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RECEIVED 30 June 2025

ACCEPTED 27 October 2025

PUBLISHED 25 November 2025

CITATION

Mayamba A, Mutuku B, Ayuya OI, Kansime M,
Bateman M, Phelps S, Aloit C,
Owembabazi L, Aliamo C, Bundi M, Ochilo W,
Bitange N, Lutomia CK, Jong AO and
Alworah GO (2025) Gendered risk
perceptions and structural barriers to
sustainable pest management: evidence from
Uganda's tomato value chain.
Front. Sustain. Food Syst. 9:1656739.
doi: 10.3389/fsufs.2025.1656739

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Gendered risk perceptions and structural barriers to sustainable pest management: evidence from Uganda's tomato value chain

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Sustainable pest management amid the intensifying adverse effects of climate change is critical to the resilience of agrifood systems. Yet the transition to low-risk and sustainable pest management practices, which often unfolds within gendered and generational constraints, remains limited in sub-Saharan Africa. This study aimed to examine how risk perceptions of pesticides influence pest management decisions among 584 men, women, youth, and non-youth farmers in five regions of Uganda. While chemical pesticides were broadly perceived as high-risk, farmers continued to use them due to structural constraints, such as market pressures, limited access to low-risk alternatives, and gendered decision-making dynamics. Biopesticides were perceived as low risk but remained underutilized, particularly among women and youth. Barriers to the use of biopesticides included affordability, limited availability, inadequate advisory services, and insufficient promotion of biopesticides as a safer alternative to chemical pesticides. The results indicated that risk awareness alone does not necessarily translate into the adoption of low-risk and sustainable pest management practices. Interventions must address both supply-side constraints and power asymmetries to strengthen the resilience and agency of marginalized groups within climate-vulnerable food systems.

KEYWORDS

climate-smart agriculture, gender, youth, pesticides, gendered risk perception, pest management, biopesticides, sustainability

1 Introduction

The need to reduce the environmental and health impacts of farm chemical inputs is gaining traction globally (Garcia, 2020; UNEP, 2024). Shifts toward sustainable pest and disease management through eco-friendly agricultural practices have become paramount in addressing the negative externalities of chemical pesticides while maintaining or increasing productivity (Wilson and Tisdell, 2001; Tyagi et al., 2019; Kumar and Khurana, 2024). Within the broader push for climate-smart agriculture, pest management practices that simultaneously

enhance productivity, reduce ecological harm, and increase adaptive capacity have become essential to the resilience of food systems.

Biopesticides, defined as “commercial products or homemade preparations containing active substances made from living or dead microorganisms, such as bacteria, algae, protozoa, viruses, and fungi; pheromones and other semiochemicals; and plants or parts of plants designed to repel, destroy, or control any pest or regulate the growth of plants,” have emerged as viable alternatives to chemical pesticides (Codex Alimentarius, 2022). They are considered less toxic to non-target species and the environment and are increasingly promoted as integral to integrated pest management (IPM) strategies (Samada and Tambunan, 2020; Fenibo et al., 2022; Sawangproh et al., 2025). Commercial biopesticides are defined as products produced by agrochemical companies and recognized by farmers, including microbes, trap cropping, and branded products that are sold in the market. Homemade preparations, known locally as ‘homemade biopesticides’ for pest control, are formulated at the household level, mainly from plant-based ingredients (International Programme on Chemical Safety, 2019).

Despite their potential contribution to climate-smart agriculture and food safety, smallholder farmers in sub-Saharan Africa rely heavily on chemical pesticides (Wilson and Tisdell, 2001; Van Huis, 2009). This reflects both the perceived efficacy of synthetic pesticides and market pressures on outbreaks (Sheahan et al., 2017; Midingoyi et al., 2019). Continued use of high-risk pesticides also reflects structural inequalities and limited access to biopesticides. Barriers such as limited knowledge, resource constraints, restrictive social norms, and a weak policy environment impede transitions toward sustainable pest management (Rwomushana et al., 2019; Kumar and Khurana, 2024).

In high-value, pest-prone crops like tomato, farmers are incentivized to prioritize yields and higher market supplies by using synthetic pesticides, even at the expense of long-term ecological and health risks (Fenibo et al., 2021; Ayilara et al., 2023). For instance, 89% of vegetable vendors, with tomato being the most traded in Fort Portal (Kabarole District, western Uganda), acknowledged the use of synthetic pesticides in production. Nevertheless, 44% expressed a preference for vegetables sprayed with pesticides (Ndagire et al., 2024). These dynamics underscore the importance of intersectional analysis in pest management practices to understand the differentiated capacities, constraints, and risks experienced by men and women in adopting alternative approaches.

Biopesticides and cultural practices offer climate-resilient alternatives. With technical training, they can be prepared using locally available materials (Fenibo et al., 2021, 2022). They also align with broader climate mitigation goals by reducing chemical runoff and emissions associated with synthetic inputs (Fenibo et al., 2021, 2022). However, the use of commercial biopesticides remains low in Uganda, largely due to unavailability (Udayanga et al., 2024). As of 2022, only 16 out of 643 registered agricultural chemical products in Uganda contained at least one biopesticide component (Ministry of Agriculture, Animal Industry and Fisheries, Republic of Uganda, 2022). Conversely, nearly 65% of registered active ingredients are classified as highly hazardous under FAO/WHO criteria, raising serious concerns for food safety (Yahyah et al., 2024; Musoke, 2025).

Tomato production offers a critical lens through which to examine gender dynamics in pest management. Climate change has intensified pest prevalence, exposing limitations in conventional chemical

solutions and reinforcing the need for adaptive, low-risk strategies. In Uganda, tomato production is particularly pesticide-intensive. Ddamulira et al. (2021) found that 96% of tomato farmers in eight districts across five agroecological zones reported using chemical sprays. Of these, 62% were sprayed weekly and 21% twice a week. These statistics align with broader national trends: Uganda accounts for approximately 0.1% (18,928 tonnes) of global pesticide consumption, with usage escalating in recent years (Nasiima, 2025). Commonly used products such as glyphosate-based Roundup and Weed Master have been linked to soil degradation and potential carcinogenicity (Musoke, 2025).

However, low-risk pest management alternatives are not equally accessible or adopted. Gendered and generational inequalities in access to resources and decision-making authority shape pest management behavior and risk exposure (Christie et al., 2015; Okonya et al., 2021). The issue stems from a lack of awareness and training on alternative pest control methods, as well as safe use of chemical pesticides, compounds, and existing structural barriers. For example, only 8% of farmers in vegetable-producing districts could interpret pesticide labels, while 41% reported no access to training on pesticide use (Nasiima, 2025). This knowledge gap has contributed to an estimated 20,000 cases of pesticide poisoning annually in Uganda (Musoke, 2025).

The limited uptake of sustainable pest management practices is more pronounced among women, largely due to intersecting challenges including low access to information, training, and capital (Christie et al., 2015). Cultural norms often restrict women and youth participation in pest management decisions, while gender roles may expose different groups to varying degrees of chemical hazards or exclude them from information on low-risk alternatives. Moreover, perceptions of both pest and disease severity, as well as perceived effectiveness of different control methods, are gendered (Erbaugh et al., 2003; Ntow et al., 2006). Despite these dynamics, there is limited focus on how pesticide risk perceptions influence pest management practices through a gender and generational lens.

This study addresses this gap by investigating the relationship between pesticide risk perceptions and the adoption of pest management practices in tomato production. It focuses on gendered decision-making, defined here as differential control over pest management decisions based on intra-household power dynamics and generational factors. The study examines how perceptions of health, environmental, and food safety risks associated with both chemical pesticides and biopesticides influence farmers’ pest management decisions. Guided by established behavioral and gender frameworks, the study explored the hypothesis that farmers’ risk perceptions are associated with the adoption of low-risk pest management practices, with variation by gender and age. Findings reveal how structural and behavioral barriers constrain the uptake of sustainable pest management practices among tomato farmers and contribute to the literature on inclusive agricultural transitions by highlighting the intersection of risk perception, gendered agency, and pest management.

2 Conceptual framework

The health and social risks cover perceptions of the effect of exposure to pesticides on individual health and vulnerable groups

(Shammi et al., 2020; Higley, 2025). In this study, health and social risks encompass farmers' perceptions of the potential harm to household members and vulnerable groups, including unborn infants, children, pregnant and nursing women, and the elderly. Environmental risks refer to concerns about the effects of pesticides on soils, water, biodiversity, and pest resistance (Lelamo et al., 2023). The last dimension is food safety risks, which refers to the perceived effect of pesticide residues on food safety and consumer health (Koch et al., 2017; Beyuo et al., 2024; Tambo et al., 2024).

This study was grounded on three integrated theoretical models to explain how risk perceptions shape adoption decisions in pest management. First, we integrated the concepts of threat appraisal, coping appraisal, and behavior change of the protection motivation theory (PMT) (Badsar et al., 2023; Abdollahzadeh et al., 2024). The threats considered by the farmers were framed as health and environmental risks associated with pesticide use. Coping appraisal compared the efficacy of biopesticides vs. chemical pesticides via risk perception questions and farmers' ability to use them, given access to resources, training, and advisory services. The study argues that men and women, as well as young and older farmers, may appraise risks differently due to differences in knowledge, access to support services, resources, constraints, and roles in pest management and households (Asmare et al., 2022).

The technology acceptance model (TAM) was used to explain how farmers' perceptions influence pest management adoption decisions. Specifically, we applied perceived usefulness and perceived ease of use to explain the adoption of chemical pesticides, biopesticides, and cultural methods. Perceived usefulness is a farmer's belief that either chemical pesticides or biopesticides are effective. The study expected perceived ease of use (e.g., safety and simplicity) to be associated with gender roles in pest management and age (Sharifzadeh et al., 2017). The study also applied a gender relations framework to demonstrate the role of access to resources, gender roles, and power dynamics in influencing the adoption of pest management practices. Resources considered were education, credit, training, and advisory services. Social norms often position men as household heads and primary decision-makers in resource allocation and pest management. The gender relations framework also allowed an intersectional analysis of gender and socioeconomic disparities in the context of pest management (Tavener et al., 2022).

3 Materials and methods

3.1 Study area

The study was conducted in the Western, Northern, Central, and Eastern regions of Uganda. One district was selected from each region: Kasese in Western Uganda, Gulu in the Northern region, Mukono in the Central region, and Sironko in the Eastern region. Farmers in these districts are actively involved in tomato production. Some of these districts are project areas for interventions in the tomato value chain. For instance, the Action for Livelihood Enhancement in Northern Uganda (ALENU) project is active in Gulu district, and the tomato farming is part of the Presidential Initiative on Wealth and Job Creation in Mukono district. Kasese and Sironko districts are high-potential tomato-producing zones for their fertile volcanic soils and favorable agroecological conditions.

The global PlantwisePlus program implemented by CABI International (CABI) in 27 countries supports smallholder farmers to improve their incomes and livelihoods by promoting sustainable crop production for safer and higher-quality food products. The implementation of PlantwisePlus was mainly concentrated on six focus countries: Kenya, Ghana, Pakistan, Zambia, Uganda, and Bangladesh. For over 10 years, the program has evolved from the Plantwise and Action on Invasives programs that addressed tomato pests and diseases in tomato production through plant clinics (2011–2021) to building the capacity of farmers and plant health systems to predict, prepare for, and prevent plant health threats, especially in the context of climate change (CABI, 2025). CABI started integrating community conversations into Plantwise programs to address gender inequalities and other constraints (e.g., gender roles, workload, time constraints, and mobility issues) that are major challenges to women's active involvement in pest and disease management.

In Uganda, PlantwisePlus reached 22 districts across diverse agroecological zones. Two of the four districts, Kasese and Mukono, had established PlantwisePlus program presence, while the other two had no direct exposure to its interventions. This heterogeneity captures a wider spectrum of tomato-producing contexts, enhancing the representativeness of districts both exposed and unexposed to the program in the study.

3.2 Sampling and data collection

A mixed-methods study involving a household survey for quantitative data and qualitative data collection was conducted from October to November 2024. A multistage random sampling was used to select the study participants. A purposive sampling technique was used to select Uganda and the four regions (Western, Northern, Central, and Eastern regions of Uganda). The districts were purposively selected to capture variation in agroecological and socioeconomic conditions of tomato producers in Uganda. Kasese district represented high altitudes and mixed farming systems in Uganda, where smallholder farmers cultivate small- to medium-sized plots. Most farmers have moderate access to output markets and extension services. Located in the Northern Uganda Agroecological Zone with moderate rainfall, the Gulu district features larger land holdings but generally low-income levels, partly due to the district's recovery from historical conflicts. Mukono district is situated within the Lake Victoria zone, which is characterized by small landholdings and intensive horticulture. Sironko is situated in the Eastern Highlands Agroecological Zone, with a unique climate. Farmers in Sironko manage small to medium acreage of land and practice intensive mixed farming, with tomatoes being one of the most grown vegetables. The selection of the four districts was not only purposed to ensure agroecological and socioeconomic representativeness but also to cover the diverse experiences with tomato pests and diseases.

The second phase involved stratified random sampling at sub-counties, parishes, and villages within each district. Further, the sampling relied on lists of farmers provided by market agents, farmers' groups, and district extension officers. These lists constituted the sampling frame from which participants were randomly drawn, ensuring the inclusion of diverse socio-economic profiles of farmers. However, deliberate quotas were implemented to achieve a balance in terms of gender and age group, with at least 40% women and 30%

young people in each district. The procedures resulted in a sample of 584 farmers. The distribution of the 584 farmers by districts is shown in [Table 1](#). The study also collected data from six key informants: a female farmer group representative and community-based facilitator, two district agricultural officers (male and female), one food safety NGO representative (male), an online private pesticide dealer (male), and a district labor officer (female).

3.3 Development of data collection tools

Two sets of data collection instruments were developed: a household questionnaire to collect quantitative data from farmers and an interview schedule to collect information from key informants. Development of these tools followed a four-stage process. The first stage involved a desk review of academic studies (e.g., peer-reviewed articles and research papers) focusing on how differently men, women, and youth engage with pest management and biocontrol technologies. This review also focused on two key areas of pest management—health and environmental risks of pesticides and eco-friendly alternatives—to build a solid foundation and understanding of the current landscape in pest management. Attention was given to understanding the importance of IPM, the combination of low-risk chemical pesticides, biopesticides, and cultural methods of pest control.

The second stage involved developing data collection tools to gather farmers' risk perceptions of pest management practices, including chemical pesticides and biopesticides. In this study, risk perception is a subjective construct that reflects farmers' personal judgments and beliefs about the potential negative health and environmental effects of pest management practices in tomato production. Thirteen risk perception items were assessed separately for chemical pesticides and for biopesticides across three dimensions: field-based health and social risks (five items), environmental risks (six items), and food-safety risks (two items). This separation allowed direct comparison of perceived risks between the two types of pesticides.

The health and social risks dimension captured farmers' perceptions of direct harm (e.g., acute poisoning, respiratory effects, impacts on pregnant women and children) of pesticides to applicators, farmworkers, household members, and other bystanders. The environmental risk perception dimension captured farmers' views or concerns over the ecological effects of pesticide use, including perceived effects on soil degradation, water contamination, loss of beneficial organisms, and accelerated pest resistance. The food safety risks reflected farmers' worries about pesticide residues on tomato harvests and their potential to cause adverse health effects in end users

([Table 2](#)). Farmers were expected to indicate their level of agreement or disagreement with each risk perception statement on a 5-point scale from “strongly disagree” (1) to “strongly agree” (5).”

A critical lens on gender and age was considered by incorporating information on the gender and age of participants. We defined gender as roles played by respondents in tomato production and age as a youth (35 years and below) or non-youth (> 35 years) (see [Table 1](#)). This categorization was essential in examining how gender and age influenced risk perceptions, knowledge gaps, and adoption of pest management practices. We also incorporated modules to collect socioeconomic characteristics for intersectional analysis and information on support services (e.g., access to training and advisory services) to draw policy implications.

The third and fourth stages in tool development were expert review and pre-testing of the survey tool, respectively. The tools were reviewed by PlantwisePlus project implementors at CABI and partners in Uganda. The interview schedule was reviewed by gender and social inclusion at CABI. The survey tool was pretested with 30 farmers who were excluded from the final analysis. The 5-point Likert scale (1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly agree) was used to measure farmers' risk perceptions of chemical pesticides and biopesticides. The choice of a 5-point Likert scale was based on its widespread use in capturing farmers' perceptions and attitudes toward innovations and technologies in agricultural and social research ([Gesese et al., 2016](#); [Apeh et al., 2024](#)). The questionnaire was then pretested with 30 farmers from comparable agroecological settings not included in the main sample. The pre-testing was critical in not only ensuring that questions were understandable to farmers and reflected their context, but also helping to minimize cultural biases in how respondents interpreted the scale. Questions and response options were refined to ensure that farmers understood. These procedures ensured that the survey questions were understood by respondents. The perception ratings were consistently applied in line with its intended gradations of agreement.

Reliability tests were conducted for the risk perception question that we scored on a 5-point Likert scale. The reliability test using Cronbach's Alpha for the selected variables yields a coefficient of 0.912, indicating high consistency among items used to measure the three dimensions of risk perception and therefore reliability for analysis. Composite scores were then calculated as an aggregated measure of health and social risks, environmental risk, and food safety risks.

The study categorized both commercial and homemade plant extracts as biopesticides. Pre-survey visits established that farmers also used plant-based formulations referred to locally as ‘homemade biopesticides’ for pest management in tomato production. Some of the botanical materials included Marijuana, and tobacco, which may contain toxic compounds ([International Programme on Chemical Safety, 2019](#)). Enumerators were therefore instructed to record the specific plant materials used by farmers, document brand names of commercial pesticides, and, where possible, collect packaging samples. This information was later used to distinguish between low-risk and high-risk chemical pesticides.

3.4 Data analysis

Analysis of household survey data involved descriptive statistics, such as mean, to assess items related to risk perception of pesticides

TABLE 1 Distribution of the sample by district.

District	Kasese	Gulu	Mukono	Sironko	Total
Female	47	37	27	69	180
Male	100	109	117	78	404
Youth	69	76	68	102	315
Non-youth	78	70	76	45	269
Total	147	146	144	147	584

TABLE 2 Pesticide risk perception statements.

	Statement	Chemical	Biopesticides
1	Pesticides can pose significant health risks to farmers and family members.		
2	Chemical pesticides can pose significant health risks to farm workers.		
3	Chemical pesticides cause the death of farm livestock/poultry.		
4	Consistent exposure to chemical pesticides leads to a rise in healthcare expenses.		
5	Some groups of people (e.g., the elderly, children, or those with health issues) are more vulnerable to pesticides.		
6	Pesticides, when sprayed, can spread through the air and affect the air quality.		
7	Pesticides pollute ground and surface water resources.		
8	Pesticides can contaminate soil and the farm environment over time.		
9	Pesticides cause the death of wildlife, including birds, fish, and beneficial insects.		
10	Prolonged use of pesticides can result in the development of resistance among pest populations.		
11	Pesticides produce toxic waste products (e.g., containers) in the environment.		
12	Pesticide application leaves residues on the tomato.		
13	Pesticide residues in tomatoes can affect consumer health in the long run.		

Health and social risks (1–5); environmental risks (6–11); food safety risks (12 & 13).

and biopesticides and other continuous variables of interest to the study (e.g., age, farming experience, and household size). The data were also cross-tabulated to reveal the distribution (frequencies and percentages) of categorical variables based on gender and age. Means of risk perceptions were tested for any systematic differences by gender and age using an independent sample t-test and chi-square test of independence, respectively. Inferential analyses were conducted using partial correlation to determine whether health and social, environmental, and food safety risk perceptions influenced adoption, controlling for confounders. Paired t-tests for risk perception differences between chemical pesticides and biopesticides were also performed. Content analysis of qualitative data was then conducted to triangulate quantitative results.

4 Results

4.1 Farmer characteristics

The description of selected characteristics of farmers is presented in Table 3. Approximately 77% of farmers were household heads, of which 66% were reported to be male-headed households, 30% accessed advisory services, and 91% owned a mobile phone. The proportions of responses to these variables were significantly higher for men than for women. Conversely, only the proportion of non-youth farmers (90%) who were household heads was significantly higher than the percentage of youth (67%). Farmers experienced an average of four pests, and their frequency did not differ significantly by age and gender. Five frequently experienced pests were African bollworm, whiteflies, aphids, cutworms, and *Tuta absoluta*.

4.2 Adoption trends through a gender-age lens

Table 4 presents adoption levels of pest management practices. Approximately 92% of farmers used chemical pesticides. Farmers

highlighted several brands of synthetic pesticides used. Dudu variants (e.g., “Dudu Acelamectin” and “Dudu AgriKill”), MacoZeeb/Mancozeb, Umeme, and Umeme 5EC, Secure, Easy Grow, Rocket, Ambush, Mistress (including “Mistress 75WP”), and Abamet 18EC were mentioned brands of synthetic pesticides. About 10% used biopesticides—primarily homemade plant extracts (9%) and microbes and trap cropping (1%); 20% used cultural methods (e.g., intercropping, timely planting, ash, monitoring and identification of pests, manual removal, and adjusting planting dates). Only 2% reported integrated pest management (IPM) practices (a combination of external pesticides, homemade biopesticides, and cultural methods), the two most common pest-control practices. No significant differences in the use of pest management practices were observed based on gender and age.

The quantitative results in Table 4 conform to the analysis of qualitative data that indicated low use of commercial biopesticides, as noted by key informants. However, despite noting purchases of low-risk pesticides such as Nembecidine, Nematode, and Lemidicidine, a private e-commerce pesticide dealer reported that “*nonetheless, high-risk pesticides and disease control chemicals are preferred by our customers so far.*” These observations were echoed by a women farmer group representative who explained that all farmers recognize the potential hazards of chemical pesticides, but practical barriers make them persistently use hazardous chemical pesticides.

Qualitative data indicate that even though both spouses recognize the hazards, men's control over finances can lead to the continued purchase of higher-risk pesticides. An interview with a representative of an NGO involved in community food safety and food security indicates that “*men control most resources (e.g., land and finances), and the women are disadvantaged in accessing land to produce food,*” which possibly creates a disjuncture between shared risk perception and the ultimate purchase decision, which may have favored the purchase of fast-acting chemical pesticides. Another informant noted that women's limited access to and adoption of biopesticides was also alluded to as not *having access to or owning land. We give them capital, which is not so much.*

TABLE 3 Gender and age disaggregated demographic characteristics of farmers.

Variable	Total	Gender		p-value	Age		p-value
		Women	Men		Youth	Non-youth	
Household head (%)	77.23	53.89	87.62	0.000	66.67	89.59	0.000
Advisory services (%)	30.14	24.44	32.67	0.045	29.52	30.86	0.727
Decision-maker (%)	66.44	17.22	88.37	0.000	66.03	66.91	0.822
Mobile ownership (%)	90.92	86.11	93.07	0.007	90.79	91.08	0.905
No. of pests experienced	3.84	3.71	3.90	0.179	3.87	3.81	0.663

The most experienced pests are African bollworm (52%), whiteflies (37%), aphids (25%), cutworms (24%), and Tuta absoluta (23%).

TABLE 4 Adoption level of pest management practices by gender and age.

	Gender			p-value	Age		p-value
	Total	Women	Men		Youth	Non-youth	
Chemical	91.61	89.44	92.57	0.208	91.75	91.45	0.898
Biopesticides	9.59	11.11	8.91	0.404	8.25	11.15	0.236
Cultural methods	19.69	21.67	18.81	0.423	21.27	17.84	0.299
IPM	2.05	2.22	1.98	0.849	2.22	1.86	0.758

Farmers prepared biopesticides from plant extracts (9%), burnt papaw leaves, chilies (e.g., red pepper), tobacco, Cannabis sativa leaves, neem, local trees, plant seeds, and fermented sweet potato vines. 1% used microbes and trap cropping.

Only 1% of farmers used microbes and trap cropping, and none used Nembecidine, Nematode, and Lemicidicine, mentioned in KII, because they are unavailable or unaffordable. The explanation for adopting homemade biopesticides and not adopting commercial biopesticides was:

All farmers—men, women, and youth—use them [homemade plant extracts] because it is not difficult for them to buy the inorganic chemicals. The organic chemicals are readily available; for example, red peppers are around, you can buy onions at a very low price from the local markets, and you can pick a neem tree in our compound. Therefore, these methods cannot make you spend more money. It is very easy for our elderly women to use, even without spending much. [KII, Women Group Representative]

Three interviews with government representatives, extension officers, and farmer group officials revealed economic and market pressures and the need for quicker returns as key drivers. One of the informants explained that “for example, when I invest in one acre of sorghum and a quarter acre in tomatoes, I will buy all the sorghum inputs using income generated from tomatoes. The one box of tomatoes is equivalent to 2–3 bags of sorghum in value. That is why many people use chemical pesticides to control pests because they are fast acting unlike plant extracts.”

Tomatoes are heavily affected by pests, which makes the problem economically significant. You cannot go away from it. So, farmers find it very easy to deal with the problem by adopting chemical pesticides. [KII, Government Officer]

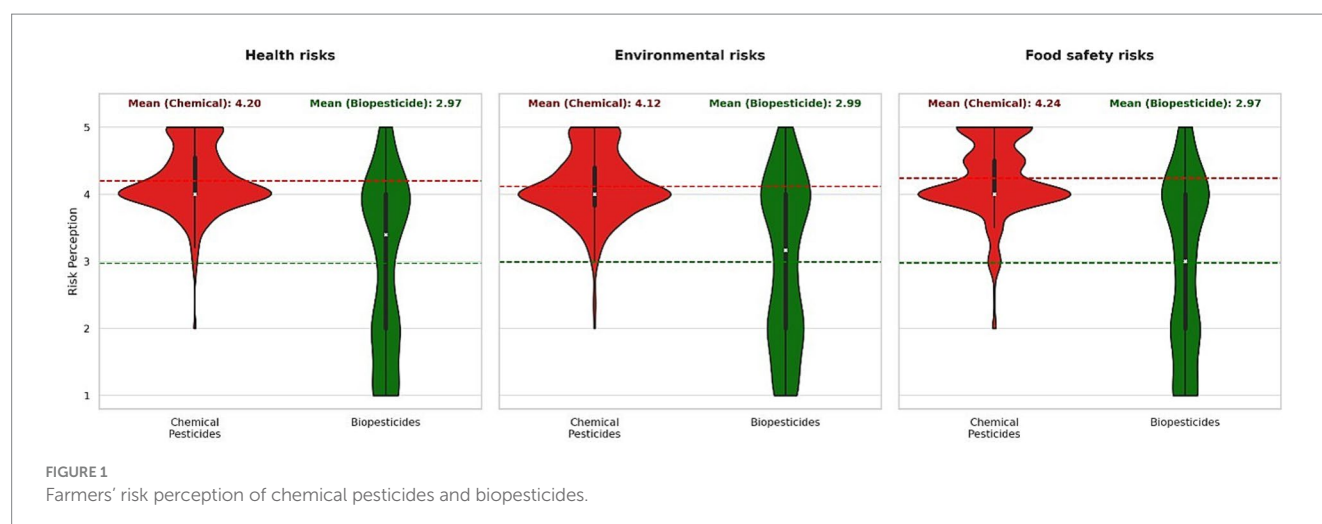
It [plant extracts used as biopesticide] does not make tomatoes look good. For example, keeping the tomatoes green and spot-free. This

issue compels us to use modern technologies [chemical pesticides] in farming tomatoes. It encourages it so much, especially for high tomato production for the market. [KII, Extension Officer]

4.3 Gender and age in risk perception

The distribution of farmers’ perceptions of health, environmental, and food safety risks for chemical pesticides and biopesticides is shown in Figure 1. Chemical pesticides were generally perceived to pose greater risks than biopesticides. On average, synthetic pesticides were perceived as significantly more hazardous—mean scores ranged from 4.12 for environmental to 4.24 for food safety, each significantly above ($p < 0.001$) the corresponding biopesticide mean of 2.9. This confirms that farmers agree that chemical pesticides pose greater health hazards, environmental harm, and threats to food safety than biopesticides. However, the green violins are much faster and more irregular than the red ones, showing that farmers’ views on biopesticide risk are highly heterogeneous.

The plots for risk perception of synthetic pesticides are “fat” (wide) around the 4–5 scores and short. Conversely, green violin plots for biopesticides are taller and show multiple bulges at low, middle, and even high values. This evidence indicates that whereas chemical risk perceptions are tightly bunched near the top (agreement that they are hazardous), perceived health, environmental, and food-safety risks of biopesticides are spread out across the entire scale. The result indicates that some farmers perceive biopesticides’ health, environmental, and food-safety risks as high as those of conventional chemicals. A key takeaway is that, although biopesticide risk perceptions are generally lower than those of synthetic pesticides, they are significantly more



variable. This reflects the need for improved extension around biopesticides to address farmers' heterogeneous views on biopesticide risks.

The differences in the distribution of health, environmental, and food safety risk perceptions of chemical pesticides between men and women (Figure 2) were not statistically significant. The mean perceptions for health risks and environmental risks were both 4.2 for both men and women. These results indicate that men and women farmers perceive health risks, environmental dangers, and food safety concerns for chemical pesticides at similar levels. However, despite similar risk perceptions, tasks such as spraying are often handled by men, while women do daily field monitoring, as indicated by key informants. Informants emphasized that spraying was mostly done by men, while women frequently engaged in field monitoring and post-harvest handling, which increased their exposure to residues.

Similarly, mean differences in health, environmental, and food safety risk perceptions of chemical pesticides did not significantly differ by age. The distribution of food safety risk perception is uniform across both youth and non-youth, while it is narrower for environmental risks, indicating that youth and non-youth farmers shared similar concerns about the residual effects of pesticides on food and their consistency in agreement with the environmental footprint of chemical pesticides, respectively.

Figure 3 shows the distribution of risk perceptions of biopesticides among women and men farmers. The difference in health, environmental, and food safety risk perceptions of biopesticides did not statistically significantly differ by gender, indicating that men and women farmers have similar perceptions that biopesticides are low-risk pest management products. The risk perceptions did not significantly differ by age, suggesting that both youth and non-youth have comparable perceptions of biopesticides as safer. Stakeholders' interviews in the agrochemical sector and tomato value chain revealed that risk perceptions tend to be uniformly high for chemical pesticides and low for biopesticides across gender and age categories. This mirrors the quantitative results that established no statistically significant differences by gender and age in perception of biopesticides' health, environmental, and food safety risks. For instance, a private e-commerce pesticide dealer noted that *"more male than female buyers buy low-risk pesticides, but women are more receptive to low-risk pesticides compared to men."*

4.4 Correlation results

Figure 4 highlights the correlation between risk perceptions and the adoption of pest management practices. All the risk perception coefficients for health risks (-0.201), environmental risks (-0.224), and food safety risks of chemical pesticides were negative and statistically significant at the 1% level. The correlation between health risks (-0.109) and adoption of biopesticides and environmental risk perception (-0.093) and use of biopesticides was negative and significant but weak. No significant relationship between health and environmental risks of chemical pesticides and the use of cultural methods was observed. However, the food safety risk of chemical pesticides was associated with the adoption of cultural pest control methods.

The study sought to isolate and quantify the relationship between risk perceptions, controlling for the potential confounding effects of gender and age. Given the low adoption rates of biopesticides and cultural methods and the near-universal adoption of chemical pesticides, the magnitude of the partial correlation coefficient was not relevant. Rather, we interpret the direction and strength of the relationships with other dimensions, risk perceptions, age, and gender (Figure 4). There was a moderate negative relationship ($p < 0.05$) between the health risk perception of chemical pesticides and the adoption of chemical pesticides. The relationship between environmental risk perception and adoption of chemical pesticides was negative and strong ($p < 0.01$). Food safety risk perceptions are moderately and negatively correlated with the adoption of cultural methods. None of the risk perception dimensions was significantly correlated with the adoption of biopesticides. Relationships between age, gender, and adoption of pest management practices were not statistically significant (Figure 4).

To further isolate true relationships of interest, we added more confounders to the partial correlation that generated the results shown in Figure 5. This was critical in allowing us to conclude that we are less prone to spurious or misleading associations based solely on age and gender. In addition to gender and age, the analysis controlled for education level (secondary and post-secondary) and cultivated land area as a proxy for farm size, which are important structural variables that influence access to information and resource endowments. Additional variables that capture power dynamics and social and

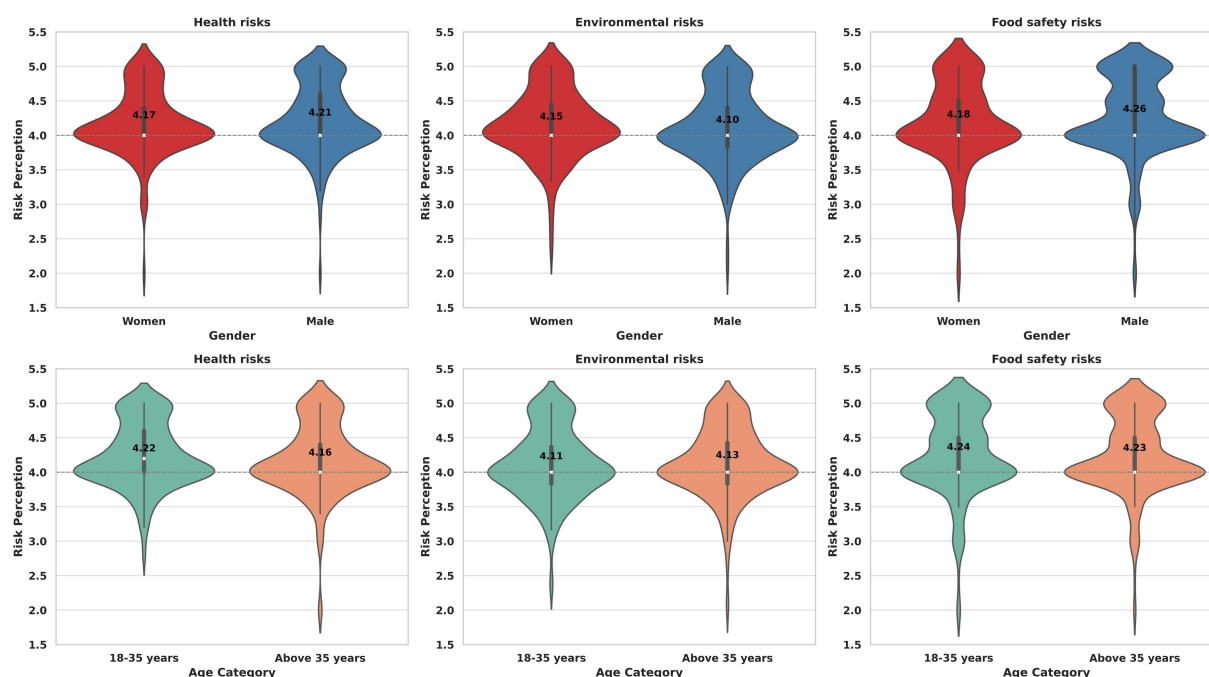


FIGURE 2
Farmers' risk perception of chemical pesticides by gender and age.

cultural influences on the position of the farmer in the household and the tomato production decision-maker were included. The study also added variables that reflect institutional and information access to advisory services and ownership of mobile phones and other digital assets. The environmental context variable pest pressure, measured by the count of pests experienced, was also added to the partial correlation analysis. Pest pressure variables accounted for both regional and agroecological conditions.

Results presented in Table 5 show that health and environmental risk perceptions were moderately, negatively, and significantly correlated with adopting chemical pesticides. Conversely, post-secondary education exhibited a statistically significant negative correlation with biopesticide adoption. This suggests that more formally educated farmers were more likely to adopt biopesticides. The number of pests experienced (pest pressure) and mobile ownership had also had a strong positive and significant relationship with the adoption of chemical pesticides. Access to advisory services had a significant negative correlation with the adoption of chemical pesticides. Male decision-making on tomato production was also negatively and marginally related to biopesticide adoption.

5 Discussion

This study provides empirical insights into the interplay of gender, age, and risk perceptions in pest management behavior. The findings reveal that while farmers recognize the health, environmental, and food safety risks of synthetic pesticides, they continue to use high-risk pest management practices due to a complex mix of economic incentives, market demands, and structural barriers. The findings have

broader practice and policy implications for climate adaptation, gender equity, and sustainable pest management.

5.1 Risk perception and adoption of pest management practices

The study confirmed that farmers' risk perceptions influence their use of chemical pesticides. Higher perceived risks were associated with lower adoption rates. This is consistent with findings by Damalas (2021) and Garcia et al. (2024), who observed that heightened perceptions of health and environmental risks were significantly linked to lower use of chemical pesticides and greater adoption of low-risk alternatives, respectively.

The negative correlation between food safety risk perception and chemical pesticide use reflects farmers' awareness of growing consumer demand for safer foods in Uganda. For instance, Ssemugabo et al. (2023) found that consumers in the Kampala Metropolitan Area were aware of and concerned about the presence of pesticide residues in fruits and vegetables, and the long-term health effects of prolonged exposure.

The high adoption aligns with Demi and Sicchia's (2021) finding of high (85%) use of chemical pesticides in Ghana despite the acknowledgment of their serious health risks. Reasons for the persistence of chemical pesticide use are well-grounded in crop protection and plant health system literature. Fuhrmann et al. (2021), Demi and Sicchia (2021), and Mengistu et al. (2024) found cultural and behavioral factors, economic constraints, lack of or high cost of labor, and limited access to training as factors influencing the adoption of chemical pesticides. This points to a structural disconnect between risk awareness and adaptive behavior. This suggests that awareness of risk perceptions is not a necessary condition for the adoption of

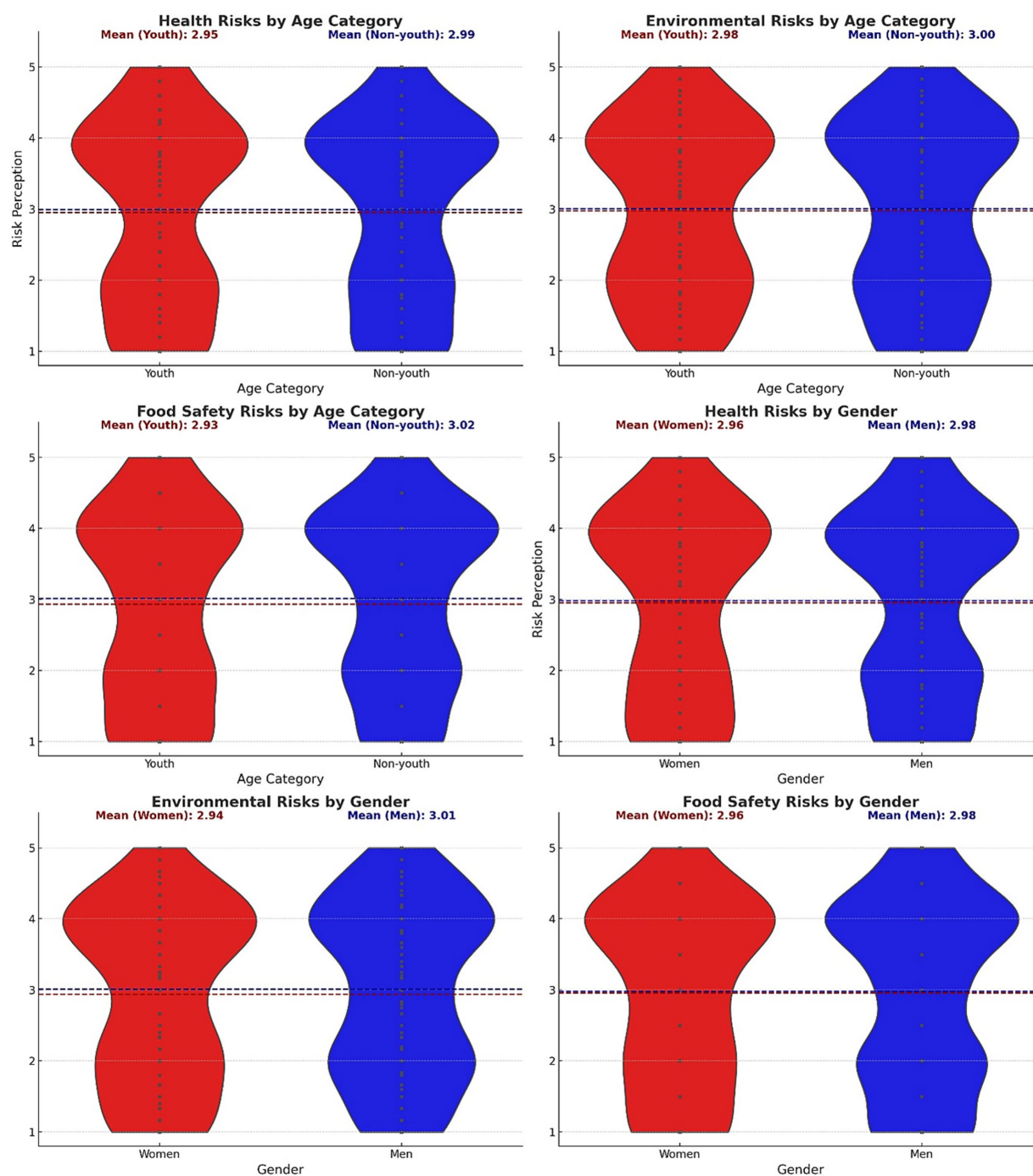


FIGURE 3
Farmers' risk perceptions of biopesticides by gender and age.

low-risk pest and disease management practices. The finding confirms that behavior change is a constellation of factors. These include the limited availability of biopesticides in rural markets, the affordability of low-risk products, the market pressure and economic trade-offs perceived by farmers, weak institutional promotion, and doubts about the efficacy of alternative pest management practices (CABI, 2024; Yahyah et al., 2024; Ndagire et al., 2024).

The paradox is evident at the regional level. Akutse et al. (2020) found that awareness alone is insufficient to disrupt entrenched dependence on synthetic inputs. Conversely, Kafle et al. (2024)

reported low awareness of safer alternatives in Nepal. They attributed this to a combination of sociodemographic factors (e.g., age and cropping systems) and institutional gaps in extension services.

Our results suggest that post-secondary education was negatively associated with biopesticide adoption, possibly due to skepticism toward non-synthetic methods. Meanwhile, larger land size and mobile phone ownership were positively linked to chemical pesticide use. The latter finding is counterintuitive, as land and digital access are typically associated with market integration, information access, and the uptake of innovation. This finding reinforces the need for

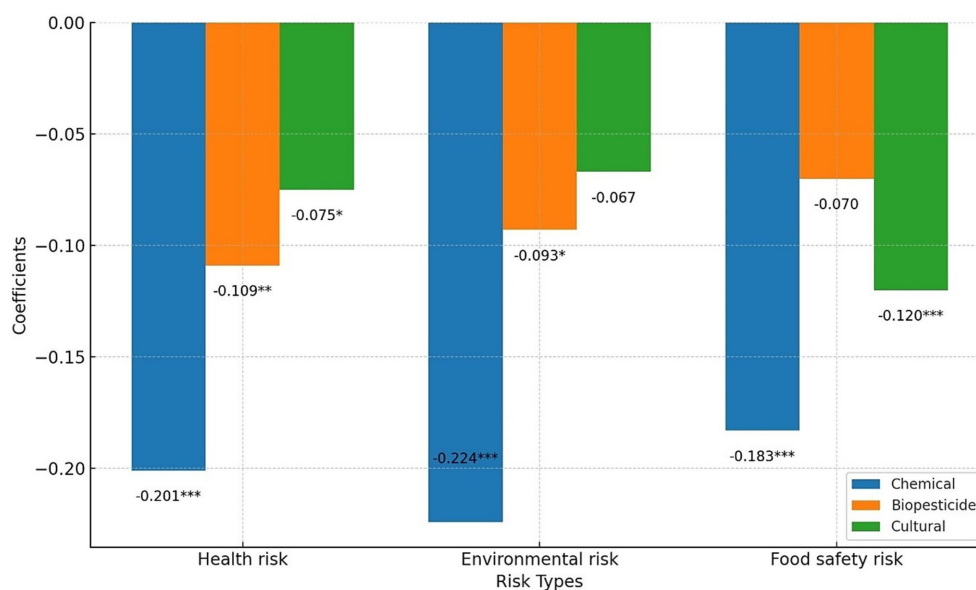


FIGURE 4

Correlation between perceived risks of pesticides and adoption of pest management practices. *, **, and *** represent significance at $p < 0.10$, $p < 0.05$, $p < 0.01$, respectively, obtained from pairwise correlation analysis.

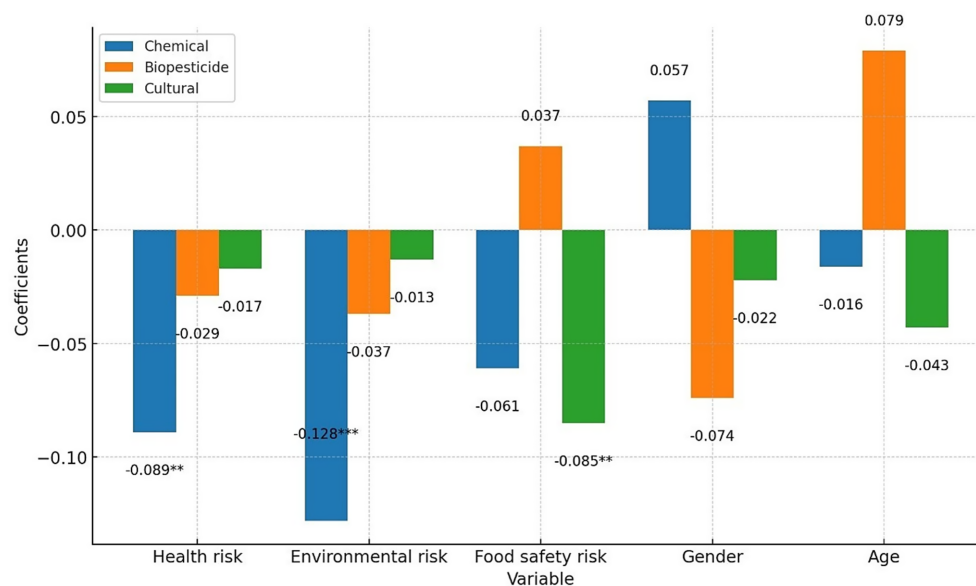


FIGURE 5

Partial correlation between risk perceptions, controlling for the confounding effects of gender and age. *, **, and *** represent significance at $p < 0.10$, $p < 0.05$; $p < 0.01$, respectively, obtained from partial correlation analysis.

deliberate integration of biopesticides into extension systems, as well as regulatory harmonization, to shift persistent reliance on synthetic inputs.

The low adoption of biopesticides and cultural practices, despite their low-risk profile and ecological benefits, raises critical concerns about the inclusivity and scalability of climate-smart pest management. However, it is important to note that while farmers broadly categorize plant-based preparations as biopesticides, some tobacco-based extracts contain highly toxic

compounds like nicotine, classified as Class Ib (“highly hazardous”) by the WHO ([International Programme on Chemical Safety, 2019](#)). This distinction is crucial, as some homemade formulations may carry acute health risks comparable to or exceeding those of certain synthetic pesticides. For example, 10% of farmers using such plant-based sprays may face greater acute health risks than peers applying lower-toxicity chemicals. Extension services should therefore train farmers to distinguish between safer biopesticides, whether commercial or homemade,

TABLE 5 Partial correlation of risk perceptions and use of pest management practices and confounders.

Variable	Chemical	Biopesticides	Cultural
Gender	0.015	0.031	−0.015
Age	0.002	0.003	−0.036
Secondary	0.021	−0.020	−0.078*
Post-secondary	−0.016	−0.044	0.025
Cultivated land area	0.047	0.169***	0.058
Health risk perception	−0.102**	−0.082**	−0.035
Environmental risk perception	−0.091**	−0.047	−0.002
Food safety risk perception	−0.049	0.028	−0.081*
Position in HH	−0.065	0.023	−0.077*
Access to advisory services	−0.088**	0.032	0.031
Tomato production decision-maker (male)	0.042	−0.112***	0.016
Number of pests experienced	0.199***	0.036	0.062
Ownership of a mobile phone	0.143***	−0.009	0.071*

*, **, ***, represents significance at $p < 10$, $p < 0.5$, & $p < 0.01$, respectively.

and more hazardous botanical extracts or synthetic pesticides. Pesticide messaging should also emphasize that “natural” does not equate to “harmless.”

5.2 Gender and age dynamics

Contrary to expectations in the literature (Erbaugh et al., 2003; Christie et al., 2015), this study found no significant gender or age differences in risk perceptions. This suggests that awareness of chemical hazards is relatively uniform across demographic groups. However, qualitative data reveal that exposure patterns and decision-making roles in pest management remain deeply gendered within tomato production systems.

Key informant interviews highlighted distinct gender roles in pesticide use and exposure. Women are typically engaged in routine field monitoring, harvesting, and post-harvest handling of tomatoes. Conversely, men are more often responsible for purchasing and applying chemical pesticides. The disjuncture between qualitative data and quantitative data suggests that while risk awareness is shared across, actual exposure, direct in the case of men and secondary or prolonged via residues in the case of women, is shaped by household power dynamics, gendered division of labor, and differential access to resources.

The marginally positive correlation between age and biopesticides suggests that older farmers, perhaps due to greater farming experience

or heightened health concerns (Tran et al., 2020; Yang et al., 2023), may be more inclined to adopt biopesticides or return to traditional low-risk methods. This finding challenges assumptions in the literature (e.g., Rezaei et al., 2020) that youth are inherently more innovative or open to practices than older farmers. It underscores the importance of understanding how age intersects with knowledge systems, resource control, and institutional visibility in shaping the adoption of low-risk pesticides.

Structural barriers also constrain the adoption of biopesticides, particularly among women and youth. Limited access to land, capital, and extension services intersects with their restricted participation in household decision-making on pest management. This weak intra-household agency may prevent women from acting on their knowledge of pesticide risks, reducing their ability to respond effectively to climate-induced pests in tomato production. Similarly, Muriithi et al. (2024) found that women mango farmers in Kenya, though actively engaged in production, were often excluded from marketing and decision-making spaces. This exclusion diminished their incentives and capacity to adopt IPM strategies. The findings in both cases underscore the need for gender-responsive extension models. Such models should consider the differentiated capacities and constraints across gender and age groups, address knowledge asymmetries, and promote inclusive decision-making in pest management.

5.3 Broader implications and limitations

The findings underscore the importance of integrating gender- and age-responsive strategies into pest management interventions. Specifically, the findings have implications for both supply-side and demand-side efforts aimed at promoting the adoption of low-risk pesticides and alternative pest control methods. From a climate-smart agriculture perspective, these findings suggest that integrating cultural practices and biopesticides into the extension system, particularly those targeting marginalized farmers, can offer a dual benefit for men, women, and youth. First, such integration may reduce the use of harmful chemicals (supporting both adaptation and health) while minimizing environmental impacts (mitigation). Second, when delivered accurately to the marginalized groups, these practices could help maintain yields and ensure productivity. The observed relationships among resource endowments (e.g., land size, digital access), education levels, and adoption patterns highlight the need for tailoring pest management messages and delivery platforms to different farmer segments. However, advancing adoption also requires dismantling entrenched structural inequities.

On the supply side, increasing the availability and affordability of low-risk products is essential. Public-private partnerships could support this by enhancing biopesticide distribution networks and quality assurance mechanisms. On the demand side, tailored communication and inclusive training are crucial in shifting behavior. This includes correcting misconceptions about biopesticide efficacy, raising awareness of low-risk chemical options, and incorporating the needs and perspectives of women and youth into pest management decision-making processes.

Nonetheless, the study has several limitations. Its focus on tomato production may not fully represent pest management dynamics in other input-intensive crops in Uganda. While

triangulation with key informant interviews helped validate farmer responses, self-reported data remain susceptible to bias. Future studies could strengthen reliability by incorporating observational data or agrodealer sales records. Furthermore, although the inclusion of both PlantwisePlus and non-PlantwisePlus districts in the study enhanced the representativeness of the sample, district-level findings may still overlook important variations in pest management dynamics. The use of data from a single growing season also limits the ability to assess temporal fluctuations in pest pressure, pesticide access, or farmer behavior. While the behavioral patterns, institutional gaps, and structural constraints documented here may be relevant to other high-input vegetable systems, further research should assess cross-crop generalizability using multi-season or panel designs to capture temporal dynamics. Future studies should also evaluate gender-targeted interventions through experimental or quasi-experimental designs to generate more robust causal evidence.

6 Conclusion

The study investigated risk perceptions of chemical pesticides and how they shape adoption decisions. The findings reflect the multi-layered constraints and trade-offs that shape pest management behavior in tomato production in Uganda. Chemical pesticides were generally perceived as risky; yet, their adoption remained high due to economic pressures, perceived effectiveness, and the limited availability of low-risk alternatives. Although biopesticides were perceived as low-risk pesticides, this did not translate into widespread adoption. Cultural control methods and IPM were also underutilized, highlighting broader barriers to climate-smart pest management. While gender and age did not matter in risk perceptions or adoption behavior, qualitative and correlational evidence pointed to persistent structural barriers, particularly for women and youth, that may influence the adoption of biopesticides when robustly introduced and integrated in extension systems. The youth and women face structural barriers that make gender-responsive interventions in extension and advisory services essential to avoid undermining the adaptive capacity of marginalized groups and weakening resilience within the broader agri-food system.

To enable uptake of low-risk pest management practices, interventions should move beyond information provision to address both supply-side and demand-side barriers. First, policies should support the availability, accessibility, and affordability of biopesticides through incentives to agrodealers (e.g., start-up capital or credit lines) and inclusion of biopesticides into subsidy programs and a regulatory framework that streamlines distribution. Second, both public and private sector players in plant health systems should promote inclusive extension models that engage women and youth as partners in climate adaptation and as agents of resilience. Third, extension programs and development projects should deploy participatory learning approaches and blended advisory approaches, field-based demonstrations, farmer field schools, local language radio broadcasts, SMS-based tips, and farmer-to-farmer extension to improve knowledge and correct misconceptions about pest management practices across diverse farmer profiles.

Data availability statement

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

Ethics statement

The studies involving humans were approved by Lira University Research Ethics Committee (LUREC), Uganda Clearance Number: LUREC-2024-250, Uganda National Council for Science and Technology (UNCST) Clearance Number: A534ES. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin because written informed consent was obtained from all participants in accordance with the approved research protocol.

Author contributions

BM: Methodology, Writing – review & editing, Supervision, Conceptualization, Investigation, Writing – original draft, Visualization, Project administration. OA: Conceptualization, Investigation, Writing – review & editing, Methodology. MeB: Investigation, Writing – review & editing, Methodology. SP: Methodology, Writing – review & editing. MK: Conceptualization, Supervision, Writing – review & editing, Project administration, Methodology. ChA: Supervision, Investigation, Writing – review & editing, Project administration, Conceptualization, Validation, Methodology. LO: Methodology, Conceptualization, Writing – review & editing. CaA: Writing – review & editing. MaB: Methodology, Writing – review & editing, Conceptualization. WO: Writing – review & editing. NB: Writing – review & editing. AJ: Writing – review & editing, Formal analysis, Investigation. GA: Conceptualization, Investigation, Writing – review & editing. AM: Writing – review & editing. CL: Formal analysis, Methodology, Visualization, Writing – review & editing, Conceptualization.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. The study was supported by Centre for Agriculture Biosciences International (CABI), an international intergovernmental not-for-profit organization, gratefully acknowledges the generous support received from our many donors, sponsors, and partners. We thank our Member Countries for their vital financial and strategic contributions. These donors include UKAID, Swiss Agency for Development and Cooperation SDC, Australian Centre for International Agricultural Research, Ministry of the Foreign Affairs of the Netherlands and Ministry of Agriculture and Rural Affairs (MARA).

Acknowledgments

We express our profound gratitude for the assistance rendered by the PlantwisePlus program project team. Their guidance and invaluable expertise were instrumental throughout the study design, fieldwork, and reporting process. We extend our heartfelt appreciation to Uganda's district and national government, farmers, and other local stakeholders for their unwavering support during data collection. Their substantial contributions, including their time and data, played a pivotal role in shaping this report.

Conflict of interest

OA, AJ, and GA were employed by Afridev Economic Consulting Ltd.

The remaining 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.

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