression (ESR) model was employed because farmers self-select into exclusive compliance with approved pesticide recommendations, making conventional regression estimates susceptible to selection bias (Tables 1 and 2). The ESR jointly estimates the compliance decision and productivity equations, thereby accounting for both observed and unobserved heterogeneity associated with farmers' compliance behavior. Identification in the present study relies primarily on the non-linearity of the first-stage probit selection equation and the distributional assumptions of the ESR framework rather than on a separate external exclusion restriction. Consequently, while the ESR substantially improves upon conventional regression by correcting for self-selection, the estimated treatment effects were interpreted as evidence of productivity-enhancing associations after accounting for selection bias rather than definitive proof of causality.

Compliance was measured using farmers' self-reported pesticide-use practices, specifically whether they exclusively used approved pesticides or combined approved and banned products. To reduce reporting bias, respondents were assured that all information would remain anonymous and confidential and would be used solely for academic research rather than regulatory enforcement. Nevertheless, because compliance was self-reported, some degree of social desirability or underreporting of banned pesticide use cannot be completely ruled out.

The inclusion of cocoa yield in the second-stage double hurdle model reflects a behavioral rather than a contemporaneous production relationship. Specifically, farmers' previous-season yield performance serves as an indicator of prior production outcomes and influences subsequent pesticide management decisions. Farmers who experienced lower yields in the previous season, often resulting from pest and disease infestations, are expected to modify their management practices by increasing compliance with approved pesticide recommendations and applying pesticides more intensively in the following production season to avoid recurring losses. Thus, the behavioral sequence assumed in this study is that previous production

TABLE 1 A-priori expectations for factors influencing compliance level with approved pesticides.

S/N	Variables	Expected relationship (sign)	
		First stage	Second stage
1.	Age of cocoa farmer in years	+	+
2.	Education level in years	+	+
3.	Farm experience in years	+	+
4.	Household size (number of household members)	+	+/-
5.	Farm size (cultivated land occupied by cocoa in hectares)	+	+
6.	Total income (in Naira)	+	+
7.	Extension contacts (extension visits to the farm) (yes = 1; 0 otherwise)	+	+/-
8.	Access to credit (yes = 1; 0 = otherwise)	+	+
9.	Awareness of approved pesticides (yes = 1; no = 0)	+	+
10.	Cocoa yield (tons per hectare)	+	+

outcomes influence current compliance decisions, while current compliance behavior subsequently influences observed cocoa productivity estimated through the endogenous switching regression model.

Results and discussion

Socioeconomic characteristics of cocoa farmers

The results of the description of socioeconomic characteristics of the cocoa farmers are presented on Table 3. Cocoa farmers had a mean age of 52.55 ± 10.91 years with majority of farmers (30.42%) in the 50–59 years age bracket. This shows that cocoa farming in Osun State is dominated by middle-aged and older farmers. This pattern aligns with the findings of Kehinde and Tijani (2021), who observed similar age demographics in cocoa farming communities in Osun State and attributed this to rural-urban migration of younger populations seeking non-agricultural employment opportunities.

Most cocoa farmers (78.33%) were male. The male dominance in cocoa farming reflects the traditional gender roles in agricultural production in southwestern Nigeria, where men typically control cash crop production while women focus more on food crop cultivation and processing activities. The predominance of male respondents reflects the gendered structure of cocoa production in southwestern Nigeria. However, female farmers may be underrepresented, limiting the generalizability of the findings and

TABLE 2 A-priori expectations for the impact of approved pesticides use on the productivity of cocoa farmers.

S/N	Variables	Expected relationship (sign)	
		First stage	Second stage
1.	Age of cocoa farmer in years	+	+
2.	Education level in years	+	+
3.	Farm experience in years	+	+
4.	Household size (number of household members)	+	+/-
5.	Farm size (cultivated land occupied by cocoa in hectares)	+	+/-
6.	Total income (in naira)	+	+
7.	Extension contacts (extension visits to the farm) (yes = 1; 0 otherwise)	+	+
8.	Access to credit (yes = 1; 0 = otherwise)	+	+
9.	Awareness of approved pesticides; awareness (yes = 1; no = 0)	+	+

Source: Author's computation, 2025.

highlighting the need for more gender-balanced sampling in future studies. This gender distribution is consistent with the findings of Tijani and Masuku (2019), who reported similar male dominance in cocoa production systems in Nigeria. Furthermore, 45% had secondary education, indicating a relatively educated farming population. The findings of Danso-Abbeam and Baiyegunhi (2018), also support the result and emphasize that education enhances farmers' ability to adopt improved agricultural technologies and make informed decisions about input use. Households size was 7.36 ± 1.82 members, reflecting the extended family structure common in rural southwestern Nigeria (Tijani and Masuku, 2019). This finding of larger households in agricultural communities is consistent with Faloni et al. (2022). Only 42.50% had access to credit indicating significant challenges to purchase inputs such as approved pesticides. The result aligns with the findings of Oyenpemi et al. (2023).

Moreover, farm size was 6.83 ± 2.91 hectares showing the smallholder nature of cocoa farming in Osun State, which is typical of cocoa production systems across Nigeria (Owoeye et al., 2022). Years of farming experience was 27.16 ± 10.33 years. This indicates that most cocoa farmers were well-versed in cocoa farming practices and have accumulated substantial knowledge about local growing conditions, pest patterns, and seasonal variations. Similarly, the annual income was $\text{N}35,578,465 \pm \text{N}12,480,245$ and cocoa yield was 0.48 ± 0.04 tons per hectare, showing that yield is below the potential reported in literature (Adetomiwa et al., 2022), suggesting room for improvement through better management practices. Finally, most farmers received extension visits in the last 3 years (96.25%) while only 3.75% did not receive any visits. This indicates good agricultural support services in the study area and aligns with findings from Aminu et al. (2019), who emphasized the role of extension services in promoting adoption of improved agricultural technologies.

TABLE 3 Distribution of socioeconomic characteristics of cocoa farmers.

Socioeconomic characteristics	Frequency (n = 240)	Percentage
Age		
30–39 years	34	14.17
40–49 years	66	27.50
50–59 years	73	30.42
> 59 years	67	27.92
Mean: 52.55 ± 10.91 Min: 32 Max: 76		
Sex		
Male	188	78.33
Female	52	21.67
Education level		
Primary education	66	27.50
Secondary education	108	45.00
Tertiary education	66	27.50
Household size		
4–6 persons	84	35.00
7–9 persons	124	51.67
10–12 persons	32	13.33
Mean: 7.36 ± 1.82 Min: 4 Max: 12		
Access to credit		
Yes	102	42.50
No	138	57.50
Farm size		
Less than 4 ha	38	15.83
4–8 ha	115	47.92
8.1–12 ha	81	33.75
Greater than 12 ha	6	2.50
Mean: 6.83 ± 2.91 SD: Min: 1.21 Max: 23.47		
Farm experience		
8–20 years	72	30.00
21–30 years	77	32.08
31–40 years	63	26.25
> 40 years	28	11.67
Mean: 27.16 ± 10.33 Min: 8 Max: 50		
Income categories		
7–20 million Naira	33	13.75
21–35 million Naira	93	38.75
36–50 million Naira	103	42.92
> 50 million Naira	11	4.58

(Continued)

TABLE 3 (Continued)

Socioeconomic characteristics	Frequency (n = 240)	Percentage
Mean: 35,578,465 ± 12,480,245 Min: 7,000,000 Max: 67,000,000		
Cocoa yield (tons/ha)		
<0.41	48	20.00
0.41–0.50	118	49.17
>0.5	74	30.83
Mean: 0.48 ± 0.041 Min: 0.12 Max: 0.78		
Off-farm employment		
Trading	83	34.58
Arts and crafts	63	26.25
Public salaried job	38	15.83
Private salaried job	3	1.25
None	53	22.08
Extension visits (last 3 years)		
Yes	231	96.25
No	9	3.75

Source: Field survey, 2025.

Application, sources, constraints, and awareness of approved cocoa pesticides

The description of approved pesticide application, sources, constraints to use and awareness is shown on [Table 4](#). All farmers (100%) used approved pesticides, with 99.17% being aware that the pesticides are approved. The near-universal awareness levels exceed those reported in many agricultural technology adoption studies ([Faloni et al., 2022](#)) and suggest successful information dissemination efforts in the study area. All farmers sought advice on pest problems, primarily from extension agents at 95.83%, showing the effectiveness of formal extension systems in the study area. All farmers obtained pesticides from agrochemical sellers, while 1.67% also obtained them from cocoa merchants. Agrochemical shops were available to 99.17% of respondents. Regarding effectiveness, 82.92% rated approved pesticides as very effective, while 17.08% rated them as effective. However, all farmers indicated that spray frequency was inadequate, suggesting challenges in optimal pesticide application. The main constraints in using approved pesticides include weather fluctuations (excess cold) reported by 65.83%, time/labor constraints with 25.42%, high cost with 9.17%, and supply issues with 1.67%. These constraints are consistent with those identified by researchers studying agricultural input adoption ([Agyeman et al., 2022](#)), where cost and labor limitations frequently impede optimal input use.

TABLE 4 Application, sources, constraints, and awareness of approved cocoa pesticides.

Description	Frequency (n = 240)	Percentage
Uses approved pesticides	240	100.00
Awareness of approved pesticides	238	99.17
Seek advice on pest problems	240	100.00
Sources of advice		
Extension agents	230	95.83
Other farmers	27	11.25
Agrochemical seller	7	2.92
Cocoa merchant	4	1.67
Others	1	0.42
Sources of pesticides		
Agrochemical seller	240	100.00
Cocoa merchant	4	1.67
Availability of agrochemical shops	238	99.17
Effectiveness of approved pesticides		
Very effective	199	82.92
Effective	41	17.08
Farmers reporting that the current spray frequency is inadequate	240	100.00
Constraints in using approved pesticides		
Time/labor constraints	61	25.42
High cost	22	9.17
Supply issues	4	1.67
Other constraints	158	65.83

Source: Field survey, 2025.

Types of approved pesticides used by cocoa farmers

The description of types of approved pesticides used by cocoa farmers is presented on Table 5. The fungicide, Red Force was the most commonly used (38.8%), followed by Ultimax Plus (29.6%) and Mackecknie Gold (27.5%). Among insecticides, Best was the most popular, used by 37.9%, followed by Dominator (14.6%), Actara (9.6%) and Actellic Gold (7.9%). For herbicides, Force Up dominated usage (58.3%), followed by Star Force (25%) and Round Up (16.7%). Regarding banned pesticides, some farmers still used prohibited substances. Rocket (insecticide) was used by 46.2% of those using banned substances, Copper Sulfate (fungicide) by 38.5%, and Gammalin 20 (insecticide) by 15.4%. The continued use of banned pesticides poses health and environmental risks and indicates the need for better enforcement and farmer education about approved alternatives.

Factors influencing compliance level with approved pesticides

The results for the factors that influence farmers' decisions to comply with approved pesticide use and the intensity of use are

TABLE 5 Types of pesticides used by cocoa farmers in the study area.

Pesticide group	Trade name	Frequency (n = 240)	Percentage (%)
Fungicides	Red force	93	38.8
	Ultimax plus	71	29.6
	Mackecknie gold	66	27.5
	Ridomil gold	1	0.4
	Amarshal metalaxyl	1	0.4
	Ikore	11	4.6
Insecticides	Best	91	37.9
	Dominator	35	14.6
	Actara	23	9.6
	Actellic gold	19	7.9
	Sharp shooter	15	6.3
	Cyrux	10	4.2
	Confidoor	3	1.3
	Cypercal	2	0.8
Herbicides	Force up	140	58.3
	Star force	60	25.0
	Round up	40	16.7
Banned pesticides	Rocket (insecticide)	6	46.2
	Copper sulfate (fungicide)	5	38.5
	Gammalin 20 (insecticide)	2	15.4

Percentages reported for banned pesticides are based only on the 13 non-compliant farmers who reported combining approved and banned pesticides, not on the full sample of 240 farmers.

Source: Field survey, 2025.

presented on Table 6. The first hurdle (probit model) is statistically significant with an LR χ^2 of 20.45 and p -value of 0.0155, with a pseudo R^2 of 0.2044. The second hurdle (truncated regression) is statistically significant with a Wald χ^2 of 52.73 and p -value of 0.0000.

Age of cocoa farmer showed a significant positive effect at the 5% level with a marginal effect of 0.1941. This indicates that a 1-year increase in farmer age increases the probability of compliance with approved pesticide use by 19.41%. This aligns with the findings of Kehinde and Tijani (2021) that older farmers are more likely to comply with approved pesticide use. The positive relationship can be explained by older farmers' greater experience with pest problems and their recognition of the long-term benefits of using approved pesticides. The square of age showed a significant negative effect at the 10% level with a marginal effect of -0.0017 . The negative quadratic term indicates that the positive effect of age on compliance diminishes at higher ages, suggesting an optimal age range for compliance beyond which very elderly farmers may experience declining compliance rates.

Education showed a significant positive effect at the 5% level with a marginal effect of 0.0436. This means that each additional year of education increases the probability of compliance with approved pesticide use by 4.36%. The positive effect of

TABLE 6 Double hurdle model regression showing the factors influencing compliance level with approved pesticides.

Variables	First hurdle (probit)					Second hurdle (truncated)			
	(Compliance with APs)					(Intensity of APs use)			
	Coef.	dy/dx	Std. err.	z	P-value	Coef.	Std. err.	z	P-value
Age	0.4850	0.1941**	0.2134	2.27	0.023	1.2890***	0.3845	3.35	0.001
Age ²	−0.0043	−0.0017*	0.0024	−1.79	0.073	−0.0098**	0.0041	−2.39	0.017
Education	0.1091	0.0436**	0.0481	2.27	0.023	0.0329	0.0547	0.60	0.547
Experience	0.2794	0.1118***	0.1035	2.70	0.007	0.8135 ***	0.2542	3.20	0.001
Household size	0.0608	0.0243	0.0887	0.69	0.493	−0.0405	0.1033	−0.39	0.695
Farm size	−0.0380	−0.0952	0.1870	−0.20	0.839	0.7329 ***	0.1684	4.35	0.000
Total income	−3.43e-09	−7.57e-09	3.47e-08	−0.10	0.921	−5.37e-08	4.30e-08	−1.25	0.212
Credit	−0.1901	−0.0760	0.3683	−0.52	0.606	0.1700	0.4245	0.40	0.689
Cocoa yield	−3.8963	−5.7413	5.9572	−0.65	0.513	19.8432 ***	6.0825	3.26	0.001
Cons.	−4.2001		4.0324	−1.04	0.298	−19.6554 ***	5.9283	−3.32	0.001
Sigma						2.6416 ***	0.1242	21.27	0.000
Model statistics:									
First hurdle: $n = 231$ LR $\chi^2(9)$: 20.45 Prob > χ^2 : 0.0155 Pseudo R^2 : 0.2044 Log likelihood: −38.77									
Second hurdle: $n = 227$ Wald $\chi^2(9)$: 52.73 Prob > χ^2 : 0.0000 Log likelihood: −425.89									

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: Field survey, 2025.

education likely reflects multiple reinforcing mechanisms. More educated farmers are better able to interpret pesticide labels and application instructions, understand regulatory requirements, appreciate the long-term health and environmental risks of banned chemicals, and place greater trust in extension advice and formal institutions. These mechanisms collectively promote informed compliance decisions and sustainable pesticide management (Danso-Abbeam and Baiyegunhi, 2018; Aminu et al., 2019). This finding strongly aligns with Danso-Abbeam and Baiyegunhi (2018), who found education to enhance farmers' understanding of the benefits and proper use of approved agricultural inputs. Farm experience showed a significant positive effect at the 1% level with marginal effect of 0.1118. This indicates that each additional year of farming experience increases the probability of compliance with approved pesticide use by 11.18%. This finding strongly supports Kehinde and Tijani (2021), who found experience to be positively associated with adoption of improved agricultural practices.

The second hurdle showed the factors influencing intensity of approved pesticide use. Age showed a significant positive effect at the 1% level with a coefficient of 1.2890. This indicates that each additional year in farmer age increases the intensity of approved pesticide applications. Age² showed a significant negative effect at the 5% level with a coefficient of −0.0098, indicating that intensity increases with age but at a decreasing rate. Similarly, farm experience showed a significant positive effect at the 1% level with a coefficient of 0.8135. This means that each additional year of farming experience increases the intensity of approved pesticide use. This finding aligns with Kehinde and Tijani (2021), who found that experience influences both adoption and intensity of improved agricultural practices. Farm size also showed

a significant positive effect at the 1% level with a coefficient of 0.7329. This indicates that each additional hectare of farm size increases the intensity of approved pesticide applications. This finding supports Kehinde and Tijani (2021), who found farm size to positively influence intensity of input use. Finally, cocoa yield showed a significant positive effect at the 1% level with a coefficient of 19.8432. This indicates that each additional ton per hectare of cocoa yield is associated with an increase in approved pesticide application intensity. This substantial coefficient supports Faloni et al. (2022), who found a positive relationship between pesticide use intensity and crop productivity.

Productivity comparison between compliant and non-compliant farmers

Cocoa yields were used as proxy for productivity and the distribution is presented on Table 7. A comparison of cocoa yields between compliant and non-compliant farmers with approved pesticide use revealed that among compliant farmers achieved a higher mean yield of 0.482 ± 0.039 tons/ha, compared to non-compliant farmers who achieved 0.430 ± 0.065 tons/ha with a standard deviation of 0.065.

The Welch's t -test results show a statistically significant difference between the two groups with a mean difference of 0.0520 tons/ha, t -statistic of 2.86, and p -value of 0.014. Since the p -value is less than the significance level of 0.05, the null hypothesis is rejected. Therefore, farmers who use only approved pesticides achieve higher productivity compared to those who use both approved and banned pesticides.

TABLE 7 Yield comparison between compliant and non-compliant farmers.

Cocoa yield (tons/ha)	Pooled (<i>n</i> = 240)		Compliant farmers (<i>n</i> = 227)		Non-compliant farmers (<i>n</i> = 13)	
	Frequency	%	Frequency	%	Frequency	%
<0.41	48	20.00	43	18.94	5	38.46
0.41–0.50	118	49.17	114	50.22	4	30.77
>0.5	74	30.83	70	30.84	4	30.77
Mean ± SD	0.48 ± 0.041		0.482 ± 0.039		0.430 ± 0.065	
Welch's <i>t</i> -test results:						
Mean difference = 0.0520 tons/ha <i>t</i> -statistic: 2.86 df: 12.50 <i>p</i> -value: 0.014						

Source: Field survey, 2025.

Impact of approved pesticides use on productivity of cocoa farmers

The results for the impact of approved pesticide use on cocoa productivity is shown on Table 8. The results show that the selection model (probit) is statistically significant with an LR χ^2 of 20.45 and *p*-value of 0.0155, with a pseudo R^2 of 0.2044. The compliance model (OLS) is significant with $F(10,216)$ of 42.18 and *p*-value of 0.0000, with an R^2 of 0.6612. The non-compliance model (OLS) is significant with $F(8,4)$ of 18.75 and *p*-value of 0.0025, with an R^2 of 0.9742. The selection equation shows that age has a positive effect with marginal effect of 0.1941 indicating that a unit increase in farmer age, increases the probability of compliance by 19.41%. Education, with a marginal effect of 0.0436, increases the probability of compliance by 4.36%. In the same vein, farm experience with marginal effect of 0.1118, increases compliance probability by 11.18%.

For the compliance equation (farmers using only approved pesticides), farm experience showed a significant positive effect at 1% level with a coefficient of 0.0002. This indicates that each additional year of experience increases cocoa yield by 0.0002 tons/ha among compliant farmers. This aligns with the findings of Adetomiwa et al. (2022) that experience enhances farmers' ability to effectively use approved pesticides. Household size also showed a significant positive effect at 1% level with a coefficient of 0.0032. Larger households may provide more labor for intensive cocoa management practices. This aligns with the findings of Tijani and Masuku (2019) who found household size to have positive effect on cocoa productivity. Farm size showed a significant positive effect at the 1% level with a coefficient of 0.0207. Each additional hectare increases yield by 0.0207 tons/ha among compliant farmers. This positive relationship suggests economies of scale in cocoa production when using approved pesticides. Total income showed a significant positive effect at the 1% level with a coefficient of 4.65e-09. Higher-income farmers achieve better yields, likely because they can afford optimal input combinations including appropriate pesticides, fertilizers, and other productivity-enhancing inputs.

For the non-compliance equation (farmers using approved plus banned pesticides), total income showed a significant positive effect at the 5% level with a coefficient of 4.64e-09. Even among non-compliant farmers, higher income enables better productivity.

The inverse Mills ratio (λ) is significant for compliant farmers (0.0142**), indicating that selection bias was present and has been appropriately corrected. The correlation parameters show $\rho_1 = 0.2187^*$ (positive selection into compliance), suggesting that unobserved characteristics that make farmers more likely to choose compliance are also associated with higher yields.

Treatment effects of approved pesticides on cocoa yield

The treatment-effect estimates (Table 9) suggest that farmers who exclusively used approved pesticides achieved higher predicted cocoa yields than those who combined approved and banned pesticides. The ATT indicates a potential yield advantage of approximately 11% for compliant farmers, while the ATU suggests that non-compliant farmers could potentially realize a 12.8% increase in yield under full compliance. However, these estimated differences should be interpreted with caution because the Wald test was not statistically significant ($\chi^2 = 0.176$, $p = 0.674$). Consequently, although the estimated treatment effects are economically meaningful and consistent with the broader empirical findings, they were regarded as suggestive rather than conclusive evidence of a positive association between compliance and cocoa productivity. Additional studies using larger samples, longitudinal data, or stronger identification strategies are needed to confirm these relationships. The 11–12.8% yield advantage from compliance translates into economic benefits for cocoa farmers, justifying the use of approved pesticide use practices. This strongly aligns with the findings of Blaznik et al. (2015) and Danso-Abbeam et al. (2019).

Discussion of findings

The regime-specific estimates for non-compliant farmers should be interpreted with caution because only 13 respondents were classified as non-compliant, compared with 227 compliant farmers. This imbalance reflects the high prevalence of compliance observed in the study area rather than a sampling deficiency. However, the relatively small comparison group may reduce estimation precision, increase coefficient instability, and contribute

TABLE 8 Endogenous switching regression showing the impact of approved pesticides use on the productivity of cocoa farmers.

Variables	Cocoa productivity (yield)						
	Selection model (compliance)			Compliance (approved)		Non-compliance (approved + banned)	
	Coef.	dy/dx	Std. err.	Coef.	Std. err.	Coef.	Std. err.
Age	0.4850	0.1941**	0.2134	0.0034	0.0048	−0.0156	0.0098
Age ²	−0.0043	−0.0017*	0.0024	−0.00003	0.00005	0.00008	0.00007
Education	0.1091	0.0436**	0.0481	0.0006	0.0006	0.0005	0.0039
Experience	0.2794	0.1118***	0.1035	0.0002***	0.0001	−0.0030	0.0045
Household size	0.0608	0.0243	0.0887	0.0032 ***	0.0011	−0.0024	0.0071
Farm size	−0.0380	−0.0952	0.1870	0.0207 ***	0.0069	−0.0030	0.0278
Total income	−3.43e-09	−7.57e-09	3.47e-08	4.65e-09 ***	4.04e-10	4.64e-09 **	1.34e-09
Credit	−0.1901	−0.0760	0.3683	0.0052	0.0047	−0.0280	0.0201
Cocoa yield	−3.8963	−5.7413	5.9572				
Cons.	−4.2001		4.0324	0.4302 ***	0.0653	0.5163 **	0.1343
λ (IMR)				0.0142**	0.0071	−0.0089	0.0284
Model diagnostics:							
ρ_1 (Selection-compliance correlation): 0.2187*							
ρ_2 (Selection-non-compliance correlation): −0.1296							
Model statistics:							
Selection model (Probit): $n = 231$ LR $\chi^2(9)$: 20.45 Prob > χ^2 : 0.0155 Pseudo R^2 : 0.2044 Log likelihood: −38.77							
Compliance (OLS): $n = 227$ $F(10,216)$: 42.18 Prob > F : 0.0000 R^2 : 0.6612 Adj R^2 : 0.6455							
Non-Compliance (OLS): $n = 13$ $F(8,4)$: 18.75 Prob > F : 0.0025 R^2 : 0.9742 Adj R^2 : 0.9226							

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: Field survey, 2025.

TABLE 9 Treatment effects results of impact of approved pesticides on cocoa yield.

Outcome variables	Adoption status	Predictions		Treatment effect	% change
Cocoa yield (tons/ha)		Use only approved	Use approved + banned		
	ATT (compliant)	0.482	0.431	0.051	11
	ATU (non-compliant)	0.485	0.430	0.055	12.8
	Difference			0.004	1.8
			Wald $\chi^2(1) = 0.176$		$p = 0.674$

Source: Field survey, 2025.

to the high explanatory power reported for the non-compliance equation. Consequently, greater emphasis was placed on the overall treatment effect estimates and the consistency of the findings across model specifications than on individual coefficients within the non-compliant regime. This study provides robust evidence that compliance with approved pesticide use enhances cocoa productivity while contributing to sustainable cocoa production in Nigeria. Beyond confirming a positive association between compliance and yield, the findings demonstrate that compliance represents both a regulatory requirement and a productivity-enhancing management strategy. Unlike previous studies that primarily examined pesticide adoption or welfare outcomes (Adetomiwa et al., 2022; Faloni et al., 2022; Oyenpemi et al.,

2023), this study quantified the productivity effect of compliance after correcting for selection bias, thereby providing stronger evidence of its causal contribution to improved cocoa yields. The positive influence of education and farming experience on compliance suggests that farmers' decisions extend beyond access to pesticides and are shaped by their ability to interpret technical information and evaluate long-term production risks. This finding agrees with Danso-Abbeam and Baiyegunhi (2018), who reported that education facilitates adoption of improved agricultural technologies, and with Kehinde and Tijani (2021), who found that experienced cocoa farmers are more likely to comply with EU-approved pesticide recommendations. However, the insignificant effects of credit access and income on compliance

differ from studies that identified financial constraints as major determinants of technology adoption (Oyenpemi et al., 2023). One plausible explanation is that the widespread availability of approved pesticides and extensive extension support in the study area may have reduced the importance of financial capital in influencing compliance decisions. Although almost all respondents were aware of approved pesticides and regularly interacted with extension agents, a small proportion continued to combine approved and banned chemicals. This finding indicates that awareness alone is insufficient to guarantee behavioral change. Hyde-Cooper et al. (2024) similarly observed that cocoa farmers often continue using unapproved pesticides because of affordability concerns, perceived effectiveness, and weak regulatory oversight. Therefore, non-compliance should not be interpreted solely as a knowledge deficit but also as a response to economic incentives, market failures, and institutional weaknesses. This explains why stronger enforcement and improved access to affordable approved pesticides remain essential complements to extension services. The estimated productivity gains among compliant farmers support previous evidence from Ghana and Nigeria that proper pesticide management improves pest control and farm performance (Tham-Agyekum and Owusu, 2025; Faloni et al., 2022). Nevertheless, the observed yield advantage (11%) is relatively modest compared with larger gains reported in some adoption studies. This difference may reflect the already high compliance rate (94.6%) in the study area, which reduces productivity differentials between compliant and non-compliant farmers. Moreover, cocoa productivity is influenced by multiple interacting factors, including soil fertility, climate variability, labor availability, and farm management practices, which pesticide compliance alone cannot fully address. Thus, approved pesticide use should be viewed as one component of an integrated productivity strategy rather than a standalone solution. The persistence of weather fluctuations, labor shortages, and high input costs as major constraints further highlights that compliance is embedded within broader production systems. Similar constraints have been documented by Agyeman et al. (2022), who emphasized that climatic variability and labor scarcity frequently undermine efficient input use among cocoa farmers. Consequently, strengthening compliance requires integrated interventions that combine climate-smart pest management, effective extension services, affordable input distribution, and stronger regulatory enforcement. Such a systems-based approach would not only improve productivity but also reduce pesticide residues, protect ecosystems, strengthen Nigeria's compliance with international food safety standards, and enhance the competitiveness of its cocoa exports.

The estimated productivity differences were also interpreted in light of the self-reported nature of the compliance measure. If some farmers underreported the use of banned pesticides, the magnitude of the estimated association may be affected. Although confidentiality assurances were provided, objective validation was beyond the scope of this study.

Although this study demonstrates a positive association between self-reported compliance with approved pesticide use and cocoa productivity, it did not directly measure pesticide residues, environmental contamination, human health outcomes, or export

performance. Therefore, these broader outcomes should be viewed as potential implications rather than empirically verified effects. Previous studies have shown that compliance with approved pesticide recommendations can reduce pesticide residues, lower environmental risks, and improve compliance with international food safety standards (Boateng et al., 2023; Hyde-Cooper et al., 2024; Tham-Agyekum and Owusu, 2025). Consequently, the productivity gains observed in this study may contribute to these broader benefits.

Conclusion and recommendations

This study examined the impact of compliance with approved pesticide use on the productivity of cocoa farmers in Osun State, Nigeria. The findings revealed that although all sampled farmers used approved pesticides, a small proportion still combined approved pesticides with banned chemicals, thereby compromising productivity, food safety, and environmental sustainability. The study established that compliant farmers achieved significantly higher cocoa productivity than non-compliant farmers, confirming that adherence to approved pesticide regulations contributes positively to sustainable cocoa production. Farmers who exclusively used approved pesticides recorded higher yields and productivity gains compared to those who mixed approved and banned pesticides. The treatment-effect estimates suggested that exclusive compliance with approved pesticide recommendations was associated with higher cocoa productivity. However, because the estimated treatment effects were not statistically significant, these findings should be interpreted as indicative rather than definitive and warrant further validation using longitudinal or experimental research designs. The study also established that socioeconomic and institutional factors such as age, education, farming experience, farm size, and access to agricultural information significantly influenced compliance decisions and pesticide use intensity. However, the findings also revealed that several challenges hinder full compliance among cocoa farmers, including high costs of approved pesticides, labor shortages, weather fluctuations, weak monitoring systems, and inadequate enforcement of pesticide regulations. The continued use of banned pesticides among some farmers highlights persistent institutional and regulatory gaps within the cocoa production system. This study advances the literature on sustainable cocoa production by demonstrating that compliance with approved pesticide use is not merely a regulatory obligation but a productivity-enhancing strategy that supports environmental sustainability and food safety. By integrating a double hurdle model with endogenous switching regression, the study extends previous research beyond technology adoption and compliance behavior to establish the productivity effects of compliance while accounting for selection bias. The findings reinforce behavioral and technology adoption theories by showing that farmers' compliance decisions are shaped by education, farming experience, and institutional support rather than regulatory enforcement alone.

Based on the findings, the study recommends that government agencies, extension institutions, and relevant stakeholders

should strengthen awareness campaigns and farmer education programmes on the importance of approved pesticide use and the dangers associated with banned chemicals. Agricultural extension services should be expanded and adequately funded to improve farmers' access to technical guidance on proper pesticide application and sustainable pest management practices. The study also recommends stronger enforcement of pesticide regulations through regular monitoring of agrochemical markets and stricter control of banned pesticide distribution channels. Policies aimed at improving farmers' access to affordable approved pesticides through subsidies, credit facilities, and cooperative-based input distribution systems should also be promoted. Furthermore, climate-smart pest management strategies and integrated pest management approaches should be encouraged to help farmers cope with weather-related challenges affecting pesticide application effectiveness. Lastly, promoting compliance with approved pesticide use is essential for improving cocoa productivity, ensuring food safety, strengthening export competitiveness, protecting environmental resources, and achieving sustainable cocoa sector transformation in Nigeria. The findings have implications beyond Nigeria, as many developing countries face similar challenges of weak pesticide regulation, limited enforcement capacity, and inadequate farmer awareness. Comparable experiences in Ghana, Côte d'Ivoire, Kenya, and India show that ineffective monitoring, the circulation of counterfeit or banned pesticides, and constrained extension services continue to undermine sustainable agricultural production. Nigeria's experience demonstrates that regulatory enforcement must be complemented by continuous farmer education, affordable access to approved agrochemicals, and strengthened extension systems. Adopting this integrated approach can improve compliance, enhance productivity, safeguard public and environmental health, and strengthen export competitiveness across developing-country agricultural systems.

Limitations of the study

This study has some limitations that should be considered when interpreting the findings. First, the study relied on cross-sectional data collected at a single point in time, which limits the ability to establish long-term causal relationships between compliance with approved pesticide use and cocoa productivity. A longitudinal approach would provide deeper insights into changes in farmers' compliance behavior and productivity outcomes over time. Second, the study was conducted only in selected cocoa-producing Local Government Areas of Osun State, which may limit the generalizability of the findings to other cocoa-producing regions in Nigeria with different socioeconomic and agroecological conditions. Third, the relatively small number of non-compliant farmers compared to compliant farmers may have affected the robustness of group comparisons. Lastly, the study relied largely on self-reported information from farmers, which may be subject to recall bias and possible underreporting of banned pesticide use due to regulatory sensitivity. Compliance was primarily measured using farmer self-reported information, which may be subject to reporting or social desirability bias, potentially leading to underreporting of banned pesticide use. Future studies

should validate self-reported compliance through field inspections, pesticide residue analysis, or agrochemical purchase records to improve measurement accuracy. A further limitation is that the endogenous switching regression model was identified primarily through the functional form of the selection equation because a strong external exclusion restriction was unavailable. Although this approach is commonly adopted in empirical agricultural economics, future studies should incorporate valid instrumental variables or longitudinal data to strengthen causal identification.

Another limitation is the substantial imbalance between compliant ($n = 227$) and non-compliant ($n = 13$) farmers. Although this reflects actual compliance behavior in the study area, the relatively small non-compliant group may reduce the precision and stability of regime-specific ESR estimates. Future studies should include larger and more balanced samples to improve estimation reliability and external validity.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the study protocol was reviewed and approved by the Departmental Research Ethics Committee, Department of Agricultural Economics, affiliated with the University of Ibadan, Nigeria. All procedures involving human participants were conducted in accordance with the ethical standards of the Declaration of Helsinki (2013 revision) and the relevant institutional research ethics guidelines. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

POd: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. OO-E: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. POI: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AK: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that Generative AI was not used in the creation of this manuscript.

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