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Assessment of Cabbage (*Brassica oleracea* Linnaeus) Insect Pests and Management Strategies in Eastern Democratic Republic of Congo

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Abstract

Cabbage (*Brassica oleracea* Linnaeus) is an important vegetable crop for food security and income generation for farmers in the Democratic Republic of Congo (DRC). However, production is severely undermined by a complex of insect pests. This study investigates farmers' knowledge, perception, and pest management practices in key cabbage-growing areas surrounding Goma city in Eastern DRC. A total of 430 farmers were interviewed using a structured survey administered via the KoboToolbox platform. The diamondback moth (*Plutella xylostella* Linnaeus, 1758) and the cabbage aphid (*Brevicoryne brassicae* Linnaeus, 1758) were identified as the main pests, with peak incidences reported during the dry mid-season. Pest damages are most frequently observed at the post-transplanting and heading stages of cabbage. Although chemical control was the dominant strategy (69.4%), concerns arise due to the widespread use of moderately to highly hazardous insecticides, including pyrethroid, organophosphorus, and avermectin-based formulations. The insufficient use of personal protective equipment (PPE) and limited training on safe pesticide handling remain further challenges. While indigenous practices, such as crop rotation, handpicking of insects, and the use of botanical extracts, are employed to a lesser extent, awareness and implementation of biological control are almost nonexistent. The findings underscore the need to promote integrated pest management (IPM) approaches based on agroecological principles, including the safe use of (bio-)pesticides, training programs, and stakeholder engagement to enhance sustainable cabbage production.

Keywords: cabbage pests; IPM; indigenous practices; botanicals; pesticides; Democratic Republic of Congo

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1. Introduction

Cabbage (*Brassica oleracea* Linnaeus) plays a vital role in household food security and income generation for smallholder farmers across sub-Saharan Africa. In the Democratic Republic of Congo (DRC), where agriculture is largely subsistence-based, cabbage plays a crucial role in improving nutrition and livelihoods [1]. It is rich in essential nutrients and bioactive compounds, making it vital for enhancing dietary quality and health outcomes in the region [2].

The infestation of cabbage by insect pests is a major concern for smallholder farmers in the region. Phytophagous insects not only reduce crop yields but also affect the quality of the products, thereby threatening food security. Major pests affecting cabbage crops include aphids [3], moth caterpillars [4], and flea beetles [5], which cause significant damage at different growth stages of the crops. Aphids, including the cabbage aphid *Brevicoryne brassicae* (Linnaeus, 1758) and the green peach aphid *Myzus persicae* (Sulzer, 1776), mainly feed on the undersides of cabbage leaves, extracting sap and nutrients, which can lead to stunted growth and reduced yield [3,6]. The cabbage aphid can reduce growth by up to 35%, and infestations can result in 85% yield losses [7]. Also, several lepidopteran species pose significant threats [8], particularly in the larval stage, affecting cabbage crops globally and leading to substantial yield losses [4]. For example, the larvae of the diamondback moth (DBM), *Plutella xylostella* (Linnaeus, 1758), feed on cabbage leaves, leading to distinct diamond-shaped holes and reduced plant vigor [9]. The estimated annual economic loss due to *P. xylostella* infestations on cabbage farmers globally is up to $US 4–5 billion, highlighting the significant threat this pest poses to global food security and agricultural productivity [9,10]. Other pests have been reported to cause economic damage to cabbage crops, including the cabbage webworm *Hellula undalis* (Fabricius, 1781) [11], the cabbage looper *Tricoplusia ni* (Hübner, 1803) [12], the cabbage white butterfly *Pieris brassicae* (Linnaeus, 1758) [13], and the flea beetle *Phyllotreta striolata* (Fabricius, 1803) [5]. Climate change is expected to alter the distribution and severity of pest infestations, potentially increasing the risk of pest outbreaks in the Great Lakes countries of Africa [14]. Global warming can potentially create opportunities for pests to thrive in regions where they were less prevalent because of former unsuitable climatic conditions [15]. Infestation peaks during specific seasons are directly correlated with climatic factors, mainly temperature and humidity. Higher temperatures promote pest populations, particularly the flea beetle and DBM, which peak during warmer months [16].

To manage cabbage pests, Congolese farmers mainly resort to broad-spectrum insecticides. The main synthetic chemicals applied against a range of pests in DRC include organophosphates (e.g., profenofos, chlorpyrifos), pyrethroids (e.g., cypermethrin), and avermectin-based formulations (e.g., abamectin) [17–19]. The chemical control, while aimed at effectively managing pests, significantly contributes to biodiversity loss, environmental pollution, pest resistance, and higher production expenses for farmers [20,21]. This reliance raises concerns about the health risks to consumers and farmers associated with pesticide misuse [22,23]. Farmers who frequently and closely work with pesticides face an increased risk of exposure, by contact and inhalation [24]. Recent studies reveal an alarming situation in DRC, particularly as many farmers do not use personal protective equipment (PPE) and have not received specific training on the use of pesticides [25–27].

Additionally, smallholder farmers rely on traditional knowledge, although these methods are often insufficient alone. Farmers employ crop rotation, weeding, and handpicking to manage pest populations [4,28]. Plant diversification through crop rotation, intercropping, and mixed cropping enhances biodiversity and reduces pest populations [29,30]. An interesting variant of crop association for pest control is companion planting, where plants are grown next to the main cash crop to ensure ecosystem services such as pest regulation, by discouraging pest establishment or hosting natural enemies [31,32]. Another ancestral approach to control pests is the use of plant-based pesticides [33]. Many recent studies in DRC have assessed pesticidal properties of several species, including *Azadirachta indica* (A.Juss.), *Ricinus communis* (Linnaeus) [34], *Nicotiana tabacum* (Linnaeus), *Allium cepa* (Linnaeus), *Piper nigrum* (Linnaeus) [35], *Tephrosia vogelii* (Hook.f.), *Tetradenia* *riparia* (Hochst.) Codd, *Tithonia diversifolia* (Hemsl.) A.Gray [36], and *Capsicum frutescens* (Linnaeus) [37]. Traditional methods, such as using ash, smoking, and storing crops in pods, are standard for managing storage pests, highlighting the importance of indigenous knowledge in reducing crop losses [38].

The transmission of indigenous knowledge is often community-based, with a risk of loss due to the increasing adoption of modern practices. Therefore, it is essential to understand farmers' knowledge and perceptions of cabbage pests and current management practices to develop a suitable approach to pest management. Such information is largely lacking for eastern DRC, particularly in Goma and surrounding areas, highlighting the need for locally grounded evidence.

This study aims to investigate insect pests affecting cabbage in eastern DRC and pest control strategies adopted by farmers. Specifically, we assess (i) smallholder farmers' knowledge and perceptions of insect pests, (ii) the types of control methods used, and practices applied to manage pest damage. Understanding farmers' perspectives and practices is critical for designing sustainable and context-specific IPM interventions.

2. Materials and Methods

2.1. Study Area

Surveys were conducted in the Eastern part of the DRC, focusing on vegetable-growing areas surrounding Goma (1°41′01″ S, 29°14′07″ E, 1502.09 m altitude), the capital of the North-Kivu province. Besides the peri-urban areas of Goma city, three administrative territories across two provinces were covered. In North-Kivu province, the Nyiragongo and Masisi territories were surveyed, while in South-Kivu province, the Kalehe territory was surveyed (Figure 1). In DRC, a "territory" is a second-level administrative division under a province. The selected areas are the leading suppliers of market garden produce, including *Brassica* crops, to Goma. A tropical Afro-mountain climate dominates this high-altitude region. It is characterized by mild temperate conditions with a correlation between temperature and elevation, and the area is endowed with rich volcanic soil [39], making it ideal for growing cabbage. Most of the population in the regions surveyed relies on small-scale agriculture and livestock farming, fishing, and informal trade. The main grown cruciferous vegetables are cabbage and cauliflower.

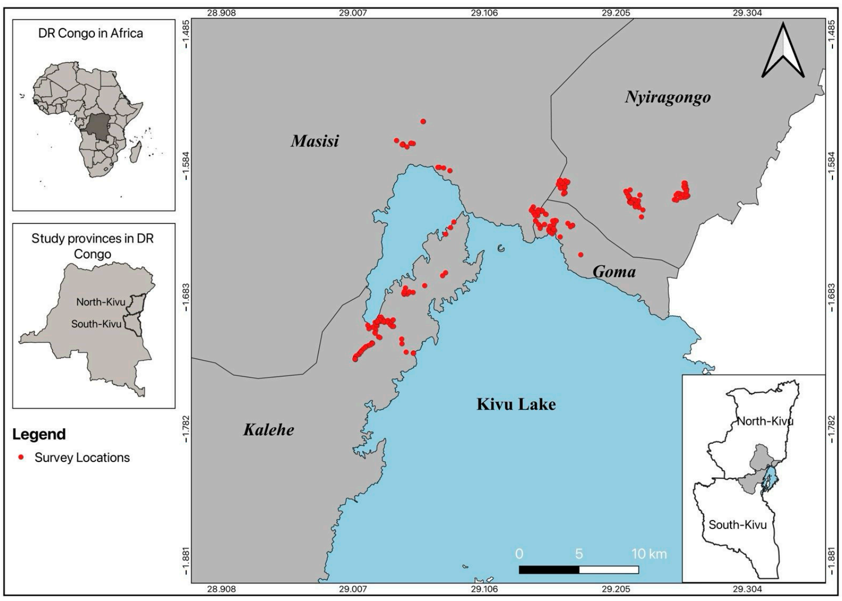

Figure 1. Map showing the survey locations (red dots) in the North-Kivu and South-Kivu provinces, Democratic Republic of Congo.

2.2. Data Collection

The survey was conducted using a structured questionnaire. Before its deployment, the questionnaire underwent a pre-validation process involving a pilot test with a sample of farming households from the target survey areas. This pre-test served to assess the clarity, relevance, and consistency of the instrument, allowing for modifications to enhance its reliability and validity [40]. After revision, the final version of the questionnaire was administered to a total of 430 farmers. The number of respondents per territory was determined based on estimates of cabbage producers and accessibility to the area. Participants were randomly selected from distinct villages within each study territory. Only farmers who had cabbage and/or another cruciferous cultivar among their cultivated crops were selected.

To facilitate fieldwork with producers, the questionnaire was encoded on the KoboToolbox platform "https://www.kobotoolbox.org/ (accessed on 26 April 2023)". The survey was conducted using smartphones programmed with the KoboCollect application, which allowed for the import of the questionnaire form. This setup enables rapid data collection, automatic recording of GPS coordinates, online data storage and transmission, and real-time monitoring of the survey progress [41]. The collected GPS coordinates were used to generate Figure 1 in QGIS 3.34. Investigations were carried out in 2023 and 2024 during growing seasons (short rainy season and long rainy season, respectively). The survey consisted of open- and closed-ended questions, administered face-to-face in French and Swahili to ensure the farmers' understanding. The survey covered the socioeconomic profiles of farmers (e.g., gender, education, and family size), farm characteristics (e.g., farm size, cabbage cropping systems), knowledge and perceptions of the main pests affecting cabbage, including insect identification, seasonal pest incidence, information and training about insect pests received from public services and non-governmental organizations (NGOs). The survey also focused on the management strategies undertaken by smallholder farmers (e.g., control methods, cultural practices, chemical pesticides used, and the safety precautions during application). Most farmers were interviewed on their fields to gather more information on key elements, including pests and pesticides used. In addition, clear printed pictures of the cabbage pests and their damage were provided to ensure their recognition by farmers. Empty bottles of chemical pesticides were checked to confirm the active ingredients and their concentration.

2.3. Data Analysis

Data processing and statistical analyses were conducted using RStudio 4.4.1. Chi-square tests of independence were used to assess relationships between categorical variables, including socioeconomic characteristics, farmers' perceptions of cabbage pests, and pest control strategies, across different regions. The same analytical approach was consistently applied across all relevant qualitative variables. Given the non-normal distribution and heterogeneity of variances among groups, a non-parametric approach was used to assess differences across territories for the quantitative variables, including the household size, household active members, and the insecticide use patterns. A Kruskal–Wallis test assessed overall differences among territories for each response variable. When significant, Dunn's post hoc test was used for pairwise comparisons with Bonferroni correction applied to adjust p-values. Analyses were conducted using "dunn.test" package [42] and the "multcompView" package [43]. All tests were set at the significance level of 5%.

3. Results

3.1. Socioeconomic and Farm Characteristics

Significant socioeconomic variations were observed across geographical regions. The gender distribution reveals that males were predominant (76.3%) in all survey areas;

however, a significant gender disparity was found between regions (χ^2 = 8.89, df = 3, p = 0.028) (Table 1). Educational levels also differed, with 34.0% and 32.6% of farmers on average who have completed secondary school and primary school, respectively. There is significant regional variation in educational levels (χ^2 = 39.87, df = 9, $p < 0.001$). The average household size in the sample was 7 ± 2.5 members with significant regional differences (H = 52.21, df = 3, $p < 0.001$). The average number of active household members was 5 ± 2.3, with significant differences across territories (H = 67.31, df = 3, $p < 0.001$) (Table 1).

Table 1. Socioeconomic profiles and farm characteristics across the four surveyed areas.

		Survey Areas						
Variables	**Categories**	**Goma n = 71**	**Nyiragongo n = 145**	**Masisi n = 30**	**Kalehe n = 184**	**Overall n = 430**	**χ^2 Test**	**Kruskal–Wallis**
Gender (%)	Female	33.8	22.8	6.7	23.4	23.7	8.89 *	
	Male	66.2	77.2	93.3	76.6	76.3		
Level of studies (%)	Uneducated	8.5	19.3	26.7	34.8	24.7	39.87 ***	
	Primary school	23.9	36.6	33.3	32.6	32.6		
	Secondary school	47.9	34.5	30.0	28.8	34.0		
	University level	19.7	9.7	10.0	3.8	8.8		
Household size		5.4 ± 2.3 a	6.5 ± 2.3 c	8.3 ± 3.1 b	7.6 ± 2.2 b	6.9 ± 2.5		52.21 ***
Household active members		3.8 ± 2.1 a	5.4 ± 2.3 c	6.5 ± 2.3 b	6.4 ± 1.9 b	5.6 ± 2.3		67.31 ***
Farm size (%)	<0.5 Ha	77.5	29.7	23.3	10.3	28.8	136.16 ***	
	0.5–1 Ha	21.1	46.9	56.7	40.2	40.5		
	1–2 Ha	1.4	21.4	16.7	41.3	26.3		
	>2 Ha	0.0	2.1	3.3	8.2	4.4		
Proportion of land used for cabbage (%)	<25%	23.9	30.3	46.7	32.1	30.7	14.55 *	
	25–50%	45.1	45.5	43.3	53.3	49.1		
	>50%	31.0	24.1	10.0	14.7	20.2		
Cropping systems (%)	Monoculture	47.1	61.1	42.9	46.1	51.5	57.49 ***	
	Intercropping	37.7	15.8	40.7	40.7	31.3		
	Companion planting	14.5	15.4	5.7	5.4	11.0		
	Agroforestry	0.7	7.7	5.7	7.9	6.2		

Note: * and *** correspond to statistical significance at $p < 0.05$ and $p < 0.001$, respectively; different letters in a row indicate statistically different groups determined by a post hoc Dunn's test.

The distribution of farm sizes indicated that Goma city had the most significant number of small farms (<0.5 ha), whereas Kalehe had more farmers with larger farms (1–2 ha and >2 ha). The overall trend indicated significant differences in farm size distribution across urban and rural regions (χ^2 = 136.16, df = 9, $p < 0.001$). Regarding cabbage cultivation, Goma had the highest proportion of farmers dedicating over 50% of their land to cabbage, whereas Masisi had the most farmers using less than 25% for cabbage. The cropping systems across the surveyed regions showed significant variations (Table 1). Monoculture was the dominant cropping system, particularly in Nyiragongo (61.1%). Intercropping ranked second, while a small portion of farmers used companion plants in all regions. Agroforestry was relatively rare, with the highest usage in Kalehe (7.9%).

3.2. Farmers' Knowledge and Perception of Cabbage Pests

Seven pests were highlighted by farmers as the most dominant, namely: *Plutella xylostella*, *Brevicoryne brassicae*, *Trichoplusia ni*, *Hellula undalis*, *Pieris brassicae*, *Myzus persicae*, and *Phyllotreta* spp. (Figure 2). The DBM (*P. xylostella*) was the most frequently cited pest overall (28.9%), with high proportions in Masisi (35.4%), Kalehe (34.9%), and

Goma (27.1%). The cabbage aphid (*B. brassicae*) was also highly prevalent in Kalehe (35.7%) and Goma (23.6%), resulting in the second-highest average perception rate across all territories (27.0%). The cabbage looper (*T. ni*), the cabbage webworm (*H. undalis*), and the white butterfly (*P. brassicae*) were moderately cited, with ± average values of 12.8%, 10.4% and 9.3%, respectively. *T. ni* had a high perception rate in Goma (17.2%) and Nyiragongo (12.9%). *H. undalis* was notably mentioned in Masisi (22.9%), while *P. brassicae* had moderate perception across all zones, ranging from 6.4% in Kalehe to 12.5% in Masisi. *M. persicae* and *Phyllotreta* spp. had lower overall frequencies (6.5 and 5.2%, respectively), though the green aphid was more prevalent in Nyiragongo (12.3%). Other cabbage pests occasionally reported include cutworms (*Agrotis* spp.) and millipedes.

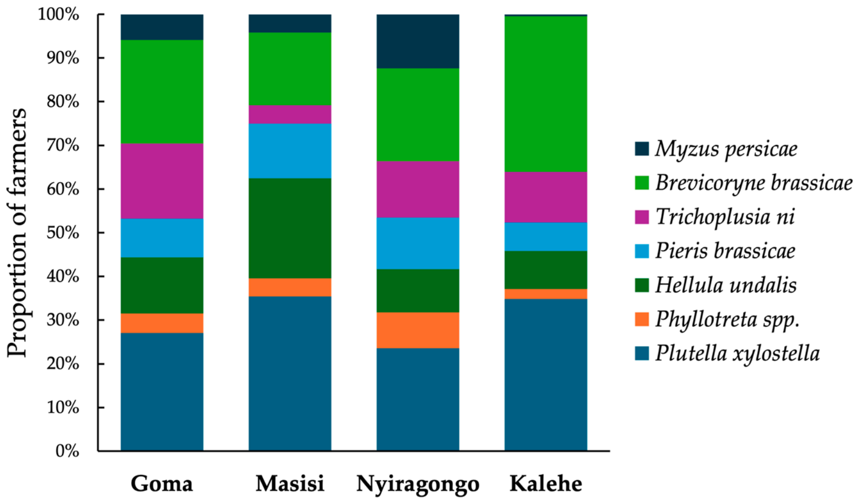

Figure 2. Farmers' perception of the main cabbage pests in the survey areas.

Pest incidence varied by season, with the dry mid-season reporting the highest pest pressure across all regions (59.1%). The long rainy season showed lower pest incidence, particularly in Kalehe (7.6%). These differences highlighted varying pest dynamics across the different seasons and regions (χ^2 = 27.52, df = 9, $p < 0.001$). Across all sites, the post-transplanting stage was most frequently identified as the stage when pests cause damage, with 38.9% of farmers indicating this stage. This was followed by the cabbage heading stage (30.2%) and the vegetative growth stage (22.0%). The observed variation was statistically significant (χ^2 = 52.58, df = 3, $p < 0.001$). Information and training sources of pest management varied significantly among territories (χ^2 = 83.18, df = 12, $p < 0.001$). Non-governmental organizations (NGOs) and radio/TV were the primary sources of pest management information, with 24.0% and 23.9% average, respectively (Table 2). Other farmers rely on agricultural public services and related projects for 18.3%, and on the Food and Agriculture Organization (FAO) and its partners for 17.8%. Other sources, including peer farmers and local initiatives, also contribute to agricultural knowledge dissemination.

Table 2. Farmer's perception of cabbage pest incidence and sources of information.

		Survey Areas					
Variables	**Categories**	**Goma n = 71**	**Nyiragongo n = 145**	**Masisi n = 30**	**Kalehe n = 184**	**Overall n = 430**	**χ^2 Test**
Seasonal pest incidence (%)	Long rainy season	21.1	23.4	20.0	7.6	16.0	27.52 ***
	Short rainy season	33.8	26.2	23.3	20.7	24.9	
	Dry mid-season	45.1	50.3	56.7	71.7	59.1	
Crop damage stage (%)	Nursery stage	5.8	10.8	7.7	3.6	6.9	52.58 ***
	Vegetative growth stage	21.2	21.6	36.8	17.2	22.0	
	Post-transplanting stage	46.0	40.6	33.3	36.6	38.9	
	Cabbage heading	24.8	25.9	18.8	41.3	30.2	
	Post-heading stage	2.2	1.1	3.4	1.3	1.7	
Information and/or training on pest management (%)	Agriculture public services	16.8	22.6	14.3	16.7	18.3	83.18 ***
	FAO	8.8	25.9	4.8	17.7	17.8	
	NGOs	32.8	33.2	19.0	15.1	24.0	
	Radio/TV	26.4	11.5	26.2	31.4	23.9	
	Other sources	15.2	6.2	20.0	19.1	15.9	

Note: *** corresponds to statistical significance at $p < 0.001$.

3.3. Farmers' Management Strategies of Cabbage Pests

Regarding endogenous practices (Table 3), the use of available resistant varieties was relatively consistent across regions, with the highest adoption in Goma (47.9%). The differences were not statistically significant, suggesting that resistant varieties were used similarly across the regions as a potential method of pest control. Early planting was significantly more practiced in Nyiragongo (53.8%), compared to other regions, particularly Kalehe (21.7%) and Goma (21.1%). A statistically significant difference was observed, indicating that early planting was a widely adopted strategy in Nyiragongo. Crop rotation was a widely used strategy in controlling pests in all areas, but it was more frequent in Masisi (46.7%) and Goma (45.1%), compared to Nyiragongo (30.3%). Intercropping with non-Brassica crops was more practiced in Goma (22.5%), but less common in Kalehe (9.8%). Differences were statistically significant, indicating that farmers in Goma may rely more on diversifying their crops. Although intercropping with repellent or trap plants may be practiced in some regions, with the highest adoption in Nyiragongo (12.4%), this strategy was adopted by a small percentage of farmers across regions (Table 3). Regular mechanical weeding was widely practiced across all regions, with the highest adoption in Goma (62.0%) and the lowest in Kalehe (47.8%), reflecting its high adoption by farmers. Fertilization, including the use of organic and chemical fertilizers, was more widespread in certain regions, notably in Goma (26.8%). Ash or sawdust application was used similarly across most regions, with the highest usage in Nyiragongo (22.1%), suggesting that this practice was not a significant method of pest control in most regions. Pest hand picking was more frequently practiced in Goma (31.0%), while it was less common in Kalehe (16.3%) and Masisi (16.7%) (Table 3). This suggests that farmers with small-sized farms are more inclined to remove pests manually. Uprooting and burning infected plants and destroying crop residues were considered in 31.2% and 25.6% of cases, respectively, when severe plant attacks occur. The practice of replanting affected areas, which can be a labor-intensive practice, was relatively low across all regions, with the highest adoption rate in Nyiragongo (19.3%). The use of locally prepared plant extracts was a prevalent practice across all territories, though not extensively adopted (14.4% overall). The difference was not statistically significant, indicating that while some farmers rely on traditional plant-based methods, these are not the dominant strategy (Table 3).

Table 3. Indigenous and agroecological approaches implemented for managing cabbage pests.

	Survey Areas					
Management Practices (%)	**Goma n = 71**	**Nyiragongo n = 145**	**Masisi n = 30**	**Kalehe n = 184**	**Overall n = 430**	**χ^2 Test**
Use of resistant varieties	47.9	33.1	36.7	43.5	40.2	5.76 ns
Early planting	21.1	53.8	43.3	21.7	34.0	44.08 ***
Practice crop rotation	45.1	30.3	46.7	40.8	38.4	6.61 ns
Intercropping with non-Brassica crops	22.5	15.9	3.3	9.8	13.5	10.50 *
Intercropping with repellent/trap plants	4.2	12.4	3.3	7.1	8.1	6.21 *
Practice regular weeding	62.0	60.7	43.3	47.8	54.2	8.63 *
Practice fertilization	26.8	26.2	16.7	8.2	17.9	22.52 ***
Application of ash/sawdust	19.7	22.1	13.3	12.5	17.0	5.94 ns
Hand picking of larvae/egg clusters	31.0	32.4	16.7	16.3	24.2	14.30 **
Uproot and burn infected plants	39.4	35.2	20.0	26.6	31.2	6.86 ns
Destruct crop residues	23.9	36.6	30.0	16.8	25.6	16.95 ***
Replanting attacked areas	12.7	19.3	16.7	17.4	17.2	1.48 ns
Use self-prepared local plant extracts	18.3	16.6	13.3	11.4	14.4	2.78 ns

Note: ns corresponds to not significant; *, **, and *** correspond to statistical significance at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

To control pests, some farmers prepare insecticide mixtures using available pesticidal plants. The listed plants span 10 botanical families, indicating a wide range of local resources available for pest management (Table 4). The most used plant parts are leaves, followed by seeds, bulbs, and fruits. Leaf extracts are used in most cases (e.g., *Cannabis sativa* (Linnaeus), *Eucalyptus* spp., *Lantana camara* (Linnaeus), *N. tabacum*, *T. riparia*, *T. diversifolia*). Some plants, such as *A. indica*, *Carica papaya* (Linnaeus), and *R. communis*, were reported to have multiple parts used, primarily leaves and seeds. The families Amaryllidaceae and Solanaceae were each represented by two species known for their insecticidal effects. For example, *A. cepa* and *Allium sativum* (Linnaeus), both of the family Amaryllidaceae, were used for their bulbs.

Table 4. List of pesticidal plants used by smallholder farmers for managing cabbage pests.

Scientific Name	Common Name	Family	Plant Parts Used
Allium cepa (Linnaeus)	Onion	Amaryllidaceae	Bulbs
Allium sativum (Linnaeus)	Garlic	Amaryllidaceae	Bulbs
Azadirachta indica (A.Juss.)	Neem	Meliaceae	Leaves, seeds
Cannabis sativa (Linnaeus)	Hemp	Cannabaceae	Leaves
Capsicum frutescens (Linnaeus)	Pepper	Solanaceae	Fruits
Carica papaya (Linnaeus)	Papaya	Caricaceae	Leaves, seeds
Eucalyptus spp.	Eucalyptus	Myrtaceae	Leaves
Lantana camara (Linnaeus)	Wild sage	Verbenaceae	Leaves
Nicotiana tabacum (Linnaeus)	Tobacco	Solanaceae	Leaves
Ricinus communis (Linnaeus)	Castor	Euphorbiaceae	Leaves, seeds
Tetradenia riparia (Hochst.) Codd	Ginger bush	Lamiaceae	Leaves
Tithonia diversifolia (Hemsl.) A.Gray	Mexican sunflower	Asteraceae	Leaves, seeds

Chemical control was the most widely used pest management practice across all regions (69.4%), with the highest usage in Masisi (78.1%) and Kalehe (76.2%). Biological control, especially the use of plant extracts, was adopted by 14.3% of farmers, while physical control techniques (such as manual removal of insect pests) were used by 16.3% of farmers. The differences in control practices were statistically significant (χ^2 = 21.44, df = 6, p = 0.002) (Table 5). Regarding the timing of chemical treatment, most farmers (73.3%) applied chemicals in the morning, with the highest proportions in Goma (84.5%) and Nyiragongo (82.1%). Use of chemicals in the midday and evening was less common. These differences in timing of chemical application were statistically significant (χ^2 = 43.50, df = 6, p < 0.001) (Table 5). The time of intervention after detecting a pest infestation was at least 2 days, while the average delay between two successive chemical treatments was 12.2 ± 3.0 days. The average number of chemical applications was 3 (Table 5). In addition, some farmers reported using preventive treatments on seedlings. Significant regional differences were observed between farmers in terms of intervention time (H = 45.97, df = 3, p < 0.001), delay between two treatments (H = 44.09, df = 3, p < 0.001), and number of chemical applications (H = 60.01, df = 3, p < 0.001).

Table 5. Management methods and insecticide use patterns against cabbage pests.

		Survey Areas						
Variables	**Categories**	**Goma n = 71**	**Nyiragongo n = 145**	**Masisi n = 30**	**Kalehe n = 184**	**Overall n = 430**	**χ^2 Test**	**Kruskal–Wallis**
Control methods used by farmers (%)	Physical control	23.7	19.1	15.6	10.4	16.3	21.44 **	
	Biological control	21.2	12.7	6.2	13.3	14.3		
	Chemical control	55.1	68.1	78.1	76.2	69.4		
Time of chemical treatment (%)	Morning	84.5	82.1	70.0	62.5	73.3	43.50 ***	
	Midday	5.6	10.3	10.3	32.1	18.8		
	Evening	9.9	7.6	20.0	5.4	7.9		
Intervention time after infestation detection (days)		3.8 ± 2.6 a	2.4 ± 1.7 b	4.3 ± 1.9 a	2.0 ± 1.3 b	2.6 ± 1.9		45.97 ***
Delay between two successive chemical treatments (days)		10.6 ± 3.4 a	12.2 ± 3.4 c	12.0 ± 2.4 bc	13.0 ± 2.3 b	12.2 ± 3.0		44.09 ***
Number of chemical applications		3.3 ± 1.5 a	4.4 ± 2.8 c	3.8 ± 2.0 ac	2.8 ± 2.2 b	3.5 ± 2.4		60.01 ***

Note: ** and *** correspond to statistical significance at p < 0.01 and p < 0.001, respectively; different letters in a row indicate statistically different groups determined by a post hoc Dunn's test.

The use of PPE when applying insecticides did not differ across territories, with an overall proportion of farmers using PPE of 41.9%. The type of PPE used did not vary significantly (χ^2 = 19.38, df = 12, p = 0.079). Rubber boots were the most used PPE across all regions (46.1%), with the highest usage in Masisi (51.1%) and Nyiragongo (44.6%). Secondly, long clothes were also used by a proportion of farmers (22.3%). The usage of gloves (11.3%) and glasses (0.8%) remained limited in all surveyed areas (Table 6). In terms of information sources, advice from other farmers was found to be the most common way of guidance for pesticide use (45.2%), with Kalehe (48.5%) and Masisi (46.9%) reporting the highest reliance on peer advice. Even without formal training, agrochemical retailers provided 27.5% of the information. Thirdly, farmers relied on their experience or, for those who are educated, on reading instructions (18.4%). Extension services provided information to fewer farmers, with an overall usage of 9.0%. Significant differences in the sources of pesticide information were finally determined (χ^2 = 18.17, df = 9, p = 0.033), indicating a varying reliance on formal and informal channels across areas (Table 6). Farmers in all territories reported experiencing the same health issues related to pesticide use (χ^2 = 13.64, df = 12, p = 0.322). Headache and skin irritation were the most common symptoms, affecting more than 25%

of farmers overall. Eye irritation and breathing problems were less frequently reported, but still present, with eye irritation at 21.6% and breathing problems at 17.3%. Less regularly, stomach problems were reported by 9.0% of farmers (Table 6).

Table 6. Farmers' safety and attitudes when using insecticides.

Variables	Categories	Survey Areas					
		Goma n = 71	**Nyiragongo n = 145**	**Masisi n = 30**	**Kalehe n = 184**	**Overall n = 430**	**χ^2 Test**
Wear PPE (%)	Yes	39.4	35.2	36.7	45.1	41.9	3.54 ns
	No	60.6	64.8	63.3	54.9	58.1	
Type of PPE used (%)	Face mask	19.1	24.7	13.3	16.2	19.5	19.38 ns
	Long clothes	25.7	17.2	24.4	24.8	22.3	
	Rubber boots	40.4	44.6	51.1	49.2	46.1	
	Gloves	12.5	12.7	11.1	9.5	11.3	
	Glasses	2.2	0.7	0.0	0.3	0.8	
Information on pesticide use (%)	Previous experience/Reading instructions	22.7	24.8	15.6	11.9	18.4	18.17 *
	Agriculture extension services	10.9	8.8	6.2	8.5	9.0	
	Other farmers	42.0	42.5	46.9	48.5	45.2	
	Agrochemical retailers	24.4	23.9	31.2	31.1	27.5	
Health problems related to pesticide use (%)	Headache/Coughing	28.0	26.6	28.0	23.5	25.5	13.64 ns
	Stomachache	13.3	6.5	6.5	9.2	9.0	
	Skin irritation	24.0	27.9	28.0	26.8	26.7	
	Eye irritation	20.4	21.1	23.7	21.9	21.6	
	Breathing problems	14.2	17.9	14.0	18.6	17.3	

Note: Ns and * correspond to not significant and statistically significant at $p < 0.05$, respectively.

A total of eleven insecticide formulations were identified, spanning several chemical families including pyrethroids, organophosphates, avermectins, neonicotinoids, and organochlorines (Table 7). Thiodan, an organochlorine insecticide classified as moderately hazardous (WHO class II), had the highest overall adoption rate (23.6%). Pyrethroid-based formulations accounted for many of the adopted products, either as single active ingredients or in combination with other insecticide classes. Roket 44EC (20.1%) and Dudu Alpha 3EC (17.1%) were the most frequently applied pyrethroids, indicating a farmer preference for cypermethrin-based formulations. Dudu Acelamectin 5%EC, a mixture of abamectin and acetamiprid, was adopted by 13.0%. Another cypermethrin-based insecticide, Cyperscope 5EC, recorded an adoption rate of 6.8%. Other insecticides, including Tafgor 40EC at 6.1% and Dudu Aba+ at 5.8%, showed moderate adoption levels. The use of organophosphorus compounds like dichlorvos (Lava; 2.5%) and chlorpyrifos (Kuu-Kill; 0.5%) was less common among farmers. Dudu Acelamectin 5% EC and Dudu Aba+ contain abamectin (Avermectin), a toxic substance classified as a highly hazardous compound (WHO Class Ib). Lava remains a highly hazardous compound, which raises safety concerns. The data indicate a heavy reliance on moderately and highly hazardous insecticides, with widespread adoption of restricted or risky compounds among farmers.

Table 7. List of commercial insecticides and corresponding active ingredients used in the study areas.

Commercial Name	Active Ingredient	Family	WHO Class	Adoption Rate (%)
Cyperscope 5EC	Cypermethrin 5%	Pyrethroid	II	6.8
Dudu Aba+	Abamectin 2%	Avermectin	Ib	5.8
Dudu acelamectin 5%EC	Abamectin 2% + acetamiprid 3%	Avermectin + Neonicotinoid	Ib + II	13.0
Dudu alpha 3EC	Alpha-cypermethrin 3%	Pyrethroid	II	17.1
Dudu cyper 5% EC	Cypermethrin 5%	Pyrethroid	II	2.1
Lava 100% EC	Dichlorvos 100%	Organophosphorus	Ib	2.5
Kuu-Kill	Chlorpyrifos 48%	Organophosphorus	II	0.5
Roket 44EC	Profenofos 40% + cypermethrin 4%	Organophosphorus + Pyrethroid	II + II	20.1
Simba +	Cypermethrin 5%	Pyrethroid	II	2.2
Tafgor 40EC	Dimethoate 40%	Organophosphorus	II	6.1
Thiodan	Endosulfan 50%	Organochlorine	II	23.6

Note: Based on the WHO (World Health Organization) Classification, Ib = highly hazardous, II = moderately hazardous [44].

4. Discussion

The predominance of male respondents across all study areas aligns with observations in other sub-Saharan African countries, where men often dominate commercial vegetable production. Women participate extensively in agricultural work, but men remain the decision-makers and farm managers [45,46]. While most farmers had completed secondary school, about a quarter are reported to have no formal education. In contrast, education is a key factor influencing the adoption of improved farming techniques and sustainable pest management practices [47]. Farm size data highlight the dominance of small-scale holdings (<0.5 ha) in urban centers like Goma. In contrast, rural territories like Kalehe show higher proportions of farmers managing larger plots (1–2 ha and >2 ha). These differences likely reflect urban land scarcity and higher land competition in cities, consistent with recent urbanization trends in DRC [48]. The dominance of monocropping cabbage farms, especially in Nyiragongo, raises concerns regarding ecological sustainability. Monoculture often fosters pest and disease buildup and depletes soil nutrients [49]. Alternative systems such as intercropping and companion planting remain underutilized, while agroforestry in cabbage production is rare, despite their potential to enhance agroecosystem resilience. These diversified systems are known to support pest regulation, biodiversity conservation, and soil fertility [30].

Results highlight two dominant pests: *P. xylostella* and *B. brassicae*, which farmers perceive as major threats. Our earlier findings [37], based on standard trapping methods, also highlighted the presence of these cabbage pests in eastern DRC. Our findings are in accordance with Asante et al. [50] and Balasha & Nsele [51], who reported that farmers are aware of these key cabbage pests. The widespread recognition of *P. xylostella* among farmers is not surprising given its status as one of the most destructive pests of cruciferous crops worldwide [8]. The DBM has been associated with substantial yield losses and is notorious for its rapid development of resistance to multiple classes of insecticides, including pyrethroids [52]. Also, aphids are known for their ability to reproduce rapidly and as major sap-sucking pests that transmit plant viruses, posing serious threats to crop productivity and marketability [53]. The cabbage looper (*T. ni)*, cabbage webworm (*H. undalis*), and white butterfly (*P. brassicae*) were also reported to affect cabbage production. Previous studies linked the prevalence of *T. ni* to high temperatures and dense foliage, which favor larval development [17]. Although *T. ni* feeds on several species, female moths prefer to lay eggs on cabbage due to its suitability for larval development, which is critical for the pest's lifecycle [54,55]. The presence of *H. undalis* and *P. brassicae* confirmed previous studies, which showed their preference for Brassicaceae crops [4,56]. As with other cabbage-specialist pests like *P. xylostella*, glucosinolates, which are secondary plant compounds characteristic of the cruciferous plants, play an important role in cabbage plant selection. For example, *H. undalis* showed a preference for plants with higher concentrations of glucosinolates, enhancing attraction and egg-laying behavior [57]. The distribution of different lepidopteran pests across survey areas may indicate wide host availability, as well as farmers' familiarity with their characteristic feeding damage and presence of larvae. The green peach aphid and flea beetles were less frequently mentioned in survey areas. While both pests are known to impact crucifers, their lower perception could be due to their less conspicuous feeding symptoms when there are few, compared to leaf-eating caterpillars. Furthermore, *M. persicae* is a generalist pest that can feed on a range of host plants grown in the survey areas, including bean, cauliflower, tomato, spinach, and pepper [58,59].

Pest incidence was reported to be highest during the dry mid-season, compared to the short rainy season and the long rainy season, indicating that seasonal climatic conditions strongly influence pest pressure. This finding aligns with broader evidence that dry seasons typically favor the proliferation of many lepidopteran and aphid pests, especially

P. xylostella and *B. brassicae*. In tropical regions, dry and hot microenvironments during dry seasons accelerate pest development cycles, thereby increasing infestation intensity [52]. In contrast, rainfall can act as a natural suppressant of pest populations by dislodging eggs and larvae and enhancing fungal pathogen activity [7,60]. Across all sites, farmers most frequently reported the post-transplanting stage and the heading stage as the most susceptible to pest damage. This suggests that pest infestations often begin during early foliar development, when plants are less structurally defended and many cabbage pests prefer young, tender tissues, leading to high vulnerability in early field stages [7]. The cabbage heading stage is also sensitive, as leaf mining or aphid feeding at this time can severely inhibit growth, leading to poor head formation and rendering heads unfit for marketing and consumption [61].

Chemical control remains the most widespread pest management practice across all areas. This finding is in line with previous studies [62,63], where smallholder farmers consider pesticide use to be more effective in reducing pest populations. Chemicals are considered economically viable to maintain high yields and to prevent financial losses, particularly in large-scale farms [23]. However, overreliance on insecticides has led to pesticide resistance, secondary pest outbreaks, and ecological disruption, particularly against cabbage pests like *P. xylostella* [52] and *B. brassicae* [64]. Recurrent use of broad-spectrum insecticides may also impact pollinators and natural enemies [65], undermining biological regulation within the cropping system. A majority of farmers apply insecticides in the morning rather than in midday and evening. This pattern is highly recommended, as morning applications avoid high solar radiation that can degrade insecticides and reduce efficacy. However, afternoon applications may coincide with peak pollinator activity and increase non-target effects, especially in open-field systems [66]. Regarding the use of insecticides, the lack of training, failure to read instructions, and low rate of PPE use are quite concerning, given the risks associated with pesticide exposure. Our findings match those of Madaki et al. [67] and Mergia et al. [68] regarding the improper pesticide handling by farmers in the global South. Farmers across all surveyed regions reported experiencing health issues related to pesticide exposure. The reported symptoms are consistent with acute pesticide poisoning syndromes [23]. Indeed, all chemical insecticides used in survey areas are classified as moderately and highly hazardous pesticides with significant concerns regarding human safety, resistance development, and environmental impact [44]. For example, the organochlorine endosulfan is widely used by farmers; however, it has been banned globally under the Stockholm Convention as a persistent organic pollutant and by many countries due to its high toxicity to humans, persistence in the environment, and bioaccumulation in food chains [23,69]. Organophosphates like dichlorvos and chlorpyrifos are still used unsafely, despite their known acute toxicity and neurological effects, including the inhibition of cholinesterase. This enzyme is important for healthy nerve function and remains a target for neurotoxins [70]. In Tanzania, a survey of farmers using organophosphorus pesticides looked at acetylcholinesterase. The enzyme was found to be at significantly lower levels in exposed farmers compared to unexposed [24]. The use of neonicotinoids, such as acetamiprid found in Dudu acelamectin 5%EC, is also concerning given their documented adverse impact on human health and non-target organisms, particularly bees [71,72].

The use of botanical extracts is limited, even though plant-based pest control offers affordable and eco-friendly alternatives, particularly for resource-limited farmers [73]. Botanicals from *A. indica*, *A. sativum*, and *R. communis* have demonstrated effectiveness against common Brassica pests and are compatible with ecological farming systems [74,75]. Detailed lists of plants to be used against cabbage pests in DRC conditions have been provided by Mayanglambam et al. [76] and Anjarwalla et al. [38]. Uptake remains low in survey areas, likely due to limited awareness, the lack of formulations, or the absence of processing tools. Also, smallholder cabbage farmers use a combination of indigenous knowledge, ecologically based practices, and low-input techniques to manage pest pressures. Early planting is adopted to avoid peak pest emergence windows during the early growth stages of cabbage [76]. Farmers rely on available resistant varieties to prevent pest infestations, despite access difficulties. Recent breeding efforts have produced cabbage varieties resistant to a wide range of pests. However, adoption in sub-Saharan Africa is hindered by poor seed system infrastructure and limited extension services [77]. Handpicking of insects, specifically caterpillars and regular manual weeding, which are typical physical control practices in small-scale systems, are highly practiced by farmers in eastern DRC, as reported by Cokola et al. [27]. Weed management reduces alternative pest habitats and promotes airflow, helping to suppress pest buildup [4]. Other farmers apply crop rotation and intercropping for their benefit against insect pests. Rotating cabbage with nonhost crops contributes to disrupting pest life cycles and reducing their harmful effects [78]. While intercropping with non-Brassica species remains limited in some areas, companion planting (e.g., repellent or trap plant) is marginally adopted. However, studies have shown that several plants, including garlic [79], onion [80], and basil [81], act as repellents against cabbage pests. Others, including flowering plants, enhance the colonization of natural enemies [82]. For example, Badenes-Pérez et al. [29] tested the attractiveness of flowering *Barbarea vulgaris* (R. Br.) to *P. xylostella* and to its parasitoids, *Diadegma insulare* (Cresson, 1865) and *Diadromus collaris* (Gravenhorst, 1829). They found that *P. xylostella* suffered 1.7 and 4.0 times more parasitism by *D. insulare* and *D. collaris*, respectively. Such prophylactic and cultivation measures are practicable in DRC, considering that many potential companion plant species are already grown in the region for other uses. Other approaches, such as push-pull, should be considered in the IPM of cabbage, as shown by Mayanglambam et al. [76] and Da Silva et al. [83]. None of the respondents reported using natural enemies (e.g., parasitoids, predators), nor did they have access to biological control inputs (e.g., microbial biopesticides) or training. This aligns with broader regional patterns where biocontrol remains underdeveloped due to a lack of capacity, limited commercial formulations, and insufficient policy support [84,85].

To achieve sustainable pest management in the region, it is essential to combine the use of available resistant cultivars, local biological pesticides, and good agricultural practices, such as regulating the planting period, real-time pest monitoring, crop rotation, and habitat management [76,85]. Chemical pesticides should only be considered as a last resort and with great caution. In this case, it will be necessary to adopt selective pesticides and rotate the insecticide mode of action to reduce the development of resistance in target insects [86]. Strategies for the efficient use of synthetic pesticides can include seed treatment or localized application to reduce the spread and direct contact of toxic molecules with beneficial insects [65]. New sustainable prospects would include the use of pheromone-based products, microbial agents (e.g., entomopathogenic fungi-based formulations) [76], and RNA interference (RNAi) [87] to control cabbage pests, particularly lepidopteran insects. For example, recent findings have demonstrated the successful application of oral RNAi in silkworms, *Bombyx mori* (Linnaeus, 1758), using chitosan/double-stranded RNA (dsRNA) nanoparticles [88].

5. Conclusions

Cabbage production in Eastern DRC faces significant challenges from key insect pests, especially *P. xylostella*, *B. brassicae*, *T. ni*, and *H. undalis*, which lead to yield losses. Farmers mostly rely on chemical insecticides, often with hazardous profiles and inadequate protective measures, raising significant concerns for both human and environmental health.

Although some indigenous practices, such as crop rotation and botanical extracts, are used by farmers, they require adequate design and broader adoption to be effective. The virtual absence of biological control and biopesticide use underscores critical gaps in knowledge transfer and policy support. These findings highlight the need to shift towards more sustainable and context-appropriate pest management strategies. This could involve promoting agroecological pest management strategies adapted to smallholder contexts, enhancing farmer training on safe pesticide handling, improving access to affordable and adequate biopesticides, and encouraging participatory research to co-develop locally relevant solutions. Integrating these actions within a coherent policy framework would support the transition towards safer and more sustainable cabbage production systems in the region.

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