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Research article

Evaluation and implications of organophosphate pesticide residues in cabbage (*Brassica oleracea*)

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ABSTRACT

The improper application of pesticides in cultivating vegetables has resulted in the buildup of pesticide residues on vegetables. This study evaluated organophosphate pesticide residue levels in cabbage with specific objectives of investigating the varieties of organophosphate pesticides employed by farmers and their awareness, assessing residue levels on cabbage using semi-structured questionnaires, and determining the distribution of pesticide residues within the layers of the cabbage head using 50 cabbage samples randomly collected from farmers from 14 cabbage-producing communities. The findings indicated that 98 % of the farmers applied pesticides in the morning, whereas 24 % preferred evening application. Meanwhile, 22 % applied pesticides twice in a day. Also, 18 % combined pesticides, 40 % applied 20 ml during the application, 72 % chose a particular pesticide based on the expected efficiency, 46 % applied pesticides between 1 and 5 times in a season and 66 % sprayed between 7 and 14 days. Pyrinex 48 EC and Perferthion emerged as the predominant organophosphates, with usage rates of 10 % and 12 % respectively. Also, eleven (11) organophosphate pesticide residues were identified in the cabbage samples. Profenofos and chlorpyrifos exhibited the highest concentrations of pesticide residues, with levels reaching 0.02 mg/kg, with 56.6 % of the samples containing chlorpyrifos pesticide residue. Nevertheless, all the identified pesticide residues did not exceed the maximum residue limits for cabbage. The study analysis disclosed the presence of various organophosphate pesticide residues in the first 10 layers of cabbage. However, it was noted that the innermost layers might not contain any detectable pesticide residues. The findings highlight the need for farmers to use pesticides judiciously and follow recommended application practices to minimize vegetable residues.

1. Introduction

Cabbage (*Brassica oleracea*) is acknowledged for its significant role in human diets due to its rich nutritional content, encompassing essential vitamins, proteins, carbohydrates, and vital minerals [1]. Farmers in many developing countries are grappling with reduced agricultural productivity caused by pest damage, prompting an upsurge in pesticide usage as a means to address the global challenge of food security [2]. Often, consumers select vegetables based on appealing features like appropriate size, vibrant colour, and absence of insect-related damage. Achieving these desirable characteristics results in farmers' increased reliance on pesticides to manage various

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pests that could harm their crops [3]. The utilization of pesticides for insect-pest control has experienced a significant surge over the last decade [4], which has resulted in an elevated presence of residues on vegetables [5].

The widespread use of pesticides in agriculture has significantly contributed to increased crop yields, ensuring food security for a growing global population [6]. However, Kim et al. [7] and Kumar and Kumar [8] have revealed that this agricultural practice is not without its concerns, as the residues of potentially toxic elements/chemicals can pose substantial risks to human health, the environment, and overall food safety. Among the various types of pesticides, organophosphates have gained attention due to their potential adverse effects [9]. In recent years, there has been growing concern about the presence of organophosphate pesticide residues in vegetables, including cabbage, one of the most commonly consumed and nutritionally rich leafy greens [10,11]. While these chemicals have proven valuable in crop protection, their residues on harvested produce raise significant concerns related to food safety, environmental impact, and potential health risks [12].

The introduction of organophosphate pesticides, despite their effectiveness in pest management, has raised alarms about their residual impact [13]. Organophosphates disrupt the nervous systems of insects and other pests, making them highly toxic compounds that require stringent regulation [14]. Their potential health risks, including acute toxicity and links to chronic health issues [15] have prompted regulatory bodies worldwide to establish Maximum Residue Limits (MRLs) to ensure that the levels of pesticide residues on vegetables remain safe for human consumption. Cabbage, being a versatile and nutritious vegetable widely incorporated into diets globally, merits particular attention due to its susceptibility to pesticide contamination. Detecting and quantifying the effects of regularly consuming pesticide residues in food can be challenging. To understand the potential consequences of this habitual exposure, an assessment of exposure and associated risks becomes necessary [16]. A study by Darko and Akoto [17] revealed that ethyl-chlorpyrifos was found in various vegetables, with a mean concentration of 0.211 $\pm$ 0.010 mg/kg detected in 42 % of tomatoes, 0.096 $\pm$ 0.035 mg/kg in 10 % of eggplants, and 0.021 $\pm$ 0.013 mg/kg in 16 % of peppers. Importantly, all these levels were well below the MRL of 0.5 mg/kg. Similarly, 52 % of 155 vegetables sampled from markets in Accra contain detectable pesticide residues [18]. However, recent studies are still lacking in the country.

This study focuses on evaluating organophosphate pesticide residues in cabbage, with a particular emphasis on *Brassica oleracea*. It explores the extent of pesticide usage, the prevalence of organophosphate residues, and their potential implications for consumers, farmers, and the environment. The study in the Atwima Nwabiagya District is strategically chosen due to its status as a major agricultural centre, particularly in cabbage production, offering insights into pesticide usage for local and national policy formulation. The district's agricultural diversity and varying socioeconomic factors provide a nuanced understanding of pesticide application's impacts, relevant not just locally but also to similar agricultural contexts nationwide. Its geographical and cultural characteristics influence farmer decisions, making it a representative case for broader agricultural regions. Collaborating with local stakeholders ensures the study's credibility and fosters practical, evidence-based recommendations for sustainable agricultural practices and pesticide management. This study significantly aligns with the Sustainable Development Goals (SDGs), particularly contributing to Zero Hunger

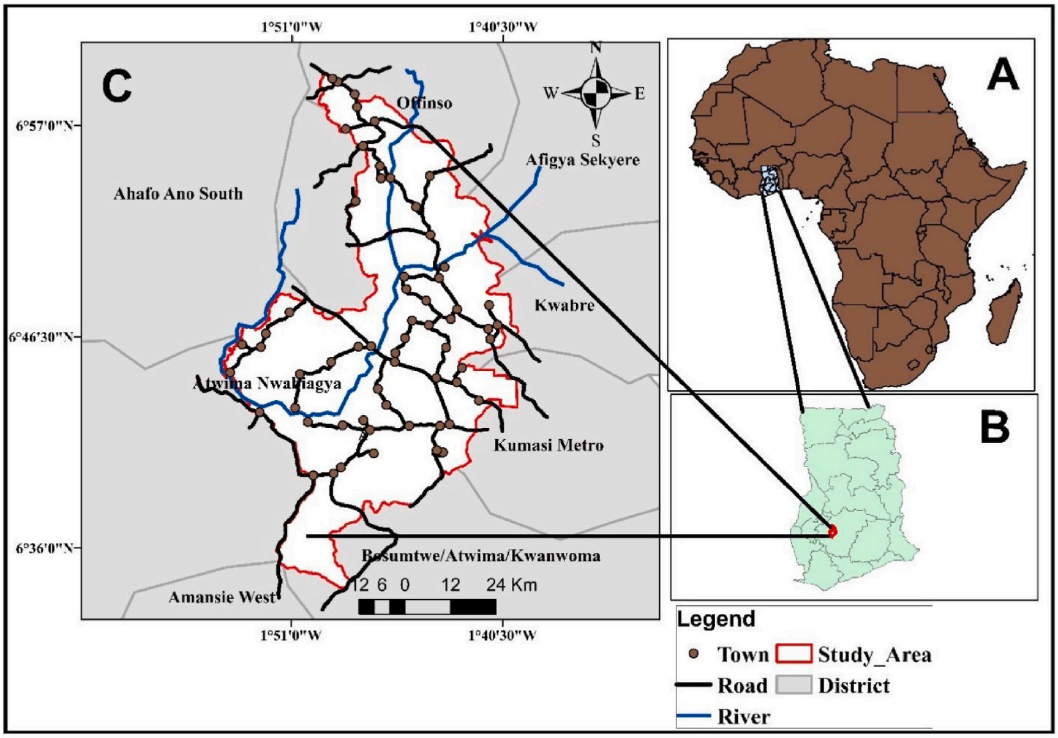

Fig. 1. Map of the study area [19].

(SDG 2) by assessing pesticide residues in widely consumed cabbage, ensuring food safety and security. Additionally, it addresses Life on Land (SDG 15) by evaluating potential adverse effects of pesticides on soil and ecosystems, promoting healthier soils and preserving terrestrial biodiversity. The research upholds human health (SDG 3) by assessing and mitigating health risks associated with pesticide residues, and promoting responsible consumption and production (SDG 12) through sustainable agricultural practices. It may also identify gender-specific implications, promote gender equality (SDG 5), and indirectly supports Life Below Water (SDG 14) by preventing pesticide runoff. In essence, this study plays a vital role in supporting multiple SDGs, emphasizing their interconnectedness.

2. Materials and methods

2.1. Study area

The Atwima Nwabiagya District is situated in the western region of Ghana, sharing borders with the Ahafo Ano South and Atwima Mponua districts to the west, the Offinso district to the north, and the Amansie West and Atwima Kwanwoma districts to the south. To the east, it borders the Kumasi Metropolis and the Kwabre district (Fig. 1) [19]. Nkawie serves as its administrative capital [20]. Covering an estimated area of 294.84 km^2, the district is situated between latitudes 6°32′N and 6°75′N and longitudes 1°45′W and 2°00′W [21]. The study district is situated along the Kumasi-Bibiani road. It falls within the wet semi-equatorial zone, characterized by a bimodal rainfall pattern ranging between 170 cm and 185 cm annually. The prevalent vegetation in the district is primarily of the semi-deciduous type. In the district, economic activities can be categorized into four main sectors: farming, industrial, trading, and service provision. The service provision sector employs the largest percentage of the population, accounting for 31.7 %. The Atwima Nwabiagya District is predominantly characterized by semi-deciduous forests and includes significant forest reserves such as the Gyemena Forest Reserve, Owabi Water Works Forest Reserve, and Barekese Water Works Forest Reserve [22]. Trading and commercial activities employ 29.9 % of the population, followed by farming and fishing activities, which engage 22.8 % of residents. Industrial activities employ the smallest proportion of the population, at 19.6 % [19].

2.2. Field survey

Interviews and questionnaire surveys were conducted with a random sample of fifty cabbage farmers drawn from 14 primary communities within the Atwima Nwabiagya District that cultivate cabbage. The communities comprised Esease, Toase, Atwima Mim, Nwabi, Akwaboa, Adankwame, Esaso, Nkawie, Pasuro, Abuakwa, Kapro, Atwima Koforidua, Barekese and Akropong. The selected communities were chosen strategically to provide a comprehensive view of cabbage farming practices and pesticide use across diverse geographical and socio-economic contexts within the district. Each community serves as a distinct example of agricultural activity, influenced by factors like land topography, farming traditions, resource access, and economic conditions. This diverse selection aimed to capture a wide range of perspectives and practices among cabbage farmers in the district. Through detailed interviews and semi-structured questionnaires, the study gathered valuable insights into farming techniques, pest management strategies, pesticide application practices, socio-economic factors shaping agricultural decisions, and the daily challenges and opportunities faced by cabbage farmers. This method ensured a thorough exploration of the factors affecting agricultural productivity and sustainability in the cabbage farming sector of Atwima Nwabiagya District.

2.3. Sample collection and preparation

In this study, a total of 150 harvested cabbage heads were directly collected from farm gates. The sampling strategy involved systematically selecting three different farms from each of the 10 communities within the district where the questionnaire was administered. At each chosen farm, five cabbage heads were randomly chosen for sampling. From each farmer, four out of the five collected cabbage heads were combined and chopped on a wooden board. Approximately 500 g of each chopped mixture was then carefully wrapped in aluminium foil and placed in properly labelled zip-locked bags.

To maintain clarity and organization, each of the three sampled farms in every community was designated as A, B, and C, with the initials of the corresponding community prefixed. For example, samples from Esease community were labelled as ESA, ESB, and ESC; from Atwima Koforidua as ATA, ATB, and ATC; from Esaso as EAA, EAB, and EAC; from Adankwame as AKA, AKB, and AKC; from Barekese as BKA, BKB, and BKC; from Nkawie as NWA, NWB, and NWC; from Kapro as KPA, KPB, and KPC; from Pasuro as PRA, PRB, and PRC; from Nwabi as NBA, NBB, and NBC; and Akwaboa as ABA, ABB, and ABC.

Furthermore, the remaining 30 cabbage heads, one from each farm, underwent a specific preparation process. The cabbage heads were segmented into distinct layers: the first 5 leafy layers, the subsequent five layers, and the final tightly fused layers were separated. Each group of layers was chopped together and labelled as layer 1 (LY1), layer 2 (LY2), and layer 3 (LY3). These prepared samples were then preserved under freezing conditions to maintain their integrity for subsequent analysis. This meticulous approach ensured that the collected cabbage samples were representative and suitable for the detailed examination of pesticide residues and other relevant parameters in the study.

2.4. Experimental procedure

2.4.1. Extraction process

Each sample underwent blending using a blender and was subsequently poured into a clean, properly labelled plastic dish. To prevent cross-contamination, the blender underwent thorough washing with distilled water before blending each new sample. Utilizing a Mettler Toledo weighing balance, 20g of each homogenized cabbage sample was accurately weighed and transferred into a glass bottle. To remove water from the sample matrix, 20g of annular anhydrous sodium sulphate (Na_2SO_4) was added, while 5g of sodium hydrogen carbonate ($NaHCO_3$) was introduced to neutralize any potential acids present in the samples. The cabbage blend in the transparent bottle underwent manual shaking for approximately 2–3 min. Subsequently, 40 ml of ethyl acetate, employed as a solvent, was added, and the mixture was subjected to 30 min of sonication using the Bransonic 220 sonicator. This sonication process was repeated twice for each sample, utilizing warmth and vibration to guarantee sufficient dissolution of pesticide residues in both ethyl acetate and hexane. Afterwards, the obtained extract was carefully poured into a cone-shaped flask and shielded with aluminium foil. A portion was transferred using a pipette into a 50 ml flask with a rounded bottom and subjected to evaporation to near dryness (approximately 2 ml) utilizing the Rotary Film Evaporator at a temperature of 35 °C.

2.4.2. *Extract pre-concentration*

The process began by transferring the extract from the conical flask into a round-bottomed flask. To ensure no residue was left behind, the conical flask was rinsed with ethyl acetate, the extraction solvent, and this rinse was also carefully transferred to the round-bottomed flask. Subsequently, the flask was securely attached to an evaporator and pre-concentrated at a controlled temperature of 35 °C. For the chromatographic separation, a piece of glass wool was used to seal one end of the chromatographic column, which was then placed in a stable glass jar and balanced accurately. The column was packed with 3 g of silica gel (SiO_2), followed by 2.5 g of Na_2SO_4 layered on top. Prior to sample introduction, the column was conditioned with 10 ml of ethyl acetate to optimize its performance.

The extract from the round-bottomed flask was carefully introduced into the column and eluted with 10 ml of ethyl acetate, followed by an additional 5 ml to ensure thorough extraction of target compounds. The eluate containing the compounds of interest was subsequently concentrated to near dryness using a rotary evaporator operating below 40 °C, which effectively removed excess solvent while preserving the analytes.

Finally, the concentrated eluate, now in a reduced volume of 2 ml of ethyl acetate, was transferred into a GC vial. This prepared sample was then ready for quantification using Gas Chromatography with Electron Capture Detection (GC-ECD), a precise analytical technique suitable for detecting and measuring trace amounts of organic compounds in complex matrices. This detailed procedure ensured that the extracted compounds were effectively concentrated and prepared for accurate analysis, essential for assessing their presence and concentration levels in the original sample.

2.5. *Chromatographic parameters for analysing pesticide residue*

2.5.1. *Analytical parameters for organochlorines and pyrethroids chromatography*

Organochlorine and synthetic pyrethroid measurements were analysed using a Varian CP-3800 gas chromatograph, equipped with an Electron Capture Detector (ECD) and a CombiPAL Autosampler. The chromatographic separation was performed using a 30 m + 10 m EZ capillary column guard with a 0.25 mm internal diameter, coated with VF-5 ms (0.25 μm film thickness) from Varian Inc or an equivalent. The detector temperature was maintained at 300 °C, and the injector operated in pulsed splitless mode at 270 °C. The oven temperature program was set as follows.

- For organochlorines: 70 °C for 2 min, then ramping from 70 °C to 180 °C at 25 °C/min, followed by a ramp from 180 °C to 300 °C at 5 °C/min.
- For synthetic pyrethroids: 90 °C for 1 min, then ramping from 90 °C to 240 °C at 30 °C/min, and finally from 240 °C to 300 °C at 5 °C/min, holding for 5 min.

The carrier gas was nitrogen with a flow rate of 1.0 ml/min, and the injection volume was set to 1 μL.

2.5.2. *Chromatographic parameters for organophosphates*

Organophosphate analysis was meticulously conducted using advanced instrumentation—a Varian CP-3800 gas chromatograph equipped with a specialized Phosphorus Flame Photometric Detector (PFPD) and a CombiPAL Autosampler. To achieve optimal chromatographic separation, a highly efficient 30 m EZ capillary column guard with a 0.25 mm internal diameter and coated with VF-1701 ms (0.25 μm film thickness) from Varian Inc or its equivalent was employed. The operational parameters were carefully controlled: the detector was maintained at a precise temperature of 280 °C to ensure accurate detection of phosphorus-containing compounds. Meanwhile, the injector functioned in pulsed splitless mode at 270 °C, facilitating the introduction of the sample into the chromatographic system without compromising sensitivity. Temperature programming of the oven was methodically executed to enhance analyte separation: starting from an initial temperature of 70 °C held for 2 min, followed by a rapid ramp to 180 °C at 25 °C/min and a brief 1-min hold, and then a gradual increase to 300 °C at 5 °C/min with a final 5-min hold period. This temperature gradient was meticulously designed to achieve optimal resolution of the organophosphate analytes present in the samples. Nitrogen gas, employed as the carrier gas, flowed through the system at a constant rate of 2.0 ml/min, ensuring efficient transport of analytes through the column for accurate detection. The injection volume was carefully controlled at 1 μL, allowing precise introduction of the sample into the chromatographic flow path for thorough analysis. This analytical setup provided robust capabilities for detecting and quantifying organophosphate residues, essential for ensuring the safety and compliance of agricultural products and environmental samples with stringent regulatory standards.

2.6. Gas chromatography (GC)

The GC analysis was performed using a Varian CP-3800 gas chromatograph, configured for online analysis to monitor critical gas and liquid process streams. A 25 μL glass Hamilton syringe was utilized for sample injection, with 2–4 μL of the sample being introduced into the column. Prior to filling, the syringe was thoroughly inspected. A small volume of the sample was drawn into the syringe and expelled back into the sample container to rinse it, ensuring an accurate measurement of the sample composition. This rinsing process was repeated twice. Subsequently, the syringe was filled with the sample by slowly drawing up the plunger. The presence of small air bubbles in the syringe did not affect the GC run. The sample was then injected into the injector port with two swift actions: the needle was inserted into the injector port, and the plunger was immediately pressed to inject the sample. Simultaneously, the start button on the recorder was pressed. The recorder was monitored for several minutes to capture multiple peaks until the GC run was completed. The determination of pesticide residue concentration was derived from Eqn. (1) which is expressed as:

$$C = \frac{a}{b} \times d \times f \tag{1}$$

Where C is the concentration of pesticide residue (ppm), a is the concentration of the analyte in the sample solution, b represents the sample equivalent during the extraction step (ppm), d denotes the dilution factor from the GC cleanup step, and f signifies the dilution factor from the silica gel cleanup step.

2.7. Data analysis

The data obtained from the assessment of cabbage samples was organized and presented using Microsoft Excel (2021). This approach allowed for structured and clear tabulation of key findings, including the types and levels of organophosphate pesticide residues, farmers' knowledge and practices regarding pesticide usage, and the socio-economic characteristics of respondents across different communities within the Atwima Nwabiagya District.

3. Results

3.1. Socio-economic characteristics of respondents

Approximately 12 % of the study participants were residents of Esease, a significant representation within the sample. Adankwame, Barekese, and Esaso collectively accounted for 15 respondents, making up 30 % of the total participants, highlighting their substantial presence in the study. Conversely, Abuakwa, Atwima Mim, and Toase each had a minimal representation, comprising only 2 % of the respondents each. Gender distribution among the participants revealed a predominance of males, constituting 80 % of the respondents, while females made up the remaining 20 %. Educational attainment among the participants was notably characterized by a high proportion (68 %) having completed basic education. This trend was slightly higher among females, with 70 % having attained basic education compared to 67.5 % among males. In terms of age distribution, the majority of respondents (60 %) were under the age of 40, indicating a youthful demographic within the study sample. The average age across all participants was calculated at 39.7 years, with ages ranging from a minimum of 21 years to a maximum of 65 years. These demographic insights provide a comprehensive snapshot of the diverse socio-economic backgrounds and age ranges represented among cabbage farmers in the study area.

3.2. Pesticides used by farmers

Table 1 presents the locations of the farmers included in this study. Table 2 presents an overview of the organophosphate and

Table 1
Location of respondents.

Location	Symbols used for selected samples	Frequency	Percentage	Cumulative
Abuakwa*	ABA	1	2.0	2.0
Adankwame	AK	5	10.0	12.0
Akropong*	AKG	3	6.0	18.0
Akwaboa	AB	4	8.0	26.0
Atwima Koforidua	AT	4	8.0	34.0
Atwima Mim*	ATM	1	2.0	36.0
Barekese	BK	5	10.0	46.0
Esaso	EA	5	10.0	56.0
Esease	ES	6	12.0	68.0
Kapro	KA	4	8.0	76.0
Nkawie	NW	3	6.0	82.0
Nwabi	NB	4	8.0	90.0
Pasuro	PA	4	8.0	98.0
Toase*	TOA	1	2.0	100.0
Total		50	100.0	

pyrethroid pesticides used by farmers, detailing their active ingredients and prevalence. Farmers in the study area utilize a variety of organophosphates, including Pyrinex 48 EC, Sunpyrifos, Dursban 4E, Frankophos, Perferthion, and Termex. Among these, Pyrinex 48 EC and Perferthion are the most frequently employed, each accounting for 12 % and 10 % of pesticide usage, respectively. Additionally, farmers employ several pyrethroids for insect control on cabbage, including Lambda super, Attack, K-Optimal, PAWA, Regent 50SC, Golan, and Confidor. Notably, Regent 50SC, Attack, and Golan are particularly favoured, collectively chosen by 34 % of respondents for their efficacy in pest management.

A recent innovation in the pesticide market, Bypel, which combines viral and bacterial agents, has garnered significant adoption among farmers, with 20 % utilizing this new pesticide due to its effective control of insect infestations on cabbage. Furthermore, approximately 18 % of farmers implement multiple pesticides concurrently to enhance their pest control strategies, reflecting a diverse approach to managing agricultural challenges in the study area. These insights underscore the varied pesticide preferences and strategies employed by cabbage farmers to optimize crop protection and yield.

3.3. Farmers' knowledge of pesticides usage

Table 3 provides valuable insights into farmers' practices and attitudes towards pesticide usage. The data reveals that a significant majority of farmers (82 %) exercise caution by refraining from mixing pesticides, acknowledging the potential health risks associated with such practices. This precaution is consistently observed across both male (82.5 %) and female (80 %) farmers in the study. Regarding pesticide dosage, the survey indicates varying preferences among farmers. Forty percent of respondents reported using 20 ml, while 24 % opted for 25 ml. Another 20 % utilized 30 ml, and the remaining 16 % applied 15 ml of pesticide per application. This distribution reflects diverse approaches to pesticide application among farmers, influenced by factors such as pest severity and crop stage. Furthermore, when purchasing pesticides, farmers prioritize efficacy in controlling insect pests, with 72 % emphasizing this factor. Price consideration follows closely, with 24 % of farmers weighing cost as a significant factor in their purchasing decisions. The availability of the pesticide in the market also plays a role, though to a lesser extent.

During the growing season, the frequency of pesticide application among cabbage farmers varied widely, with applications ranging from 1 to 13 times. A substantial portion of respondents (46 %) reported applying pesticides between 1 and 5 times before harvesting, indicating a strategic approach to pest management early in the crop cycle. In contrast, 42 % of farmers applied pesticides more frequently, ranging from 6 to 10 times before harvest, suggesting a more intensive pest control regimen for managing persistent threats. A smaller group (12 %) applied pesticides more than 10 times throughout the growing season, likely in response to severe pest pressures or specific crop conditions (Table 4).

Spraying intervals during the cabbage life cycle also exhibited variability among farmers. The majority (66 %) adhered to a spraying schedule of every 7–14 days, a common practice aimed at maintaining consistent pest control measures as cabbage plants matured. Approximately 16 % of farmers opted for spraying intervals of 15–21 days, while the remaining 18 % sprayed more frequently, with intervals ranging from 1 to 6 days. These spraying intervals reflect the diverse pest management strategies employed by farmers based on pest dynamics, crop growth stages, and environmental factors. All respondents utilized knapsack sprayers for pesticide application, highlighting their practicality and suitability for small-scale agricultural operations.

Regarding the interval between the last pesticide spraying and harvesting, the majority (60 %) of farmers allowed 11–14 days to elapse before harvesting the cabbage. This interval is crucial as it ensures that pesticide residues reduce to safe levels before the crop enters the market, aligning with food safety standards and consumer expectations. A smaller proportion (30 %) sprayed between 7 and 10 days before harvesting, while only 10 % sprayed within 1–6 days of harvest. Notably, a higher percentage of males (62.5 %) adhered

Table 2
Types of pesticides used.

Pesticides Used	Active Ingredients	Number	Percent (%)	Percent of cases
Organophosphates				
Sunpyrifos	*Chlorpyrifos-methyl*	3	14.3 %	6 %
Pyrinex 48 EC	*Chlorpyrifos*	5	23.8 %	10 %
Dursban 4E	*Chlorpyrifos*	3	14.3 %	6 %
Perferthion	*Dimethoate*	6	28.6 %	12 %
Frankophos	*Chlorfenvinphos*	2	9.5 %	4 %
Termex	*Chlorpyrifos-ethyl*	2	9.5 %	4 %
Total		21	100.0 %	42.0 %
Pyrethroids				
Lambda Super	*Lambda-cyhalothrin*	3	7.9 %	6 %
PAWA	*Lambda-cyhalothrin*	3	7.9 %	6 %
Golan	*Acetamiprid*	4	10.5 %	8 %
Attack	*Emamectin benzoate*	8	21.1 %	16 %
K-Optimal	*Lambda-cyhalothrin*	2	5.3 %	4 %
Regent 50SC	*Fipronil*	5	13.2 %	10 %
Confidor	*Imidacloprid*	3	7.9 %	6 %
Others (Biological)				
Bypel	*Pierix rapae darnulosis virus (10000 pib/mg) + Bacillus thurinbiensis* (15000 μ/mg)	10.0	26.3 %	20 %
Total		38	100 %	76 %

Table 3
Farmers' knowledge of pesticide usage.

Knowledge variables	Females		Males		Total	
	N	%	N	%	N	%
Using pesticides combination						
Yes	2	20.0	7	17.5	9	18.0
No	8	80.0	33	82.5	41	82.0
Total	10	100.0	40	100.0	50	100.0
Pesticide dosage application						
15 ml	0	0.0	8	20.0	8	16.0
20 ml	6	60.0	14	35.0	20	40.0
25 ml	4	40.0	8	20.0	12	24.0
30 ml	0	0.0	10	25.0	10	20.0
Total	10	100.0	40	100.0	50	100.0
Reasons for choosing a particular pesticide						
Moderate price	3	30.0	9	22.5	12	24.0
Pesticide efficacy	7	70.0	29	72.5	36	72.0
Availability	0	0.0	2	5.0	2	4.0
Total	10	100.0	40	100.0	50	100.0
Frequency of spraying in a growing season						
1-5 times	4	40.0	19	47.5	23	46.0
6-10 times	4	40.0	17	42.5	21	42.0
More than 10 times	2	20.0	4	10.0	6	12.0
Total	10	100.0	40	100.0	50	100.0
Spraying intervals						
1–6 days	2	20.0	7	17.5	9	18.0
7–14 days	5	50.0	28	70.0	33	66.0
15–21 days	3	30.0	5	12.5	8	16.0
Total	10	100.0	40	100.0	50	100.0
Type of spraying equipment used						
Knapsack sprayer	10	100	40	100	50	100
Total	10	100	40	100	50	100

Table 4
Spraying interval between last spraying and harvesting.

Spraying interval	Female		Male		Total	
	N	%	N	%	N	%
1–6 days	2.0	20	3.0	7.5	5	10.0
7–10 days	3.0	30	12.0	30	15	30.0
11–14 days	5.0	50.0	25.0	62.5	30	60.0
Total	10.0	100.0	40.0	100.0	50	100.0
Spraying whiles harvesting						
Yes	0	0.0	3	7.5	3	6.0
No	10	100.0	37	92.5	47	94
Total	10	100.0	40	100.0	50	100.00

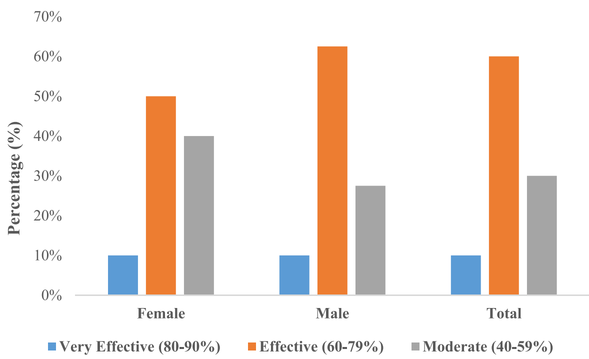

Fig. 2. Pesticides efficacy assessment by farmers.

to the 11 to 14-day interval, compared to half of the females (50 %). The study also investigated whether farmers engaged in pesticide spraying during harvesting to prevent infested produce from entering the market. Results indicated that only a small fraction (6 %) of farmers employed this practice, while the vast majority (94 %) did not. Interestingly, no female farmers participated in spraying pesticides during harvesting, underscoring potential gender differences in agricultural practices and roles.

Farmers in the study area demonstrated a rigorous approach to evaluating pesticide efficacy before making purchasing decisions, as illustrated in Fig. 2. A substantial majority (60 %) expressed strong confidence in the effectiveness of the pesticides they utilized, highlighting their reliance on these products for robust pest control. Approximately 30 % of farmers found the pesticides moderately effective, indicating a level of satisfaction with their performance but with some room for improvement. Only a minority (10 %) considered the pesticides very effective, suggesting that while effective, there may be perceptions of variability in performance across different pest pressures and environmental conditions.

Gender differences were also observed in farmers' perceptions of pesticide effectiveness. Among male farmers, 62.5 % believed their chosen pesticides were effective, demonstrating a higher level of confidence compared to 50 % of female farmers who shared this perspective. This variation could reflect differences in experience, exposure to pest management strategies, or preferences for specific pesticide brands among male and female farmers. The timing of pesticide application emerged as a critical factor influencing perceived efficacy. Nearly all farmers (98 %) preferred applying pesticides in the morning. This preference aligns with agricultural best practices, as morning applications can optimize pesticide effectiveness by targeting pests during their most active periods while minimizing potential risks associated with high temperatures later in the day. In contrast, a smaller proportion (24 %) of farmers preferred evening applications, indicating a preference for cooler temperatures or specific pest behaviours that are more active during twilight hours. Interestingly, none of the farmers engaged in pesticide application during the afternoon, suggesting a consensus among farmers regarding optimal timing for effective pest control practices.

Farmers' decisions to apply pesticides were influenced by various sources, as outlined in Table 5. A significant portion (44.3 %) relied on field scouting to detect pest presence, guiding their decisions on when to apply pesticides based on observed pest activity and damage levels. About 17 % adhered to a regular spraying schedule as a proactive measure against insect pests throughout the growing season. Additionally, recommendations from agrochemical dealers influenced 15.7 % of farmers, providing valuable guidance on product selection and application timing. A smaller group (8.6 %) sought advice from Agricultural Extension Agents, who offer expert insights into integrated pest management practices. Furthermore, 14.3 % of farmers preferred consulting fellow farmers for practical advice and experiences with specific pesticides and application techniques. These diverse influences underscore the multifaceted approach farmers use to make informed decisions about pesticide application, integrating field observations, scheduled routines, professional advice, and peer-to-peer knowledge sharing.

3.4. Organophosphate pesticide residues level

In the cabbage samples analysed, eleven residues of organophosphate pesticides were identified, as detailed in Table 6. Chlorpyrifos emerged as the most prevalent pesticide residue, detected in 56.6 % of the samples. Following closely were fenitrothion, pirimiphos-methyl, and profenofos, each present in 26.7 % of the samples. Notably, the highest concentration of chlorpyrifos, at 0.02 mg/kg, was found in the sample from Pasuro, although it remained well below the MRL of 1.0 mg/kg set by European Union standards for cabbage. In Adankwame, a total of six pesticide residues were identified: phorate, chlorfenvinphos, fenitrothion, chlorpyrifos, parathion, and ethoprophos. In contrast, samples from Esaso and Esease revealed only four pesticide residues each. Pasuro exhibited the highest diversity of pesticide residues, with ten different residues detected. Importantly, all pesticide residues detected in the samples complied with the permissible levels established by European Union food standards. This indicates that current agricultural practices in the study area effectively manage pesticide application to ensure compliance with regulatory safety standards, thereby safeguarding public health.

3.5. Pesticide residue levels in the different leafy layers

Table 7 outlines the results of pesticide residue analysis across different leaf layers of cabbage samples. In the first layer, six organophosphate pesticides were identified: fenitrothion, profenofos, malathion, parathion, ethoprophos, and dimethoate. Moving to the second layer, seven organophosphate residues were found: malathion, phorate, dimethoate, profenofos, chlorpyrifos, pirimiphos-

Table 5
Decision to apply pesticides.

Decision to apply pesticides	Responses		Percent of cases
	N	Percent	
Presence of pests based on scouting	31.0	44.3 %	62 %
Spray on a routine schedule	12.0	17.1 %	24.0 %
Agricultural Extension Agent's recommendation	6.0	8.6 %	12.0 %
Recommendation from Agrochemical dealers	11.0	15.7 %	22.0 %
Recommendations from other farmers	10.0	14.3 %	20.0 %
Total	70.0	100 %	140.0 %

NB: Percentage of cases more than 100 % (multiple response analysis).

Table 6
Types and levels of organophosphate pesticide residues.

Pesticide Residue	Number of samples detected	Min (mg/kg)	Max (mg/kg)	Mean (mg/kg)	Std. Deviation
Ethoprophos	7.0	0.01	0.01	0.0100	±0.00001
Phorate	5.0	0.01	0.01	0.0100	±0.00001
Dimethoate	3.0	0.01	0.01	0.0100	±0.00001
Fonofos	2.0	0.01	0.01	0.0100	±0.00001
Pirimiphos_methyl	8.0	0.01	0.01	0.0100	±0.00001
Fenitrothion	8.0	0.01	0.01	0.0100	±0.00001
Malathion	4.0	0.01	0.01	0.0100	±0.00001
Chlorpyrifos	17.0	0.01	0.02	0.0106	±0.00243
Parathion	7.0	0.01	0.01	0.0100	±0.00001
Chlorfenvinphos	6.0	0.01	0.01	0.0100	±0.00001
Profenofos	8.0	0.01	0.02	0.0125	±0.00463

methyl, and parathion. Notably, chlorpyrifos was the sole pesticide detected in the third layer, with a concentration of 0.01 mg/kg, significantly below the MRL. These findings underscore the distribution and concentration variations of pesticide residues within different layers of cabbage. The presence of multiple residues in the outer layers suggests varying pesticide uptake and exposure during cabbage growth.

4. Discussion

The study revealed that a higher percentage of males (80 %) engaged in cabbage cultivation, likely due to the labour-intensive demands of cabbage production [23]. The educational levels among farmers in the study area were generally modest, with the majority (67.5 %) having basic education. Additionally, 27 %, predominantly males, possessed secondary education. No respondent in the study held tertiary education, likely reflecting the perception that agriculture is less appealing to graduates in this particular country. It was noted that most farmers (82 %) refrained from combining pesticides for spraying. This precaution is taken to avoid potential risks to the farmers, stemming from chemical combinations' synergistic or potentiating effects [24]. In contrast to Anjum [25], 61 % of cabbage farmers in the Ejisu-Juaben Municipality were observed to combine various pesticides for spraying. The remaining 18 % of the respondents who mix two or more chemical pesticides for spraying do it to swiftly control insect pests. This outcome aligns with the findings of Appiah-Kubi [26], indicating that some farmers hold the belief that combining pesticides yields favourable results. A majority of farmers (78 %) employed one or more protective measures during pesticide application, demonstrating a commendable level of knowledge of pesticide use, which aligns with the findings reported by Moradhaseli et al. [27]. Pests and diseases pose significant challenges in vegetable production [28]. Every participant in the survey utilized pesticide spraying as a means of controlling these issues. Without exception, pesticides were extensively applied in both small and large vegetable farms, with farmers employing a diverse array of chemicals functioning as herbicides, fungicides, and/or insecticides [29]. The study implies that cabbage cultivation is predominantly male-dominated due to its labour-intensive nature and that the educational attainment of farmers is generally low, with no participants having tertiary education. This highlights a potential gap in advanced agricultural knowledge and skills among farmers. The majority of farmers avoid mixing pesticides to prevent health risks, contrasting with practices in other regions where pesticide combinations are more common. This suggests a cautious approach among farmers in the study area, but also indicates a need for education on safe and effective pesticide use.

From the survey, 14 different pesticides were used by the cabbage farmers. These included 6 organophosphates, 7 pyrethroids, and 1 bio-pesticide. Farmers in the study area opt for these pesticides primarily because they are deemed effective (72 %) and affordable (24 %). Respondents highlighted that chlorpyrifos-based pesticides are particularly efficient in managing cabbage pests. This suggests

Table 7
Pesticide residue levels across the various leafy layers.

Pesticide residue	Layer 1	Layer 2	Layer 3
Methamidophos	Nd	Nd	Nd
Ethoprophos	<0.01	Nd	Nd
Phorate	Nd	<0.01	Nd
Dimethoate	<0.01	<0.01	Nd
Fonofos	Nd	Nd	Nd
Pirimiphos-methyl	Nd	<0.01	Nd
Fenitrothion	<0.01	Nd	Nd
Malathion	<0.01	<0.01	Nd
Chlorpyrifos	Nd	0.01	0.01
Parathion	<0.01	<0.01	Nd
Chlorfenvinphos	Nd	Nd	Nd
Profenofos	<0.01	<0.01	Nd

Nd = Not detected.

that a substantial proportion of the pesticides used by cabbage farmers in Ghana for insect pest control are chlorpyrifos-based. Achiri et al. [30] observed that cabbage farmers in Cape Coast use pesticides containing chlorpyrifos such as Pyrinex, Desbin and Dursban 4E. No traces of Methamidophos were found in any cabbage samples collected from the district. This contrasts with the results reported by Machekano et al. [11], where methamidophos was detected across all types of markets. This could be attributed to farmers not using pesticides containing methamidophos as an active ingredient, or it could be presumed that complete decomposition of methamidophos had occurred before the analysis was conducted. Nine organophosphate pesticide residues were identified in all the distinct leafy layers of the cabbage samples. The majority of these residues were found in the initial two groups (layers 1 and 2) of the leafy layers. Notably, except for chlorpyrifos, none of the organophosphate pesticide residues were observed in the third layer. Furthermore, all the detected organophosphate pesticide residues had residual levels of 0.01 mg/kg or less, significantly below the established MRL. These findings highlight that chlorpyrifos-based pesticides are widely preferred among cabbage farmers in the study area for their perceived effectiveness in pest management. This reliance on chlorpyrifos aligns with previous observations in other regions of Ghana and underscores its significant role in insect pest control strategies for cabbage cultivation. The absence of methamidophos residues in cabbage samples suggests either limited use of this pesticide by farmers or effective degradation processes before sampling. Additionally, the detection of low levels of organophosphate residues, predominantly in the initial leafy layers of cabbage, indicates cautious pesticide application practices among farmers. These findings underscore the importance of continuous monitoring and adherence to safety standards to ensure minimal pesticide residues in agricultural produce, thus safeguarding consumer health and environmental sustainability.

The findings of this study hold significant relevance in various domains, including agriculture, food safety, and public health. These findings are important because.

- ➢ Gender disparities in agriculture: The observation that a higher percentage of males are engaged in cabbage cultivation due to its labour-intensive nature highlights gender disparities in agriculture. This finding is essential for understanding gender roles in farming and can inform policies and programs aimed at promoting gender equity and women's participation in agriculture.
- ➢ Educational background of farmers: The prevalence of basic and secondary education among farmers, along with the absence of tertiary education respondents, reflects the educational landscape in the study area. This finding can inform educational and extension programs tailored to the specific needs of farmers in the region.
- ➢ Pesticide usage patterns: The study provides insights into pesticide usage practices among cabbage farmers. Understanding the reasons behind combining or refraining from combining pesticides, along with the use of protective measures, is crucial for promoting safe pesticide application and reducing health risks for farmers.
- ➢ Food safety considerations: The diversity of pesticides used, including their effectiveness and affordability, sheds light on the factors influencing pesticide choices. It also underlines the need for monitoring and regulating pesticide use to ensure food safety and environmental protection.
- ➢ Chlorpyrifos-based pesticides: The preference for chlorpyrifos-based pesticides for cabbage pest management has implications for pesticide management and regulations. Monitoring and controlling the use of such pesticides is crucial to prevent potential health and environmental risks.
- ➢ Absence of methamidophos residues: The absence of methamidophos residues in cabbage samples is reassuring for food safety. It suggests responsible pesticide use or the absence of this particular pesticide in the region, contributing to safer agricultural produce.
- ➢ Low organophosphate residue levels: The detection of organophosphate pesticide residues within safe levels is a positive finding, indicating responsible pesticide application. Adherence to MRLs is crucial for consumer safety.

These findings are relevant for improving agricultural practices, promoting food safety, and safeguarding the health of both farmers and consumers. They can guide policy interventions, educational programs, and regulatory measures to ensure sustainable and safe agricultural practices in the study area and similar agricultural contexts.

5. Further insights from the study

5.1. Limitation of the study

Though the study identified several pesticide residues and their levels, the analysis might not have covered all potential pesticide contaminants or metabolites that could be present in cabbage samples. This could impact the comprehensiveness of the risk assessment related to pesticide exposure among consumers.

5.2. Policy plan to manage pesticide use

Creating a policy plan to manage pesticide usage among cabbage farmers in Ghana involves several key considerations and the involvement of relevant institutions. Firstly, addressing gender disparities in agriculture requires collaboration with institutions like the Ministry of Food and Agriculture (MoFA) and non-governmental organizations (NGOs) focused on empowerment women in agriculture. These institutions can develop programs and initiatives to encourage more women to participate in cabbage cultivation and provide them with the necessary support and resources.

Addressing the educational background of farmers involves working with agricultural extension officers. MoFA can develop tailored educational programs and training workshops for farmers, focusing on safe pesticide use, integrated pest management (IPM) practices, and sustainable farming techniques. These can further be enforced by extension officers.

Promoting responsible pesticide usage patterns requires collaboration with regulatory bodies like the Environmental Protection Agency (EPA) and the Ghana Standards Authority (GSA). These institutions can enforce regulations on pesticide registration, monitor pesticide residues in agricultural produce, and provide guidance on safe pesticide handling and application practices.

To maintain public health, it is important to ensure food safety considerations involve partnerships with institutions such as the Food and Drugs Authority (FDA) and the Ghana Health Service (GHS). These institutions can conduct regular inspections of agricultural produce, test for pesticide residues, and educate consumers and farmers about food safety practices.

Managing the use of chlorpyrifos-based pesticides necessitates engagement with agricultural research institutions like the Council for Scientific and Industrial Research (CSIR) and the University of Ghana's Department of Crop Science. These institutions can conduct research on alternative pest management strategies, develop guidelines for reducing reliance on chlorpyrifos, and promote the use of biopesticides and integrated pest management (IPM) approaches.

Collaborating between farmers' associations and local agricultural cooperatives is crucial for implementing and monitoring the policy plan at the grassroots level. These organizations can facilitate training workshops, disseminate information about safe pesticide use practices, and provide support to farmers in adopting sustainable farming methods.

By involving these institutions and stakeholders, the policy plan can effectively address the challenges related to pesticide usage among cabbage farmers in Ghana, promote sustainable agriculture practices, and ensure the safety of agricultural produce for consumers.

6. Conclusion

The study unfolded in two phases, exposing the prevalent use of 14 pesticides in cabbage farming within the Atwima Nwabiagya District, with chlorpyrifos dominating as the active ingredient. Cabbage farmers displayed a commendable understanding of pesticide application, with 82 % avoiding the simultaneous use of multiple pesticides due to awareness of potential repercussions. Outstanding findings from both field surveys and laboratory analyses highlighted the judicious application of pesticides by farmers, maintaining correct dosages and adhering to a 10–14 days pre-harvest interval. However, a concerning trend emerged as most farmers neglected protective clothing during pesticide handling, despite being cognizant of associated health risks. Laboratory results unveiled the prevalence of chlorpyrifos in 56 % of cabbage samples, emerging as the primary pesticide in use. Encouragingly, organophosphate pesticide residues detected fell well below both EU MRLs and CODEX MRLs allowed in cabbage (0.01 mg/kg - 0.02 mg/kg). The study also shed light on the distribution of pesticide residues in cabbage layers, emphasizing low concentrations in inner layers, possibly free from residues. While cabbage farmers in the Atwima Nwabiagya District demonstrated informed pesticide practices, the oversight of protective measures raises concerns. The prevalence of chlorpyrifos, though within permissible limits, warrants ongoing monitoring to ensure sustainable and safe cabbage production.

Based on the findings of this study, it is recommended that.

- A continuous monitoring system to track pesticide residues in cabbage crops is established and regular surveys and laboratory analyses to assess changes in pesticide usage patterns and residue levels are conducted.
- The adoption of Integrated Pest Management strategies that focus on a combination of biological, cultural, and chemical control methods is promoted.
- Farmers are encouraged to diversify their pesticide usage to minimize the reliance on a single active ingredient, such as chlorpyrifos and promote the use of alternative, less harmful pesticides, and explore organic farming practices.
- Collaboration with agricultural extension services is strengthened to disseminate information on best practices and safety measures.
- Research initiatives to explore innovative, non-chemical methods of pest control are encouraged and supported.

Data availability statement

Data used for this study will be made available on request following due procedures.

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CRediT authorship contribution statement

Bernard Fei-Baffoe: Writing – original draft, Validation, Supervision, Investigation, Conceptualization. **Kofi Adu Dankwah:** Writing – original draft, Visualization, Software, Formal analysis, Data curation, Conceptualization. **Alfredina Sangber-Dery:** Writing – original draft, Visualization, Formal analysis, Conceptualization. **Ebenezer Ebo Yahans Amuah:** Writing – review & editing, Software, Formal analysis, Conceptualization. **Lyndon Nii-Adjiri Sackey:** Writing – review & editing, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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