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RESEARCH ARTICLE

Assessing the Impacts of Different Cropping Systems and Pesticide Use on Pollinator Communities in Mbire District, Zimbabwe

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ABSTRACT

Pollination contributes immensely to food security, yet little is known about pollinator conservation practices in rural communities. This work assessed farmers' knowledge of pollinators and examined pesticide use in Mbire district of Zimbabwe. A structured questionnaire was distributed to 102 respondents who were sampled using the stratified purposive approach to collect information on perceptions of pollinators and chemicals used to control pests. Pan traps and sweep nets were used to capture pollinators from chemically treated and untreated plots in different cropping systems. Honeybees were the most cited pollinators (99% of respondents), while other pollinators like wasps, beetles, and true flies were mentioned. Awareness of pollinators was higher in males than in females and among middle-aged to old-aged farmers. A total of 38 different pesticides were used, with four belonging to the highly toxic pesticide category. Field sampling collected 239 individuals from nine pollinator families and three orders, with Lepidoptera (55.2%) being the dominant order. Pollinator abundance was highest in mixed-cropping systems and lowest in natural plots. Generalized Linear Mixed Models (GLMMs) showed that sweep netting captured significantly more pollinators than pan trapping ($\beta = 0.575$, $SE = 0.173$, $p = 0.009$). In addition, spraying alone showed no significant association with pollinator abundance. However, the interaction between monocropping and spraying resulted in relatively fewer pollinator visitors compared to the interaction between mixed cropping and spraying ($p = 0.055$). Further, *Maerua edulis* was the most mentioned plant used in traditional pest management. To increase pollinator awareness, there is a need for farmer training to promote systems such as mixed-cropping systems, as they support more pollinators. The use of highly toxic pesticides is concerning, and efforts are needed to minimize their application and promote eco-friendly alternatives and traditional methods.

1 | Introduction

Despite global efforts to protect pollinators, such as the United Nations' 2017 Declaration of World Bee Day and Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessments warning of severe pollinator declines, farmers' knowledge remains underrepresented and underdeveloped in both policy and science (Hall and Steiner 2019; Breeze et al. 2019; Garbach and Morgan 2017). Yet, understanding the disconnect between global pollinator protection efforts and the lack of inclusion of farmers' knowledge in those efforts can provide critical information on locally adapted conservation strategies and support systems tailored to fulfil local needs (Osterman et al. 2021). Recent studies have demonstrated that educating local farmers can significantly enhance pollinator conservation strategies and ensure better crop outcomes, particularly in low-input systems which are common across the Global South (Díaz et al., 2019; Potts et al., 2021). In developing nations especially in the global south, the complex relationships between livelihoods, crop yields and climate change in the socio-ecological contexts of the areas calls for investigations to explore pollinator conservation while ensuring food security.

Among the three primary modes of pollination of hydrophily (water-mediated), anemophily (wind-mediated), and zoophily (animal-mediated), zoophily provides a vital ecosystem service, supporting the reproduction of over 90% of angiosperm species worldwide (Kearns et al. 1998; van der Sluijs and Vaage 2016; Cariveau et al. 2020). Animal-mediated pollination is crucial for maintaining ecosystem functioning, promoting biodiversity, and ensuring food security, with a diverse group of pollinators, including bees, butterflies, moths, birds, and bats, playing a key role globally (Kamala and Devanand 2021; Tanda 2024). However, pollinator populations, particularly bees, have experienced significant declines in regions characterized by intensive land use, habitat loss and fragmentation, and high agrochemical inputs (Biesmeijer et al. 2006; Winfree 2010; Michez et al. 2025), hence the need to understand pollinator abundance, diversity and distribution in these farming landscapes for the development of effective pollinator conservation strategies.

Pollinator-dependent crops account for approximately one-third of global food production (McGregor 1976; Klein et al. 2007; Aizen et al. 2019), valued at around USD 200 billion annually (Gallai et al. 2009; Rahimi and Jung 2024). However, lower pollinator activities are observed in intensive monocultures (Vinod et al. 2025). Moreover, research from Kenya and South Africa has indicated that insect-mediated pollination improves crop productivity by 20%–40%, with higher yields observed in areas bordering forests and grasslands (Carvalheiro et al. 2012; Sagwe 2021). Similarly, insect pollinators have been noted to have the potential of unlocking an annual monetary value of more than USD 100 million from crop production in East Africa (Yocgo et al. 2023), highlighting the importance of pollination services for smallholder farmers and ensuring food security, thereby underscoring the importance of conserving pollinators.

Within agricultural landscapes, pesticides represent one of the most notable threats to pollinator health, which pose a significant risk to agricultural productivity, as an estimated 40% of pollinator species are at risk of extinction (Aizen et al. 2019; Biesmeijer et al. 2006). In South Africa alone, over 3000 pesticides are registered (Dabrowski 2015), yet pesticides may cause long-term declines in non-target pollinators (Wan et al. 2025), as non-target exposure is just as toxic to pollinators (Akhter et al. 2024; Dabrowski 2015). Exposure to pesticides through direct contact with sprayed surfaces and ingesting contaminated pollen and nectar (sprayed with acute toxicity) has often led to disorientation, paralysis, and sometimes death of pollinators (Basu et al. 2024; Johansen 1977). For instance, neonicotinoids are well known for targeting the nervous system of pollinators, disturbing their ability to locate food sources, forage, navigate, and communicate effectively (Paoli 2024). Hence, the need to assess the impact of pesticides on pollinator populations in farmlands.

Mbire district sits in the mid-Zambezi Valley along the ZIMOZA Transfrontier Conservation Area corridor between Mana Pools National Park in Zimbabwe and Lower Zambezi National Park in Zambia (Matema et al. 2022). The district is a mosaic of smallholder farms growing crops such as cotton, sorghum, maize, sesame, and cow peas, creating a landscape where farming practices directly intersect with wildlife conservation and ecosystem function (Matema et al. 2022). Despite its ecological and agricultural importance, pollinator research remains limited, whereas pesticide use and land conversion are prevalent (Matema et al. 2022). Given this overlap of agriculture, wildlife, and data gaps, Mbire offers a relevant and timely setting to assess farmer knowledge of pollinators, effects of cropping systems, and pesticide use on pollinator communities. Understanding these interactions is critical for designing conservation strategies that balance crop production with biodiversity protection in agro-ecological landscapes of the mid-Zambezi Valley.

To this end, this study hypothesizes that (i) farmer knowledge of pollinator species and their ecological role is limited, (ii) mixed cropping systems with higher floral diversity support greater pollinator abundance and diversity than monocultures, and (iii) pesticide (*carbaryl 85*) application during flowering reduces pollinator visitation in sprayed fields relative to unsprayed fields.

2 | Methods

2.1 | Study Area

The study was conducted in Mbire District, Zimbabwe (Figure 1). The district covers an area of 4696 km^2 and is divided into 17 wards. Mbire is located between 30° 00′ and 31° 45′ E longitude and 16° 00′ and 16° 30′ S latitude. The district has a dry climate with erratic annual rainfall, ranging from 350 to 1300 mm, and an average winter temperature of 15°C and average summer temperatures of 40°C. The district's altitude averages 400 m above sea level (Gumindoga et al. 2020).

The soil types in Mbire include *eutric leptosols*, tropically leached iron-bearing soils, and *calcic luvisols* (Gumindoga et al. 2020). The natural vegetation is primarily deciduous dry savannah, dominated by *Colophospermum mopane*. Further, human settlements are along the Angwa and Manyame rivers, which are famous for community-based wildlife management models such as the Communal Areas Management Program for Indigenous Resources (CAMPFIRE)wildlife conservation and human activity intersect. Agriculture is the primary human activity in Mbire, with dryland farming of cotton, maize, and sorghum being a common practice. Sesame (a partially pollinator-dependent crop) is emerging to be a crop that cannot be foraged by elephants, and it is gaining traction in reducing human-wildlife conflict.

2.2 | Research Ethics

Ethical clearance was initially obtained from Chinhoyi University of Technology. The research project also got clearance from the local leadership in Mbire including the District Development Coordinator, Mbire Rural District Council

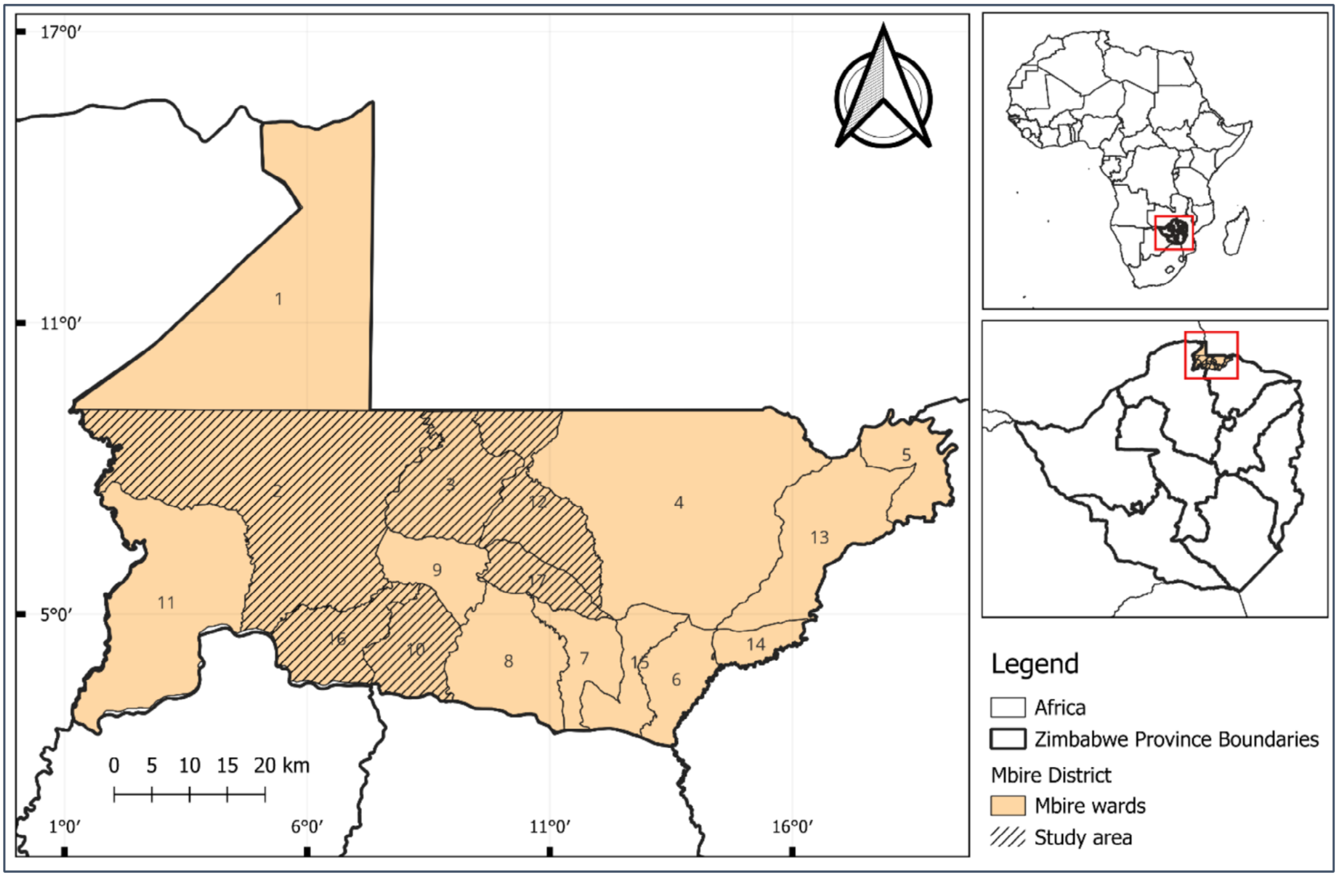

FIGURE 1 | The depiction of the study area in Mbire District, Zimbabwe illustrating the wards in which information on pollinator perceptions and field sampling took place.

Natural Resource office, Ward Counsellor, Ward extension Office, Utariri area coordinator, and Utariri lead farmers before conducting any field work. Every farmer participated in this study voluntarily. Lastly, no harm was caused to the farmers.

2.3 | Data Collection

The study involved two main components, the farmer survey and the pollinator field experiment. Data collection was conducted between January and March 2025. This window corresponded with the blooming period of key pollinator-dependent crops and the seasonal presence of pollinators and flowering plant species in Mbire district. These crops include cow peas (*Vigna unguiculata*), watermelon (*Citrullus lanatus*), pumpkin (*Cucurbita pepo*), and squash (*Cucurbita* sp.), all of which rely mainly on insect pollination for fruit and seed set. Moreover, sorghum (*Sorghum bicolor*) and maize (*Zea mays*), although mainly wind-pollinated, were also present in the agricultural landscape and may contribute to floral resource availability for pollinators.

2.3.1 | Farmer Surveys

Due to the similar agrarian characteristics across wards, including comparable farm sizes, cropping systems, and pesticide use and practical constraints of time and field accessibility, we started by conducting a baseline survey of the knowledge of pollinators, farming systems, and pesticide use using structured questionnaires (Supporting Information) (see Johansen 1977; Ojija and Leweri 2022). This study employed the stratified purposive sampling technique, in which six wards (ward 2, 3, 12, 10, 16, and 17) were selected out of the 17 wards in the district to gather data from 102 willing farmers. The research team comprised three trained enumerators, who participated in questionnaire piloting to ensure uniformity. All interviews were conducted in the native language (Shona), which was also comfortable for all the respondents engaged in this study. Every farmer was informed that the interviews were voluntary, will be anonymised, and that the interviews could be dropped at any time. In each ward, only respondents owning a field and growing more than one crop in their fields were interviewed. The questionnaire (Table A1) was designed to collect socio-demographic data (gender, age, gender, ward, village, and occupations) and core study questions about the knowledge of pollinators, farming systems used, and pesticide use. Within each ward, the enumerators would stop sampling when they were no longer getting new information from respondents.

2.3.2 | Pollinator Field Experiment

Although farmers in the baseline survey mentioned a variety of cropping systems, our field assessment revealed that the two

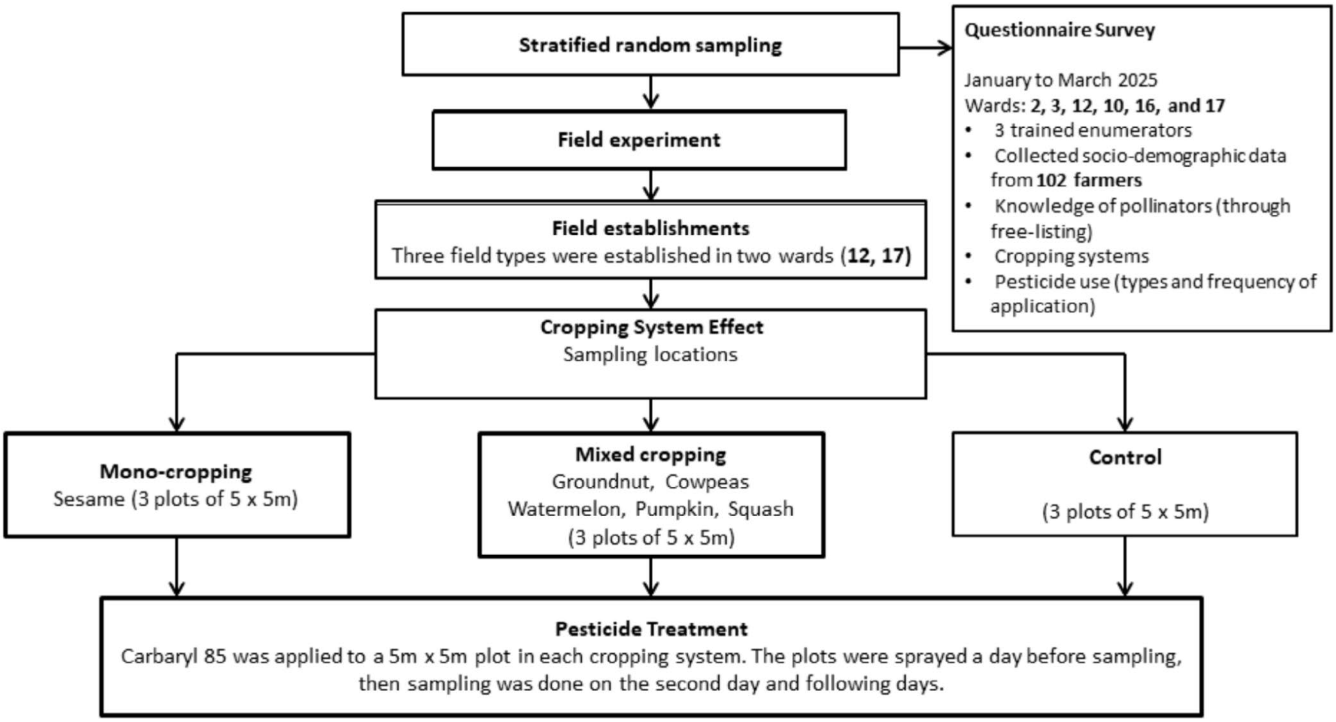

FIGURE 2 | Flowchart of the study conducted in Mbire District, Zimbabwe, 2025.

dominant cropping systems actively practised in wards 12 and 17 were mono and mixed cropping. As such, three field types were established, representing a mono-cropping system (i.e., sesame *Sesamum indicum* field), a mixed cropping system (including groundnut *Arachis hypogaea*, cowpeas *Vigna unguiculata*, watermelon *Citrullus lanatus*, pumpkin *Cucurbita* sp., and squash *Cucurbita* sp.), and a control site in the wards. The forest patches were semi-natural woodland patches which were not used for any crops but were periodically accessed by local communities for firewood collection, pole cutting for kraals and housing, brush for fencing (especially the *Vachellia* species). These control areas varied in sizes (usually one hectare and above) were mostly separating fields and villages. These fields were embedded within a predominantly modified landscape characterized by smallholder agricultural fields and residential homesteads. Although, the exact field sizes were not recorded, the study plots were established within this mosaic of cultivated and forest patches. Within each of the three field types per ward, three plots of 5 m × 5 m were established at three locations of each field, two on opposite edges of the fields, and one in the centre to account for the edge effects, giving a total of 18 sampling sites. Pollinator sampling was done using sweep nets and pan traps. For the sweep nets, an active search for 10 min was done in each 5 m × 5 m sampling plot, which ensured that the whole plot was sampled. Since pollinators are attracted to different colours, pan traps of colours, white, yellow, and blue were placed a meter apart in each established 5 m × 5 m plot and remained in the field for 24 h over 4 days. The pan traps were filled with a mix of water and an odourless drop (0.05 mL) of detergent to break surface tension and allow for the drowning of pollinators. Captured pollinators from sweep nets were suffocated using Acetone, while the ones captured by pan traps were collected into vials and pinned in insect collecting boxes, waiting for identification, as illustrated in Figure 2.

Pollinators observed visiting flowers and verified by literature were included in the analysis (ensuring that pests were excluded). Voucher specimens, serving as a reference for future research, are currently housed in Chinhoyi, but they will be deposited in the Natural History Museum of Zimbabwe upon completion of this study. All specimens were identified at family level.

2.3.3 | Pesticide Effects

To ensure that the non-sprayed plots served as valid controls, field owners were interviewed prior to and during the sampling period and confirmed that their fields had not received any pesticide application in the 2 weeks preceding sampling. This 2-week period was considered sufficient for residual pesticide effects to dissipate, given that commonly used smallholder pesticides such as synthetic pyrethroids and organophosphates have relatively short field half-lives under tropical conditions (Aktar et al. 2009; Weiss 2021). The active presence and flight activity of pollinators observed in the non-sprayed plots during sampling provided additional field-based confirmation that acute pesticide toxicity was not a confounding factor in those plots at the time of sampling. To assess the impact of pesticides on pollinators (sprayed vs. non-sprayed), a different plot of 5 m × 5 m was randomly selected within each cropping system (mixed cropping, mono-cropping, and control) and treated with the most cited pesticide in Mbire district, *Carbaryl 85*. For this purpose, the pesticide was prepared by dissolving 12.5 g of *Carbaryl 85* per 5 L of water, following the manufacturer's label instructions. The spatial arrangement, plot size, number of plots, and sampling methods were identical across both sprayed and non-sprayed plots to ensure comparability. Non-sprayed plots were sampled first, after which *Carbaryl 85* was applied to the designated plots

1 day prior to their pollinator sampling, with sprayed plots subsequently sampled using sweep nets and pan traps as described above. Although not sampled on the same day, both sets of plots were sampled within the same 4-day sampling period to minimize temporal variability in pollinator community composition, and pollinators were also collected and preserved. The experiment is summarized in Figure 2.

2.4 | Statistical Analysis

Socio-demographic and farming system data were summarized using frequency tables and cross-tabulations. Cropping system adoption, as a multi-response variable, was reported as proportions. Pesticide formulations were classified according to their toxicity levels into four colour-coded triangle categories, as outlined in the Pesticide Use and Policies in Zimbabwe: green (Harmful if Swallowed), amber (Poison), red (Dangerous Poison), and purple (Very Dangerous) (Mudimu et al. 1995). Descriptive statistics were used to report chemical use across age group and gender, where farmers were categorized into three age groups: young (18–30 years), middle-aged (31–50 years), and old farmers (Above 50 years). Further, the knowledge of pollinators was assessed using binary logistic regression, modelling the probability of a respondent listing each pollinator group as a function of age group (taking the 18–30 years category as the reference) and gender (taking female as the reference).

Shannon diversity was calculated using the vegan package (Oksanen et al. 2026). Pollinator abundance and richness were modelled with poisson distributions following failure to meet normality after log-transformation, while diversity was log-transformed and modelled with a Gaussian distribution. The richness of pollinator families, diversity and abundance across field type and cropping types were analysed using Generalized Linear Mixed Models (GLMMs), with the field identity included as random variables to account for repeated measures within fields. The analysis therefore analysed the richness and diversity across cropping system (monoculture versus mixed) in unsprayed fields. Second, within cropping systems (sprayed versus unsprayed within the mixed and monocropping fields). Lastly, Non-metric Multidimensional Scaling (NMDS) was used to explore pollinator family overlap between cropping systems.

Figures were produced using ggplot2 (Wickham 2016). All analyses were performed in R version 4.5.1 (R Core Team 2026).

3 | Results

3.1 | Population Demography

Across the six wards, 102 participants were interviewed, with 66 males (64.7%) and 36 females (35.3%), as categorized in Table A1. The sample was characterized by a male-dominated middle-aged cohort (31–50 years; $n = 38$, 37.3%), while female representation was highest in the 18–30 age category ($n = 18$, 17.6%) and was nearly absent above age 50 ($n = 1$, 1%). Crop farming was the primary occupation across all age groups, while 10 males and two females of these farmers were also involved in beekeeping and three serving as Agritex extension workers. The alluvial diagram reveals that cropping system practice among the surveyed smallholder farmers was characterized by significant overlap, with most farmers practicing at least two main systems simultaneously (Figure 3). Mixed cropping and monocropping were the dominant systems across all demographic groups, and their co-occurrence was particularly evident among male farmers in the 31–50 age group, where bands for multiple systems converged most prominently. Female farmers showed a relatively stronger association with mixed cropping, while male farmers displayed a greater tendency toward monocropping. Younger and middle-aged farmers (18–30 and 31–50) were more strongly associated with mixed cropping than older farmers (above 50) (Figure 3).

3.2 | Crop Diversity and Mixing Patterns Among Smallholder Farmers

The number of different crops grown per household ranged from 2 to 11, with an average of 7 crops. Of these, vegetables (25%), cereals (23.1%), and leguminous (22.18%) were the most grown, while fibre crops like cotton were the least (1.9%) (Figure 4).

Analysis of crop combination frequencies revealed that mixed cropping in this farming system is structured around a small number of dominant combinations, with Maize ($n = 1017$), Watermelon ($n = 912$), and Pumpkin ($n = 412$) being the most frequently occurring mixing partners (Figure 4). Vegetables (Pumpkin, Cucumber, Bottle gourd, Watermelon) contributed the greatest diversity of combinations, appearing across nearly all intersection groups, while leguminous crops such as Cow peas and Groundnut appeared in mid-frequency combinations. Oil seed crops including Sunflower, Sweet reed, and Rapoko were confined to lower-frequency, specialized combinations, and Cotton was recorded in only a single combination ($n = 39$) (Figure 4).

3.3 | The Knowledge of Pollinators

The respondents listed six groups of insects during the study. All the 102 farmers mentioned at least one insect pollinator species among the eight listed during the study. The majority (99.01%, $n = 100$) of the respondents listed the honeybee, *Apis mellifera*. Wasps, beetles, stingless bees, Diptera, butterflies were listed by 1%, 1%, 8.8%, 10.8%, 49% respectively. All farmers knew about the benefits of *Apis mellifera* as a honey producer, yet more than half (58.8%) of the respondents confirmed that honey production is on the decline. Furthermore, 67.6% of respondents ($n = 69$) perceived trends of pollinators were declining. More than half of the respondents (59.8%) reported not receiving any training on pollinator conservation in the sampled wards, while 40.2% of the respondents indicated that they had received training, primarily focused on bee conservation.

3.4 | The Knowledge of Pollinators Across Age Groups and Gender

Farmer age was a significant predictor of butterfly awareness, with middle-aged farmers (31–50 years) significantly less likely

FIGURE 3 | Demographic composition and farming practices of smallholder farmers across age groups and gender in Mbire in 2025.

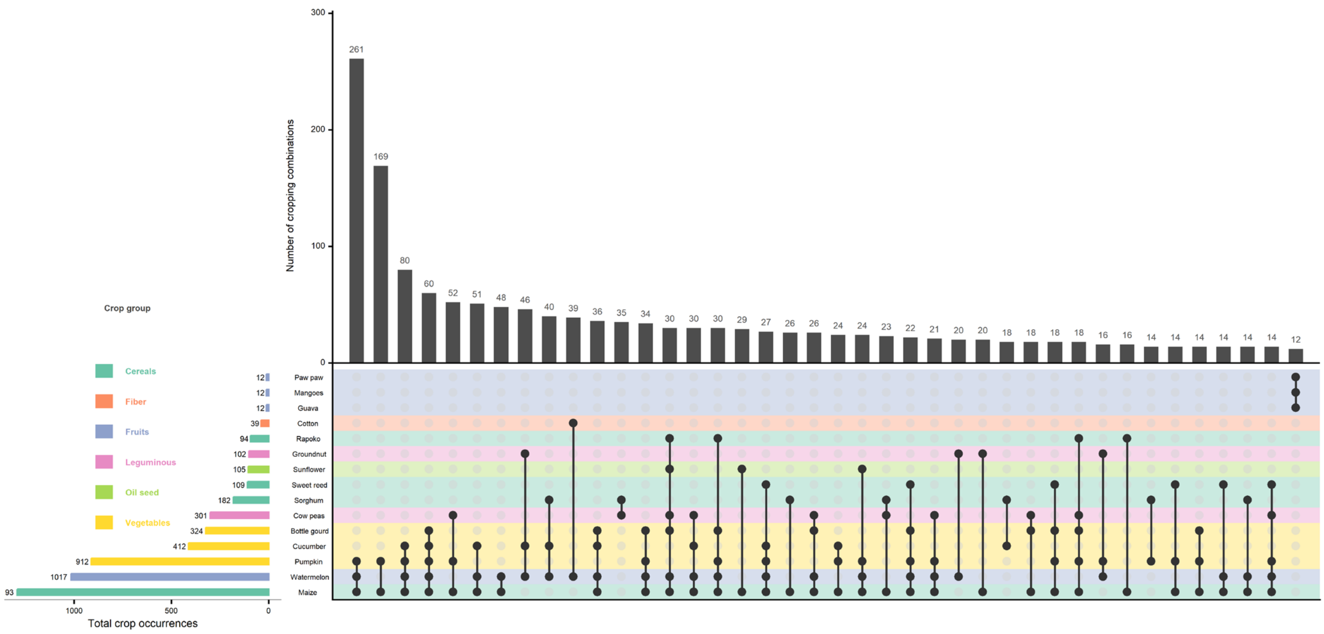

FIGURE 4 | Upset plot showing the frequency and composition of cropping combinations across smallholder farming systems. Horizontal bars (left) indicate the total occurrence of each crop across all surveyed plots, grouped by crop category (cereals, fibre, fruits, leguminous, oil seed, and vegetables). Vertical bars (top) represent the number of cropping combinations in which each cropping combination occurred, ordered by decreasing frequency. Connected dots indicate which crops co-occur within each combination.

to report butterflies compared to young farmers (18–30 years) ($\beta = -1.194$, SE = 0.549, $p = 0.030$). For honeybees, middle-aged and older farmers tended to show a higher likelihood of reporting bees compared to young farmers, although these effects were only marginally significant ($p = 0.090$ and $p = 0.124$, respectively). Gender was a significant predictor of stingless bee awareness, with *female* farmers significantly *more* likely to report stingless bees compared to male farmers ($\beta = -1.094$, SE = 0.543, $p = 0.044$) (Table 1; Figure 5).

3.5 | Chemical Use Patterns Among Farmers

A total of 38 different pesticide formulations were recorded across six wards in Mbire (Figure A1). Insecticides constituted the primary chemical input across the sample (57.6%), followed by herbicides (42.2%), while fungicide application was negligible (0.2%) (Figure A1). The use of agrochemicals varied with age group, with the 31–50 category accounting for 57.3% of total applications. Although the 18–30 and 31–50 age groups exhibited a balanced distribution between herbicide and pesticide use, respondents above 50 years of age showed a pronounced reliance on pesticides, which comprised 64.8% of their chemical inputs (Table 2). Chemical use differed by gender, with males accounting for most applications (68.5%), while females contributed 31.5%. Both male and female farmers exhibited similar usage

TABLE 1 | Logistic regression results on the effects of farmers' age and gender on the likelihood of reporting different pollinator groups in Mbire.

Predictor	Estimate	SE	*z* value	*p* value	Sig.
Butterflies					
Intercept	−0.234	0.307	−0.761	0.447	
Age 31–50	−1.194	0.549	−2.176	0.030	*
Above 50	−0.573	0.390	−1.469	0.142	
Bees					
Intercept	−0.624	0.320	−1.951	0.051	
Age 31–50	0.818	0.482	1.697	0.090	.
Above 50	0.600	0.390	1.539	0.124	
Stingless bees					
Intercept	−1.953	0.542	−3.608	< 0.001	
Age 31–50	1.210	0.791	1.531	0.126	
Above 50	0.633	0.650	0.975	0.330	
Gender (male)	−1.094	0.543	−2.013	0.044	*

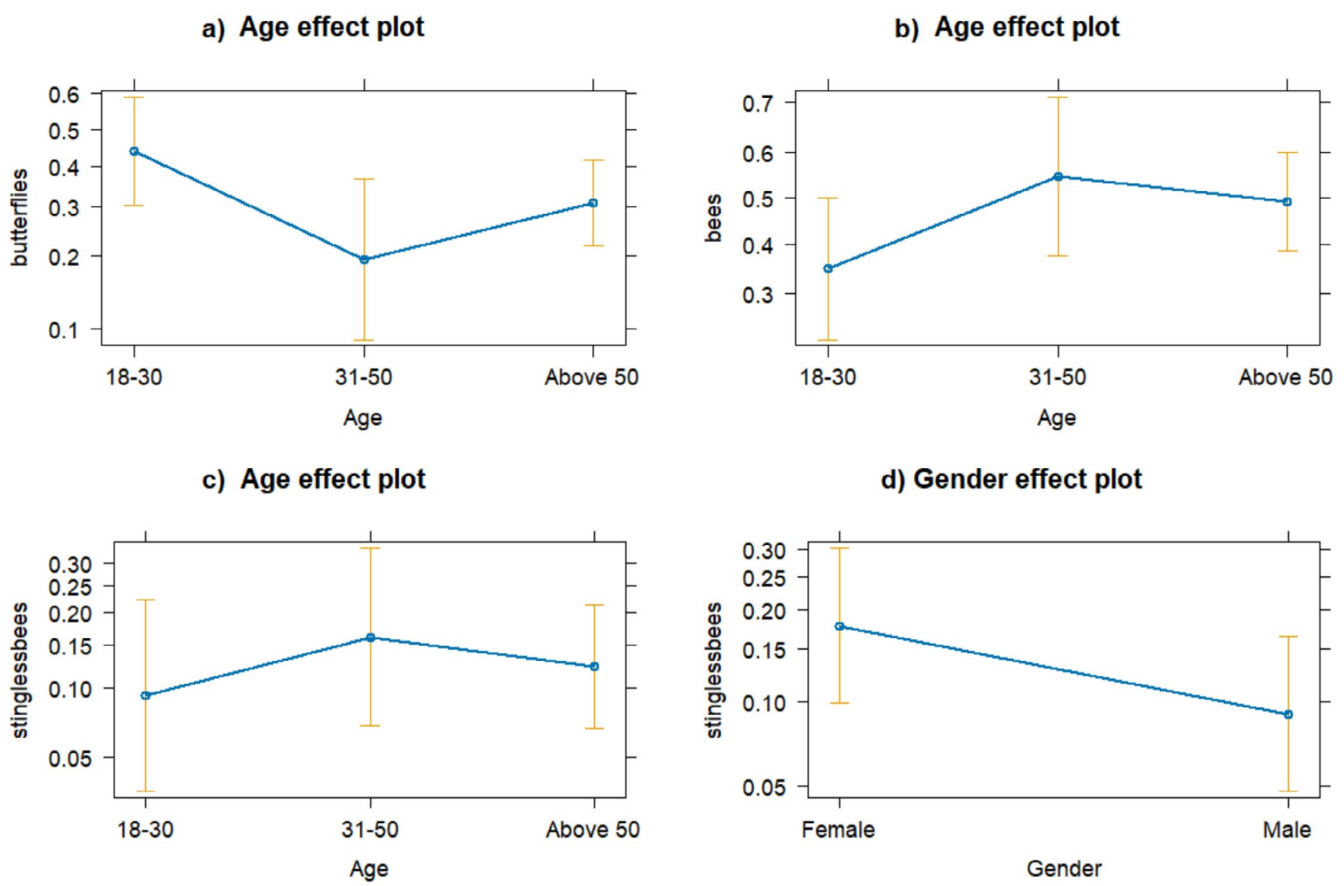

FIGURE 5 | Effect plot on the probability of (a) butterflies, (b) bees, and (c-d) stingless bees, being listed across gender and age in Mbire in the year 2025.

patterns, prioritizing pesticides over herbicides. However, male farmers dominated the use of both herbicides (67.1%) and pesticides (69.5%) (Table 2).

3.6 | Toxicity Levels Across Age Groups and Gender

The use of pesticide with various toxicity levels was not the same across people of different age groups, with low-toxicity (green) pesticides accounting for the largest proportion of use (49.2%), followed by moderately hazardous (amber) (22.4%), highly hazardous (red) (18.3%), and extremely hazardous (purple) pesticides (10.1%) (Figure A1). Farmers aged 31–50 contributed most pesticide applications across all toxicity classes (57.6%). Younger farmers (18–30) exhibited a stronger preference for low-toxicity pesticides (55.8%) and had the lowest use of highly hazardous chemicals. In contrast, farmers above 50 showed the highest proportional use of highly and extremely hazardous pesticides (37.5% combined) (Table 3). The distribution of pesticide toxicity classes differed by gender. Female farmers predominantly used lower-toxicity (green) pesticides (54.6%), whereas male farmers exhibited a higher reliance on more hazardous classes, particularly pesticides (20.7% compared to 13.1% in females) (Table 3).

TABLE 2 | Distribution of pesticide applications across age groups in Mbire in the year 2025.

Variable	Fungicide	Herbicides	Insecticides
Age group			
18–35	0	46 (44.2%)	58 (55.8%)
31–50	1 (0.4%)	102 (43.4%)	132 (56.2%)
50+	0	25 (35.2%)	46 (64.8%)
Total	1	173	236
Gender			
Female	0	57 (44.2%)	72 (55.8%)
Male	1 (0.4%)	116 (41.3%)	164 (58.4%)
Total	1	173	236

3.7 | Traditional Control Methods

Of the 63.4% respondents who confirmed using traditional methods for pests' control, 27.8% were using *Maerua edulis* (Katunguru) followed by chilli (27.8%), while urine from pregnant women was rarely used (Figure 6).

3.8 | Pollinator Families

A total of 239 individuals representing three orders and nine families were sampled in the study area (Table 4). Lepidoptera was the most abundant order (55.2%), while Hymenoptera was the least abundant (5.9%; Table 4). Sweep netting accounted for 82.4% of all collections, with the remaining 17.6% (n = 42) caught using pan traps (i.e., 15 in blue, 14 in white, and 13 in yellow), representing five of the nine pollinator families. Muscidae and Syrphidae were the only families captured in every pan trap colour regardless of colour (Table 4).

3.9 | Cropping Systems and Sampling in Relation to Pollinator Community Structure

Pollinator abundance was highest in mixed-cropping (n = 104) and mono-cropping (n = 103) systems, and lowest in the control (n = 32). Both cropping systems recorded eight pollinator families compared to five in the control. In the control, Pieridae was the dominant family and Hesperiidae the least represented, whereas Noctuidae, Muscidae, and Syrphidae dominated both cropping systems. Apidae and Arctiidae were the least recorded families across all cropping treatments (Figure 7).

The relative abundance of pollinators varied across treatments (i.e., control, mono-cropping, and mixed-cropping), with mixed-cropping and mono-cropping being similar in relative abundance compared to control. Of the nine pollinator families observed, the most pollinator families were recorded in mixed-cropping

TABLE 3 | Distribution pesticide toxicity levels across age groups and gender according to the Pesticide Use and Policies in Zimbabwe.

Variable	Green	Amber	Red	Purple
Age group				
18–35	58 (55.8%)	25 (24.0%)	12 (11.5%)	9 (8.7%)
31–50	116 (48.5%)	53 (22.2%)	47 (19.7%)	23 (9.6%)
50+	30 (41.7%)	15 (20.8%)	17 (23.6%)	10 (13.9%)
Total	204	93	76	42
Gender				
Female	71 (54.6%)	30 (23.1%)	17 (13.1)	12 (9.2%)
Male	133 (46.7%)	63 (22.1%)	59 (20.7%)	30 (10.5%)
Total	204	93	76	42

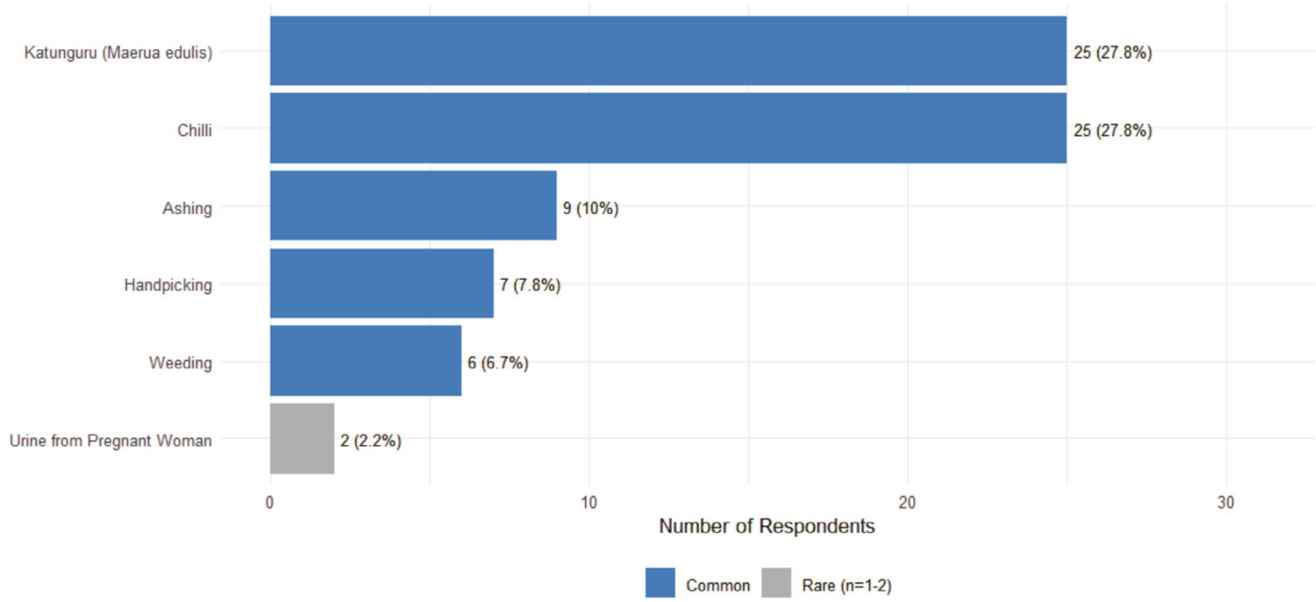

FIGURE 6 | Traditional ways of controlling pests.

TABLE 4 | Pollinators recorded in the Mbire in 2025.

Order name	Family name	Abundance per family	Percentages
Hymenoptera	Apidae	9	3.8%
	Halictidae	5	2.1%
Lepidoptera	Arctiidae	1	0.4%
	Hesperiidae	12	5%
	Noctuidae	68	28.5%
	Nymphalidae	12	5%
	Pieridae	39	16.3%
Diptera	Syrphidae	41	17.2%
	Muscidae	52	21.8%

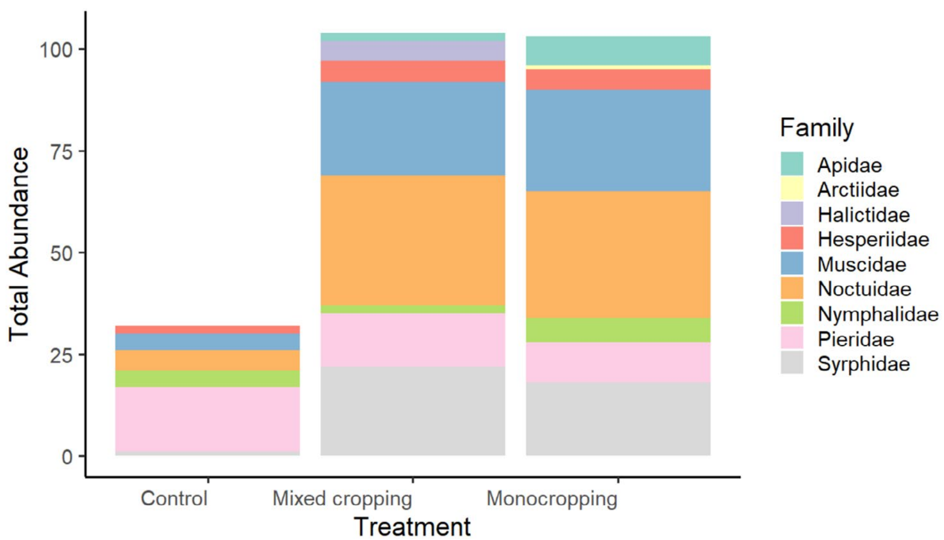

FIGURE 7 | The relative abundance of families found within treatments in Mbire in 2025.

($n = 8$) and mono-cropping ($n = 8$), while the least were collected in the control ($n = 5$). The most abundant pollinator family in the control was Pieridae, while the least abundant was Hesperiidae. Pieridae, Muscidae, and Noctuidae were the most dominant pollinator families in both mixed-cropping and mono-cropping, with Apidae and Arctiidae being the least recorded pollinator families (Figure 7).

Despite these descriptive differences, the generalized linear mixed model (GLMMs) showed that sampling method was the only significant predictor of pollinator abundance, while family richness and diversity did not significantly differ. Cropping system had no significant effect on any of these response variables, and this was also confirmed by the results from Non-Metric Multidimensional Scaling (NMDS) that a strong overlap between mixed cropping and monocropping revealed a lack of distinct insect communities between systems, although mixed cropping showed greater internal variability (Figure 8). Sweep netting consistently captured significantly more individuals than pan trapping ($\beta = 0.575$, SE = 0.173, $p = 0.009$) (Table 5).

3.10 | Pesticide Use and Pollinator Communities

GLMM retained the interaction between cropping system and spraying status as the most informative aspect for family abundance (Table 6). In unsprayed conditions, monocropping did not differ significantly from mixed cropping in family abundance. Spraying alone had no significant main effect in mixed cropping. However, the monocropping and sprayed interaction was marginally significant ($\beta = -0.829$, SE = 0.432, $p = 0.055$), while

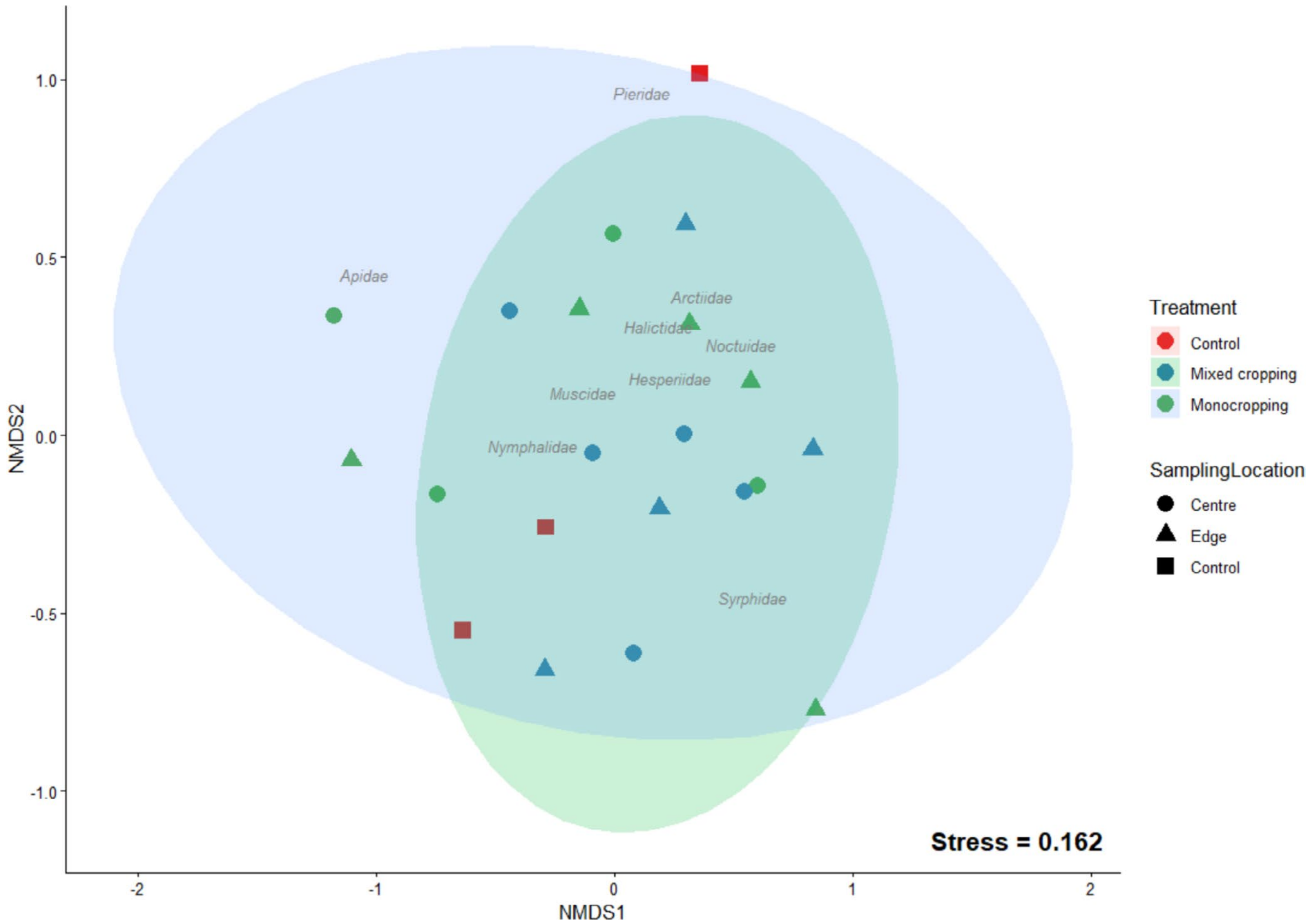

FIGURE 8 | Illustrates the non-metric multidimensional scaling (NMDS) (Stress = 0.162) of the overall study survey across sampling locations and treatment. Mixed-cropping and mono-cropping significantly overlapped, but a control had too few points to calculate the ellipse in Mbire, Zimbabwe, in 2025.

TABLE 5 | GLMM outputs for the effects of sampling method on pollinator family abundance, richness, and diversity in unsprayed plots.

Term	Estimate	SE	*z* value	*p* value	Sig.
Abundance					
Intercept	0.4055	0.1543	2.628	0.0086	*
Sweep netting	0.575	0.173	3.335	0.0009	**

TABLE 6 | Generalized linear mixed model outputs for the interaction between pesticide application and cropping systems on pollinator abundance.

Term	Estimate	SE	*z* value	*p* value	Sig.
Abundance: Treatment × Spraying status interaction					
Intercept	0.717	0.109	6.574	< 0.001	***
Monocropping	0.215	0.150	1.433	0.152	ns
Sprayed	0.148	0.254	0.582	0.561	ns
Monocropping × Sprayed	−0.829	0.432	−1.920	0.055	†

mixed cropping maintained relatively stable abundance under spraying. The random effect of field treatment was negligible (Table 6).

4 | Discussion

During this study, a two-staged approach combining qualitative and quantitative techniques was employed to investigate the farmers' knowledge of pollinators and the relationship between cropping systems and pesticide use, and pollinator community structure. The findings on pollinator communities represent a snapshot from a single sampling period conducted in February 2025, coinciding with the peak flowering season, a time when pollinators are attracted to croplands and flowering plants in Mbire.

The predominance of male respondents during the study is mainly attributable to the greater availability of men during data collection, which may itself reflect the broader pattern of men occupying key decision-making roles in agriculture, pesticide application, and cropping preferences, which directly determine pesticide use (Tiringo 2025). Research from the Niger State, Nigeria confirms this finding when significant gender disparities were indicated in farming experience, access to land, training, and credit, with men significantly benefiting from these opportunities, while women being more engaged in labour hiring and post-harvest decisions such as maize end-use (Ahmed et al. 2024).

Most farmers in Mbire practised more cropping systems simultaneously and this suggests an adaptation strategy to hedge against environmental risks, food insecurity, and the looming effects of climate change (Berhanu and Wolde 2019), unique and complex habitats for pollinators are created in the process. Given that rainfall patterns have become increasingly more erratic, sporadic, and droughts more frequent (Chanda 2024; Kusangaya et al. 2021), mixed cropping via its integration of different crop varieties increases agro-ecological resilience (Kremen and Miles 2012). Maize, pumpkin, and watermelon were typically grown in mixed systems, further demonstrating how traditional systems intertwine and overlap with pollination ecology. Out of these, pumpkins (*Cucurbita* sp.) and watermelons (*Citrullus lanatus*) depend on insect pollinators, in particular bees, for successful fruit set and good yields (Tettey-Enyo 2017). The diversity and abundance of pollinators can improve productivity and stability, helping to reduce pollination deficits and improve food security (Maggi et al. 2025). Maize (*Zea mays*), while it relies on wind-pollination (Harris-Shultz et al. 2025), is frequently included in mixed cropping systems because of its agronomic compatibility and as a staple food in the country. Its presence in mixed cropping systems contributes to the panorama heterogeneity, which can provide pollinator habitats by supplying structural range and shelter (Maggi et al. 2023). Farmers who exercise such diversification stand to gain not only improved yields of fruits and vegetables but also by means of supporting pollinator biodiversity. While mixed cropping can be beneficial for pollinators, the system also introduces a complexity in pest and disease management.

The farmer's knowledge of the full spectrum of pollinators remains poor. Although nearly all respondents could list *Apis mellifera* as an important pollinator, knowledge of non-bee pollinators (wasps, beetles, butterflies, flies) was much lower, reflecting a honeybee-centric understanding of pollination services among communities across Africa. This mirrors global trends where conservation awareness disproportionately favours honeybees over non-bee pollinators (Tarakini et al. 2021; Halvorson et al. 2021; Ollerton et al. 2022). The reported decline in honey production and perception of pollinator decline align with reductions in both managed and wild pollinator populations worldwide due to habitat loss, pesticide use, and climate change (Potts et al. 2016). There is a critical knowledge gap in recognising the diversity and ecological roles of non-bee pollinators, suggesting an urgent need for targeted farmer education on pollinator conservation.

Furthermore, the knowledge of pollinators varied across age-groups, with middle-aged farmers being less likely to report butterflies compared to younger farmers. This pattern may reflect the tendency of middle-aged farmers to focus predominantly on economically important and commonly known pollinators such as honeybees, potentially at the expense of broader pollinator recognition. Younger farmers, by contrast, may have greater exposure to formal environmental and agricultural education programmes that increasingly incorporate biodiversity awareness, which could explain their relatively higher likelihood of recognizing butterflies as pollinators (Christ and Dreesmann 2022; Cruz and Grozinger 2023). The significant gender difference observed for stingless bee awareness, with female farmers more likely to report stingless bees than male farmers, may reflect gendered differences in agricultural roles and daily interactions with the environment. In many smallholder farming communities, women are more closely involved in household food production and garden management, contexts in which stingless bees are more commonly encountered. These patterns suggest that pollinator knowledge is structured by both agricultural experience and cultural exposure rather than by formal training alone (Garbach and Morgan 2017), reinforcing the need for gender-sensitive and age-specific extension approaches.

In addition to limited awareness of pollinator diversity, the widespread reliance on agrochemicals in Mbire causes significant threats to pollinators. The predominance of *glyphosate* and the broad array of pesticide products used reflect a global trend of intensive herbicide reliance in agriculture (Benbrook 2016). Glyphosate, while primarily targeting weeds, has been linked to indirect pollinator impacts through the destruction of floral resources and possible sub-lethal physiological effects (Motta et al. 2018). Of particular concern is the frequent application of *carbaryl 85*, a carbamate pesticide known for its high toxicity to non-target insects, including bees (Goulson et al. 2015). The heavy reliance on pesticide inputs has inflicted severe and pervasive damage on pollinators in the region (Semwal et al. 2026) and underscores the urgent need for integrating pollinator-friendly systems into local agricultural systems.

Furthermore, the community structure of pollinators in Mbire also reveals important disparities in pollinator dynamics. The dominance of Lepidoptera over bees during the study may indicate that habitat modifications, such as the shift toward monoculture farming and reduced floral diversity, are favouring generalist pollinators over more specialized species (Fried et al. 2010; Vujanović et al. 2023). Moreover, pesticide exposure may disproportionately affect bee populations, which are often more vulnerable to the toxic effects of these pesticides (Chmiel et al. 2020; Schmolke et al. 2024).

The similarity of pollinator family diversity and richness across sprayed and unsprayed treatments suggests that pesticide application, specifically *Carbaryl 85*, may have reduced pollinator visitation frequency and activity rather than fundamentally altering the composition of the pollinator community present in the sampled plots. As a broad-spectrum contact toxicant, *Carbaryl 85* is highly lethal to non-target pollinators and does not possess repellent qualities that deter foraging entry (Stanley and Preetha 2016). Therefore, the observed decline in abundance in sprayed plots likely reflects the disruption of active foraging rather than behavioural avoidance. However, the stability of family-level richness and diversity across cropping systems, as confirmed by the Non-Metric Multidimensional Scaling (NMDS), implies that while population densities were suppressed across families, entire taxonomic groups were not entirely eliminated during the brief sampling window, which may have been insufficient to detect longer term shifts in pollinator community composition. Therefore, future studies should incorporate longitudinal sampling to determine whether the absence of family-level diversity and richness differences between treatments reflects a genuinely resilient community or simply the temporal limits of a short-term study. Furthermore, farmers acknowledged the use of Traditional Knowledge Systems (TKS) for pest management, with blue bush-cherry (*Maerua edulis*) being the commonly used. Therefore, future studies should investigate the effectiveness of such systems in pest management, as this could contribute to the development of more eco-friendly and sustainable pest control approaches.

Regarding sampling methods, sweep netting proved to be more efficient as compared to pan trapping. This underscores the importance of accounting for methodological variation in multi-method surveys, especially for capturing flying pollinators (Westphal et al. 2008). Notably, the sampling method effect on abundance was not mirrored in diversity or richness metrics, suggesting that sweep netting detected more individuals of already-present families rather than additional family groups, a distinction with practical implications for survey design in African agricultural systems where both methods are commonly deployed (Gemmill-Herren et al., 2014).

The marginal treatment and spraying status interaction for pollinator abundance suggests that pesticide application disproportionately suppressed pollinator abundance in monocropping relative to mixed cropping, with a modelled 50% reduction in abundance in sprayed monocropping plots compared to sprayed mixed cropping. This pattern is ecologically consistent with the resource concentration hypothesis, which posits that monocultures concentrate host plant resources, making them simultaneously more attractive to insect pests, thereby prompting greater pesticide use and being more vulnerable to chemical disruption of pollinator communities (Kaur et al. 2024; van der Werf and Bianchi 2022). In contrast, the structural and floral complexity of mixed cropping systems may dilute both pest pressure and pesticide exposure for beneficial insects, consistent with the buffering role of intercropping documented by Hatt and Döring (2023) and the intercropping as a refugia concept by Dingha et al. (2021).

5 | Conclusion

This study demonstrated that smallholder farmers in Mbire predominantly practised mixed-cropping and mono-cropping systems, with male farmers constituting most respondents. Although farmers showed knowledge of pollinators in general, knowledge of non-bee pollinators remained limited. Pesticide use was widespread across farming systems, with *Carbaryl 85* identified as the most applied pesticide. The interaction between monocropping and sprayed plots was associated with lower pollinator abundance, highlighting the potential ecological risks of combining simplified cropping systems with pesticide use. Conversely, mixed-cropping systems supported relatively higher pollinator abundance and family representation, likely due to increased floral diversity and resource availability. Traditional pest management approaches, particularly the use of *Maerua edulis* "*Katunguru*", were also commonly practised among farmers. This study underscores that cropping system choice and pesticide application interact to shape pollinator abundance at the farm level, a context underrepresented in pollinator research.

These findings highlight the need to strengthen farmer education and extension programmes on the ecological importance of both bee and non-bee pollinators, as well as the potential health risks associated with excessive pesticide use. Promoting conservation agriculture practices, such as diversified mixed-cropping systems and safer integrated pest management approaches, can help conserve pollinator communities while improving agricultural resilience in drought-prone areas such as Mbire. Future studies should incorporate longer-term and seasonal sampling to better understand temporal changes in pollinator communities and pesticide-associated responses.

Author Contributions

Matengo Tafadzwa: writing – original draft, resources, project administration, methodology, investigation, funding acquisition, formal analysis, data curation. **Tarakini Gugulethu:** writing – review and editing, supervision, conceptualization. **Musundire Robert:** writing – review and editing, supervision, conceptualization. **Guia Diaz Laura:** writing – review and editing, writing – original draft, supervision, methodology. **Tarakini Tawanda:** writing – review and editing, supervision, methodology, formal analysis, conceptualization.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Respondents' knowledge of different pollinator groups and their perceptions of long-term population trends during their lifetime. **Table S2:** Respondents' knowledge and use of pesticides, including pesticide type (synthetic or organic) and intended application. **Table S3:** Respondents' pesticide application methods and perceived effects of pesticides on pollinators.

Appendix A

TABLE A1 | Showing variable categories of the socio-demographic data collected in Mbire in 2025.

Variable	Description
Gender	Biological sex of the respondent grouped as male and females
Age group	Age range of the respondent, with young adults (18–30), middle-aged (31–50), and old (above 50)
Ward	Administrative ward within Mbire district
Occupation	The primary economic activity of the respondent, like Teacher, farmer and beekeeper

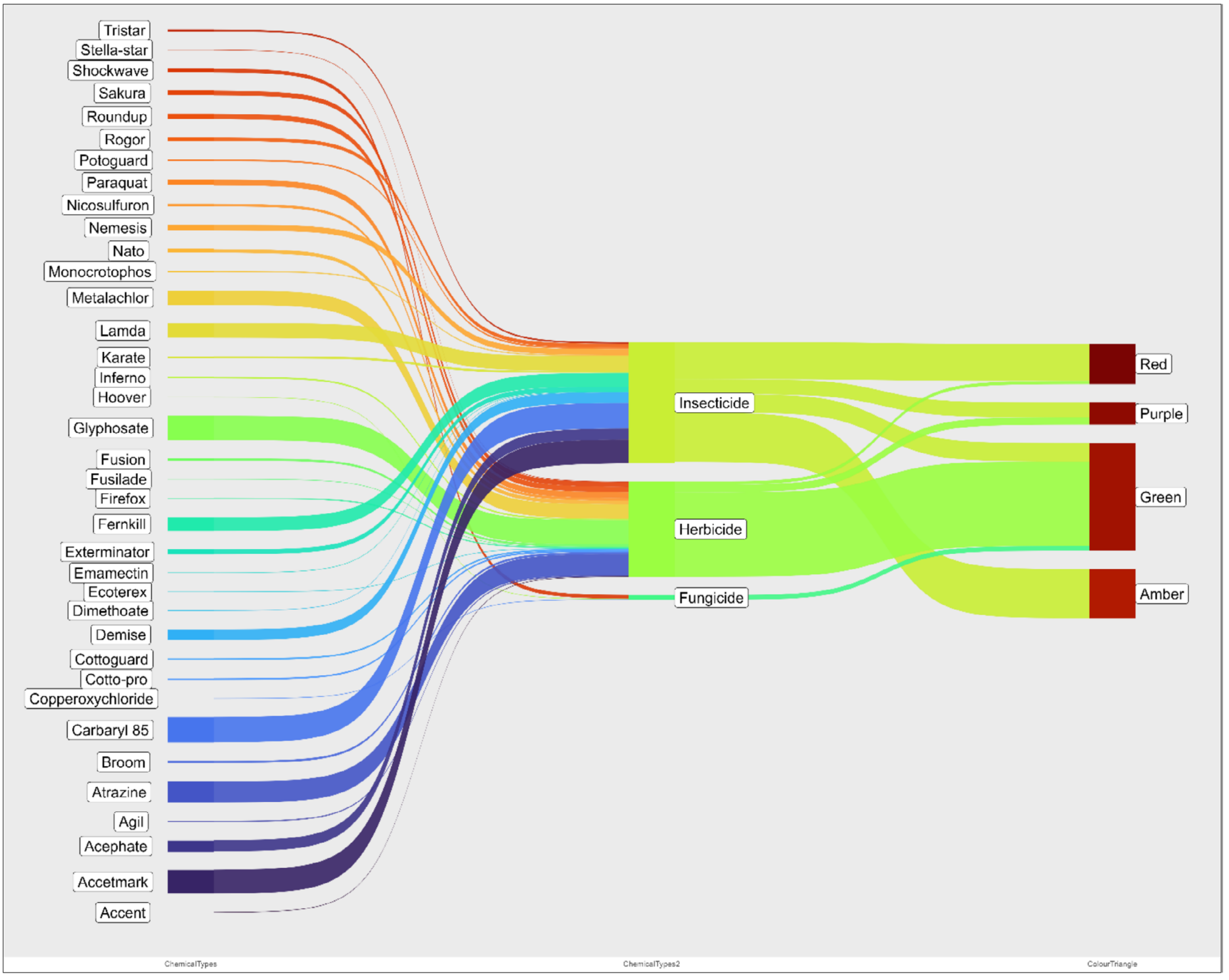

FIGURE A1 | Illustrating the different pesticide types grouped into three (fungicides, herbicides, and insecticides) and into four colour triangles (green, amber, red, and purple) being used in Mbire, Zimbabwe in 2025.