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Regional variations and determinants of pesticide use among farmers in Southwestern Nigeria: implications for sustainable agriculture

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Pesticides are integral to the agricultural practices of Southwestern Nigeria, yet their varied usage patterns and the factors influencing their adoption remain poorly understood. Understanding pesticide usage is crucial for sustainable agricultural development. This study used a cross-sectional design and mixed-methods approach to examine pesticide usage, regional preferences, and pest control patterns in crop farming in Ogun, Ondo, and Oyo States, Nigeria. Data was collected from 472 farmers during the 2022 and 2023 farming seasons. Descriptive statistics, Pearson chi-square tests, and a generalized linear model were used to identify factors influencing farmers' choices. Data were gathered through surveys and field observations from farmers in the three states. Pesticide usage varied across states, with Dichlorvos/DDVP (56.5%) and Lambda-cyhalothrin (49.8%) being the most common insecticides. Glyphosate (81.9%) and Paraquat (69.1%) dominated herbicide application, while Mancozeb emerged as the most widely used fungicide (38.6%). Imidacloprid and Thiram were the most used pesticide mixtures (44.5%), with significant variations observed across regions (χ^2 = 14.27, p < 0.001). Ondo State farmers preferred physical control methods (97.3%), Ogun State favored biological (67.3%) and botanical approaches (66.7%), while chemical control was predominant in Ondo (98.0%) and Oyo (99.4%). Demographic factors, including gender (F = 4.13, p = 0.04), education level (F = 3.59, p = 0.002), and farming locality (F = 1.56, p = 0.003), significantly impacted the adoption of specific pesticides and their mixtures. The study highlights the diverse crop protection strategies employed across Southwestern Nigeria and underscores the need for region-specific interventions. Tailored educational programs and resource allocation that consider local environmental conditions and demographic factors are essential for promoting sustainable agricultural practices and reducing chemical dependency. Addressing these regional and demographic disparities will enhance pest management effectiveness and support environmentally sustainable farming.

KEYWORDS

crop protection practices, demographic factors, pesticide adoption and usage, regional variations, sustainable agriculture practices

1 Introduction

Pesticides are critical to Nigerian agriculture, controlling pests and enhancing crop productivity by mitigating pre- and post-harvest losses, thus significantly impacting food security and farm income (Osabohien, 2024). As global agricultural practices increasingly rely on chemical interventions to maximize yields, applying pesticides has become widespread across various sectors, including agriculture and industry (Shah and Wu, 2019; Washuck et al., 2022). Pesticides are typically categorized based on their target organisms, such as herbicides for weeds, fungicides for fungi, and insecticides for insects.

The global consumption of pesticides, including herbicides, insecticides, and fungicides, is estimated to be between 2.0 and 3.5 million metric tons annually (Sharma et al., 2019). The United States accounts for approximately 25% of this consumption, Europe for about 45%, and the remaining 30% is distributed among other regions (Tang et al., 2022). Though Africa's pesticide consumption is lower accounting for only 2–4% (Sharma et al., 2019) compared to other regions, the reliance on these chemicals is growing, particularly in countries like Nigeria. South Africa, Nigeria, and Ghana are the leading importers of pesticides on the continent, with Nigeria using herbicides as the most common type of pesticide (48.3%), followed by insecticides (23.5%) and fungicides (28.2%) (Tolera, 2020).

Agriculture is a cornerstone of Nigeria's economy, providing essential resources such as food, raw materials, employment, and foreign exchange. Over 70% of Nigeria's population is directly or indirectly engaged in agriculture, making it a vital sector for the nation's economic stability and growth (Ekenta et al., 2023). As the country strives to increase agricultural production, there has been a growing reliance on agrochemicals, particularly among smallholder farmers, to combat the adverse effects of pests on crops (Apeh, 2018). For instance, 70% of rice and yam farmers in Nigeria utilize pesticides, with 41% applying them to at least one food crop (Rahman and Chima, 2018). The significance of understanding pesticide usage patterns in Nigeria is underscored by the fact that a substantial portion of smallholder farmers in the region, amounting to 36%, have not undergone formal education (Oluwatayo, 2019). The widespread use of pesticides and limited knowledge of their potential consequences on soil and human health presents a significant challenge. Labels on pesticide products often fail to provide adequate information on mixtures involving multiple active ingredients or their synergistic effects (Weisner et al., 2021). Consequently, farmers frequently mix pesticides without fully understanding the potential risks involved.

A key issue is the prevalent use of pesticide mixtures, which farmers frequently apply without adequate knowledge of the potential synergistic toxicities or environmental consequences. Product labels often do not provide sufficient guidance on mixing different active ingredients (Weisner et al., 2021), contributing to practices that may increase human and ecosystem health risks. Studies have shown that certain pesticide combinations can result in elevated toxicity, greater than the sum of individual effects, thereby posing significant risks to applicators, consumers, and the surrounding environment (Bolognesi and Holland, 2016; Nagy et al., 2020; Wang X. et al., 2021). Yet, most research in Nigeria focuses on individual pesticide residues, with limited attention to the health and ecological impacts of commonly used pesticide combinations (Babarinsa et al., 2018).

The adoption of pesticides in Nigerian agriculture is influenced by a complex interplay of socioeconomic, demographic, institutional, agroecological, and economic factors (Timprasert et al., 2014; Khan and Damalas, 2015; Mwangi and Kariuki, 2015; Danso-Abbeam and Baiyegunhi, 2018). In southwest Nigeria, grain producers' decisions regarding pesticide application are shaped by factors such as age, education, farming experience, and grain prices (Adejumo et al., 2014). For example, while the age of the household head negatively impacts the choice of pesticides, education, farming experience, and income positively influence the likelihood of pesticide use (Obayelu et al., 2016).

Despite the critical role of pesticides in modern agriculture, there is a notable gap in research on the specific combinations of pesticides used and the implications for environmental and human health in Nigeria. A few studies have suggested that pesticide mixtures may pose more significant health risks than individual pesticides due to increased toxicity and synergistic interactions (Bolognesi and Holland, 2016; Nagy et al., 2020; Wang T. et al., 2021). However, the effects of these combinations remain challenging to determine, particularly in the context of Nigerian agriculture. Most existing research in Nigeria focuses on individual pesticide residues and their impacts rather than examining the combined effects of multiple pesticides (Babarinsa et al., 2018; Rahman and Chima, 2018; Oshatunberu et al., 2023). This study aims to address some of these gaps by first identifying the existing and most frequently used pesticide mixtures and assessing the factors influencing their adoption among farmers in Ogun, Ondo, and Oyo states in southwestern Nigeria.

Given the increasing complexity and health risks associated with pesticide use in Nigerian agriculture, especially the growing reliance on unregulated mixtures (Madaki et al., 2024), there is a need for sustainable alternatives. Integrated Pest Management (IPM) presents a holistic solution by combining biological, cultural, physical, and chemical tools to control pests to minimize harm to human health and the environment (Zhou et al., 2024). The effectiveness of IPM, however, depends on a nuanced understanding of region-specific pest pressures, pesticide preferences, and farmer behavior.

Therefore, this study addresses the lack of comprehensive research on the specific combinations of pesticides commonly used by Nigerian farmers by conducting extensive surveys across three states in southwestern Nigeria: Ogun, Ondo, and Oyo. The primary objective was to identify the most frequently used pesticide mixtures and to understand the factors driving their adoption among farmers in these regions. By exploring the patterns and determinants of pesticide use, this research seeks to uncover how regional variations in agricultural practices influence pesticide usage. The findings are expected to contribute to developing sustainable agricultural practices and inform policy interventions that promote responsible pesticide use while mitigating the potential risks associated with chemical-intensive farming.

2 Methodology

2.1 Study area description

This study was conducted across three states in southwestern Nigeria: Ogun, Ondo, and Oyo. These states are situated between latitudes 6°21’ and 8°37’ North and longitudes 2°31’ and 6°00’ East, encompassing a total land area of 77,818 km^2 (Figure 1). The region falls within the tropical rainforest zone, classified as ‘Af,’ and the monsoon climate zone, classified as ‘Am,’ according to the Köppen-Geiger classification (Dorcas-Mobolade and Pourvahidi, 2020). This area is characterized by a consistent temperature range throughout the year, with convectional storms due to its proximity to the equator (Akinbode et al., 2008). The climate includes two distinct seasons: a rainy season from April to October and a dry season from November to March, with average temperatures ranging between 21°C and 28°C and humidity levels

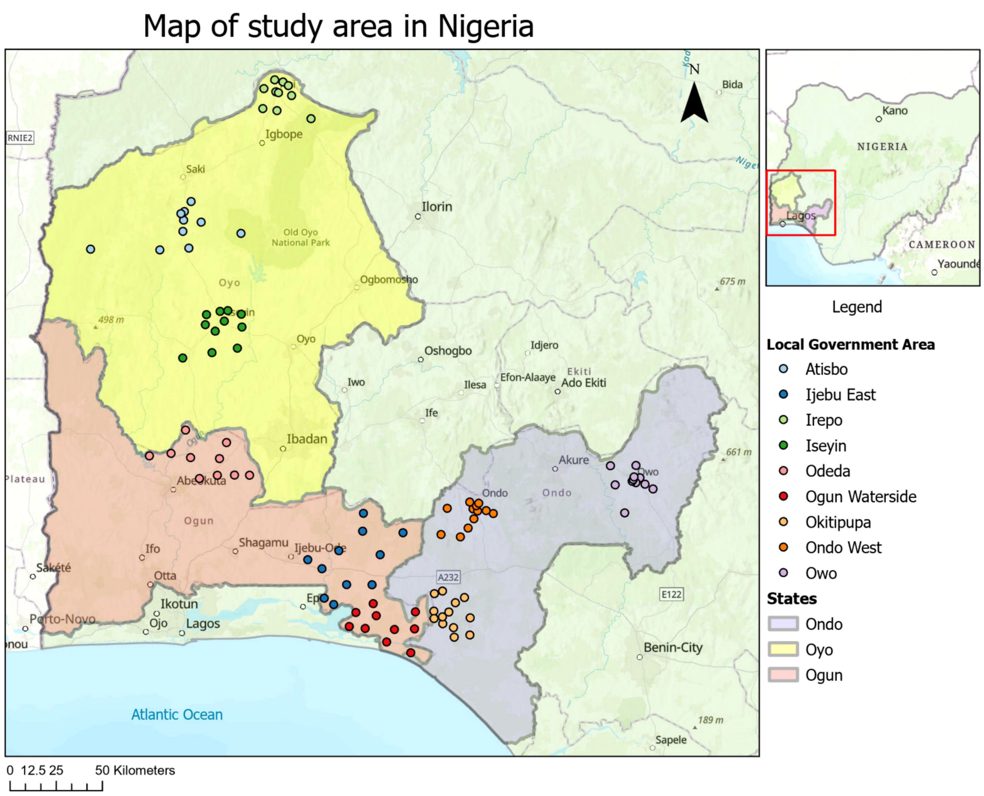

FIGURE 1
Map of the study area in Nigeria, showing the different states with areas where the study on factors determining pesticide use was conducted.

averaging around 77% (Akinbode et al., 2008; Omogbai, 2010). The selected states are prominent agricultural hubs, especially for crops such as plantains, cocoa, palm oil, yams, cassava, maize, oranges, and kola nuts (Lamidi et al., 2018).

2.2 Study design

The study employed a cross-sectional design using a mixed-method approach to gather data during the 2022 and 2023 farming seasons, particularly from May to September, when farming activities are at their peak. The research targeted farmers irrespective of gender, education level, or crop type. Quantitative and qualitative methods were utilized to comprehensively understand farming practices and pesticide use in the study areas.

2.3 Selection of study sites and sampling method

A multistage random sampling technique was adopted for selecting study respondents. In the first stage, three states—Ogun, Ondo, and Oyo—were randomly selected from the six states in southwestern Nigeria. In the second stage, three Local Government Areas (LGAs) were randomly chosen from each selected state, resulting in nine LGAs: Irepo, Iseyin, and Atisbo from Oyo State; Owo, Ondo West, and Okitipupa from Ondo State; and Odeda, Ijebu East, and Ogun Waterside from Ogun State. A total of 472 farmers were randomly selected from these nine LGAs, with 50 farmers interviewed in each LGA, except for Irepo and Atisbo, where 60 and 63 respondents were interviewed, respectively. For illiterate farmers, data were collected directly from the fields to ensure accuracy in reporting pesticide use, while literate farmers were provided with questionnaires to complete and return.

2.4 Data collection methods

2.4.1 Quantitative data collection

Quantitative data were collected through structured surveys using semi-structured questionnaires. The questionnaire was developed and uploaded to note-pad mobile devices installed with open data kit (ODK) software. The questionnaire was pre-tested with a small group of farmers in Ogun State to ensure clarity and effectiveness. The survey captured demographic information, farming practices, and pesticide usage. The questionnaire was divided into sections covering demographic characteristics, commonly used pesticides, and general farming practices. Trained enumerators conducted the interviews, ensuring respondents fully understood the questions to collect accurate and reliable data.

2.4.2 Pesticide data collection

Data on pesticide use were initially recorded according to the trade names of locally available products and later categorized by their active ingredients. The formulations varied, with some containing multiple active ingredients. The study documented farmers' perceptions, factors influencing pesticide adoption, the number of different products used, the most used pesticides, and the frequency of use for each active ingredient, as reported by the respondents.

2.5 Data management and analysis

The collected data were entered into Excel for cleaning and coding, followed by statistical analysis using the Statistical Package for the Social Sciences (IBM SPSS version 29.0, 2022). Descriptive statistics were used to summarize the data, with results in tables and figures. The SPSS multiple response command was used to group farmer responses by region for multiple response data. Differences in variables between states were analyzed using Pearson chi-square tests with a significance level of 0.05 to compare patterns across states for the variables considered. A generalized linear model (GLM) was also applied to examine significant factors influencing farmers' decisions to adopt pesticides. The model is specified as:

$$\begin{aligned} Y_i = \beta_0 + \beta_1\ \text{Gender} + \beta_2\ \text{Education\_Level} \\ + \beta_3\ \text{Local\_Government\_Area} + \beta_4\ \text{Place\_of\_Farming} \\ + \varepsilon_i \end{aligned}$$

Where:

- Pesticide adoption (Y_i) is the dependent variable representing farmers' level of adoption in different surveyed states.
- β_0 is the intercept term representing the baseline level of adoption when all predictors are zero.
- β_1, β_2, β_3, and β_4 are the coefficients representing the impact of each predictor on pesticide adoption.
- ε_i is the error term representing the random variability in pesticide adoption that is not accounted for by the predictors.

3 Results

3.1 Sociodemographic characteristics of the participants

Figure 2 summarizes the demographic and socioeconomic attributes of the respondents from each state. A total of 472 farmers participated in the survey. The gender distribution among farmers was relatively uniform across the three states (χ^2 = 1.4890, p = 0.475), with a majority being male (81%) compared to female farmers (19%). Age distribution significantly varied across states (χ^2 = 99.95, p < 0.001). Among the respondents, 33.6% were aged 40–49 years, only 0.6% were between 10–19 years old, and 4.6% were aged 60 and above (Figure 2, Supplementary Table S1). This suggests that most respondents were relatively young and within their productive years.

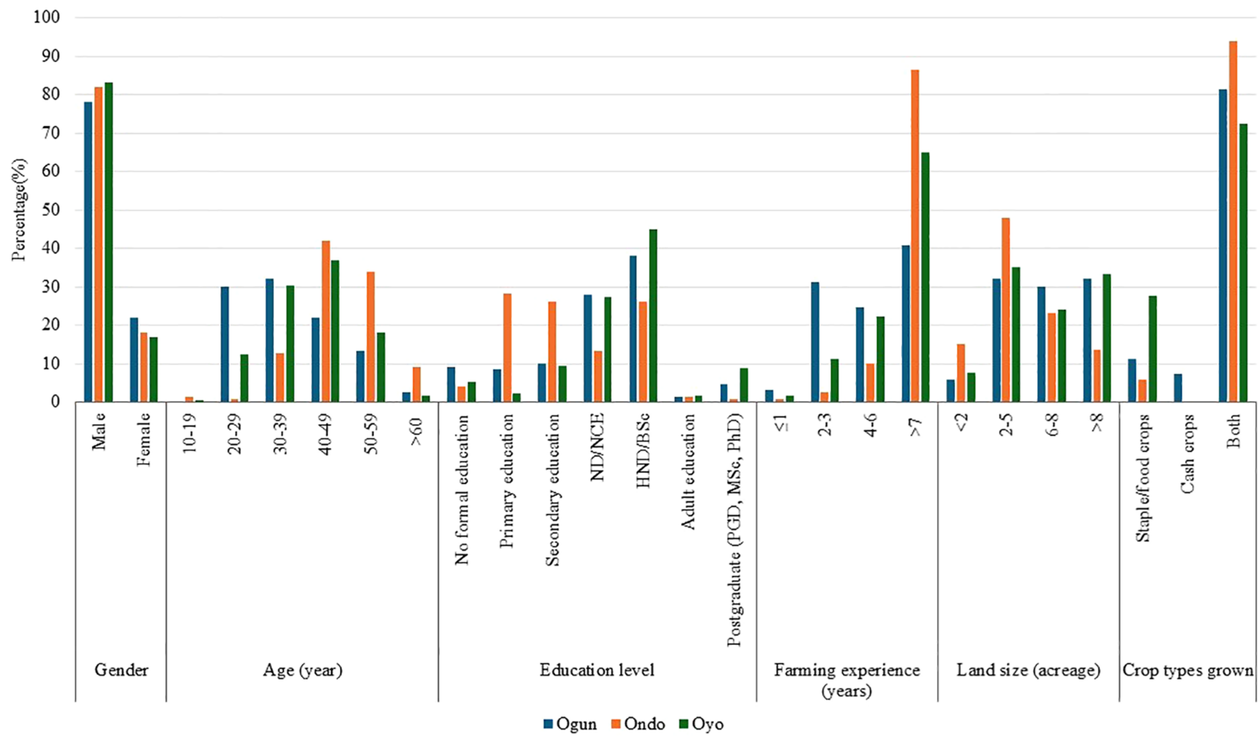

FIGURE 2
Sociodemographic characteristics of the participants in the survey on factors determining pesticide use among farmers from three states (Ogun, Ondo, Oyo) in Southwest Nigeria.

Educational levels also varied significantly between states (χ^2 = 95.05, p < 0.001). Three respondents did not disclose their educational background. Of those who did, 6.2% had no formal education, and 1.5% had received adult education. In contrast, most respondents (64.1%) had attained higher or post-secondary education, with specific qualifications as follows: National Diploma/National Certificate of Education (23.0%), Higher National Diploma/bachelor's degrees (36.4%), and postgraduate degrees (4.7%) (Figure 2, Supplementary Table S1). This indicates that most respondents were literate and capable of understanding chemical instruction manuals.

Farming experience also varied significantly between states (χ^2 = 80.29, p < 0.001). A significant majority (64%) of farmers had been farming for at least seven years, indicating substantial experience in pesticide application. Conversely, only 1.9% of respondents had less than one year of farming experience (Figure 2, Supplementary Table S1). Farm size distribution differed significantly among respondents (χ^2 = 23.17, p < 0.001). Most respondents (38.3%) managed farms of 2–5 acres, while 9.6% farmed less than 2 acres. Most respondents had farms smaller than eight acres (Supplementary Table S1).

3.2 Distribution and prevalence of crop types among farmers

The distribution of crop types grown by farmers exhibited significant variation between states (χ^2 = 55.22, p < 0.001) (Supplementary Table S2). A substantial majority of respondents (82.5%) cultivated staple/food crops and cash crops, while 15% focused exclusively on staple/food crops, and only 2.4% grew cash crops alone (Figure 3). The distribution of farmers who planted the same crop type annually was nearly equivalent to those who did not (n = 223 and n = 237, respectively).

Among the food crops cultivated in the study areas, maize was the most prevalent, grown by 84.1% of farmers, particularly in Ondo and Oyo states. This was followed by yam (69.7%) and soybeans (53.1%). The least commonly grown staple crops were tomato (10.5%) and wheat (15.9%) (Figure 3). Regarding cash crops, cashews were the most widely grown, with 65.1% of the farming population cultivating them, especially in Oyo State (91.9%). This was followed by plantains (36.3%), predominantly in Ondo State (80.8%), oil palm (33.6%), and mango (30.9%). The least cultivated cash crops were cocoa (24.7%) and kola nuts (31.2%). Notably, Ondo State recorded the highest cultivation rates for cocoa (66.9%), kola nuts (70%), and oil palm (73.8%) (Supplementary Table S2). The findings indicate a higher prevalence of staple crops than high-value commercial crops such as cotton, vegetables, coffee, and cocoa.

3.3 Insecticide use patterns among farmers in Ogun, Ondo, and Oyo states

Significant variations in insecticide use were observed among farmers across Ogun, Ondo, and Oyo states (χ^2 = 1346.486, p <

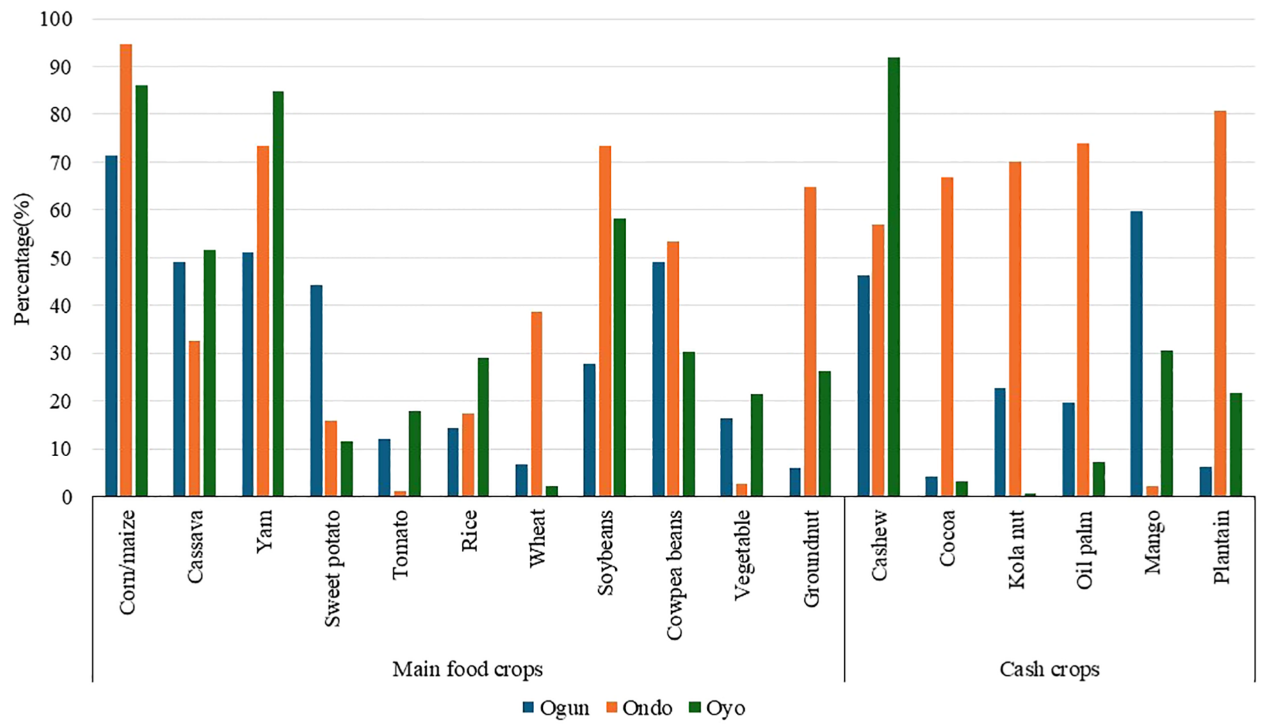

FIGURE 3
Distribution and prevalence of crop types among farmers in three states (Ogun, Ondo, Oyo) of Southwest Nigeria.

TABLE 1 Insecticides used by farmers in the three surveyed states in Southwest Nigeria. Also given are the outcomes of statistical analysis of the variation in variables between states.

Insecticides	State			Mean	Chi-square	df	*p*-value
	Ogun (%)	Ondo (%)	Oyo (%)				
Beta-cyfluthrin	12.4	51.0	11.3	24.9	1346.486	76	<0.001
Carbofuran	55.2	20.4	23.2	32.9			
Dichlorvos/DDVP	66.2	15.6	87.5	56.5			
Lamda-cyhalothrin	37.9	48.3	63.1	49.8			
Lambda-cyhalothrin+Dimethoate	44.1	13.6	38.1	31.9			
Cypermethrin	28.3	11.6	63.1	34.3			
Cypermethrin+dimethoate	15.2	25.9	27.4	22.8			
Dimethoate	42.8	6.1	19.6	22.8			
Chlorpyrifos	28.3	19.0	61.3	36.2			
Chlorpyriphos + Emamectin Benzoate	26.2	17.7	13.1	19.0			
Imidacloprid	20.7	76.9	23.2	40.3			
Imidacloprid + beta-cyfluthrin	26.2	51.7	15.5	31.1			
Lindane	26.9	38.1	41.1	35.4			
Profenofos + Cypermethrin	43.4	8.8	38.7	30.3			
Emamectin Benzoate	18.6	11.6	38.1	22.8			
Monocrotophos	24.8	6.1	30.4	20.4			

(Continued)

TABLE 1 Continued

Insecticides	State			Mean	Chi-square	df	*p*-value
	Ogun (%)	Ondo (%)	Oyo (%)				
Abamectin	25.5	5.4	28.0	19.6			
Abamectin +Acetamiprid	6.2	5.4	19.0	10.2			
Diazinon	6.9	2.7	13.7	7.8			
Alpha-cypermethrin	7.6	6.1	12.5	8.7			
Fentrothion	10.3	5.4	20.8	12.2			
Fipronil	11.0	6.1	17.9	11.7			
Thiametoxam	7.6	4.1	18.5	10.0			
Deltamethrin + Thiacloprid	7.6	5.4	10.1	7.7			
Dioxacarb	6.9	2.0	10.7	6.6			
Isoprocarb	7.6	6.8	12.5	9.0			
Propoxurr	11.0	4.1	10.7	8.6			
Endosulfan	21.4	11.5	23.8	18.9			
Deltamethrin	4.8	5.4	13.1	7.8			
Chlorfenapyr	16.6	7.5	13.7	12.6			
Azaderachtin	11.0	6.1	16.1	11.1			
Acetamiprid	11.7	5.4	13.7	10.3			
Acetamiprid +Lambda-cyhalothrin	12.4	6.1	22.0	13.5			
Acetamiprid + Cypermethrin	9.0	0.7	16.7	8.8			
Methomyl	9.0	70.7	13.7	31.1			

0.001) (Table 1). The most commonly used insecticides included Dichlorvos/DDVP, applied by 56.5% of respondents, with a notable concentration in Oyo State (87.5%), and Lambda-cyhalothrin, used by 49.8% of farmers, particularly in Oyo State (63.1%). Approximately two in five respondents reported using Imidacloprid (40.3%), and one-third used Chlorpyrifos (36.2%), Lindane (35.4%), Cypermethrin (34.3%), Carbofuran (32.9%), Lambda-cyhalothrin + Dimethoate (31.9%), Imidacloprid + Beta-cyfluthrin (31.1%), Methomyl (31.1%), and Profenofos + Cypermethrin (30.0%). Conversely, insecticides such as Dioxacarb (6.6%) and Acetamiprid + Cypermethrin (8.8%) were used less frequently, potentially due to their limited availability, higher cost, or perceived lower efficacy within the farming community.

3.4 Herbicide application practices among farmers in Ogun, Ondo, and Oyo states

Herbicide application practices varied significantly among farmers in Ogun, Ondo, and Oyo states (χ^2 = 498.237, p < 0.001) (Table 2). Glyphosate was the most widely used herbicide, with 81.9% of farmers applying it, and its use was particularly prevalent in Oyo State, where 97.1% of farmers employed it. Paraquat was also commonly used, reported by 69.1% of farmers, with a notably high usage rate in Oyo State at 90.8%. Other frequently used herbicides included diuron (48.6%) and atrazine (45.1%), with 41.2% of farmers using butachlor. Oxyfluorfen and Quinclorac + Pyrazosulfuron Ethyl were among the least-used herbicides, applied by only 6.7% and 9.1% of farmers, respectively.

3.5 Fungicide use patterns among farmers in Ogun, Ondo, and Oyo states

Fungicide use patterns varied significantly among farmers in Ogun, Ondo, and Oyo states (χ^2 = 656.368, p < 0.001) (Table 3), reflecting regional differences in fungicide application. Mancozeb was the most widely used fungicide, applied by 38.6% of farmers, with the highest usage observed in Oyo State (75.8%). Copper Hydroxide + Metalaxyl-M, the second most commonly used fungicide, was utilized by 43.3% of farmers and showed particular prevalence in Ondo State (63.3%). In contrast, Carboxin + Thiram (13.9%) and Tin Triphenyl acetate (13.6%) were among the least frequently used fungicides.

TABLE 2 Herbicides used by farmers in the three surveyed states in Southwest Nigeria. Also given are the outcomes of statistical analysis of the variation in variables between states.

Herbicides	State			Mean	Chi-square	df	*p*-value
	Ogun (%)	Ondo (%)	Oyo (%)				
Glyphosate	83.9	64.8	97.1	81.9	498.237	56	<0.001
Paraquat	55.9	60.6	90.8	69.1			
Atrazine	36.4	19.7	79.2	45.1			
Diuron	30.8	47.9	67.1	48.6			
Diuron + Paraquat	24.5	67.6	15.0	35.7			
Butachlor	35.7	26.8	61.3	41.2			
2,4-D	25.9	22.5	54.3	34.2			
Propanil	15.4	18.3	28.9	20.9			
Bentazone	14.0	14.1	20.8	16.3			
Oxidiaxone	12.6	23.9	21.4	19.3			
Alachlor	10.5	12.7	16.8	13.3			
Imazethapyr	18.2	12.7	27.7	19.5			
Propaquizafop	6.3	18.3	12.1	12.2			
Clethodium	9.1	11.3	13.3	11.2			
Nicosulfuran	8.4	16.9	23.1	16.1			
S-Metolachlor	12.6	9.9	11.6	11.3			
Pendimenthalin	11.2	9.9	19.1	13.4			
Metolachlor + Metobromuron	13.3	15.5	13.3	14.0			
S-Metolachlor + terbutryn	7.7	11.3	11.6	10.2			
Metolachlor + Atrazine	11.2	14.1	25.4	16.9			
Acetochlor + Terbethylazine	7.0	16.9	9.2	11.0			
Quinclorac +Pyrazosulfuron Ethyl	5.6	11.3	10.4	9.1			
Quinclorac +Bensulfuron Methyl	8.4	22.5	14.5	15.1			
Haloxyfop-p-methyl	9.1	19.7	11.0	13.3			
Fluazifop-p-butyl	20.3	12.7	23.1	18.7			
Trichlopyr	11.9	12.7	19.1	14.5			
Oxyfluorfan	8.4	0.0	11.6	6.7			
Benazolin +Quizalofopethyl	6.3	26.8	13.3	15.4			

3.6 Differences in pesticide mixing across Ogun, Ondo, and Oyo states

Significant differences were observed in the prevalence of pesticide mixing among farmers in Ogun, Ondo, and Oyo states ($\chi^2 = 14.27$, $p < 0.001$) (Table 4). The chi-square test revealed considerable regional variations in the use of pesticide combinations. In Ondo State, 50.0% of farmers reported using multiple chemical pesticides, surpassing the rates observed in Ogun (40.7%) and Oyo (29.5%). The most frequently used pesticide mixtures included Imidacloprid + Thiram (44.5%), Lambda-cyhalothrin + Dimethoate (37.9%), Profenofos + Cypermethrin (36.3%), Imidacloprid + Beta-cyfluthrin (34.4%), Copper Hydroxide + Metalaxyl-M (33.4%), and Mancozeb + Carbendazim (32.9%). Conversely, the least commonly used mixtures were Pyraclostrobin + Dimethomorph (17.3%), Cuprous Oxide + Metalaxyl (15.5%), and Quinclorac + Pyrazosulfuron Ethyl (8.7%).

TABLE 3 Fungicides used by farmers in the three surveyed states in Southwest Nigeria. Also given are the outcomes of statistical analysis of the variation in variables between states.

Fungicides	State			Mean	Chi-square	df	*p*-value
	Ogun (%)	Ondo (%)	Oyo (%)				
Mancozeb	29.9	10.1	75.8	38.6	656.368	50	<0.001
Sulfur	13.1	4.6	38.9	18.9			
Propineb	13.1	10.1	27.4	16.8			
Isothiazolin	25.2	5.5	18.9	16.6			
Isoprothiolane	21.5	9.2	37.9	22.9			
Carbendazim	31.8	9.2	29.5	23.5			
Copper hydroxide	24.3	6.4	28.4	19.7			
Cuprous oxide	27.1	10.1	35.8	24.3			
Cuprous oxide+ Metalaxyl-M	24.3	12.8	22.1	19.7			
Copper hydroxide + Metalaxyl-M	23.4	63.3	43.2	43.3			
Pentahydrate	29.9	13.8	31.6	25.1			
Mancozeb +Metalaxyl	29.9	4.6	28.4	21.0			
Mancozeb + carbendazim	17.8	70.6	40.0	42.8			
Propineb +Cymoxanil	33.6	62.4	16.8	37.6			
Cuprous oxide + Metalaxyl	20.6	9.2	33.7	21.1			
Copper oxide + Cymoxanil	18.7	9.2	25.3	17.7			
Metalaxyl+Difenoconazole	15.0	6.4	28.4	16.6			
Captan	23.4	4.6	30.5	19.5			
Carboxin + thiram	8.4	9.2	24.2	13.9			
Tin Triphenyl acetate	11.2	5.5	24.2	13.6			
Copper sulphate + Lime	12.1	5.5	32.6	16.8			
Copper sulphate + 5H20	13.1	12.8	26.3	17.4			
4-Cyclohexane Dicarboxymide	17.8	7.3	24.2	16.4			
Izozystrobin +Difenoconazole	17.8	1.8	42.1	20.6			
Pyraclostrobin + Dimethomorph	8.4%	32.1	27.4	22.6			

3.7 Crop protection practices and application frequency of pesticides among farmers in Ogun, Ondo, and Oyo states

This study investigated crop protection practices and the application frequency of pesticides among farmers in Ogun, Ondo, and Oyo states in Nigeria (Table 5). Adoption of physical control methods varied significantly across the states, with 26.8% of farmers in Ogun, 97.3% in Ondo, and 58.4% in Oyo employing these techniques (χ^2 = 156.507, p < 0.001). Biological control methods were predominantly utilized in Ogun (67.3%), compared to Ondo (1.3%) and Oyo (17.9%) (χ^2 = 175.464, p < 0.001). Conversely, chemical or synthetic control methods were highly adopted in Ondo (98.0%) and Oyo (99.4%), but less so in Ogun (36.7%) (χ^2 = 238.748, p < 0.001). Botanical or non-synthetic methods were more common in Ogun (66.7%) than in Ondo (44%) and Oyo (1.2%) (χ^2 = 486.207, p < 0.001).

Insecticide use was notably higher in Ondo (89.3%) and Oyo (99.4%) compared to Ogun (44.2%) (χ^2 = 506.380, p < 0.001). The frequency of insecticide application varied, with once-per-season being most common in Ondo (90.5%), while in Oyo, application frequency was dependent on pest problems (53.8%) (χ^2 = 438.053, p < 0.001). Herbicide use was most prevalent in Oyo (100%), followed by Ogun (64.4%) and Ondo (72.7%) (χ^2 = 133.548, p < 0.001). The frequency of herbicide application also varied significantly, influenced by weed pest prevalence, with Ondo (46.2%) and Oyo (42.7%) reporting more frequent use (χ^2 = 131.685, p < 0.001). Fungicide use was reported by 36.1% of respondents in Ogun, 40.0% in Ondo, and 54.9% in Oyo (χ^2 =

TABLE 4 Pesticide mixtures used by farmers in the three surveyed states in Southwest Nigeria. Also given are the outcomes of statistical analysis of the variation in variables between states.

Pesticide mixtures	State			Mean	Chi-square	df	*p*-value
	Ogun (%)	Ondo (%)	Oyo (%)				
Insecticide + Insecticide							
Lambda-cyhalothrin+Dimethoate	49.2	14.1	50.4	37.9	784.05	64	<0.001
Cypermethrin+dimethoate	16.9	26.8	36.2	26.6			
Chlorpyriphos + Emamectin Benzoate	29.2	18.3	17.3	21.6			
Deltamethrin + Thiacloprid	8.5	5.6	13.4	9.2			
Acetamiprid +Lambda-cyhalothrin	13.8	6.3	29.1	16.4			
Acetamiprid + Cypermethrin	10.0	0.7	22.0	10.9			
Imidacloprid + beta-cyfluthrin	29.2	53.5	20.5	34.4			
Profenofos + Cypermethrin	48.5	9.2	51.2	36.3			
Abamectin +Acetamiprid	6.9	5.6	25.2	12.6			
Fungicide + Insecticide							
Metalaxy + Difenoconazole +Thiamethoxam	6.9	6.3	27.6	13.6			
Imidacloprid + Thiram	23.1	79.6	30.7	44.5			
Herbicide + Herbicide							
Diuron + Paraquat	26.9	33.8	20.5	27.1			
Metolachlor + Metobromuron	14.6	7.7	18.1	13.5			
S-Metolachlor + terbutryn	8.5	5.6	15.7	9.9			
Metolachlor + Atrazine	12.3	7.0	34.6	18.0			
Acetochlor + Terbethylazine	7.7	8.5	12.6	9.6			
Quinclorac +Pyrazosulfuron Ethyl	6.2	5.6	14.2	8.7			
Quinclorac +Bensulfuron Methyl	9.2	11.3	19.7	13.4			
Fungicide + Fungicide							
Cuprous oxide+ Metalaxyl-M	20.0	9.9	16.5	15.5			
Copper hydroxide + Metalaxyl-M	19.2	48.6	32.3	33.4			
Mancozeb +Metalaxyl	24.6	3.5	21.3	16.5			
Mancozeb + carbendazim	14.6	54.2	29.9	32.9			
Propineb +Cymoxanil	27.7	47.9	12.6	29.4			
Cuprous oxide + Metalaxyl	16.9	7.0	25.2	16.4			
Copper oxide + Cymoxanil	15.4	7.0	18.9	13.8			
Carboxin + thiram	6.9	7.0	18.1	10.7			
Izozystrobin +Difenoconazole	14.6	1.4	31.5	15.8			
Pyraclostrobin + Dimethomorph	6.9	24.6	20.5	17.3			

192.357, $p < 0.001$). Farmers in Ogun and Oyo predominantly applied fungicides once per growing season, whereas in Ondo, application twice per season was more common ($\chi^2 = 249.871$, $p < 0.001$).

Overall, insecticides were the most frequently used, particularly in Ondo (49.3%), while herbicides were predominantly used in Oyo (67.1%) ($\chi^2 = 64.620$, $p < 0.001$). Herbicides were least used in Ondo (86.7%), and fungicides were least used in Oyo (93.6%) ($\chi^2 = 310.493$, $p < 0.001$). Weeds were perceived as the most severe threat to crop production in Oyo (56.4%) and Ogun (40.3%), while insects were viewed as the biggest threat in Ondo (92.7%) ($\chi^2 = 125.869$, $p < 0.001$).

TABLE 5 Crop protection practices and application frequency of pesticides among farmers in Ogun, Ondo, and Oyo states.

Question	Variable	States			Mean	Chi-square	Df	*p*-value
		Ogun (%)	Ondo (%)	Oyo (%)				
What type of control measure(s) do you use to protect your crops? (Tick as many as applied)	Physical control	26.8	97.3	58.4	60.8	156.507	6	<.001
	Biological control	67.3	1.30%	17.9	28.8			
	Chemical/ synthetic control	36.7	98	99.4	78			
	Botanicals/ non-synthetic	66.7	44	1.2	37.3			
Do you apply insecticide(s)?	Yes	44.2	89.3	99.4	77.6	506.38	2	<.001
	No	55.8	10.7	0.6	22.4			
If YES, how often do you apply insecticide(s)?	Once in the growing season	12.8	90.5	11.2	38.2	438.053	6	<.001
	Twice in the growing season	15.4	4.7	30.8	17			
	Thrice in the growing season	57	0.7	4.1	20.6			
	Depending on insect pests' problem	14.8	4.1	53.8	24.2			
Do you apply herbicide(s)?	Yes	64.4	72.7	100	79	133.548	2	<.001
	No	35.6	27.3	0	21			
If YES, how often do you apply herbicide(s)?	Once in the growing season	59.2	6.2	12.8	26.1	131.685	6	<.001
	Twice in the growing season	25.9	37.7	37.2	33.6			
	Thrice in the growing season	2	10	7.3	6.4			
	Depending on weed pests' problem	12.9	46.2	42.7	33.9			
Do you apply fungicide(s)?	Yes	36.1	40	54.9	43.7	192.357	2	<.001
	No	63.9	60	45.1	56.3			
If YES, how often do you apply fungicide(s)?	Once in the growing season	62.6	7.7	21.3		249.871	6	<.001
	Twice in the growing season	19.1	46.2	13.8	26.4			
	Thrice in the growing season	8.4	43.4	7.4	19.7			
	Depending on pests' problem	9.9	2.1	57.4	23.1			
Which of these pesticide groups is most used by you?	Insecticides	43	49.3	31.8	41.4	64.62	4	<.001
	Herbicides	52.3	38	67.1	52.5			
	Fungicides	4.7	12.7	1.20%				
Which of these pesticide groups is least used by you?	Insecticides	20	7.3	4.6	10.6	310.493	4	<.001
	Herbicides	38	86.7	1.7	42.1			
	Fungicides	42	6	93.6				

(Continued)

TABLE 5 Continued

Question	Variable	States			Mean	Chi-square	Df	p-value
		Ogun (%)	Ondo (%)	Oyo (%)				
What do you think is the most serious threat to crop production?	Weeds	40.3	6.7	56.4	34.5	125.869	6	<.001
	Insects	57	92.7	32.6	60.8			
	Fungi	1.3	0	4.1	1.8			
	Rodents	1.3	0.7	7	3			
Do you mix or apply more than one chemical pesticides at the same time?	Yes	40.7	50	29.5	40.1	506.38	2	<.001
	No	59.3	50	70.5	59.9			

Additionally, 50.0% of farmers in Ondo reported using more than one chemical pesticide, compared to 40.7% in Ogun and 29.5% in Oyo ($\chi^2 = 14.270$, $p < 0.001$) (Table 5).

3.8 Factors influencing farmers' adoption of fungicides, insecticides, and herbicides

Various factors influenced Nigerian farmers' adoption of agricultural chemicals (Tables 6, 7). The model for fungicide adoption was highly significant (F = 7.43, $p < 0.001$) with an R-squared value of 0.673, indicating that the model explained 67.3% of the variance in fungicide adoption (Table 6). The results showed that only the place/town of farming significantly impacted fungicide adoption ($p < 0.001$), while gender, education level, and local government area did not ($p > 0.05$). For the pesticide mixtures, the model was also significant (F = 2.2, $p < 0.001$), with an R-squared value of 0.368. Gender (F = 4.13, $p = 0.04$), educational level (F = 3.59, $p = 0.002$), local government area (F = 9.32, $p < 0.001$), and place/town of farming (F = 1.56, $p = 0.003$) significantly influenced pesticide mixture adoption (Table 6).

The insecticide adoption model was highly significant (F = 11.06, $p < 0.001$) with an R-squared value of 0.745, indicating that the model explained 74.5% of the variance in insecticide adoption (Table 7). Significant predictors included the local government area (F = 2.69, $p < 0.015$) and place/town of farming (F = 4.72, $p < 0.001$), whereas gender and education level did not significantly influence insecticide adoption ($p > 0.05$) (Table 7). Finally, the herbicide adoption model was highly significant (F = 6.05, $p < 0.001$), with an R-squared value of 0.618. Significant predictors of herbicide adoption included education level (F = 3.63, $p = 0.002$) and place/town of farming (F = 4.42, $p < 0.001$), whereas gender and local government area did not have significant effects ($p > 0.05$) (Table 7).

4 Discussion

4.1 Sociodemographic characteristics of the participants

This study revealed a significant gender disparity in agricultural labor, with males comprising 81% of the farming population,

TABLE 6 Factors influencing the adoption of fungicides or pesticide mixtures by farmers in the surveyed areas of Southwestern Nigeria.

Source	Fungicides					Pesticide mixtures				
	SS	DF	MS	F	p-value	SS	DF	MS	F	p-value
Corrected model	290.397[a]	97	2.99378	7.43276	<0.001	41.395[a]	98	0.4224	2.1999	<0.001
Intercept	246.616	1	246.616	612.283	<0.001	180.051	1	180.051	937.71	<0.001
Gender	0.90952	1	0.90952	2.2581	0.13	0.79283	1	0.79283	4.1291	0.04
Level of education	0.96981	6	0.16163	0.4013	0.88	4.13206	6	0.68868	3.5867	0.002
Local government area of farming	2.93638	6	0.4894	1.21504	0.3	10.7422	6	1.79037	9.3243	<0.001
Place/town of farming	165.008	82	2.01229	4.99599	<0.001	24.7888	83	0.29866	1.5554	0.003
Error	141.376	351	0.40278			71.0441	370	0.19201		
Total	1955	449				1315	469			
Corrected total	431.773	448				112.439	468			

The table shows the results of analysis using a model accounting for the different investigated variables (see text for explanation).
[a]R Squared for fungicides (0.673) and pesticide mixtures (0.368), SS = Sum of Squares, df = Degrees of Freedom, MS = Mean Square, F = F-statistic, Sig. = Significance indicates the probability of observing the obtained F-statistic.

TABLE 7 Factors influencing the adoption of insecticides and herbicides by farmers in the surveyed areas of Southwestern Nigeria.

Source	Insecticides					Herbicides				
	SS	DF	MS	F	*p*-value	SS	DF	MS	F	*p*-value
Corrected model	436.271[a]	97	4.49764	11.0642	<0.001	179.750a	98	1.83418	6.05424	<0.001
Intercept	268.317	1	268.317	660.059	<0.001	119.668	1	119.668	395	<0.001
Gender	0.29701	1	0.29701	0.73063	0.39	0.23182	1	0.23182	0.76518	0.38
Level of education	3.14514	6	0.52419	1.2895	0.26	6.59768	6	1.09961	3.62959	0.002
Local government area of farming	6.53202	6	1.08867	2.67812	0.015	1.02099	6	0.17016	0.56168	0.76
Place/town of farming	157.17	82	1.9167	4.71508	<0.001	111.156	83	1.33923	4.42052	<0.001
Error	149.594	368	0.40651			110.883	366	0.30296		
Total	2359	466				1128	465			
Corrected total	585.865	465				290.632	464			

The table shows the results of analysis using a model accounting for the different investigated variables (see text for explanation).
[a]R Squared for insecticides (0.745) and herbicides (0.618), SS = Sum of Squares, df = Degrees of Freedom, MS = Mean Square, F = F-statistic, Sig. = Significance indicates the probability of observing the obtained F-statistic.

consistent with previous research indicating male dominance in farming activities in Southwest Nigeria (Adekunle et al., 2017; Daud et al., 2018; Omotayo, 2020; Amusat et al., 2023). This gender imbalance reflects broader trends where female farmers often face barriers to accessing productive resources, including land, inputs, and services, compared to their male counterparts (Croppenstedt et al., 2013). In addition, Croppenstedt et al. (2013) reported that 88.9% of cocoa growers in Edo State were male, underscoring Nigeria's gendered nature of agricultural labor.

The survey found that most farmers were between the ages of 30 and 49, indicating that farming remains an attractive occupation for individuals in their productive years in Oyo, Ogun, and Ondo states (Daud et al., 2018; Aminu, 2020). This aligns with findings on determinants of farming choices of small farmers in Nigeria by (Begho and Begho, 2023). Despite this, reports suggest that youth in developing countries often hesitate to enter farming due to economic constraints and status aspirations (Leavy and Hossain, 2014). However, young and literate individuals are increasingly drawn to farming due to educational engagement, economic incentives, supportive policies, and resource availability (Kumar et al., 2022). While limited land access and economic challenges may deter youth from farming (Chamberlin and Sumberg, 2021; Wamuyu, 2022), some studies indicate that higher incomes and sustainability can attract young and educated farmers (Jansuwan and Zander, 2022; Kumar et al., 2022; Alrawashdeh et al., 2023).

The high literacy rate observed among farmers in this study reflects the outstanding educational attainment in Southwest Nigeria, with most farmers holding at least a basic schooling degree (Adepoju and Olapade-Ogunwole, 2015; Ijatuyi et al., 2018). Higher educational levels are associated with better comprehension of agricultural information and greater receptiveness to innovation (Šūmane et al., 2018; Vecchio et al., 2020). Research by Sharafi et al. (2018), Mubushar et al. (2019), and Pobhirun and Pinitsoontorn (2019) suggests that high literacy rates promote safe and responsible pesticide use. However, Amusat et al. (2023) found that many farmers in Southwest Nigeria had never attended professional pesticide application training or read application instructions, indicating a gap in knowledge dissemination.

The finding that nearly three-fifths of the respondents have at least seven years of farming experience highlights a high level of expertise. Farmers in Southwest Nigeria typically have 16 to 22 years of experience, contributing to their understanding of agricultural practices and technology adaptation (Akintonde et al., 2022). Given their extensive experience, these farmers are well-positioned to enhance productivity and manage pest control effectively. The importance of training and advisory programs in improving farmers' knowledge and safe pesticide handling practices cannot be overstated (Mubushar et al., 2019).

Farm sizes of 2–5 acres, as reported in this study, are consistent with typical farm sizes in Southwest Nigeria, where farmers often cultivate 3–6 acres (Eniola et al., 2016; Amusat et al., 2023). Babarinsa et al. (2018) also reported that 92% of Oyo State farmers have at least two acres of land. Farm size influences pesticide use and acceptance, with smaller farms often using more pesticides due to higher labor and plowing costs, while larger farms may adopt integrated pest management strategies due to better resource access (Rahman and Chima, 2018; Olasunkanmi et al., 2022).

4.2 Distribution and prevalence of crop types among farmers

In Africa, high pesticide use is often associated with crop types highly susceptible to pests, coupled with limited alternative pest control methods (Rioba and Stevenson, 2020). In Nigeria, major crops include maize, cowpeas, plantains, cassava, yam, and various fruits and vegetables such as mangoes, pineapples, and tomatoes (Aworh, 2015; Ibrahim et al., 2021). The prevalence of maize, a dominant crop in Nigeria (Ibrahim et al., 2021; Akintonde et al., 2022), likely contributes to high pesticide usage, as maize is known for its susceptibility to pests (Williamson et al., 2008). Farmers in Southwest Nigeria, who grow both cash and staple crops, exhibit a higher propensity for pesticide use, particularly since staple crops are more prone to pest damage (Williamson et al., 2008; Rahman and Chima, 2018).

Despite the lower growth rates of high-value and perennial crops like cocoa, oil palm, plantains, and kola nuts observed in this study, other research highlights high pesticide usage on staple crops and vegetables (Himmelstein et al., 2017). This suggests a greater focus on pesticide application for staple crops due to their pest susceptibility, while high-value crops may not be as intensively treated.

4.3 Regional variations and preferences for insecticides among Nigerian farmers

This survey highlights a notable prevalence of Dichlorvos/DDVP and Lambda-Cyhalothrin use among farmers, particularly in Oyo State. Significant differences in the classes of insecticides applied across states reveal diverse preferences and pest control practices, reflecting regional variations (Barbosa et al., 2016; Zhao et al., 2020). In Oyo, Ogun, and Ondo states, at least one-third of the farmers utilized a range of insecticides, including Methomyl, Lindane, Cypermethrin, Carbofuran, Lambda-Cyhalothrin + Diphenyl, Imidacloprid + Beta-Cyfluthrin, and Profenofos + Cypermethrin. These findings are consistent with the reports of Gnankiné et al. (2013) and Donald et al. (2016), who identified Chlorpyrifos, Gammalin 20 (Lindane), Cypermethrin, Dimethoate, Profenofos, and Deltamethrin as prevalently used insecticides in West African countries, including Ghana, Senegal, and Benin. Of particular concern, Lambda-Cyhalothrin and Dichlorvos are associated with serious adverse environmental and human health effects. Dichlorvos, an organophosphate insecticide, is known for its high acute toxicity and potential to harm many organisms and cause environmental damage (Ilahi et al., 2020). Similarly, Lambda-Cyhalothrin, a pyrethroid insecticide known for its broad-spectrum effectiveness, is associated with multiple toxic effects in non-target organisms, including hepatotoxicity, nephrotoxicity, neurotoxicity, and reproductive toxicity, primarily through oxidative stress mechanisms (Xu et al., 2023). In addition to its impact on human health, Lambda-Cyhalothrin also poses serious ecological and environmental risks because it is highly toxic to some aquatic species, including odonate nymphs (Ilahi et al., 2020).Nigeria's significant role as a cocoa exporter (Verter, 2017; Edeki et al., 2018) further underscores the widespread use of these insecticides, particularly among cocoa farmers (Oyekunle et al., 2017). Variations in pesticide use across Nigerian states are influenced by factors such as access to alternative pest control methods, farm size, and economic conditions (Babarinsa et al., 2018; Nwadike et al., 2021; Amusat et al., 2023). Additionally, cultural practices, crop types, farmer education, and socioeconomic conditions contribute to these differences (Omeje et al., 2018; Nwaubani et al., 2020; Nwadike et al., 2021; Ofuya et al., 2023). For instance, Oyo State is noted for its higher use of herbicides compared to other states (Babarinsa et al., 2018), while Cross-River State exhibits a preference for insecticides over herbicides (Eta et al., 2023). These regional variations are attributed to local farming techniques, resistance levels, and pest species (Barbosa et al., 2016; Zhao et al., 2020).

4.4 Regional variations and preferences of herbicides among Nigerian farmers

Glyphosate and Paraquat emerged as the most applied herbicides, with average utilization rates of 81.9% and 69.1%, respectively, and the highest usage recorded in Oyo State. Previous studies have also identified Atrazine, Paraquat, and Glyphosate as prevalent herbicides in Nigeria (Otorkpa, 2017; Olughu et al., 2019; Eta et al., 2023). The popularity of these herbicides can be attributed to their cost-effectiveness and efficacy in weed control (Otabor et al., 2022). However, concerns have been raised regarding their potential impacts on non-target species, such as termites, and their broader ecological and human health effects, which underscore the need for safer application practices and careful management (Otorkpa, 2017; Otabor et al., 2022). Furthermore, because of its acute toxicity to humans, Paraquat is categorized as a highly hazardous pesticide (HHP) by the FAO and WHO (Kim and Kim, 2020). Particularly in low-resource farming contexts, where farmers often lack access to personal protective equipment (PPE), it has been linked to serious health risks, such as fatal poisoning from inhalation or skin exposure (Nkwatoh et al., 2024; Sookhtanlou and Allahyari, 2021).

The heavy use of glyphosate and paraquat, especially in corn fields, leads to toxic effects on carabids, natural predators of lepidopteran pests (Bergeron and Schmidt-Jeffris, 2023). This indirect effect may lead to an increase in early-season lepidopteran pests, thereby prompting a higher application of insecticides, such as Lambda-Cyhalothrin, known for its efficacy against lepidopteran pests (Gao et al., 2021).

4.5 Regional variations and preferences of fungicides among Nigerian farmers

Ondo State exhibited the highest usage of fungicides, with Mancozeb + Carbendazim (70.6%), Copper Hydroxide + Metalaxyl-M (63.3%), and Propineb + Cymoxanil (62.4%) being the most common. Oyo State also showed a high utilization of Mancozeb (75.8%), which is likely due to its effectiveness and broad-spectrum activity against fungal pathogens affecting yam cultivation in the region (Thind and Hollomon, 2018; Ben Naim and Cohen, 2023). The efficacy of copper-based fungicides against *Phytophthora megakarya*, the pathogen responsible for cocoa black pod disease, further explains their high usage in cocoa-producing regions (D. Adeniyi et al., 2018; Sowunmi et al., 2019). Adejori and Akinnagbe (2022) attribute the increased use of copper-based fungicides in Ondo State to the state's status as Nigeria's largest cocoa producer (Owoeye and Sekumade, 2016). The Cocoa Research Institute of Nigeria (CRIN) has endorsed several critical fungicides, including Red Force (Cuprous oxide + Metalaxyl), Ultimax Plus (Cuprous oxide + metalaxyl), and Ridomil Gold (Mancozeb + Metalaxyl), contributing to the high application rates of these fungicides in the region (Adeniyi and Ibiyinka, 2017; Adejori and Akinnagbe, 2022).

Mancozeb and carbendazim have been linked in some toxicological studies to adverse health effects, such as genotoxicity and hepatotoxicity (Zhou et al., 2023), neurotoxicity (Ebid and Trombetta, 2023), biochemical and physiological changes in aquatic organisms (Baliarsingh et al., 2023), and reproductive and developmental toxicity in animals (Aranha et al., 2021; Garcia et al., 2021). Due to their single toxicities and potential for synergistic effects, Copper Hydroxide + Metalaxyl-M together present serious environmental and toxicological concerns. These issues show how their use must be carefully managed and observed in order to reduce hazards to ecosystems and public health (Kungolos et al., 2009; Wang X. et al., 2021). On the other hand, research indicates that the combination of Propineb and Cymoxanil does not present dietary risks because it has been demonstrated that this formulation in tomatoes is safe for human health due to its low dietary risk and rapid dissipation behavior (Kumar et al., 2020; Tripathy et al., 2021). However, other research suggests that Cymoxanil has been associated with alpha-synuclein protein aggregation linked to Parkinson's disease (Amaral et al., 2024). Therefore, our findings reveal the importance of continued evaluation of such agrochemicals to balance agricultural benefits with long-term human health considerations.

4.6 Regional preferences and patterns in pesticide mixtures among Nigerian farmers

Farmers in the surveyed states typically utilized combinations of up to two classes of pesticides. Approximately one-third of farmers in each state mixed pesticides, with Oyo State showing the lowest percentage at 29.5%. This practice aligns with (Babarinsa et al., 2018), who found that 31% of Oyo State farmers mixed pesticides to enhance effectiveness. In Osun State, farmers commonly use multiple pesticide mixtures (Ugwu et al., 2015; Adeniyi and Ibiyinka, 2017; Aminu, 2020). A statistically significant difference was observed in pesticide mixtures used across Ogun, Ondo, and Oyo states ($p < 0.001$). Imidacloprid and Thiram were the most used combinations, consistent with findings by Babarinsa et al. (2018) and Adewoye and Amusa (2021), who noted their effectiveness against a broad spectrum of pests. Thiram is a fungicide that protects against various fungal pathogens, while imidacloprid, a neonicotinoid insecticide, acts on the nervous system of insects (Macaulay et al., 2021). This combination of pesticides is likely to be popular with farmers because of its dual functionality in simultaneously controlling insect pests and fungal diseases, ease of application, and perceived reliability. Comparable synergistic combinations, such as Imidacloprid and Validamycin, have been shown to have enhanced pest and disease control and extend field protection (Liu et al., 2023) The high prevalence of cashew farming in our study areas, particularly in areas where cashew pests like *Analeptes trifasciata* are a concern, may be related to the mixture's frequent use. Although Thiamethoxam has been reported as effective against *Analeptes trifasciata* (Mokwunye et al., 2023), the frequent use of Imidacloprid in our study may reflect farmers' familiarity with the product, its wider availability, or its perceived effectiveness when used in combination with Thiram. This pattern is consistent with earlier research in southwest Nigeria (Babarinsa et al., 2018; Adewoye and Amusa, 2021), where farmers frequently combine products for broad-spectrum protection, particularly in situations where access to focused extension advice is scarce. Imidacloprid works well to control pests, but using it puts insects and aquatic species health and survival at serious risk. Imidacloprid, though widely used for its effectiveness against insect pests, has raised environmental concerns, especially regarding non-target species. In particular, studies have linked it to problems in honeybee populations, such as reduced colony health and interference with normal behavior and immune response (Nicodemo et al., 2014; Dively et al., 2015; Sukkar et al., 2025), induces oxidative stress and neurodegeneration in insects like Drosophila (Martelli et al., 2020), significant behavioral and physiological changes in freshwater clams and crayfish (Shan et al., 2020; Huang et al., 2021).The frequent use of lambda-cyhalothrin (Pyrethroid) and dimethoate (organophosphate) mixtures was also noted, attributed to their efficacy in pest control (Babarinsa et al., 2018; Adewoye and Amusa, 2021). Despite the effectiveness of these combinations, lambda-cyhalothrin is also known to be extremely toxic to aquatic life and arthropods that are not its intended target (Yahia and Ali, 2018). Its acute toxicity and environmental persistence place it in the category of highly hazardous pesticides (HHPs), which raises concerns about runoff into adjacent water bodies (Yao et al., 2024). Therefore, careful management and application are necessary to mitigate environmental and health risks. In contrast, mixtures containing pyraclostrobin and dimethomorph were less common, likely due to their specific target pests and higher costs (Wang et al., 2018).

The study revealed that pesticide mixtures were based on individual farmers' preferences rather than recommendations from extension agents or label instructions. Most mixtures comprised chemicals from the same class, except for combinations like Metalaxyl + Difenoconazole + Thiamethoxam and Imidacloprid + Thiram, which included both fungicides and insecticides. This practice contrasts with Adejori and Akinnagbe (2022), who observed that well-educated farmers in Ondo State accurately followed label instructions and avoided mixing herbicides with fungicides. In contrast, Babarinsa et al. (2018) and Amusat et al. (2023) found that farmers in Southwest Nigeria often misused pesticides by combining different classes of chemicals, leading to potential ineffectiveness and increased environmental risks.

4.7 Crop protection practices and application frequency of pesticides among farmers in Ogun, Ondo, and Oyo states

Our study revealed significant regional differences in crop protection practices among farmers in Ogun, Ondo, and Oyo states, highlighting varied approaches influenced by local conditions, resources, and knowledge. For instance, the significant variation in the adoption of crop protection practices among farmers in Ogun, Ondo, and Oyo reflects the regional differences in agricultural practices and pest management strategies (Zhang et al., 2018). The high adoption of physical control methods in Ondo (97.3%) compared with Ogun (26.8%) and Oyo (58.4%) suggests that farmers in Ondo may have better access to resources or training that emphasizes physical control techniques. This aligns with findings from similar studies that indicate the importance of localized training and extension services in promoting specific agricultural practices (Ofuya et al., 2023).

The predominant use of biological control methods in Ogun (67.3%) contrasts sharply with the minimal use in Ondo (1.3%) and Oyo (17.9%), suggesting that biological control may be more culturally or ecologically suited to Ogun's farming systems (Ratto et al., 2022). This could be due to the greater awareness or availability of biological control agents in Ogun, as Constantine et al. (2023) suggested, who found that the availability of biological control agents and local farmer education significantly influences their adoption. The widespread use of chemical/synthetic control in Ondo (98.0%) and Oyo (99.4%) compared with Ogun (36.7%) indicates a reliance on chemical inputs in these states, potentially driven by higher pest pressures or greater market access to pesticides. This is consistent with the findings of Ofuya et al. (2023), who reported that chemical control methods are often preferred in regions with a higher pest incidence and better market integration. Although Ondo State had the highest perennial crop cultivation, where classical biological control might be expected to be most successful, this was not the case in this study. Instead, Ogun, where mostly annual crops such as maize (74%) and cowpeas (49.0%) were grown, had the highest proportion of farmers who used biological control, perhaps reflecting better access to inputs, farmer training, and extension support, as reported by Constantine et al. (2023).

Botanical/non-synthetic methods were more common in Ogun (66.7%) than in Ondo (44%) or Oyo (1.2%), which could be attributed to the traditional knowledge and practices prevalent in Ogun. This supports the findings of (Shai et al., 2024), who found that traditional botanical knowledge significantly influences pest management practices in sub-Saharan Africa, including Nigerian communities. The high use of insecticides in Ondo (89.3%) and Oyo (99.4%) compared with Ogun (44.2%) reflects differing pest pressures and possibly differing levels of extension service effectiveness. According to Adejori and Akinnagbe (2022), regions with more intensive farming practices and higher pest pressure tend to have higher insecticide use.

4.8 Factors influencing farmers' adoption of fungicides, insecticides, and herbicides

Understanding the factors influencing the adoption of fungicides, insecticides, and herbicides among Nigerian farmers is crucial for designing targeted interventions that promote sustainable agriculture and mitigate the negative effects of chemical-intensive farming practices (Oyenpemi et al., 2023). This study highlights the significant influence of local environmental conditions and educational levels on farmers' decisions regarding adopting agricultural chemical inputs. These findings underscore the need for tailored interventions and educational programs that consider the specific contexts in which farmers operate (Ahmadipour and Nakhei, 2024; Sapbamrer et al., 2023; Hamba et al., 2024). Our study also revealed that the adoption of fungicides in farming practices is significantly influenced by the specific location or town where farming activities occur. This suggests that environmental or community factors such as disease prevalence, local agricultural practices, and fungicide accessibility play a critical role (Olita et al., 2024). These findings are consistent with those of Demi and Sicchia (2021), who also highlighted the influence of local agricultural practices and environmental factors on the adoption of fungicides by farmers in Ghana.

Our study further revealed that the adoption of pesticide mixtures was significantly influenced by gender, education level, local government area, and the place/town of farming. These findings underscore the critical roles of demographic factors, educational background, and local administrative divisions in farmers' adoption decisions (Kangavari et al., 2024). This aligns with the research by Tham-Agyekum et al. (2023), which highlighted the influence of gender on agricultural practices. Additionally, Sapbamrer et al. (2023) and Ahmadipour and Nakhei (2024) demonstrated that education level and local government factors significantly impact the adoption of integrated pest management practices. This underscores the need for tailored interventions that consider these key demographics and administrative factors to enhance the adoption of pesticide mixtures.

In addition, our study showed that the adoption of insecticides is significantly influenced by the local government area and the place/town of farming, highlighting the importance of regional factors such as pest prevalence and local agricultural practices. This finding aligns with that of Oyenpemi et al. (2023), who emphasized the role of regional characteristics in adopting agricultural technologies. Furthermore, the adoption of herbicides is significantly influenced by educational level and the place/town of farming. This suggests that educated farmers are more likely to adopt herbicides and that local environmental conditions also play a key role. These findings are corroborated by Sun et al. (2022), who noted that education significantly affects the adoption of agricultural innovations. Overall, this study highlights the importance of considering local environmental conditions and educational initiatives to promote the adoption of agricultural innovations. Tailored interventions that address these factors are likely to be more effective in regulating the use of fungicides, insecticides, and herbicides by farmers.

5 Conclusions and recommendations

This study comprehensively analyzed the factors influencing pesticide use in Southwestern Nigeria, revealing significant regional and demographic variations in adopting insecticides, herbicides, fungicides, and pesticide mixtures. The findings highlight that local agricultural needs and pest pressures dictate distinct preferences for different pesticide types, with fungicide and insecticide use particularly influenced by regional conditions. Educational level, gender, and local government area emerged as significant factors affecting the adoption of pesticide mixtures, indicating a need for targeted educational and support interventions. The study underscores the predominance of male farmers and a positive correlation between education and pesticide use, suggesting that expanding access to training and resources, especially for underrepresented groups such as female and less-educated farmers, is critical. The prevalent use of pesticide mixtures without sufficient guidance poses serious human and environmental health risks, highlighting the urgent need for stricter regulatory oversight and improved extension services. These measures are essential to ensure safe and effective pesticide use across farming communities. In Nigeria, local governments and research institutions have specific regulations and recommendations that govern the approval and use of pesticides. Because of this, Nigeria only has a small number of approved pesticide active ingredients, which limits farmers' options and could lead to the overuse of certain chemical formulations. A more varied and secure pesticide portfolio is required to promote sustainable agriculture. To advance towards more sustainable agricultural practices, promoting integrated pest management (IPM) is crucial. This approach reduces the over-reliance on chemical inputs and encourages the adoption of alternative pest control methods. Policymakers should focus on enhancing access to training, credit, and alternative pest management strategies while ensuring effective enforcement of pesticide regulations. Emphasizing the safe and effective use of pesticides tailored to localized pest management needs is also vital. Addressing these challenges will facilitate Nigeria's transition to a more sustainable and equitable agricultural system, safeguarding human health, protecting the environment, and supporting food security and economic growth within farming communities. Future research should investigate the socioeconomic and cultural factors influencing pesticide adoption and the long-term impacts of current practices on soil health, water quality, and biodiversity. Understanding these dynamics is essential for designing targeted interventions to foster sustainable and equitable pesticide use in Nigeria's agricultural sector.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author/s.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants.

Author contributions

AA: Conceptualization, Data curation, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. CV: Data curation, Methodology, Supervision, Validation, Writing – review & editing. VD: Writing – review & editing. IA: Writing – review & editing. FA: Writing – review & editing. FK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research 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) declare that Generative AI was used in the creation of this manuscript. Grammarly and ChatGPT 3.5 were used to assist in proofreading and language refinement for some sections, but the original draft was by the authors, and the authors took final responsibility and decision for the final content.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fagro.2025.1503899/full#supplementary-material

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