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Pesticide use and alternative pest control strategies in Liberia: a comparative analysis of staple and market-oriented crop farmers

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Introduction: Given the rising concern for food safety and environmental sustainability of agricultural intensification in the Global South, we examined drivers of pesticide use and Integrated Pest Management (IPM) in Liberia.
Methods: We draw on a unique dataset combining 336 cocoa, 320 coffee, and 291 cassava farmers with evidence from 72 midstream value chain actors, including buyers, aggregators, and processors, to capture both farm-level decision-making and downstream market incentives. Using econometric choice models, we analyze how household, farm, and institutional factors shape pest management practices across market-oriented tree crops and staple food systems.
Results: Our results show the difference and similarity in the determinants of pesticide use and IPM adoption between farmers producing market-oriented crops (cocoa and coffee) and cassava farmers. Contrary to the conventional wisdom that organic production dominates in high-value cash crops like coffee and cocoa, our findings show that farmers in these sub-sectors rely more on pesticides than less market-orientated crops like cassava.
Discussion: Evidence from downstream actors suggests limited market demand and weak price incentives for low-pesticide use, which helps explain the continued reliance on chemical pesticides, particularly in tree crop systems. We therefore recommend that promoting sustainable pest management in Liberia requires not only strengthening advisory services and farmer training, but also transmission of food safety and sustainability requirements through value chain governance and pricing mechanisms.

KEYWORDS
adoption, integrated pest management, Liberia, pesticides, sustainability

1 Introduction

Pests and weed infestations are critical causes of significant crop loss, and they are threats to achieving food security and poverty reduction (Aniah et al., 2021; Cai et al., 2016; Pretty and Pervez Bharucha, 2015). This is more severe in the global South—where most farmers are smallholders and vulnerable to climate impact. Pests alone contribute to the loss of food capable of feeding over a billion people (Birch et al., 2011; Pretty and Pervez Bharucha, 2015). Therefore, the use of pesticides has long been the conventional means of pest and weed control. The prevalence and widespread challenges of insect pests and diseases have resulted in a high demand for pesticides (Aniah et al., 2021). Intensive pesticide use has become a significant challenge in achieving sustainable agriculture (Kabir and Rainis, 2015), as it threatens farmers, consumers, and the environment (Schreinemachers et al., 2016). Pesticide use may adversely impact farmer health, reduce worker productivity, and counterpoise the on-farm benefits of pesticide use (Mahmoud and Shively, 2004). Bandanaa et al. (2024) also posit that the excessive use of pesticides increases production costs and the environmental cost including adverse risk on non-target organisms, land food chain, and biodiversity (Aniah et al., 2021), land degradation, and water pollution (Lelamo et al., 2023).

The total pesticide use is about 3.7 million tons worldwide, while only 209 thousand tons of pesticides were used in Africa (FAO, 2022). Despite the low[1] intensity of pesticides use in Africa, 99 percent of those suffering from food poisoning are from low- and middle-income countries [Okoffo et al., 2016; World Health Organization (WHO), 2009]. High dosage of pesticides use to combatting pests, diseases, and weeds has been attributed to rising food poisoning and fatalities in many developing countries (Aniah et al., 2021; Bandanaa et al., 2024; Okoffo et al., 2016). Factors such as inadequate protective measures, continued use of prohibited pesticides, weak enforcement, poor or inadequate labeling, low literacy rates, and limited awareness of pesticide concentration, improper use and disposal also contribute to food poisoning and fatalities in the region (Aniah et al., 2021; Bandanaa et al., 2024; Damalas et al., 2008; Lelamo et al., 2023; Mubushar et al., 2019).

Consequently, promoting sustainable agricultural and food production requires a critical understanding of how agricultural technologies and best practices can meet people's needs with little or no harm to the environment and without compromising the needs of the future generation (Mengistie et al., 2017). Farming systems that are based on effective and efficient pesticide use and integrated pest management (IPM) technologies can reduce pesticides use without causing harm to the yield (Kabir and Rainis, 2015). IPM is a dynamic, complex and ecological approach to managing pests in agricultural system which combines and integrate multiple control methods including biological, cultural crop specific, physical and chemical management strategies and practices (Angon et al., 2023; Zhou et al., 2024). It helps to grow healthy crops and risks posed by pesticides to human health and the environment for sustainable pest management (Angon et al., 2023; Zhou et al., 2024). Similarly, effective and efficient use of pesticides is critical to both farmers' and consumers' health, food security, and environmental sustainability (Akter et al., 2018). Thus, understanding the pathways to promoting IPM adoption and effective use of pesticides is critical for developing countries like Liberia.

In Liberia, agriculture is an important source of livelihood as it engages more than 70% of the country's population (World Bank, 2021) and contributes about 26% of the GDP (Dogba et al., 2020). While cocoa and coffee are important forest and market-oriented crops produced by farming households, cassava is one of the important staple crops cultivated by about 80% of farm households primarily for consumption and surplus sold in local and informal markets (Awoyale et al., 2020; Dogba et al., 2020). Cassava value chain is short and weakly integrated, characterized by minimal quality differentiation, limited processing standards, and price formation driven largely by local supply and demand conditions (Sahel Capital, 2021). Market participation is flexible, entry barriers are low, and production decisions are closely tied to food security rather than profit maximization. In contrast, coffee and cocoa are principal export-oriented cash crops, embedded in longer, more structured global value chains as prices are influenced by international markets, and farmers often engage with cooperatives, licensed buyers, and certification schemes (FAO, 2021; Lescuyer et al., 2024). Gender roles also differ sharply: cassava production and processing are more female-managed with relatively greater control over income, while coffee and cocoa systems are largely male-dominated, reflecting higher capital requirements, land tenure norms, and women's concentration in labor-intensive tasks with limited control over revenues (FAO and ECOWAS Commission, 2018; World Bank, 2021).

Farmers continue to rely on synthetic pesticides to achieve agricultural intensification in Liberia. For instance, the rate of pesticide use, including insecticides, herbicides, fungicides, and others, is on a rising trend, with an average use of 1.5 kg/ha, which is significantly higher than the 0.69 kg/ha African average (FAO and WHO, 2022). This concern has increased the government's effort toward promoting safe practices in pesticide application and sustainable alternatives to enhance food security and growth and reduce both the health and environmental impact of excessive pesticide application (FAO and ECOWAS Commission, 2018; Ministry of Agriculture Government Republic of Liberia, 2018). One of these efforts is the promotion of the use of IPM, which projects a more sustainable impact of insect pest and weeds management as noted in the Liberia Pesticides Regulatory Safety Act (MoARL, 2019).

However, most previous literature in developing countries has tilted toward pesticide use behavior (Yami et al., 2025; Bagheri et al., 2021; Aniah et al., 2021; Mehmood et al., 2021; Mengistie et al., 2017) pesticides waste disposal (Damalas et al., 2008), and how it affects human health (Akter et al., 2018; Okoffo et al., 2016) or the effect of training on pesticides use behavior (Madaki et al., 2024; Mubushar et al., 2019; Schreinemachers et al., 2016). Yami et al. (2025) noted that empirical evidence on what drives farmers' choices of pest management practices remains scarce, and, which limits insights for policymakers and development practitioners. Lelamo et al. (2023) and Bandanaa et al. (2024) consider factors influencing pesticide use in Ethiopia and Ghana among vegetable crop farmers. Timprasert et al. (2014) and Rahman (2021) investigate the factors driving IPM adoption among vegetable farmers in Thailand and Bangladesh. Thus, despite a growing literature on pesticide use and IPM, empirical evidence remains scarce on how farmers' pest management decisions differ across contrasting agrifood systems, particularly between export-oriented tree crops and staple food crops, and little is known about the role of downstream value chain actors in shaping these decisions.

1 The pesticide use intensity in Africa is about 0.69 kg/ha or 0.15 kg/cap compared to the world average of 2.37 kg/ha or 0.46/cap.

In the rapidly changing food market, farmers' pesticide use decisions are not solely driven by agronomic and supply-side factors but also shaped by their perceptions and the incentive structures set by the downstream value chain actors. This aspect remains largely unexplored, particularly in the context of Africa and the Global South, where most farmers sell to informal market arrangements with little incentive structure for good agricultural practices adopted by farmers. This study addresses these gaps by (i) comparing the drivers of pesticide use and IPM adoption between market-oriented cocoa and coffee systems and cassava-based staple systems, and (iii) extending the analysis beyond the farm level by incorporating evidence from midstream value chain actors on quality requirements and incentives related to pest management practices. To our knowledge, there is no prior empirical evidence known to us on the factors associated with pesticide use and IPM adoption in Liberia.

The rest of this article is structured as follows: The next section provides a brief review of literature from global and regional perspective on pesticide behavior and IPM adoption. Section three discusses the methodology and estimation strategy employed for the study, followed by the results in section four. While section five presents the discussion of key findings, the paper concludes in section six with the policy recommendations.

2 Literature review

2.1 Pest control and management in Africa

The increasing incidence of pests and insects' infestation in the tropical and sub-tropical region are due to the impact of climate change and poor adoption of modern farm practices, which is critical to the rising food insecurity globally, and particularly higher in many African countries (Aniah et al., 2021; Birch et al., 2011; Cai et al., 2016; Pretty and Pervez Bharucha, 2015). Pest and insect infestation can cause severe on-farm and post-harvest loss if not properly managed (Birch et al., 2011; Pretty and Pervez Bharucha, 2015). While available data show that pesticide usage rate appears comparatively lower in Africa than in other regions (FAO, 2024; Yami et al., 2025), the notion that the risks and impacts must also be correspondingly lower might ignore the effect of the toxicity of the pesticides used and poor pesticide handling practices (Williamson et al., 2008; Sharifzadeh et al., 2018; Kong et al., 2025), which have been largely reported in many studies from different African countries (Okoffo et al., 2016 in Ghana; Rahman and Chima, 2018; Yami et al., 2025 in Nigeria) and other developing countries (Zhang et al., 2011 in China; Mubushar et al., 2019 in Pakistan; Schreinemachers et al., 2016; Akter et al., 2018 in Bangladesh). Nevertheless, pesticides use is on the increase in many sub-Saharan African countries, particularly among smallholder farmers (Andersson and Isgren, 2021). Likewise, there is a growing informal market for pesticides and proliferation of unauthorized pesticides (Yami et al., 2025; Williamson et al., 2008; Staudacher et al., 2020). Despite that increasing pesticide use is associated with a wide range of risks to human health and the environment, most countries in the Global South do not have the capacity for residue testing (Dinham, 2003).

The industrial agrifood system appears to be ecologically and economically unsustainable in the quest to increasing productivity (Sharifzadeh et al., 2018; Zhang, 2024) due to the intensity of synthetic chemical inputs including herbicides and insecticides which cause loss of biodiversity, pollution and risk to human health (Mahmoud and Shively, 2004; Williamson et al., 2008; Staudacher et al., 2020). To address these issues, various alternative practices and models have emerged including organic production system, climate smart agricultural practices, and IPM to achieve better economic, social, and ecological sustainability (Zhang, 2024). IPM is gaining traction across diverse farming systems and agro-climatic zones, it offers safer approach to pest management (Sharifzadeh et al., 2018). IPM integrate multiple pest control methods to prevent pest infestations and ensure quality crop produce—as pests risk-management approach that incorporate several methods to address socioeconomic, health, and environmental threat posed by pests and pesticides use while maintaining acceptable productivity levels (Zhou et al., 2024).

2.2 Pesticide use and IMP adoption

Despite the benefit of pesticide use in crop production, the levels of farmers awareness pesticides effects on human health and the environment varied significantly across countries and regions (Abdollahzadeh et al., 2015). Although, the intensity of pesticides use across most of the African countries is relatively low (FAO, 2024; Yami et al., 2025) and the conventional wisdom that farmers use low agrochemicals in many African countries (Gianessi and Williams, 2011; Oerke and Dehne, 2004; Williamson et al., 2008; Zhang et al., 2011) holds with 16% of the farmers using chemical inputs (Sheahan and Barrett, 2017). While farmers are the primary users of pesticides, the level of awareness about the risk posed by pesticides use influences the methods of pest management (Abdollahzadeh et al., 2015; Akter et al., 2018; Okoffo et al., 2016; Mahmoud and Shively, 2004). As the positive and negative effect of pesticides use are the main drivers of other methods of pest management such as biological, cultural control organic pesticides and IPM (Abdollahzadeh et al., 2015; Kong et al., 2025). While numerous studies have considered the use of chemical inputs and pesticides among farmers across many developing countries, especially in Africa, little is known of the variation across different cropping systems and crop categories based on farmers specialization.

Additionally, farmers' knowledge of both the positive and negative effect of pesticides use may be influenced by various socio-economic, farm, and institutional factors which ultimately can affects farmers choice of pest control strategies and farmer's attitudes toward pesticide use (Aniah et al., 2021; Bagheri et al., 2021; Bandanaa et al., 2024; Yami et al., 2025; Lelamo et al., 2023; Mehmood et al., 2021; Mengistie et al., 2017; Rahman, 2021; Timprasert et al., 2014). Farmers' awareness is shaped by socioeconomic characteristics, such as formal education and level of technical knowledge regarding pesticide use (Bandanaa et al., 2024; Lelamo et al., 2023; Moumenihelali and Amooghli-Tabari, 2025). Similarly, farmers choice regarding other pest control methods such as organic pesticides and IPM are subjective and may varied based on individual farmers characteristics and knowledge (Abdollahzadeh et al., 2015; Rahman, 2021; Timprasert et al., 2014). While we consider the use of chemical pesticides as the use of either herbicides, fungicides, insecticides or nematicides, the use of organic pesticides includes the use bio-pesticides, ashes and neem waters among others. In contrast, we consider IPM adoption as those farmers who combines cultural e.g., crop rotation, early planting, clean seed, scarecrow, hand picking, chemical e.g., inorganic pesticides, insecticides, and weed management and biological controls methods such as bio pesticides, organic pesticides, resistant varieties among others (Angon et al., 2023; Zhou et al., 2024). However, we have no prior knowledge of any study that have considered the heterogeneity of various factors influencing the use of pesticides and IPM adoption among farmers specialized in a more market-oriented crop and staple crops.

2.3 Specific factors influencing pesticides use and IPM adoption

Farmers' pesticide use, or organic fertilizer and IPM adoption choices, can be shaped by access to training, farmers' experience, institutional factors, and other specific socioeconomic characteristics (Sharifzadeh et al., 2018; Adeola et al., 2025). For instance, those trained in pesticide use or introduced to IPM may likely be aware of health risks associated with pesticide use or natural pest enemies and ultimately adopt pest control methods that are safe and have less impact on the environment and health (Damalas and Koutroubas, 2017; Jordan and Guerzoni, 2020). While farmers with limited farm and off-farm income or farther away from the pesticide shop may prioritize cost and accessibility factors (Wilson and Tisdell, 2001; Drall and Mandal, 2024). Likewise, access to formal education and income can shape farmers' preferences for pesticides and IPM. As educated farmers may prioritize health and environmental benefit (Angon et al., 2023; Zhou et al., 2024), while those with higher income, farm size, and experienced farmers may consider productivity and performance (Lelamo et al., 2023). Beliefs about pesticide hazards and the effectiveness of alternatives also influenced the weight given to environmental vs. performance criteria (Ahmad et al., 2024). Williamson et al. (2008) investigate pesticide use and handling practices among smallholder farmers in Benin, Ethiopia, Ghana, and Senegal with focus on cotton, vegetables, pineapple, cowpea, and mixed cereals and legumes, for export and local markets. They found that the level of crop susceptibility to insect attack, increased pest incidence, lack of access to information on alternative methods, access to credit, input support, and poor attention to the economics of pest control affect the use of pesticides. In Uganda, Andersson and Isgren (2021) found that most farmers rely heavily on pesticides, despite their health and environmental risks, which are unevenly distributed, especially across gender, and that the burden of pesticide risk falls disproportionately on already vulnerable smallholders. They also noted that structural barriers such as weak regulation, market liberalization, poor extension services, and lack of alternatives limit farmers' capacity to adopt sustainable practices like IPM. Thus, the adoption of pesticides and IPM can be influenced by a complex interplay of socioeconomic, demographic, institutional, agroecological, and economic factors (Adeola et al., 2025).

In Liberia, pre- and post-harvest crop losses due to pests and diseases are about 40 to 50% (MOARL, 2008), and most farmers employ physical and mechanical methods for pest control, but some continue to rely on chemical pesticides. However, growing demand for organic produce have intensified interest in non-chemical alternatives. Although, there has been increasing effort of the government to promote pesticide use and IPM adoption, and regulate pesticide market (Ministry of Agriculture Government Republic of Liberia, 2018; MoARL, 2019), but little is known regarding the different crop market or staple-oriented farmers behavior to the use of pesticides and IPM practices given their individual, farm and institution characteristics. Against this backdrop, this study examines the factors influencing pesticide use and IMP adoption for commodities marketed under formal contract arrangements and in informal market settings i.e., commodities with long and short value chain structures in Liberia.

3 Methodology

3.1 Study area and data

The study was carried out in Liberia, a country with a population of about 5.5 million people in the West African region, which sits on a land area of 111,370 Km2 and lies on latitude and longitude of 6° 43′ N and 9° 43′ W. It borders Guinea to the north, Sierra Leone, to the northwest, Cote d'Ivoire to the northeast and east, and the Atlantic Ocean to the south and southwest. Its terrain includes plateau, low mountains, and flat to rolling coastal plains characterized by lagoons, mangrove swamps, and river-deposited sandbars (FAO, 2005). The land area comprises 19,230 km^2 of agricultural, 75,560 km^2 of forest land, land 15,000 km^2 of inland waters. As noted earlier, most of the people in Liberia like other sub-Saharan African countries, rely on agriculture as the main source of livelihood. The map of the study area is presented in Figure 1.

Using a systematic three-stage sampling procedure, we rely on unique cross-section dataset from 947 farming households selected fromthree counties, namely Lofa, Bong, and Nimba, based on their potential production to ensure the inclusion of the most relevant areas in the first stage (Lescuyer et al., 2024; Schroth et al., 2015). These counties represent about 51% of the 338,630 agricultural households in Liberia according to the 2022/23 Liberia agriculture census (Liberia Institute of Statistics and Geo-Information Services, 2024). The selection of these counties is also informed by the presence of other value chain actors such as processors, off-takers, and agro-dealers, which are more prevalent in these three counties. Experts from the Central Agricultural Research Institute CARI also consulted for the selection of other value chain actors for the three commodity value chains. We obtained a list of enumeration areas from the Liberia Institute of Statistics and Geo-Information Services. Then, we selected 10 enumeration areas with more growers in the second stage from each county while ensuring the sample was representative of regions with significant agricultural activity. Finally, within these selected enumeration areas, we randomly sampled 947 farming households comprising

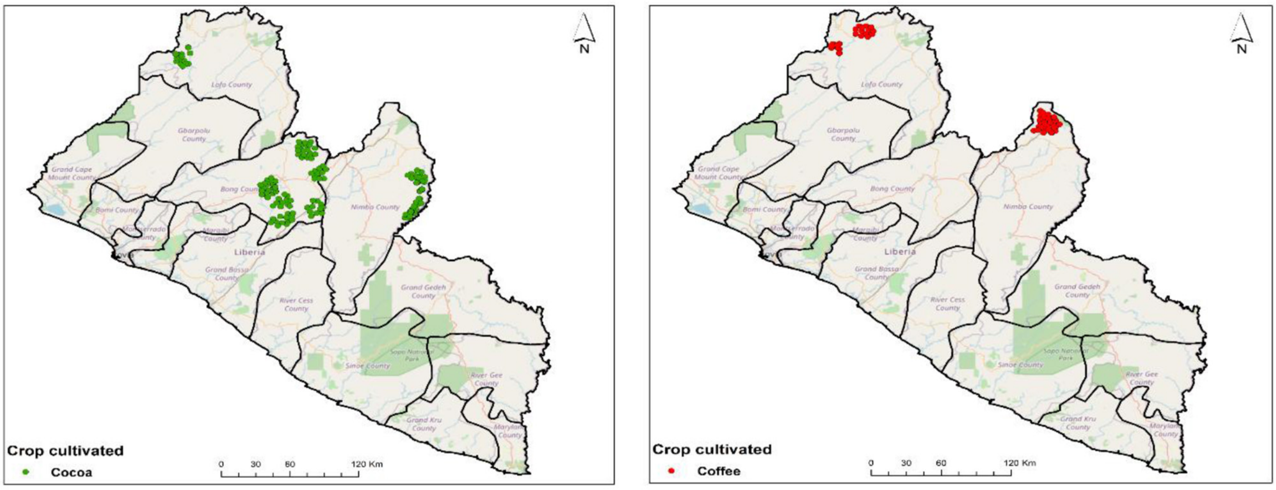

FIGURE 1
Map of Liberia showing the study areas for cocoa and coffee production.

336, 320, and 291 cocoa, coffee, and cassava farm households, respectively, selected for the study.

Specifically, the coffee growers were randomly selected from 10 enumeration areas EAs in Nimba and Lofa counties, with the selection made proportionate to the size of each area as the top two regions known for coffee production in Liberia (Lescuyer et al., 2024; Schroth et al., 2015). In contrast, the cocoa growers were selected from 10, 5, and 2 EAs in Bong, Lofa, and Nimba counties, respectively. For the cassava growers, the selection was made from 4 EAs in Bong and Nimba counties and 6 EAs in Lofa county. The household survey was supplemented by additional data from other actors involved in the agrifood supply chain to gather insights from both the markets and institutional perspectives that influence the use of pesticides and what quality aspects of pesticides are required in the marketplace. The actors involved were input suppliers $n = 14$, buyers/traders $n = 36$, processors $n = 11$, and consumers $n = 11$; selected using snowball sampling methods. Interviews with these stakeholders examined the ways in which pesticide use and pesticide residues are evaluated in their operations, the quality characteristics that are valued and transactionally important, and whether premium prices are paid to farmers who meet sustainability criteria for compliance with certain standards. Incorporating these perspectives allows us to triangulate farmer-reported practices with downstream quality assessment and procurement processes, and to situate pesticide use and IPM adoption within a broader agrifood system and sustainability context.

We deployed a structured questionnaire using open-data knowledge source ODK administered by trained enumerators, with experienced supervisors from the Central Agricultural Research Institute CARI experts. We conducted a two-day intensive in-house training between May 22 and 25, 2024, and the piloting on May 27. The actual data collection took place between May 27 and June 12, 2024. The survey gathered detailed information on farmers‘ and their households’ characteristics, agriculture production and cropping pattern, pesticide use and IPM adoption, institutional factors like access to extension, insurance, and market, among others.

3.2 Estimation strategy

Adoption of improved technology or practices is often measured using mutually exclusive binary responses (Bandanaa et al., 2024; Lelamo et al., 2023; Rahman, 2021; Schreinemachers et al., 2016; Timprasert et al., 2014). We follow the underlying assumption of the random utility theory that if the utility gained by those who adopt the technology is higher than those who do not, farmers will adopt it (Fischer and Qaim, 2012; Rahman, 2021) as farmers are often faced with the choice to adopt or not adopt it. In the dichotomous choice model, logit and probit have been commonly used in many studies to examine the factors influencing farmers’ decisions to adopt improved technology or practice (Rahman, 2021; Timprasert et al., 2014). We therefore expressed the logit model for our study as follows:

$$P(Y_i = 1) = P_i = F(Z_i) = F\left(\alpha + \sum \beta_k X_i\right) = \frac{1}{1+e^{-Z_i}}, \quad (1)$$

Where P_i is the probability of using pesticide or adopting IPM, X_i is a vector of household, farm, and institutional explanatory variables, α and β_k are estimated parameters. Similarly, the probability of not adopting IPM or using pesticides is given as:

$$P(Y_i = 0) = 1 - P_i = \frac{1}{1+e_i^{Z_i}}. \quad (2)$$

By combining Equations 1, 2, we get $\frac{P_i}{1-P_i} = e^{Z_i}$ and by taking the natural log of both sides, we are left with:

$$Z_i = \ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{i1} + \ldots + \beta_k X_{in} + u_i. \quad (3)$$

We also explore the effect of the interaction effects of some key institutional variables on the use of pesticides and IPM as stated in

TABLE 1 Summary statistics of the demographic, farm characteristics and institutional factors.

Covariates	Cocoa $N = 336$		Coffee $N = 320$		Cassava $N = 291$	
	Mean/%	Std. dev	Mean/%	Std. dev	Mean/%	Std. dev
Age years	47.79	13.42	47.80	12.94	45.00	13.11
Gender[d]	83		80		69	
Education[d]	55		42		54	
Household size	7.49	2.98	7.44	3.10	7.11	3.23
Total farm size acres	6.96	6.48	6.18	5.53	2.31	2.52
Land rights[d]	69		53		65	
Membership of association[d]	45		36		45	
Access to extension[d]	0.21		0.07		0.19	
Credit access[d]	15		14		12	
Access to market price information[d]	23		18		24	
Dist. to pesticides dealer km	17.36	10.74	11.01	9.43	15.56	11.60
Access to mobile phone[d]	67		49		63	
Non-farm income[d]	36		48		37	
Number of trusted traders	1.38	1.56	1.57	1.11	1.40	1.38

[d]Denotes binary variables 1/0.
Source: Field survey, 2023.

Equation 4.

$$Z_i = \ln\left(\frac{P_i}{1 - P_i}\right) = \gamma_0 + \gamma_1 X_{i1} + \ldots + \gamma_k X_{in} + \psi A_i + \varepsilon_i. \quad (4)$$

Where β_0, and γ_0 are the intercept, β_1, β_k, γ_1, *and* γ_k are the correlates of the covariates included in the models which are described in Table 1, ψ is the correlates of the composite function of the interactive terms of some institutional factors A, and ε and u are the error terms. Notably, we can obtain the odds ratio by exponentiating the β_k's in Equation 3, 4 to capture how a change in our covariates changes the odds of adopting IPM or using pesticides. Following Tambo and Liverpool-Tasie (2024), IPM adoption in this study is defined based on the combined use of practices across multiple IPM components rather than reliance on any single method. See Table 2 for the different components of IPM considered in this study. We estimate our model using the maximum likelihood method. The choice of our covariates includes age, gender and education of the household head, access to credit and extension services, premium price, membership of association, distance to market, pesticides dealer, number of trusted buyers, farm size, fertility, and land right. These are guided by similar previous studies (Bandanaa et al., 2024; Lelamo et al., 2023; Rahman, 2021; Schreinemachers et al., 2016; Timprasert et al., 2014).

However, three different channels for endogeneity issues may affect the fitness of our model. First, the distance to input dealers and the number of traders are often measured with substantial error in household surveys, which can attenuate coefficient estimates and bias standard errors. This is widely acknowledged in studies modeling adoption of chemical inputs (Zhang et al., 2019; Kadjo et al., 2020). Second, omitted variables such as farmers' risk preferences or environmental awareness can confound the estimated impact of factors like credit access or education on pesticide use (Riwthong et al., 2015; Kadjo et al., 2020; Drall and Mandal, 2024), and unobserved household wealth or managerial ability may bias estimates of credit access or education effects on pesticide use and IPM adoption, while both influences and is influenced by market participation or credit decisions, requiring careful temporal ordering to avoid reverse causality (Wilson and Tisdell, 2001; Kadjo et al., 2020). Several estimation strategies like instrumental variables, control function, and fixed effect have been used by several scholars (Ojo and Baiyegunhi, 2020; Kadjo et al., 2020) but due to the cross-sectional nature of our data and lack of appropriate and valid instruments, we do not account for reverse causality and endogeneity concerns that may bias our estimates. This is the caveat of our model estimate, and we do not assert causality.

4 Results

4.1 Socio-economic characteristics of the sampled farmers

The summary statistics of the socioeconomic factors of the sampled farmers included in our model are reported in Table 1. The average age of the farmers cultivating market-oriented crops primarily cocoa and coffee is approximately 48 years, and is slightly higher than the 45 years recorded for those cultivating predominantly consumption-oriented crops, such as cassava. This age gap may reflect a historical divide for cash crops, where older farmers are more likely to engage in perennial crops due to land tenure, traditional knowledge, less risky and less labor-intensive as

TABLE 2 IPM components and practices captured in the household survey.

IPM components	Cocoa $N = 336$	Coffee $N = 320$	Cassava $N = 291$
Panel A: pest monitoring			
Field scouting	33.04	49.19	28.18
Panel B: cultural and preventive practices			
Early planting	54.76	47.96	54.3
Crop rotation	38.99	48.93	45.36
Intercropping	66.07	49.79	78.07
Weed management	81.55	41.82	88.66
Use of clean seeds	47.92	41.62	52.92
Resistant varieties	24.7	40.06	19.59
Panel C: mechanical and physical controls			
Handpicking	28.57	47.77	26.46
Perching	19.05	39.09	13.75
Scarecrow	8.93	7.89	9.28
Panel D: biological and botanical controls			
Ashes and neem water	13.39	17.43	9.28
Biopesticides	5.06	14.65	1.03
Panel E: chemical control			
Synthetic pesticides	6.55	13.59	1.72
Herbicides	9.23	22.46	4.81

Source: Field survey, 2023.

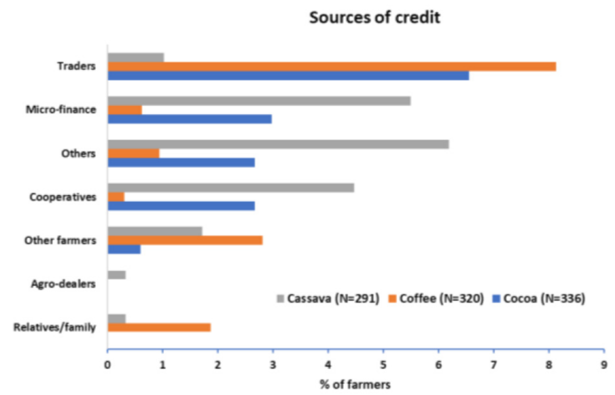

FIGURE 2
Percentage distribution of the source of credit. Source: Field survey, 2023. Values represent the percentage of farmers who reported receiving credit from various sources.

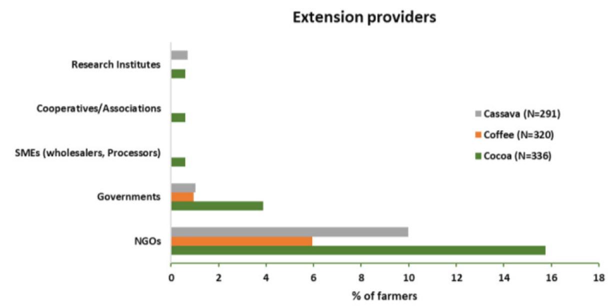

FIGURE 3
Percentage distribution of agricultural extension service providers. Values represent the percentage of farmers who reported receiving extension services from each provider and SMEs denotes Small and Medium-sized Enterprises.

previously observed in African contexts (Wheeler and Marning, 2019; Waldman and Richardson, 2018; Kassie et al., 2009, 2015). Similarly, gender differences are notable. More than 80% cocoa and coffee farmers are male, compared to 69.4% among cassava producers, suggesting a relatively higher participation of female-headed households in cassava production. This aligns with earlier findings that women in sub-Saharan Africa are more involved in food crop production, which is less capital-intensive and more oriented to household consumption (Baada et al., 2023; Palacios-Lopez et al., 2017).

Additionally, formal education is slightly higher among the cassava and cocoa farmers above 50%, than among the coffee farmers 42%. However, across the groups, access to productive resources and services remains limited. For instance, 15% and 14% of cocoa and coffee farmers and 12% of cassava farmers report receiving credit. Moreover, just one in four farmers in either group has access to market price information and reports receiving extension services except for coffee farmers, with only 7% having access to extension services. Traders are the predominant credit providers for cocoa and coffee producers, reflecting their stronger integration into commodity value chains, while cassava farmers more commonly rely on microfinance institutions and cooperatives (Figure 2). Non-governmental organizations NGOs are the leading providers of extension services for both farmer groups (Figure 3), highlighting the limited reach of state-led advisory services.

The household size across all farmer groups is at least 7 members on average, reflecting the relatively large family structure typical of rural agrarian households in sub-Saharan Africa. Landholding size varies considerably by crop orientation. Households primarily engaged in cocoa production operate an average of 7 acres, while those focused on coffee manage slightly smaller holdings of about 6.2 acres. In contrast, cassava-oriented households cultivate an average of only 2.3 acres. This disparity aligns with earlier findings that cash crop producers tend to control larger land areas due to the higher land and capital intensiveness of perennial crops like cocoa and coffee (Roessler et al., 2022; Donkor et al., 2021), as more than half 50% of them report having land right ownership.

Regarding agro-input accessibility, the average distance to pesticide dealer shops is about 17.4 km for cocoa farmers and is relatively higher than 15.6 km and 11 km for cassava and cocoa farmers respectively. This indicates a general challenge in physical access to inputs, which may constrain timely and effective pest management practices, particularly among smallholders in remote areas. Off-farm income is an important livelihood strategy, especially among coffee farmers, 48% of whom report earning

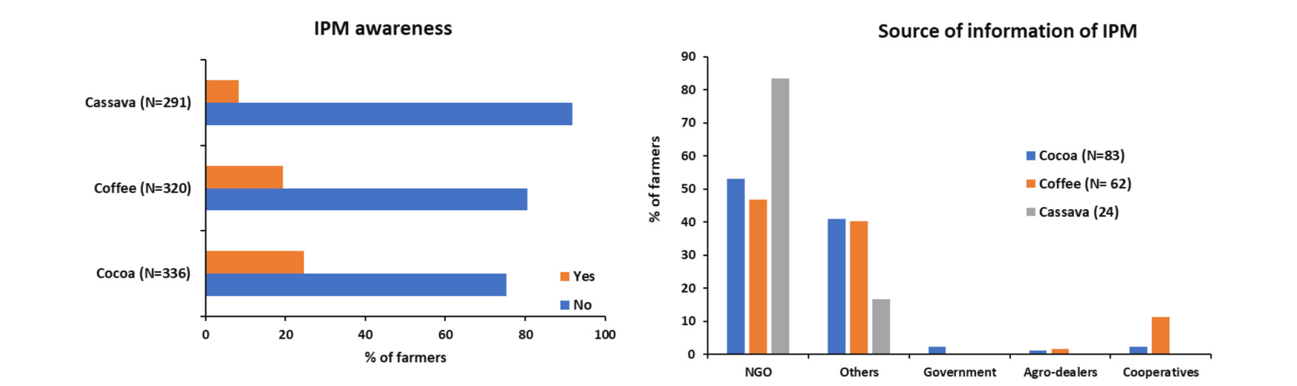

FIGURE 4
Awareness and source of information of IPM.

additional income from non-agricultural activities, compared to cocoa 36% and cassava 37% farmers.

Over half of the farmers have access to mobile phone in all groups, facilitating communication and information exchange, including market updates and extension messages. On average, farmers in both categories maintain relationships with at least one trusted trader, a crucial component of market linkage and input/output exchange.

4.2 Pesticides use and IPM adoption

Figures 4–7 present the results that show the use of pesticides and IPM for both market and consumption-oriented crops. Despite the increasing advocacy for IPM as a sustainable alternative to chemical pest control, we find that its awareness and adoption remain distinctly low among smallholder farmers across cocoa, coffee, and cassava value chains in Liberia. Specifically, Figure 4 shows that while 24.7% of cocoa and 19.4% of coffee farmers reported that they have been introduced to IPM, only 8.3% of cassava farmers indicated that they have previously been introduced to IPM. We also find that NGOs were the predominant source of IPM introduction, particularly in cassava 83.3%, while government extension services and agro-dealers played negligible roles across all crops.

Figure 5 present the result of pesticide use and IPM adoption among market and consumption-oriented crops. The results shows that 14.3% of cocoa and 11.6% of coffee farmers used chemical pesticides, while very few 5.8% of the cassava farmers report the use of chemical pesticides. On the other hands, over 20% of farmers across all three crops reported the use of organic pesticides such as neem-based solutions and other biopesticides, suggesting a modest but notable awareness of environmentally friendly pest control practices. However, adoption of IPM methods was particularly limited, with only 7.7% of cocoa farmers and 7.9% of cassava farmers indicating IPM use.

Considering the IPM practices employed as presented in Table 2, we find that the most important practices adopted are cultural methods among cocoa and coffee growers as well as cassava growers. While physical and pest monitoring pest monitoring and

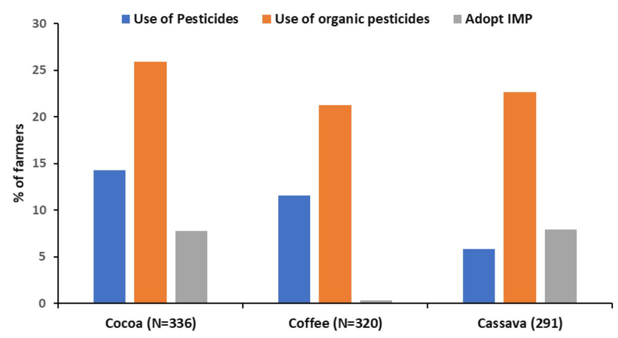

FIGURE 5
Adoption of pest control practices. Source: Field survey, 2023. Synthetic pesticide use refers to the application of chemical pesticides, while organic or botanical pesticides denote the use of ashes, neem water, and biopesticides. IPM refers to the combined use of practices across multiple IPM components.

physical control method are somewhat common >25%, only few of them <20% applied various biological control i.e., ash, neem water, biopesticides and chemical control methods.

Figure 6 shows the result of the pesticides used by cocoa coffee and cassava growers and we find that 13% of them applied pesticides herbicide, insecticide, fungicide, or synthetic pesticide as the use of herbicides and spraying of insecticides are the most used pesticide categories. For non-adopters of IPM, Figure 7 reveals the reasons for not adopting. We find that the primary reason for not adopting is insufficient knowledge of IPM methods above 85% across all the crop category, followed by high cost approximately between 6 and 10%. The other reasons emphasized include lack of knowledge of IPM and high level of pest infestation.

4.3 Determinants of pesticides use

Table 3 presents the regression estimates of the factors associated with pesticide use among cocoa, coffee, and cassava farmers (Equation 3), while extends the model to include key interaction effects (Equation 4). Results are disaggregated by crop

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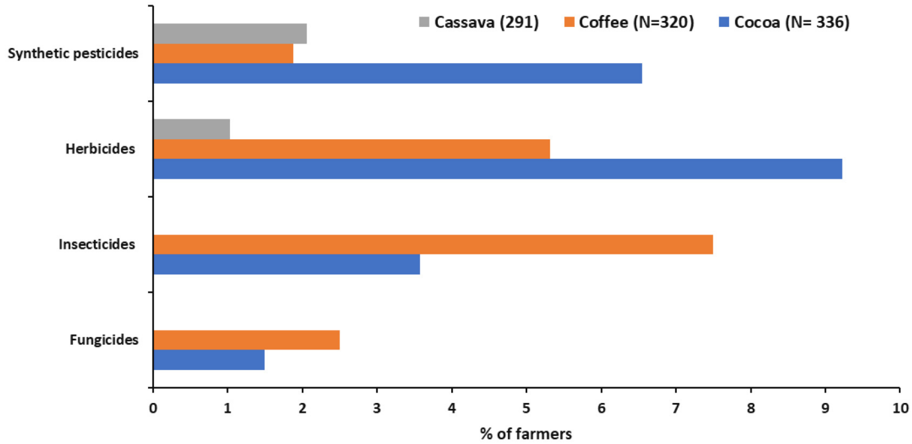

FIGURE 6
Pesticides used by cocoa coffee and cassava growers. Source: Field survey, 2023.

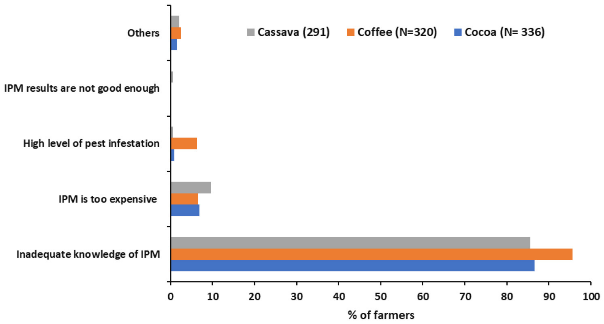

FIGURE 7
Reason for not adopting IPM. Source: Field survey, 2023.

type to capture heterogeneity across farming systems. We find that the model is statistically significant and a good fit for the coffee and cassava farmers group, unlike that of the cocoa grower, which is insignificant as the $p > 0.1$ with a very low pseudo-R^2 of 8.4%. For coffee and Cassava farmers, the pseudo-R^2 is relatively higher indicating that the explanatory variables explain about 36.7% and 16.3% of the variation in the pesticides used respectively.

The results of the correlation coefficient indicate heterogeneity across crops in the influence of socio-economic factors and institutional access. Among cocoa farmers, being male and a member of a farmer group significantly reduces the likelihood of pesticide use $p < 0.05$ with marginal effect of about 16%, while farm size positively predicts use by 7.7%. We find similar result in the extended model estimates. For coffee farmers, age negatively influences pesticide use, while access to land rights, owning a mobile phone, and larger farm size significantly increase the probability of pesticide use. Non-farm income is associated with reduced pesticide use, suggesting a substitution effect.

In the extended model Equation 4, interaction effects reveal deeper mechanisms. Notably, for coffee and cassava farmers, the combined effect of education and access to extension services significantly increases the likelihood of pesticide use $p < 0.01$ with marginal effect above 80%, highlighting the importance of knowledge pathways. Conversely, the interaction between market access and cooperative membership reduces pesticide use by 13.8% among cassava farmers, suggesting that collective marketing structures may support more cautious pesticide behavior. Access to extension alone is associated with a strong reduction in pesticide use among both coffee and cassava farmers, reinforcing its central role in promoting sustainable practices. Overall, these findings emphasize the differentiated effects of education, access to services, and institutional factors across crops and underscore the need for crop-specific policy targeting in pesticide risk mitigation.

4.4 Determinants of organic pesticides use

This section presents the results of logistic regression estimates of the factors influencing the use of organic pesticides—biopesticides such as neem seed or leaf extracts—among cocoa, coffee, and cassava farmers. Table 4 reports the results from Equation 3, which considers direct effects, and the interaction terms to capture moderating effects (Equation 4). In Table 4, land rights and non-farm income consistently exhibit strong and significant positive effects across all three crops. Farmers with secure land tenure are significantly more likely to adopt organic pesticide practices, suggesting that tenure security encourages long-term investment in environmentally sustainable inputs.

Access to agricultural extension services positively and significantly influences organic pesticide adoption among cocoa farmers, but not for coffee or cassava. Interestingly, education has a negative effect on adoption for cocoa and cassava farmers, a counterintuitive result that may suggest educated farmers lean more toward conventional pesticide use, possibly due to their greater access to commercial products or skepticism about traditional methods.

Among cassava farmers, gender significantly influences organic pesticide use, with female farmers less likely to adopt. Additionally,

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TABLE 3 Logistic regression estimates of the determinant of pesticides use.

Explanatory variables	Cocoa farmers				Coffee farmers				Cassava farmers			
	Equation 3		Equation 4		Equation 3		Equation 4		Equation 3		Equation 4	
	dy/dx	Robust SE	*dy/dx*	Robust SE	*dy/dx*	Robust SE	*dy/dx*	Robust SE	*dy/dx*	Robust SE	*dy/dx*	Robust SE
Age years	0	0.002	0	0.002	−0.003**	0.002	−0.003**	0.002	0.002	0.001	−0.002	0.002
Gender[d]	−0.163**	0.070	−0.163**	0.073	−0.026	0.051	−0.024	0.051	0.037	0.031	0.039	0.031
Education[d]	0.055	0.059	0.066	0.067	0.039	0.029	0.036	0.030	−0.035	0.024	−0.045*	0.026
Household size	−0.006	0.010	−0.004	0.010	0.008*	0.005	0.007	0.005	0.005	0.004	0.004	0.004
Membership[d]	−0.158**	0.065	−0.125**	0.070	0.037	0.030	0.032	0.038	−0.022	0.035	0.007	0.035
Access to extension[d]	0.077	0.065	0.152	0.107	−0.006	0.044	−0.921***	0.161	−0.047	0.065	−0.775***	0.169
Credit access[d]	0.009	0.084	0.073	0.100	0.060	0.039	0.046	0.041	0.012	0.034	0.022	0.040
Access to market price[d]	0.049	0.064	0.088	0.080	0.032	0.032	0.013	0.038	−0.022	0.050	0.019	0.057
Dist. to pesticides dealer km	0.003	0.002	0.003	0.002	0.002*	0.001	0.002*	0.001	−0.001	0.001	−0.001	0.001
Own mobile phone[d]	−0.015	0.069	−0.018	0.068	0.087**	0.040	0.093**	0.039	−0.038	0.031	−0.039	0.032
Total farm size acre	0.002*	0.001	0.002*	0.001	0.005***	0.001	0.005***	0.001	0.004**	0.002	0.005**	0.002
Have land rights[d]	–		–		0.164***	0.043	0.160***	0.042	0.141**	0.065	0.164**	0.078
Number trusted traders	−0.009	0.021	−0.009	0.022	0.016	0.015	0.019	0.015	−0.009	0.013	−0.009	0.015
Non-farm income[d]	−0.051	0.061	−0.041	0.062	−0.063*	0.033	−0.065**	0.032	0.010	0.030	0.014	0.033
Edu * extension	–		−0.068	0.128	–		0.894***	0.160	–		0.796***	0.181
Credit * extension	–		−0.166	0.169	–		0.102	0.104	–		–	
Market * membership	–		−0.083	0.132	–		0.033	0.059	–		−0.138**	0.063
Number of obs	229		229		320		320		291		281	
Log pseudo likelihood	−105.22		−104.25		−72.59		−71.940		−54.211		−51.116	
Wald chi^2	18.89		20.93		42.03		540.68		26.99		169.75	
Prob > Chi^2	0.127		0.181		0.000		0.000		0.019		0.000	
Pseudo R^2	0.084		0.092		0.367		0.372		0.163		0.203	

[d]Represent binary variable 1, 0; ***, **, and * denotes significant at p-value of 1%, 5%, and 10% respectively.
Source: Field survey, 2023.

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TABLE 4 Logistic regression estimates of the determinant of organic pesticides use.

Explanatory variables	Cocoa farmers				Coffee farmers				Cassava farmers			
	Equation 3		Equation 4		Equation 3		Equation 4		Equation 3		Equation 4	
	dy/dx	Robust SE	*dy/dx*	Robust SE	*dy/dx*	Robust SE	*dy/dx*	Robust SE	*dy/dx*	Robust SE	*dy/dx*	Robust SE
Age years	0.001	0.002	0.001	0.002	−0.001	0.001	−0.001	0.001	0.001	0.002	0.001	0.002
Gender[d]	0.016	0.058	0.007	0.059	0.017	0.037	0.017	0.036	0.106*	0.056	0.104*	0.055
Education[d]	−0.106**	0.045	−0.067	0.054	−0.014	0.039	−0.023	0.040	−0.096*	0.049	−0.117**	0.049
Household size	−0.011	0.008	−0.012	0.008	0.009*	0.005	0.010*	0.006	−0.008	0.007	−0.010	0.007
Membership[d]	−0.091*	0.047	−0.110**	0.053	−0.077*	0.042	−0.044	0.047	−0.060	0.057	−0.012	0.064
Access to extension[d]	0.107**	0.053	0.174**	0.082	0.044	0.073	−0.006	0.068	−0.087	0.085	−0.220	0.150
Credit access[d]	−0.100	0.067	−0.136	0.082	0.008	0.053	0.029	0.058	−0.027	0.059	0.020	0.062
Access to market price[d]	−0.007	0.051	−0.042	0.078	0.022	0.0368	0.071	0.047	0.079	0.059	0.174**	0.086
Dist. to pesticides dealer km	0.005**	0.002	0.005**	0.002	0.002*	0.001	0.002	0.001	−0.003	0.002	−0.003	0.002
Own mobile phone[d]	−0.077	0.050	−0.072	0.050	−0.094***	0.034	−0.097***	0.034	−0.040	0.053	−0.043	0.054
Total farm size acre	−0.000	0.001	−0.000	0.001	0.002	0.004	0.002	0.004	0.000	0.004	0.000	0.004
Have land rights[d]	0.415***	0.069	0.404***	0.069	0.299***	0.043	0.283***	0.040	0.248***	0.070	0.256***	0.069
Number trusted traders	−0.021	0.017	−0.019	0.017	0.048**	0.019	0.045**	0.018	−0.013	0.020	−0.011	0.019
Non-farm income[d]	0.161***	0.042	0.158***	0.042	0.151***	0.036	0.151***	0.035	0.115**	0.048	0.117**	0.048
Edu * extension			−0.128	0.103			0.117	0.100			0.231	0.197
Credit * extension			0.051	0.129			−0.123	0.134			−0.055	0.185
Market * membership			0.070	0.104			−0.119	0.077			−0.154	0.108
Number of obs	330		330		320		320		291		291	
Log pseudo likelihood	−144.66		−143.37		−87.662		−85.85		−134.12		−131.99	
Wald chi^2	54.05		55.96		80.52		84.48		31.92		36.27	
Prob > Chi^2	0.000		0.000		0.000		0.000		0.004		0.004	
Pseudo R^2	0.232		0.239		0.470		0.481		0.139		0.153	

[d]Represent binary variable 1, 0; ***, **, and * denotes significant at *p*-value of 1%, 5%, and 10% respectively.
Source: Field survey, 2023.

distance to pesticide dealers significantly increases the likelihood of organic pesticide use among cocoa and coffee farmers, implying that remoteness may limit access to synthetic chemicals and encourage alternatives. The interaction models Equation 4 model provide little insights. The positive and significant coefficient of the education-extension interaction for cassava, although not statistically significant, suggests that when educated farmers have access to advisory services, they are more likely to consider organic options, hinting at complementarities between formal knowledge and contextual advice. Similarly, among cocoa farmers, the inclusion of interaction terms slightly improves model fit pseudo-R^2 = 23.9% vs. 23.2%, affirming the role of institutional interactions in shaping adoption.

4.5 Determinants of IPM adoption

Table 5 presents the logistic regression estimates for the determinants of IPM adoption among cocoa and cassava farmers. The results of the marginal effect are derived from Equations 3, 4. Given the very low rate of adoption of IPM among coffee farmers we do not estimate it determinants. The models appear significant for both cocoa and cassava farmers. Among cocoa farmers, access to extension services significantly increases the likelihood of IPM adoption, with a marginal effect of 16.6%. This suggests that farmers who receive extension advice are substantially more likely to adopt IPM practices.

However, when the interaction between education and extension is introduced Equation 4, the positive effect of extension is moderated by the negative and significant interaction term with a marginal effect of 68.3%, indicating that better-educated farmers may rely less on extension services for IPM knowledge or that the current extension messages may not be well-targeted to their needs.

Membership in farmer organizations negatively affects IPM adoption across both groups, particularly among cocoa farmers, where the marginal effect is a significant 10.3% reduction. This is counterintuitive and may reflect internal dynamics within these groups that discourage experimentation with non-conventional methods, or that IPM knowledge is not adequately disseminated through these networks. Farmers with secure land tenure are more likely to adopt IPM practices across both crops, with marginal effects of 10.9–12.6%.

Interestingly, farm size exhibits contrasting effects: larger cocoa farms are associated with a lower probability of IPM adoption, while cassava farmers with larger holdings are slightly more likely to adopt. Moreover, the distance to pesticide dealers negatively correlates with IPM adoption among cocoa farmers, suggesting that farmers far from pesticide outlets may opt for IPM as a more accessible or cost-effective alternative. Education is strongly associated with higher IPM adoption only in Equation 4 for cocoa farmers, where its interaction with extension services is significantly negative.

For cassava farmers, access to extension 8.3–8.5% and land tenure 11.9–12.6% are consistently significant drivers of IPM use. Non-farm income also positively affects adoption about 5%, indicating that households with additional income sources may be more financially capable of adopting improved pest management techniques. Lastly, trust in market intermediaries measured as the number of trusted traders shows divergent effects: it discourages IPM adoption among cocoa farmers but encourages it among cassava farmers. This contrast may stem from different value chain structures or variations in how traders influence input choices across crop systems.

4.6 Perceptions of non-farm value chain actors on pesticide use and IPM adoption

This section synthesizes insights from key value chain actors including input suppliers, processors, and buyers on pesticide use and the adoption of IPM practices in Liberia. The findings reveal several systemic challenges and opportunities that shape pest control strategies along the cocoa, coffee, and cassava value chains. Among input suppliers, the pesticide market is dominated by imported products, with only one-third of respondents reporting trade in locally produced pesticides. Moreover, most suppliers 12 out of 14 source their stock from outside the county, indicating limited local access to agricultural inputs.

However, these efforts are constrained by several structural barriers. Input suppliers identified high input costs, limited sourcing options, poor road infrastructure, and concerns about product quality as the major impediments to their operations. Cassava processors reported sourcing roots either from local farmers or their own plots and typically processing them within one to seven days of harvest. They do not use pesticides, emphasizing sensory attributes such as taste, texture, and aroma in their product standards. This perspective was mirrored by cassava consumers, who noted varying shelf life across different cassava-based products. The limited relevance of pesticide use in cassava processing reflects the low incidence of postharvest pest concerns in root crops.

In contrast, cocoa and coffee buyers exhibit a different orientation. None of the interviewed buyers had organic certification, and only 19.4% reported labeling their products by origin. Quality assessment was primarily conducted through visual inspection or bean cracking. Although most buyers require adherence to postharvest protocols, particularly for fermentation and drying. As only 15.4% explicitly demanded low pesticide residues, and just 7.7% mentioned labor standards such as child labor restrictions. Notably, none required organic certification or pesticide-free production. Furthermore, only 8% of buyers stored cocoa or coffee beans without the application of chemicals for pest control. These findings suggest that while market actors recognize the importance of quality control, there is minimal formal demand for low-pesticide or organic products.

4.7 Robustness check

Prior to our estimation of the determinants of pesticides use, we assessed the potential for multicollinearity among

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TABLE 5 Logistic regression estimates of the determinant of IPM adoption Equations 3, 4.

Explanatory variables	Cocoa farmers				Cassava farmers			
	Equation 3		Equation 4		Equation 3		Equation 4	
	dy/dx	Robust SE	*dy/dx*	Robust SE	*dy/dx*	Robust SE	*dy/dx*	Robust SE
Age years	0.001	0.001	0.001	0.001	−0.002	0.001	−0.002	0.001
Gender[d]	0.039	0.057	0.014	0.048	−0.011	0.034	−0.019	0.036
Education[d]	−0.013	0.025	0.642***	0.133	0.066	0.040	0.056	0.047
Household size	−0.006	0.006	−0.006	0.006	0.003	0.004	0.003	0.004
Membership[d]	−0.074**	0.030	−0.103***	0.032	−0.068*	0.041	−0.054	0.041
Access to extension[d]	0.166***	0.023	0.788***	0.140	0.083***	0.029	0.085	0.055
Credit access[d]	0.031	0.026	−0.004	0.055	−0.003	0.042	0.032	0.039
Access to market price[d]	0.010	0.026	−0.024	0.048	−0.026	0.033	−0.012	0.045
Dist. to pesticides dealer km	−0.003***	0.001	−0.003***	0.001	0.002	0.001	0.002	0.001
Own mobile phone[d]	−0.029	0.030	−0.024	0.028	−0.041	0.039	−0.048	0.041
Total farm size acre	−0.008**	0.003	−0.007**	0.003	0.003*	0.002	0.003*	0.002
Have land rights[d]	0.109**	0.044	0.112**	0.050	0.119**	0.050	0.126***	0.048
Number trusted traders	−0.033**	0.011	−0.027**	0.011	0.023**	0.010	0.021**	0.009
Non-farm income[d]	0.008	0.025	0.006	0.023	0.052*	0.028	0.053*	0.030
Edu * extension	–		−0.683***	0.141	–		0.039	0.070
Credit * extension	–		0.042	0.060	–		–	
Market * membership	–		0.067	0.053	–		−0.012	0.071
Number of obs	330		330		291		281	
Log pseudo likelihood	−49.033		−44.162		−61.313		−59.133	
Wald chi^2	56.43		2059.16		39.27		42.59	
Prob > Chi^2	0.000		0.000		0.000		0.000	
Pseudo R^2	0.446		0.5012		0.238		0.257	

[d]Represent binary variable 1, 0; ***, **, and * denotes significant at *p*-value of 1%, 5%, and 10% respectively.
Source: Field survey, 2023.

explanatory variables by computing pairwise correlation coefficients. These results are reported in Appendix Tables 1a–1c. The analysis shows no evidence of strong multicollinearity, as all correlation coefficients are well below the conventional threshold of 0.5, indicating that the covariates used in the model are sufficiently independent. Additionally, we conducted a series of post-estimation diagnostic tests to ensure the robustness of our findings. First, we assessed multicollinearity among the explanatory variables using the Variance Inflation Factor VIF. As reported in Appendix Table 2, all VIF values are well below the commonly accepted threshold of 5, indicating no significant multicollinearity concerns. Second, we re-estimated our models using a probit specification as an alternative to the logistic regression framework. The probit estimates, presented in Appendix Tables 3–5, are consistent in sign, magnitude, and statistical significance with those obtained from the logistic models for both Equation 3 and Equation 4. This consistency across estimation techniques reinforces the reliability and stability of our main results.

5 Discussion

To address the challenges posed by pest infestation without harming the environment or post threat to farmers and consumers health, there is a need for judicious and effective use of chemical pesticides and IMP. Our findings show low awareness of IPM among farmers of the various crop commodities, despite the over reliance on information from NGO. While approximately 20–25% of market-oriented crop are aware of IMP, less than 10% of staple crop farmers are aware of IPM. Nevertheless, there is very low adoption rates of both chemical pesticides and IPM across the crop categories. Although, between 12% and 14% of the market-oriented crop adopt chemical pesticides while less than 6% of the staple crop farmers reported using chemical pesticides. In contrast about 8% of them indicates using IPM and more than 20% of them used organic pesticides irrespective of the category of crop specialization. These findings align with overreaching of the conventional evidence of low uptake of modern and improve farm technologies and practices in many SSA countries (Gianessi and Williams, 2011; Oerke and Dehne, 2004; Rahman, 2021; Timprasert et al., 2014; Sheahan and Barrett, 2017; Williamson et al., 2008; Zhang et al., 2011). Nevertheless, the overwhelming reliance on NGOs for training is a strong indictment of the public extension system, as we find that majority of the farmers across crop specialization sources information and obtained training from NGOs. While agricultural extension and education play a crucial role in knowledge transfer to farmers (Moumenihelali and Amooghli-Tabari, 2025), it is important for government to strengthen public extension services to complement the activities of the NGO to boost adoption of IPM and effective pesticides application. Likewise, inadequate knowledge about IPM practices is the main reason for the its low adoption among farmers across specialization, and this aligns with the report that farmers often lack the adequate knowledge of IPM techniques (Rahman, 2021). This may be largely attributed to the complexity nature of IPM. Generally, this pattern reflects the broader structural challenges in agricultural knowledge dissemination systems, where public extension is often underfunded or fragmented (Ragasa and Niu, 2017; Paul Jr et al., 2023; Wilson and Tisdell, 2001). Strengthening coordinated, multi-actor IPM outreach including public agencies, NGOs, cooperatives, and agro-dealers is essential for scaling up adoption and reducing farmers' reliance on hazardous pesticides (Pretty and Pervez Bharucha, 2015).

Considering the determinant of chemical pesticide use, the statistical insignificance of our model for cocoa farmers' pesticide may be attributed to omitted variable bias or endogeneity arising from unobserved factors correlated with key covariates (Wooldridge, 2010; Angrist and Pischke, 2009). Additionally, the effect of the covariates may be highly context-specific, varying across institutional, geographic, or socio-economic environments, which can attenuate average estimated effects (Deaton, 2010; Pritchett and Sandefur, 2015). However, we find negative and significant association between age and pesticides use only for coffee farmers while gender only matters among cassava farmers across all models, as female farmer is more likely to use pesticide relative to male cassava farmer. Also, we find access to formal education to be negative and significantly associated with pesticide use among cassava farmers, while membership of association is significantly associated with reduced pesticides use among cocoa farmers only across all models. Access to extension is also significant and negatively associated with pesticides use among coffee and cassava farmers across all model. In contrast, we find strong positive association between farm size, land right ownership and pesticides use across all farmers groups and models. This result aligns with the report by Bandanaa et al. (2024), Denkyirah et al. (2016), and Lelamo et al. (2023), who argued that education, farmer training, knowledge, access to pesticides shop and agricultural offices are key determinant of pesticides use. Migheli (2017) also emphasized the role of farm size and land ownership in pesticides use.

Unlike the determinant of chemical pesticide, gender is positively associated with organic pesticide use across all model, as male cassava farmers are more likely to use organic pesticides than their female counterpart. Access to extension service is only significant and positively associated with organic pesticide use among cocoa farmers. While find evidence of positive association between household size, distance to pesticides shop and organic pesticide use only for coffee and cocoa farmers, membership of association is negatively associated with organic pesticides use across model for cocoa and coffee farmers. We also find that membership of association and access to mobile phone is negatively associated with organic pesticides use only among coffee farmers and partially among cassava farmers. Interestingly, land right ownership and access to non-farm income is more likely to be positively associated with the use of organic pesticides—partly like the determinant of chemical pesticides.

Regarding IPM adoption, while we find that access to education and extension is significant and positively associated with IPM adoption among cocoa farmers across all model, we only find the same association for access to extension only among cassava farmers. Education and extension can shape farmers' knowledge of pest management and awareness of the health and environmental cost of pesticides use which may affect IPM adoption (Moumenihelali and Amooghli-Tabari, 2025; Timprasert et al., 2014; Parsa et al., 2014; Shrestha et al., 2024). However, farmers with access to both education and extension are less likely to adopt IPM particularly among cocoa farmers given the interaction effect. On the other hand, we find membership of association to be negatively associated with IPM adoption, while having land right is positively associated with IPM adoption significantly across model among cocoa and cassava farmers. Cassava farmer that has non-farm income are also more likely to adopt IPM. Lastly, we find that number of trusted traders is negatively associated with IPM adoption for cocoa farmers but positive for cassava farmers significantly. Our finding that buyers do not demand low-pesticide or organic products directly explains the lack of market incentive for IPM adoption, particularly for cocoa and coffee farmers, validating our initial hypothesis. Our findings resonate with the report that capacity building through association and stable relationships with traders are more likely to influence the adoption of sustainable farming practices (Tennhardt et al., 2023; Grovermann et al., 2015).

6 Conclusion and recommendations

In this paper we examined the knowledge and drivers of pesticide use and integrated pest management in Liberia, as utilized a unique data set from 336 cocoa, 320 coffee farmers, and 291 cassava farmers selected using a multistage stratified sampling procedure across four counties. We also utilized unique data from value chain actors including aggregator and processors to validate their roles in diffusion of innovation regarding uptake of IPM and pesticides used. The data were analyzed using descriptive statistics and logistic models. Our results show the difference and similarity in the determinants of pesticides and IPM use between farmers producing market-oriented crops i.e., cocoa and coffee and those prominent in cassava production.

Our findings are in three folds. First, like conventional knowledge regarding adoption of improved input use, we find low use of pesticides and IPM adoption among both farmers group. Although, there is higher use of pesticide than IPM adoption among cocoa farmers while there is no much difference in the use of pesticide and IPM adoption among cassava farmers. Secondly, we find over reliance on extension services from NGOs, as government extension agents have no or little contact with farmers which explain the reason for low adoption of IPM practices. Third, there is similarity and differences in the factors influencing various pest control methods across crop group or specialization. For instance, while access to education and extension increase adoption of adoption of organic pesticides and IPM particularly among cocoa and coffee farmers, it reduces the use of chemical pesticides among cassava and coffee farmers. Farm size and land right ownership is associated with increase pesticides use across all crop groups, all else equal.

We therefore recommend that the need to expand extension services and strengthening market information systems by the government, private sector, and NGO to improve pest management especially adoption of IPM and organic production system. Likewise, training and awareness programs, leveraging farmers' organizations as key players in promoting sustainable pest management, regulating chemical pesticides to promote environmentally sustainable and economically viable pest management practices, and ultimately enhancing food security and farmers' livelihoods. Overall, these findings underscore the importance of tailored policy approaches that consider crop-specific constraints, the quality of institutional support especially extension, and the socioeconomic context of farmers in promoting sustainable pest management practices.

This study has several limitations. First, despite the uniqueness of the dataset, the analysis relies on cross-sectional data, which limits causal inference and does not allow us to address possible endogeneity due to omitted and time-varying unobservable. Future research using panel data could strengthen causal interpretation. Second, our analysis relied on farmers' recall (i.e., self-reporting bias) as the data collected were based on the previous farming season, which may have affected our estimates. Third, while the inclusion of value chain actors provides important insights into market incentives for pesticide use and IPM adoption, our evidence on quality assessment and reward mechanisms remains exploratory. In terms of the traders, buyers, and processors included in this study, these participants may not fully reflect the diversity of actors and governance structures that exist within cocoa, coffee and cassava value chains, especially with regard to large multi-national buyers and exporters who may apply sustainability standards differently than small-scale intermediaries. Consequently, we were unable to thoroughly examine how observable and unobservable best agricultural practices are identified, verified and rewarded; therefore, future studies should employ larger and more stratified samples of downstream actors to further investigate how pesticide-related standards and price incentives are transmitted throughout the value chain and influence farmers' decisions to adopt IPM and alternative pest management strategies.

Data availability statement

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

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

MY: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. IO: Conceptualization, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. RB: Conceptualization, Data curation, Funding acquisition, Investigation, Resources, Supervision, Validation, Writing – review & editing. ED-O: Conceptualization, Data curation, Funding acquisition, Investigation, Resources, Supervision, Validation, Writing – review & editing. VB: Conceptualization, Data curation, Funding acquisition, Investigation, Validation, Writing – review & editing. SF: Data curation, Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing. TA: Data curation, Methodology, Supervision, Validation, Visualization, Writing – review & editing. SO: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, 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.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2026.1603653/full#supplementary-material

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