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Knowledge, perception, and pesticide application practices among smallholder cocoa farmers in four Ghanaian cocoa-growing regions

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ABSTRACT

Pesticides are widely used in Ghana, especially in cocoa farming. However, the practice is suboptimal and unsupervised. Incorrect use of these chemicals can seriously harm human health, the environment, and economies that rely on these farmers' output. The study assessed cocoa farmers' pesticide knowledge, practices, and risk perception. Four hundred and four cocoa farmers were chosen randomly from 26 communities in four cocoa-growing regions of Ghana to answer questions about their risk knowledge, awareness, and practices, including personal protective equipment, storage and disposal of leftover pesticides, and used containers. The study revealed that 87% of the respondents belonged to cooperatives and certification groups. There was a significant positive relationship between group membership and benefits derived from inputs and training in pesticide use. About 70% of insecticides used were approved by the Ghana Cocoa Board, with neonicotinoids and pyrethroids being the most highly used insecticide classes in cocoa farms. Although farmers claimed adequate pesticide knowledge, this did not translate into practice, with the majority exhibiting improper pesticide storage, application, and disposal practices. Farmers appeared to know a lot but lacked the skills and attitude to put their knowledge to use. The improper practices appear to manifest in a variety of health symptoms experienced by farmers as a result of chemical exposure. The findings from this study suggest that cocoa farmers in Ghana require adequate practical training and support on pesticide use to reduce their associated health risks, protect the environment and ensure sustainable cocoa production in the world's second-largest cocoa bean exporter.

1. Introduction

Management of pest and vector-borne diseases has been highly dependent on pesticide use, which has significantly impacted food production for the increasing populations of the world. Evidence from Food and Agriculture statistics shows global annual pesticide use of 4.12 million tonnes [1]. While Africa contributes a small percentage of global pesticide use (2%), a majority (30%) of the applied pesticides are insecticides, contrary to what pertains to other parts of the world [1]. South Africa, Ghana, and Cameroon are the biggest consumers of pesticides in Africa. The major cash crops of pesticide application include cocoa, cotton, coffee, oil palm, and vegetables [2]. Pesticides, when used responsibly, are a critical agricultural input that can protect crops from unwanted plants, insects, bacteria, fungi, and rodents. However, pesticides can have negative environmental impacts through contamination of soil, water, and non-target plants and animals that can decrease biodiversity and, in some cases, reduce crop yield [1].

Mirids infestation is the major pest problem in cocoa farms across

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West Africa. The two most important species, *Sahlbergella singularis* Haglund (Hemiptera: Miridae) and *Distantiella Theobroma* Distant (Hemiptera: Miridae) cause the destruction of foliage and young pods, which consequently results in significant production losses [3]. About a 25% reduction in cocoa production has been attributed to mirid infection. To reduce pests to acceptable levels, farmers commonly use pesticides [4]. Although effective, pesticides are potentially harmful to human health and the environment. In most West African countries, neonicotinoids and pyrethroids are the widely used pesticides in controlling mirid [5,6]. In Ghana, the active ingredients approved for cocoa cultivation are imidacloprid, thiamethoxam, acetamiprid, and imidacloprid. A combination of neonicotinoids and pyrethroids (including acetamiprid, imidacloprid, and bifenthrin) is reportedly used on some cocoa farms [3]. Additionally, farmers carry out pest control programs to combat mirids and other insects using approved and unapproved insecticides [7].

Unsafe and unregulated use of pesticides can be hazardous to human health and damaging to the environment [8,9]. Consequently, there is an urgent need to educate and regulate the use of pesticides to prevent irrational use, especially among smallholder farmers, who have low literacy levels, small investments, weak extension services, and lack training and access to awareness programs on the safe use of pesticides but handle large volumes of pesticides [10]. Poor handling of pesticides is devastating to the environment and indirectly extends to non-target organisms, particularly pollinators [11–13]. Over the past decades, pollinators, including bees, butterflies, wasps, beetles, moths, birds, bats, and other non-flying mammals, have suffered badly from using neonicotinoids [14,15]. Therefore, in May 2018, the European Union banned three neonicotinoids (clothianidin, imidacloprid, and thiamethoxam) for outdoor use due to scientific evidence confirming high risks to bee pollinators (Regulations (EU) 2018/783, 2018/784, and 2018/785). Recent studies reported that less than 50% of respondents believed insecticide application might impact beneficial insects, including pollinators [16].

Imidacloprid has also been found to be the most toxic to birds and fishes [17,18]. Both imidacloprid and thiamethoxam are highly toxic to honeybees [19]. Residual pesticide contamination of water sources, food, soil, and other non-target organisms, including humans, has been reported by many authors to have various damaging effects [20,21]. Studies on neonicotinoid use in cocoa crops and resultant soil contamination [20,22,23]. The misuse of pesticides has also resulted in pesticide poisoning [24,25], acetylcholinesterase depression [25,26], and increased health burden.

The level of awareness and knowledge of pesticide risks among certified cocoa farmers is essential for improving safety in all aspects of pesticide handling. In this study, we assessed the knowledge of cocoa farmers on exposure and risk of pesticide use, their understanding of the adverse consequences, safety practices regarding their use, and associated health risks to humans and the environment. This is the first time such a study has been conducted on certified cooperatives in Ghana and covers the four major cocoa regions. The findings will contribute to the planning and policies to prevent potential health risks of exposure in Ghana and the global south.

2. Materials and methods

2.1. Study area

Four major cocoa growing areas, namely Ashanti, Western North, and Western and Central regions of Ghana, were selected for this study. The Ashanti Region is centrally located in the middle belt of Ghana. It lies between longitudes 0.15 W and 2.25 W and latitudes 5.50 N and 7.46 N. The region is the third-largest in Ghana, with a total land area of 24,389 km^2, representing 10.2% of the total land area of Ghana. About 60% of the land area is considered arable land, and a staggering 81% of the arable land is under cultivation. The Ashanti region has a population of 5,432,485 [27]. Over 13% of the population in the region depends on agriculture as their source of livelihood. The main farming systems practised in the region are mono-cropping, mainly for cash crops, and mixed cropping systems, where different crops (tree/food) are mixed. The Ashanti Region recorded 220,238 Metric tons of cocoa in the 2021 crop calendar.

The Western North/Western regions (Western North has been part of the Western Region until 2019) is one of Ghana's high cocoa-producing areas and shares boundaries on the west with Cote D′Ivoire, Bono, Brong Ahafo, and Ashanti regions in the north and the Central Region in the southeast. The two regions cover an area of 23,921 km^2, with about 73% of the land area considered agricultural land. Western North and Western regions have 880,855 and 2,057,225, respectively. Agriculture serves as the predominant source of livelihood for the people in these regions. Cocoa, rubber, coconut, and oil palm are the primary agricultural commodities. The soils in the two regions are fertile due to the high forest cover contributing to high agricultural productivity in the two regions. The total volumes of cocoa produced in the 2021 crop calendar from the Western North and Western South (Cocoa regions) are 162,145.875 and 284,331.625, respectively (COCOBOD, 2021).

The Central Region is in the South-Western center of Ghana, where it shares boundaries with the Eastern region in the North-East and the Ashanti Region in the north, the Greater Accra Region in the South-East, the Western Region in the west, and the Gulf of Guinea in the south. The region has the longest coastline (150 km) in Ghana but is one of the smallest in the country. The Central Region has a population of 2,859,821 [27]. The Central Region reported 135,925 Metric tons of cocoa in the 2021 crop season (COCOBOD, 2021). The region has a total land area of 9830 km^2, representing 4.1% of Ghana's total land area, and 80% of the region's land area is considered arable land for agricultural activities. However, only 40% of the arable land is under cultivation. Soil type is mainly Ochrosols with other soil types, including tropical black earth, acid vlei sols, and sodium vlei sols, which is over 600,000 more than the region's population a decade ago (Fig. 1).

2.2. Study design and sampling technique

The research was designed to collect qualitative from a representative number of cocoa farmers from Ghana's four purposively selected cocoa regions. The various regions and communities were selected based on the quantities of cocoa beans produced and the volume of pesticide use. The multi-stage stratified sampling procedure was used to select farmers for the study. The districts were randomly selected from the Cocoa Health and Extension Division (CHED's) list of 60 cocoa districts. Subsequently, the communities were randomly selected from CHED's list of cocoa communities within the districts. The data was also validated with 20 spraying service providers selected from the Ashanti Region using focused group discussion.

2.3. Sample size calculation

Available information from the Ghana Cocoa Board (COCOBOD) shows that there are about 800,000 cocoa farm families (households) in Ghana. Using this information as a guide, a sample size (using the conventional formula) was then calculated to represent national cocoa farmers. The survey was designed to reach at least 384 farmers at a margin of error of 5% with a 95% confidence level. However, 404 farmers were sampled.

2.4. Data collection instrument

The questionnaire was pre-tested using 20 farmers randomly selected from Atwima Mponua communities within the Ashanti region. The Ashanti Region was selected for the pre-test because it is known to be an important hub for trade and transport in the sub-region and one of the largest users of pesticides in Ghana [28]. Enumerators were trained on

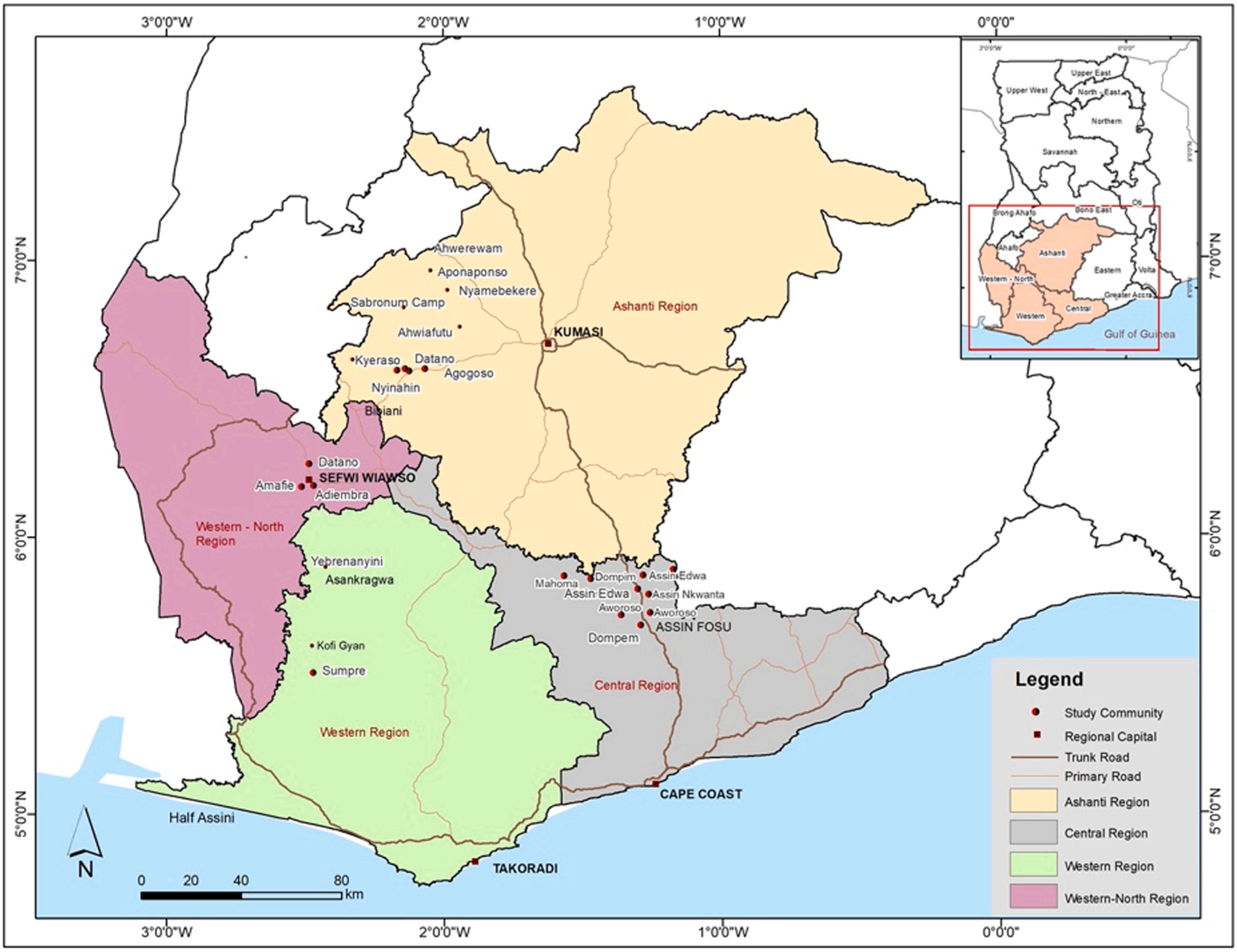

Fig. 1. A map showing the four regions (Ashanti, Central, Western, and Western-North) of Ghana where samples were taken.

the data collection.

Four hundred and four randomly selected farmers were engaged in face-to-face interviews to fill a structured questionnaire stored on an android tablet using the Kobo form. The survey tool consisted of a digital tablet sync with a backend database that can be downloaded in excel for analysis. The structure of questions consisted of a combination of open-ended, close-ended, and partially closed-ended questions. The questions were designed to assess possible risks and impacts of pesticide use neonicotinoids in cocoa (products/active ingredients and spraying practices) plus any information on impacts to human and environmental health reported using a quantitative survey. Furthermore, the study assessed the perception of farmers and Spraying Service Providers, including Cocoa Disease and Pest Control (CODAPEC) gangs, on the use and impact of insecticides on cocoa. (Products and active ingredients, and spraying practices). Any information on human and environmental health impacts was reported using focus group discussions.

2.5. Statistical analysis

Data were analyzed using statistical package for social sciences (SPSS) software, standard version, release 26.0 (SPSS Inc. 2008). Descriptive statistics provided insights into perception and pesticide application practices among smallholder cocoa farmers in four Ghanaian cocoa-growing regions. Measures of association between variables were carried out using the Chi-Square test of independence or equality of proportions for nominal Vs nominal and nominal Vs ordinal variables and Sommers' for Ordinal Vs Ordinal variables. Multiple response analysis for multiple-response questions (with the possibility for more than one response to a single question).

3. Results

3.1. Demographic characteristics of farmers and associations

Four hundred and four respondents from 26 communities, made up of ten from the Ashanti Region, eight from the central region, four from Western-North, and four from the Western Region, were sampled. One hundred and sixty-four farmers (representing 41% of the total respondents) were from the Ashanti region, 30.3% from the Central Region, 13.8%, and 16% from the Western and Western North, respectively. The population of respondents was 69.1% males and 30.9% females (Table 1). Most farmers had completed middle school or Junior High School (JHS). Many farmers (82.7%) were literate, dominated by middle school or JHS leavers within the 41–50 age bracket. About 17% of farmers had no formal education and were within the same 41–50 age bracket (Table 1). Most farmers have less than 20 years of experience in cocoa production, whereas very few (5.2%) have up to 60 years of experience in the industry.

A significant number of farmers (78.5%) were associated with certification groups and cooperatives. A chi-square test revealed a

Table 1
Demographic characteristics of cocoa farmers in the study area.

Variable	Description	Percentage (%)
Sex of farmers	Male	69.10
	Female	30.90
Age of farmers	20–29	21
	30–39	33
	40–49	11
	50–59	2
	Above 60	21.3
Educational level	No education	17.3
	Up to Primary	21.3
	Middle/JHS	50.2
	SHS	8.2
	Tertiary	3.0
Farmers' years of experience in cocoa cultivation	< 20	63.0
	21–40	31.7
	41–60	5.20

significant difference between group membership and benefits ($P < 0.05$). This means that farmers belonging to groups derived more benefits from the groups compared to farmers with no association with certification groups and cooperatives. Similarly, cooperatives or certified groups had access to pesticide training and other agrochemical inputs compared to non-group members.

3.2. Pesticides

A total of 20 different insecticides were documented as reportedly used by the farmers (Table 2). These were classified into four distinct chemical groups, with a fifth group designated as "others" since the pesticides in this group did not fit any chemical classification. Synthetic pyrethroids accounted for 44.5% of the pesticides mentioned, followed by neonicotinoids (39.6%), neonicotinoid/pyrethroid combination products (5.1%), non-specific chemical classes (9.9%) and pyrethroid/acyl derivative combination (0.7%). The pyrethroids, which topped the chart of frequently used pesticides, were dominated by bifenthrin as the popular active ingredient used by Ghanaian cocoa farmers (43%) in the sampled regions. This was closely followed by imidacloprid (29.7%) and thiamethoxam (8.5%) as farmers' third most commonly used active ingredient. A combination of acetamiprid and alpha-cypermethrin was the least patronized active ingredient in cocoa production in the four studied regions. It was important to note that 9.9% of farmers used active ingredients that were not known and unapproved (Table 2).

Table 2
Pesticides used by farmers in the four regions under study.

Chemical Family	Active Ingredients	Brand Name	Number of Users	Percentage
Neonicotinoid	Acetamiprid	Buffalo	5	1.2
	Imidacloprid	Confidor	120	29.7
	Thiamethoxam	Actara	21	5.2
		Adama	12	3.0
		Kookoo akate	2	0.5
				39.6
Neonicotinoid + Synthetic pyrethroid	Acetamiprid + Alpha Cypermethrin	Super killer	1	0.2
	Acetamiprid + Bifenthrin	Acetesta	11	2.7
	Acetamiprid + Indoxacarb	Viper	2	0.5
		Viper Super	2	0.5
	Bifenthrin & Imidacloprid	Garlin	5	1.2
Synthetic pyrethroid + acyl derivative	Alpha Cypermethrin + Chorantraniliprole	Normax	3	0.7
				5.8
Pyrethroid	Bifenthrin	Akate Asa	21	5.2
		Akate Master	117	29.0
		Akate Suro	1	0.2
		Akate Star	21	5.2
		Akatepower	1	0.2
		Akatewura	2	0.5
		Seizer	11	2.7
	Etofenprox	Akate captain	6	1.5
				43
Others & Glamopat	(Unapproved)		40	9.9

3.3. Knowledge, awareness, and perception of farmers about pesticide use

Farmers who belonged to cooperatives, including certified groups, were well resourced with information about pesticides because they had access to training and inputs. However, a Pearson's chi-square goodness of fit test revealed that farmers' knowledge of how to handle pesticides did not influence their ability to handle the risk associated with their use ($P = 0.549$). The majority of these farmers obtained their information from extension officers (377), radio (238), and cooperatives (215). Non-Governmental organizations (NGOs), License Buying Companies (LBCs), and purchasing clerks also play an essential role in training farmers. However, these entities were the least resource utilized by farmers for pesticide information (Fig. 2).

On assessing knowledge of the harmful effects of pesticides, 53.22% of farmers revealed that they were unaware that residues of pesticides remain in the food, whereas 25.25% of farmers reported being aware of this fact. Interestingly, 94.55 farmers were aware that pesticides are harmful to humans, yet 6 had no idea about the harmful effects of pesticides.

More than half of the respondents (63.6%) demonstrated that they were aware of the harmful effects of pesticides on ants and other soil microorganisms. The remaining farmers said they were neither aware nor had any idea of such effects. Also, a significantly high proportion (95%) of the respondents indicated their awareness of the possible contamination of water with pesticide residues. Similarly, most farmers were aware of the potential contamination of other agricultural products, such as food crops, with pesticides. Surprisingly, 234 farmers (>50%) mentioned they were unaware pesticides contaminate soil, and an additional 32 farmers indicated that they had no idea of the possibility of pesticides leaving toxic residues in the soil. However, most respondents (79.7%) were aware pesticides were linked to human ailments, with 15.1% having no idea regarding pesticides being the cause of human ailments.

The study also evaluated the knowledge and perception of the farmers on personal protective equipment (PPE) during pesticide applications. A majority (81.7%) of the respondents used PPEs all the time, whereas a total of 16.5% did not use the protection gear all the time (Table 3). It was recorded that 0.7% of the farmers did not use PPE at all, even though 98.8% acknowledged that using PPE was critical and

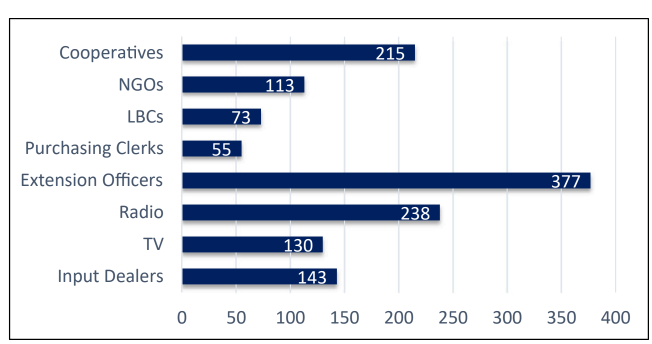

Fig. 2. Farmers' sources of information on the general and technical knowledge of pesticides.

Table 3
Perception and knowledge of the use of PPE.

Responses related to PPE use	Frequency	Percentage
How often do you use PPEs?		
I do not use PPEs at all	3	0.7
when applying pesticides	5	1.2
I use it most of the times	41	10.1
I use it occasionally	15	3.7
I use it rarely	10	2.5
I use PPEs all the time	330	81.7
Is the use of PPE critical		
No	5	1.2
Yes	399	98.8
Willingness to use PPEs		
Maybe/unsure	5	1.2
Willing	399	98.8
What do you perceive to be the benefits of using PPE		
Agricultural authorities seem interested in the use of PPE by farmers	8	2.0
It is easy to use	8	2.0
It is very effective in avoiding pesticide health effects	366	90.6
Storage, mixing, handling, and spraying of pesticides are safe with PPE use	19	4.7
The use of PPE promotes safe behavior among farmers, farm workers, and family members	3	0.7
Source of PPE information		
Farmers		
No	202	50.0
Yes	202	50.0
Radio and Tv		
No	132	32.7
Yes	272	67.3
Extension agent		
No	46	11.4
Yes	358	88.6
Technical training courses		
No	331	81.9
Yes	73	18.1
Extension materials		
No	354	87.6
Yes	50	12.4
Pesticide retailers		
No	346	85.6
Yes	58	14.4

willing to use it.

Most farmers (90.6%) indicated that using PPE was necessary to prevent the ill effect of pesticides. Farmers obtained information on the use of PPEs from colleague farmers (50%), radio and TV (67.3%), extension agents (88.6%), technical training courses (18.1%), and pesticide retailers (14.4%) (Table 3).

3.4. Farmer practices and pesticide management

The study evaluated actions taken by farmers following pesticide application to elucidate farmer practices about pesticide use and other management practices, including the disposal of used containers. The study also sought to evaluate how farmers implemented the use of full PPE in practice. Full PPE is defined as wearing a cap/hat, respirator/nose mask, goggles, hand rubber glove, overall, long coat, facemask, and Wellington boot (rubber boot). It was recorded that 83% of the farmers used whole cloth personal protection without gloves and other equipment that qualified for complete protection. A small number of farmers (6%) did not use any form of protection when applying pesticides. It was noted that only 1% of farmers protected their eyes with goggles during pesticide application. The farmers indicated that their aversion to goggles was due to the sub-standard nature of those found on the market. A validation using focused group interviews involving pesticide spraying service providers confirmed that the glass frame of the goggles becomes dark and cloudy, obscuring vision hence farmers' hesitancy in wearing the face protection (goggles).

To understand how farmers minimized health risks associated with pesticide application, they responded to questions about actions taken after using, storing, and preparing pesticide solutions. The results indicated that most farmers shower (88%) after pesticide application (Table 4). It was also recorded that 70% also changed clothing, with another 68% indicating that they washed their faces (Table 4). Only one farmer (0.002%) revealed that no action was taken as a mitigating risk measure right after pesticide application.

Regarding the storage of pesticides, the study shows that farmers store pesticides in more than one location. However, the following data shows where the farmers frequently keep pesticides before use. 17% of the farmers do not have a specific space or area to store them. Similarly, 17% of the interviewed cocoa farmers store their pesticides on their porches, and 16% keep them in the kitchen and bedroom. Only 8% of the farmers had a particular storage area for the pesticides (Table 4). The validation interviews from the Spraying Service Providers (SSP) indicated that some pesticides had no labels and could present a potential danger of misapplication.

Also, to better understand farmers' practices in pesticide application and their effectiveness, the respondents were asked if they mix different pesticides. About 94% of respondents revealed they do not mix other pesticides during the application, while only 6% mentioned that they mix pesticides (Table 4). Additionally, the validation study done through a focus group discussion with spraying service providers, including spraying gangs of the Cocoa Disease and Pest Control, revealed that farmers mixed liquid fertilizers with pesticides to reduce the fuel cost used in spraying. Most of the farmers combined the fertilizer and pesticides so that they could spray it just once to save the cost of fuel. They also mixed different pesticides intending to increase the efficacy of the pesticides. Some farmers, however, indicated that sometimes the resultant solution turned into a mass or cake immediately after mixing different pesticide solutions or pesticides with fertilizers.

In assessing how farmers dispose of surplus pesticide mix, it was evident that a higher number of farmers (98.5%) store the remaining pesticide mix and reuse it during subsequent rounds of application (Table 5). Worryingly, some farmers revealed that they release surplus pesticide mix into water bodies. Two hundred and eleven farmers interviewed expressed that they re-apply surplus pesticide mix to empty the knapsack tank or the motorized mist blower (Table 5).

9.2% of farmers indicated that they leave empty pesticide containers on the farm, while 1% of farmers revealed that they throw them into nearby water bodies. The results showed that about 1% of respondents used empty containers for financial gains by selling them. The study also

Table 4
Farmer practices on pesticide application and management (n = 404).

Pesticide application practices by farmers	Respondents (%)
Action taken by farmers after pesticide use	
Do nothing	0.002
Shower	
Yes	88
No	12
Change clothes	
Yes	70
No	30
Wash face	
Yes	68
No	32
Storage of pesticides by farmers	
No specific area	17
Special storehouse	8
Bedroom	16
Porch	16
Kitchen	16
Use all immediately	14
Others	12
Mixing of pesticides before application	
Yes	6
No	94
Not sure	0

Table 5
Disposal of leftover pesticides and used pesticide containers.

Farmer pesticide disposal practices	Respondents	
	Number	Percentage
(a) **Action taken with used pesticide containers**		
Throwing away on the farm		
No	286	70.5
Yes	118	29.2
Throwing away in water bodies nearby		
No	400	99.0
Yes	4	1.0
Disposing of regular waste		
No	382	94.6
Yes	22	5.4
Collect and sell them		
No	400	99
Yes	4	1.0
Send it back to the retailer		
No	362	89.6
Yes	42	10.4
Burning them		
No	201	49.8
Yes	202	50.0
Bury them		
No	223	55.2
Yes	177	43.8
Keeping for reuse and other purposes		
No	398	98.5
Yes	6	1.5
(b)Action taken with leftover pesticide solutions		
Store it for another application		
No	135	33.4
Yes	269	66.6
Apply on another crop		
No	396	98.8
Yes	8	1.2
Release into water bodies		
No	399	98.8
Yes	5	1.2
Re-apply on the same crop until it is empty		
No	193	47.8
Yes	211	**52.2**
Apply on a non-cropped land		
No	401	99.3
Yes	**3**	**0.7**

gathered from the SSP that some farmers use empty containers to store edible salt, drinking water, and local alcohol ("akpeteshie"). These practices may pose significant risks to participating farmers. With limited options for disposing of empty pesticide containers, some farmers responded that they burn (50%) or bury (43.8%) these items. In this regard, some farmers dig holes on farms and bury them whilst others hide them in big termite hills.

3.5. *Farmers' perception of the health risk of pesticide use*

Farmers' compliance to standard pesticide application practices as a health risk mitigation was also evaluated. A little over half of the respondents (55.9%) indicated that they complied with the dosage regimen of pesticides used on their farms, with a significant proportion being non-compliant (Fig. 3). The farmers' awareness of the potential risk of ill health following the application of pesticides was also highlighted by the high proportion of respondents who used personal protective equipment and did not recycle used pesticide containers (98.5%). However, this was not corroborated by results elsewhere which saw only 38.9% of farmers indicated that they used low-risk products (Fig. 3).

The farmers also reported at least one or more health hazards or effects immediately following applying pesticides. A considerable number of farmers (48.3%) reported having skin irritations following pesticide use. Other ill effects reported were throat irritation (17.1%), eye irritation (32.7%), difficulty in breathing (10.9%), coughing (14.6%), and headache (10.6%) (Table 6).

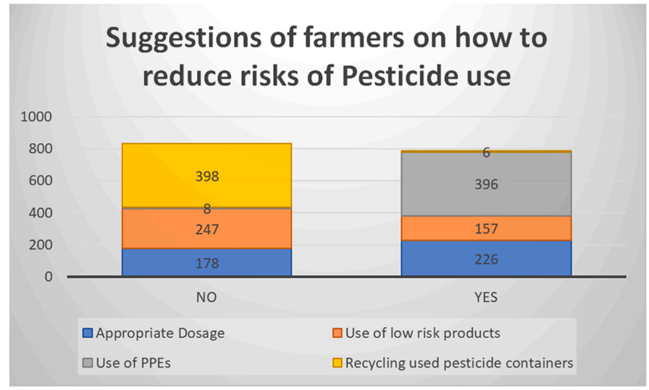

Fig. 3. Farmer practices relating to the perceived health risk of pesticide use.

Table 6
Self-reported health symptoms among cocoa farmers.

Health issues		Frequency	Percent
Skin irritation			
	No	209	51.7
	Yes	195	48.3
Throat nose irritation			
	No	335	82.9
	Yes	69	17.1
Eye irritation			
	No	272	67.3
	Yes	132	32.7
Difficult breathing			
	No	360	89.1
	Yes	44	10.9
Coughing			
	No	345	85.4
	Yes	59	14.6
Flu			
	No	398	98.5
	Yes	6	1.5
Headache			
	No	361	89.4
	Yes	43	10.6
issues Dizziness			
	No	363	89.9
	Yes	41	10.1
Excessive sweating			
	No	358	88.6
	Yes	46	11.4
Excessive salivation			
	No	328	81.2
	Yes	76	18.8
None			
	No	205	50.7
	Yes	199	49.3

4. Discussions

4.1. *Demography and characteristic profile*

The socio-demographic characteristics, including sex, marital status, age, level of education, and farmers' cocoa production experience, are documented in Table 1. On average, most farmers have had less than 20 years of experience in cocoa cultivation. The study also revealed that literate farmers were in the majority (82.7%), contrary to results elsewhere that revealed cocoa production was more prevalent among illiterate farmers [29]. Education plays a vital role in understanding the dynamics and engagements of farm innovations [30]. The dominance of male farmers over females, recorded in this study, corroborates findings from previous studies [29]. This also agreed with the reflections of [31] and [9], who found in a study that male farmers constituted about 93% and 90%, respectively, of the respondents. The results obtained in this study are not particularly surprising because in Ghana, especially in rural farming communities, males were often more resource endowed than females [32]. In other studies, it was reported that due to the labor-intensive nature of the work means, women would not be able to meet the needed effort to cultivate the crop [3]. More than half of the farmers joined farmer associations and recounted benefits such as access to training and materials, agrochemical inputs, and other support services from government organizations geared towards supporting them to improve their farm practices and productivity.

4.2. Types and sources of pesticides used by cocoa farmers

A pest attack by mirid can reduce cocoa output by up to 75% if not attended to [33,34]. This is troubling as it reduces farmers' income and affects the economy's Gross Domestic Product (GDP). Against this background, the Ghana Cocoa Board instituted the Cocoa Disease and Pest Control Programme (CODAPEC) to enhance cocoa productivity growth on a sustainable basis. This intervention promotes chemicals to control pests and diseases to increase crop output. The study showed that cocoa farmers in the four regions sampled depended heavily on pesticides for managing pests and diseases. Twenty (20) different pesticides were documented as used by farmers. These were put into six different chemical classes. Bifenthrin was the most popular active ingredient used by Ghanaian cocoa farmers (43%). Imidacloprid and thiamethoxam recorded 29.7% and 8.5%, respectively. This data is consistent with the approved pesticides by the Ghana Cocoa Board (COCOBOD) [35]. By the findings of this research, one farmer (0.2%) used a combination of acetamiprid and alpha-cypermethrin. Lastly, 9.7% of farmers used active ingredients that cannot be stated by the farmers and are therefore classified as unapproved. This result is similar to that reported earlier [3,36], where cocoa farmers disregarded the approved pesticides of the COCOBOD. COCOBOD introduced the CODAPEC program (Mass Spraying) in 2001/2002 to control black pod disease and mirids (capsids) to prevent their effects on cocoa production. The CODAPEC program is free of charge for a farmer. The package for the Capsid control comprised of a 7-member spraying gang (supervisor inclusive) ensures two (2) rounds of insecticides application in April/May and September/October. Cocoa farmers complement the first two (2) rounds with an additional two (2) in June and December. A likely explanation could be that the approved pesticides were limited in supply and, therefore, predisposed farmers to buy from the open market to complement what was supplied by the CODAPEC program [37]. This trend of pesticide uses in Ghana is reported similarly in Cameroon [38].

The most widely used active pesticide ingredients documented in the study, bifenthrin and imidacloprid, belong to the pyrethroid and neonicotinoid families, respectively and are classified as moderately hazardous compounds (Class II) according to WHO's classification [39]. Even though these pesticides are in class II, they may pose a risk to human health and environmental concerns if not correctly applied [40]. The results also showed that 6% of the pesticides were made up of neonicotinoid/synthetic pyrethroid products. The results also showed that 6% of the pesticides were neonicotinoid and synthetic pyrethroid products. A combination of Acetamiprid and Alpha Cypermethrin, Also, Acetamiprid and Bifenthrin.

Additionally, acetamiprid and indoxacarb, and lastly, bifenthrin and imidacloprid. Other combinations are acyl derivative and synthetic pyrethroid, Alpha Cypermethrin and Cloranthraniliprole. This cocktail of pesticides or combinations aims to avoid building resistance to target pest species. However, there is growing concern that their widespread use contributes to the decline of pollinator populations [41].

4.3. Knowledge, awareness, and practices of farmers relating to risk

The study revealed that most respondents joined cooperatives and certification groups and had access to information. Information is essential for cocoa farmers to optimize their management and increase yields. Extension officers, radio, and cooperatives were the preferred source of information on pesticides to cocoa farmers. NGOs, LBCs, and purchasing clerks were less preferred information flow routes. A significant highlight of this study was the role of purchasing clerks, who accounted for 13.6% of pesticide information to farmers, a marked departure from their core duties as cocoa purchasing officers. Extension services as the primary source of information to farmers (93.3%), recorded in this study, agree with that reported [42], where 89.3% of the farmers opted for this route. These findings fuel the call to increase the number of extension officers in the cocoa sector in Ghana, who are woefully inadequate, according to a report [43]. Radio, the other preferred route of information flow to farmers, represents a critical medium because of its broad reach, especially in rural communities where these cocoa farms are domiciled. To disseminate accurate and timely information to farmers on pesticide use on the radio requires the participation of experts as this will afford standardized information to all farmers across the country.

Farmers know much about pesticides and their harmful effects on humans. However, the majority (53.2%) hinted that they were unaware that pesticide application could leave residues in food. This may signal a possible lack of comprehensive information on pesticides to farmers. It is also possible that farmers may be oblivious of how pesticides leach into the soil and are subsequently taken up by food crops. Also, the significant number of farmers (36.4%) unaware of the possible effect of pesticides on ants, earthworms, and other soil organisms demonstrate the knowledge gap in pesticide information that should be addressed.

Wearing PPE is recommended as a mitigation measure against pesticide use's health risks. Farmers in the study areas perceived PPEs as critical and necessary for health reasons. This was reflected in the approximately 82% of the respondents who used it all the time, but this was understood to be partial protection as they did not protect all body parts during application. Another study found that participants were aware of the negative effects of pesticide use on their health and the environment, and they felt that the protection provided by specific equipment items was insufficient [44]. Many of these farmers used cloth protection but seldom wore hand gloves and face protection (nose and eye protection). Thus, the overwhelming knowledge of the farmers on the benefits of PPE and the perception of the risk of pesticides did not translate into practice, where full PPE should have been recorded among the majority. This discourse agrees with researchers [45], who noted that cocoa farmers used little personal protection during pesticide application. The majority wore trousers, long-sleeves, and slippers with some mixing pesticides with bare hands. Corroborating these reflections is a report [46], which showed that 58% of farmers did not use any PPE, whereas only 29% used some form of PPE. Another study [47] also reported that 45% of cocoa farmers in the study used partial PPE, whereas 20% did not wear PPE. Several factors are thought to influence farmers' decision to use PPE, but prominent among these is the discomfort caused by wearing protective equipment [48]. As seen in the present study, the spraying service providers complained of blurring the googles with mist during application which impaired visibility. Some farmers also indicated that wearing PPE made fieldwork on farms very uncomfortable. However, these reasons do not outweigh the risk of exposure to these hazardous pesticides. Thus, lifelong training and education on PPE are required to safeguard the health of the farmers. Farmers obtained information on PPE primarily from extension agents, radio, and TV. This agrees with our earlier observation that farmers mainly subscribed to these routes for information regarding pesticide use.

Nano pesticides (2- or 3-dimensional nanostructures with up to 200 nm size used to carry agrochemical ingredients) and nano fertilizers are not used on the studied products. The nano pesticide formulations have enhanced water solubility and bioavailability. As a result, they offer greater crop protection against viruses and pests. However, little is known or understood about the cytotoxicity and genotoxicity of the nanomaterials [49,50]. Therefore, a thorough evaluation of the application of nano pesticides and nano fertilizers to cocoa is essential for the crop's long-term growth.

4.4. Perception of health risks and toxic symptoms from pesticide use experienced by farmers

Farmers' awareness of the toxic effect of pesticides did not reflect in their responses to specific questions. For example, only 39% indicated they used low-risk pesticide products, and 46% were non-compliant with the dosage regimen. Inappropriate dosing of pesticides has been reported in several studies. In a study [51], about seventeen pesticides were overdosed by farmers for several reasons. Prominent among these was that some farmers attributed overdosage to the presence of dew on the leaves of plants, especially during the mornings. As a result, they usually increase the volume of pesticides product applied to compensate for the excess water on the leaves. This assertion merits attention and the necessary corrective intervention through education.

Farmers in the study reported pesticide-related health problems such as skin, eye, and throat irritations, coughing, and difficulty breathing. Skin and eye irritations dominated these symptoms, consistent with an earlier finding [52]. They identified skin and eye irritation, sweating, and salivation as the major health issues reported by farmers after pesticide application. Other symptoms, such as muscle weakness, vomiting, and blurred vision, have been reported on pesticide use [53]. Similar findings have been documented [54],[55]. The most commonly reported potential effects of chemical exposure were dizziness (44.3%), headache (39.4%), excessive sweating (34.4%), vision impairment (46%), and respiratory issues (30.2%). In agreement, some researchers [46] have indicated that these health symptoms could be linked to the inappropriate and inadequate use of PPE. The possible economic consequences of such issues, such as loss of earnings and health costs associated with these conditions, may be deterrent to the farmers and could affect the cocoa production capacity of the country.

4.5. Pesticide management practices among farmers

The study also sheds light on some pesticide management practices among cocoa farmers in the four regions. Some commendable practices demonstrated farmers' awareness of the risks associated with pesticide use. For example, most farmers washed their faces, bathed, and changed clothes immediately after pesticide application. However, unsafe practices regarding the storage and disposal of pesticide solutions and containers were evident. Many deaths and cases of poisoning are caused by the mishandling of pesticide wastes and containers. Carelessly disposed of pesticides can contaminate the air, water, and land and poison people, livestock, fish, and wildlife [56].

The majority of the respondents indicated that they do not have specific storage facilities, so they stored pesticides in their bedrooms (94.6%), kitchens (96%), and porches (100%). This is an unsafe practice and very inconsistent with farmers who belong to cooperatives and have been trained on pesticide handling on several fronts. The active ingredients of these pesticides can volatilize and saturate these storage areas around the home, predisposing residents to the likelihood of poisoning through inhalation and contaminated food [57]. Long periods of storing pesticides around the home can lead to exposure and risk of intoxication [58]. A study [47] recognized a similar trend among cocoa farmers, where 22.5% of farmers stored pesticides in bedrooms, indicating a high risk of pesticide exposure through direct inhalation. According to a Moroccan study [44], 40% of farmers do not properly store their unspent/excess pesticides.

Similar reports of farmers storing pesticides in the house are reported by several authors [59]. These practices have led to some fatalities in Ghana. For example, 15 farmers died in the Upper East Region of Ghana through pesticide poisoning related to poor storage [51]. This put Ghanaian farmers in the spotlight for training that influences attitudinal changes in pesticide use.

The study also highlights practices contrary to expectations in disposing leftover pesticide solutions and containers among cocoa farmers in the selected regions. It was evident that most farmers stored leftover pesticide solutions and reused them during the next application round. Because they have poor storage practices, these actions could be detrimental to their health. Few farmers revealed that they release surplus pesticide mix into water bodies. Again, this is a hazardous enterprise as it poses a significant risk to humans in the food chain and non-target organisms.

Other dangers arise when unwanted pesticides and containers are disposed of inappropriately. Only 1% of the respondents abandoned the containers close to water bodies. This number, though negligible, still represents a clear danger for all food chain members, especially aquatic organisms and communities that depend on these water bodies for their livelihood [47]. Only a few mentioned they disposed of the waste containers with regular household waste. Burning and burying pesticide containers, as portrayed by the majority of the respondents in this study, is also hazardous to the farmers and neighboring communities since this could lead to contamination of farm soils and surrounding water bodies through leaching and runoffs. According to research conducted in Ethiopia and Greece, farmers commonly dispose of pesticide containers by dumping them in fields and burning them over an open fire [60,61]. Another study [44] observed that half of the respondents buried or burned the empty pesticide containers, while the other half dumped them in public dumpsites or at the edge of fields. Many pesticide suppliers and national authorities recommend burying or burning waste pesticides and empty containers. However, these practices are not environmentally friendly since buried chemical waste can contaminate soil and leach into the surface or groundwater, while burning pesticide containers generate environmentally persistent toxic emissions [56]. The best practice recommended by the WHO that is likely to destroy plastic containers and pesticides is licensed high-temperature incinerators and cement kilns with adequate emission controls. However, this is either unavailable or expensive for the farmers to patronize [39].

The common practice of reusing pesticide containers to store food and water is an example of lousy disposal practices. It was alarming to note that the validation study with the spraying service providers revealed that some used empty containers to store salt, drinking water, and the local alcohol known as 'Akpeteshie'. Farmers' knowledge of pesticides and their hazards should be accompanied by a high safety attitude in their farming practices. Imoro et al., [57], on the other hand, uncovered a different pattern where none of the farmers in the Northern region of Ghana used pesticide containers for storing water and food products. Only a few of the farmers (10.4%) return their empty pesticides container to the agrochemical dealer. This practice, if encouraged, would afford safe disposal practices. Farmers could be encouraged to return pesticide containers to vendors for a small fee or incentive. According to a study [62], part of the farmers' money paid for the pesticide could be given back to them when they return the pesticide containers to manufacturers, retailers, or packaging companies.

The study has shed light on unsafe disposal practices among cocoa farmers in the four regions, which calls for coordinated efforts from all involved, including regulatory authorities, pesticide distributors, and suppliers. Other organizations that support and advise pesticide users, such as extension and health promotion services, non-governmental organizations (NGOs), agricultural colleges, and schools, have essential roles.

In this study, some farmers (6%) confirmed mixing pesticides to increase their potency. The low record may be attributed to the fact that many participating farmers in this training have been trained in agrochemical use. The Ghana Cocoa Board (COCOBOD) recommends that for effective and sustainable control of pests and diseases, cocoa farmers need to apply pesticides on their cocoa farms up to four times per season [43]. However, the COCOBOD supply of pesticides is not adequate. Therefore, farmers buy from the market to complement what has been given by the Ghana Cocoa Board. These chemicals are, however, misused or in dangerous combinations with disregard for approved pesticides and recommended frequency [43].

A thorough understanding of the knowledge, perception, and pesticide use of smallholder cocoa farmers was made possible with the use of pluralistic perspectives and methods. The method makes effective use of both qualitative and quantitative techniques to produce a wealth of evidence for the phenomenon being studied. The results of this study, however, cannot be applied to regions with various pesticide usage and storage regulatory frameworks and arrangements.

5. Conclusion

The study revealed that most farmers belonged to Cooperatives & Certification groups and used about 70% of insecticides approved by COCOBOD. Farmers are knowledgeable in pesticides, but this did not reflect in their attitude toward the storage of agrochemicals and personal protective equipment. Though farmers are trained, pesticide risk is persistent because of poor adoption and implementation. Storage, handling, and disposal of pesticides are still a challenge. Interventions such as education and training of farmers, which enhance safety behavior, should be intensified to minimize pesticide exposure among farmers.

There have not been many studies on the use of pesticides by farmers, as well as their knowledge and practices in the major cocoa-producing regions. The purpose of this study was to fill this knowledge gap by eliciting an understanding of pesticide usage among smallholder cocoa producers. These findings provide information that can be used to help cocoa growers decide whether or not to use pesticides. Furthermore, the information could aid government efforts to ensure that cocoa growers and pesticide sprayers are properly handling pesticides.

CRediT authorship contribution statement

All authors contributed to the study's conception and design. All authors performed material preparation, data collection, and analysis. The first author wrote the first draft of the manuscript, and all authors commented on previous versions. All authors read and approved the final manuscript.

Consent to Participate

Informed consent was obtained from all the participants before they answered the questionnaire.

Consent to Publish

All authors have proofread the manuscript and approved the submission.

Ethical approval

Ethical approval for the study was obtained from the Committee on Human Research, Publication and Ethics of Kwame Nkrumah University of Science and Technology.

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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.

Data availability

Data will be made available on request.

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References

[1] FAO, Pesticides use. Global, regional and country trends, 1990-2018, Anal. Br. Ser. 16 (2021) 1–9.

[2] A. Donkor, P. Osei-Fosu, B. Dubey, R. Kingsford-Adaboh, C. Ziwu, I. Asante, Pesticide residues in fruits and vegetables in Ghana: a review, Environ. Sci. Pollut. Res. 23 (2016) 18966–18987, https://doi.org/10.1007/s11356-016-7317-6.

[3] E.K. Denkyirah, E.D. Okoffo, D.T. Adu, A.A. Aziz, A. Ofori, E.K. Denkyirah, Modeling Ghanaian cocoa farmers' decision to use pesticide and frequency of application: the case of Brong Ahafo Region, Springerplus 5 (2016) 1113, https://doi.org/10.1186/s40064-016-2779-z.

[4] E.N.A. Dormon, From a technology focus to innovation development, 2006.

[5] NASAC, Neonicotinoids and their Impact on Ecosystem Services for Agriculture and Biodiversity in Africa, 2019. https://doi.org/10.17159/assaf.2019/0040.

[6] V. Wouter, A.N.T. Luc, K. Alexandre, Patrick, Evaluation of cocoa mirid (Distantiella theobroma Dist. and Sahlbergella singularis Hagl.) control practices in Cte dIvoire, Afr. J. Agric. Res. 14 (2019) 2006–2016, https://doi.org/10.5897/AJAR2019.14056.

[7] A.K. Antwi-Agyakwa, E.A. Osekre, R. Adu-Acheampong, K.D. Ninsin, Insecticide use practices in cocoa production in four regions in Ghana, West Afr. J. Appl. Ecol. 23 (2015) 39–48.

[8] C.A. Damalas, I.G. Eleftherohorinos, Pesticide exposure, safety issues, and risk assessment indicators, Int. J. Environ. Res. Public Health 8 (2011) 1402–1419, https://doi.org/10.3390/ijerph8051402.

[9] G. Bhandari, K. Atreya, X. Yang, L. Fan, V. Geissen, Factors affecting pesticide safety behaviour: the perceptions of Nepalese farmers and retailers, Sci. Total Environ. 631–632 (2018) 1560–1571, https://doi.org/10.1016/j.scitotenv.2018.03.144.

[10] G. Khanal, A. Singh, Patterns of pesticide use and associated factors among the commercial farmers of Chitwan, Nepal, EHI.S40973, Environ. Health Insights 10s1 (2016), https://doi.org/10.4137/EHI.S40973.

[11] N. Simon-Delso, V. Amaral-Rogers, L.P. Belzunces, J.M. Bonmatin, M. Chagnon, C. Downs, L. Furlan, D.W. Gibbons, C. Giorio, V. Girolami, D. Goulson, D. P. Kreutzweiser, C.H. Krupke, M. Liess, E. Long, M. McField, P. Mineau, E.A. D. Mitchell, C.A. Morrissey, D.A. Noome, L. Pisa, J. Settele, J.D. Stark, A. Tapparo, H. Van Dyck, J. Van Praagh, J.P. Van der Sluijs, P.R. Whitehorn, M. Wiemers, Systemic insecticides (neonicotinoids and fipronil): trends, uses, mode of action and metabolites, Environ. Sci. Pollut. Res. 22 (2015) 5–34, https://doi.org/10.1007/s11356-014-3470-y.

[12] B. Buszewski, M. Bukowska, M. Ligor, I. Staneczko-Baranowska, A holistic study of neonicotinoids neuroactive insecticides—properties, applications, occurrence, and analysis, Environ. Sci. Pollut. Res. 26 (2019) 34723–34740, https://doi.org/10.1007/s11356-019-06114-w.

[13] M.L. Hladik, A.R. Main, D. Goulson, Environmental risks and challenges associated with neonicotinoid insecticides, Environ. Sci. Technol. 52 (2018) 3329–3335, https://doi.org/10.1021/acs.est.7b06388.

[14] D.B. Sponsler, C.M. Grozinger, C. Hitaj, M. Rundlöf, C. Botías, A. Code, E. V. Lonsdorf, A.P. Melathopoulos, D.J. Smith, S. Suryanarayanan, W.E. Thogmartin, N.M. Williams, M. Zhang, M.R. Douglas, Pesticides and pollinators: a socioecological synthesis, Sci. Total Environ. 662 (2019) 1012–1027, https://doi.org/10.1016/j.scitotenv.2019.01.016.

[15] F. Sánchez-Bayo, The trouble with neonicotinoids, Science 346 (2014) 806–807, https://doi.org/10.1126/science.1259159.

[16] B.C. Umeh, S.W. Avicor, E. Dankyi, R. Kyerematen, B.C. Umeh, S.W. Avicor, E. Dankyi, R. Kyerematen, Farmers' knowledge and practices on pollination and insecticide use in cocoa farming in Ghana, Int. J. Agric. Sustain. (2022) 1–13, https://doi.org/10.1080/14735903.2022.2106656.

[17] A.N. Iwaniuk, C.P. Heesy, M.I. Hall, D.R.W. Wylie, Relative Wulst volume is correlated with orbit orientation and binocular visual field in birds, J. Comp. Physiol. A 194 (2008) 267–282, https://doi.org/10.1007/s00359-007-0304-0.

[18] H. Klemick, E. Lichtenberg, Pesticide use and fish harvests in vietnamese rice agroecosystems, Am. J. Agric. Econ. 90 (2008) 1–14, https://doi.org/10.1111/j.1467-8276.2007.01059.x.

[19] G. Di Prisco, V. Cavaliere, D. Annoscia, P. Varricchio, E. Caprio, F. Nazzi, G. Gargiulo, F. Pennacchio, Neonicotinoid clothianidin adversely affects insect immunity and promotes replication of a viral pathogen in honey bees, Proc. Natl. Acad. Sci. USA 110 (2013) 18466–18471, https://doi.org/10.1073/pnas.1314923110.

[20] E. Dankyi, D. Carboo, C. Gordon, I.S. Fomsgaard, Application of the QuEChERS procedure and LC-MS/MS for the assessment of neonicotinoid insecticide residues

in cocoa beans and shells, J. Food Compos. Anal. 44 (2015) 149–157, https://doi.org/10.1016/j.jfca.2015.09.002.
[21] C.A. Morrissey, P. Mineau, J.H. Devries, F. Sanchez-Bayo, M. Liess, M.C. Cavallaro, K. Liber, Neonicotinoid contamination of global surface waters and associated risk to aquatic invertebrates: a review, Environ. Int. 74 (2015) 291–303, https://doi.org/10.1016/j.envint.2014.10.024.
[22] E. Dankyi, C. Gordon, D. Carboo, I.S. Fomsgaard, Quantification of neonicotinoid insecticide residues in soils from cocoa plantations using a QuEChERS extraction procedure and LC-MS/MS, Sci. Total Environ. 499 (2014) 276–283, https://doi.org/10.1016/j.scitotenv.2014.08.051.
[23] E. Dankyi, C. Gordon, D. Carboo, V.A. Apalangya, I.S. Fomsgaard, Sorption and degradation of neonicotinoid insecticides in tropical soils, J. Environ. Sci. Health Part B 53 (2018) 587–594, https://doi.org/10.1080/03601234.2018.1473965.
[24] K. Atreya, Health costs from short-term exposure to pesticides in Nepal, Soc. Sci. Med. 67 (2008) 511–519, https://doi.org/10.1016/j.socscimed.2008.04.005.
[25] K. Atreya, B.K. Sitaula, F.H. Johnsen, R.M. Bajracharya, Continuing issues in the limitations of pesticide use in developing countries, J. Agric. Environ. Ethics 24 (2011) 49–62, https://doi.org/10.1007/s10806-010-9243-9.
[26] D. Neupane, E. Jørs, L. Brandt, Pesticide use, erythrocyte acetylcholinesterase level and self-reported acute intoxication symptoms among vegetable farmers in Nepal: a cross-sectional study, Environ. Health 13 (2014) 98, https://doi.org/10.1186/1476-069X-13-98.
[27] Ghana Statistical Service (GSS), Ghana 2021 population and housing census, Ghana Stat. Serv. 3A (2021) 112. ⟨https://census2021.statsghana.gov.gh/⟩.
[28] L. Probst, L. Aigelsperger, M. Hauser, Consumer attitudes towards vegetable attributes: potential buyers of pesticide-free vegetables in Accra and Kumasi, Ghana, Ecol. Food Nutr. 49 (2010) 228–245, https://doi.org/10.1080/03670241003766055.
[29] A. Idris, K. Rasaki, T. Folake, B. Hakeem, Analysis of pesticide use in cocoa production in Obafemi Owode local government area of Ogun State, Nigeria, J. Biol. Agric. Healthc. 3 (2013) 1–9.
[30] M. Asamoah, Utilization of cocoa farm management practices by small-scale farmers: the pressure of socio-cultural factors, Int. J. Innov. Res. Educ. Sci. 2 (2015) 17–21. ⟨https://www.ijires.org/administrator/components/com_jresearch/files/publications/IJIRES-188_final.pdf⟩.
[31] M. A.A. Abubakar, M.A. Mala, A. Mumin, T. Zainab, Fatima, Perceptions of environmental effects of pesticides use in vegetable production by farmers along River Ngadda of Maiduguri, Nigeria, J. Agric. Environ. Sci. 4 (2015) 2015.
[32] B.T. Anang, V. Boateng, Farmers' Management Practices and the Quality of Cocoa Beans in Upper Denkyira District of Ghana Efficiency analysis of smallholder rice production View project, 3 (2011) 487–491. ⟨https://www.researchgate.net/publication/230787358⟩.
[33] J.C. Anikwe, A.A. Omoloye, P.O. Aikpokpodion, F.A. Okelana, A.B. Eskes, Evaluation of resistance in selected cocoa genotypes to the brown cocoa mirid, Sahlbergella singularis Haglund in Nigeria, Crop Prot. 28 (2009) 350–355, https://doi.org/10.1016/j.cropro.2008.11.014.
[34] D.J. Sonwa, S. Weise, A. Adesina, A.B. Nkongmeneck, M. Tchatat, O. Ndoye, Production constraints on cocoa agroforestry systems in West and Central Africa: the need for integrated pest management and multi-institutional approaches, For. Chron. 81 (2005) 345–349, https://doi.org/10.5558/tfc81345-3.
[35] S.K. Avico, S. Awudzi, G.K. Adu-Acheampong, R. Ahadzi, Field guide for cocoa insect pests identification, Cocoa Res. Inst. Ghana. T B No. 28 (2019) 1–27.
[36] A.K. Antwi-Agyakwa, E.A. Osekre, R. Adu-Acheampong, K.D. Ninsin, Insecticide use practices in cocoa production in four regions in Ghana, West Afr. J. Appl. Ecol. 23 (2015) 39–48.
[37] G.K. Awudzi, R. Adu-Acheampong, S.W. Avicor, Y. Bukari, E.K.O. Boateng, S. K. Ahadzi, P. Tagbor, Pattern of insecticide usage in organic cocoa production in Ghana, Org. Agric. 12 (2022) 125–136, https://doi.org/10.1007/s13165-022-00386-2.
[38] R. Mahob, M. Ndoumbe-Nkeng, G. Ten Hoopen, L. Dibog, S. Nyasse, M. Rutherford, M. Mbenoun, R. Babin, J. Amang, A. Mbang, Y. Yede, C. Bilong Bilong, Pesticides use in cocoa sector in Cameroon: characterization of supply source, nature of actives ingredients, fashion and reasons for their utilization, Int. J. Biol. Chem. Sci. 8 (2015) 1976, https://doi.org/10.4314/ijbcs.v8i5.3.
[39] World Health Organization, The Who recommended classification of pesticides by hazard and guidelines to classification 2009, World Health Organ. (2010) 1–60, https://doi.org/ISBN 978 92 4 154796 3.
[40] K. Atreya, B. Kumar Sitaula, H. Overgaard, R. Man Bajracharya, S. Sharma, Knowledge, attitude and practices of pesticide use and acetylcholinesterase depression among farm workers in Nepal, Int. J. Environ. Health Res. 22 (2012) 401–415, https://doi.org/10.1080/09603123.2011.650154.
[41] S.M. Williamson, G.A. Wright, Exposure to multiple cholinergic pesticides impairs olfactory learning and memory in honeybees, J. Exp. Biol. 216 (2013) 1799–1807, https://doi.org/10.1242/jeb.083931.
[42] G.K. Awudzi, M. Asamoah, F. Owusu-Ansah, P. Hadley, P.E. Hatcher, A. J. Daymond, Knowledge and perception of Ghanaian cocoa farmers on mirid control and their willingness to use forecasting systems, Int. J. Trop. Insect Sci. 36 (2016) 22–31, https://doi.org/10.1017/S1742758415000247.
[43] R. Adu-Acheampong, J. Jiggins, A. Van Huis, A.R. Cudjoe, V. Johnson, O. Sakyi-Dawson, K. Ofori-Frimpong, P. Osei-Fosu, E. Tei-Quartey, W. Jonfia-Essien, M. Owusu-Manu, M.S. Nana Karikari Addo, C. Afari-Mintah, M. Amuzu, N. Nyarko Eku-X, E.T.N. Quarshie, The cocoa mirid (Hemiptera: Miridae) problem: evidence to support new recommendations on the timing of insecticide application on cocoa in Ghana, Int. J. Trop. Insect Sci. 34 (2014) 58–71, https://doi.org/10.1017/S1742758413000441.
[44] Z. Ben Khadda, M. Fagroud, Y. El Karmoudi, S. Ezrari, I. Berni, M. De Broe, T. Behl, S.G. Bungau, T. Sqalli Houssaini, Farmers' knowledge, attitudes, and perceptions regarding carcinogenic pesticides in Fez Meknes Region (Morocco), Int. J. Environ. Res. Public Health 18 (2021) 10879, https://doi.org/10.3390/ijerph182010879.
[45] W.J. Ntow, H.J. Gijzen, P. Kelderman, P. Drechsel, Farmer perceptions and pesticide use practices in vegetable production in Ghana, Pest Manag. Sci. 62 (2006) 356–365, https://doi.org/10.1002/ps.1178.
[46] M.K. Miyittah, B. Ansah, M. Kwadzo, S. Seidu-Larry, R.K. Kosivi, Assessment of pesticide exposure risks among cocoa farmers in Western region of Ghana, Int. J. Pest Manag. 59 (2022) 1–19, https://doi.org/10.1080/09670874.2022.2084175.
[47] E.D. Okoffo, M. Mensah, B.Y. Fosu-Mensah, Pesticides exposure and the use of personal protective equipment by cocoa farmers in Ghana, Environ. Syst. Res. 5 (2016) 17, https://doi.org/10.1186/s40068-016-0068-z.
[48] T.T.H.E. Rice, B. Of, C.U.S.E. In, Facing Hazards at Work – Agricultural Workers and Pesticide Exposure in Kuttanad, Kerala, SANDEE Policy Brief/South Asian Netw. Dev. Environ. Econ. 07 (2007) 2007.
[49] M. Chaud, E.B. Souto, A. Zielinska, P. Severino, F. Batain, J. Oliveira-Junior, T. Alves, Nanopesticides in agriculture: benefits and challenge in agricultural productivity, toxicological risks to human health and environment, Toxics 9 (2021) 131, https://doi.org/10.3390/toxics9060131.
[50] T. Behl, I. Kaur, A. Sehgal, S. Singh, N. Sharma, S. Bhatia, A. Al-Harrasi, S. Bungau, The dichotomy of nanotechnology as the cutting edge of agriculture: nano-farming as an asset versus nanotoxicity, Chemosphere 288 (2022), 132533, https://doi.org/10.1016/j.chemosphere.2021.132533.
[51] M. Onwona Kwakye, B. Mengistie, J. Ofosu-Anim, A.T.K. Nuer, P.J. Van den Brink, Pesticide registration, distribution and use practices in Ghana, Environ. Dev. Sustain. 21 (2019) 2667–2691, https://doi.org/10.1007/s10668-018-0154-7.
[52] Y. Mehmood, M. Arshad, N. Mahmood, H. Kächele, R. Kong, Occupational hazards, health costs, and pesticide handling practices among vegetable growers in Pakistan, Environ. Res. 200 (2021), 111340, https://doi.org/10.1016/j.envres.2021.111340.
[53] H.M. Isah, H.O. Sawyerr, M.O. Raimi, B.G. Bashir, Assessment of commonly used pesticides and frequency of self-reported symptoms on farmers health in Kura, Kano State, Nigeria, J. Educ. Learn. Manag. 1 (2020) 31–54, https://doi.org/10.46410/jelm.2020.1.1.05.
[54] C.A. Damalas, E.B. Georgiou, M.G. Theodorou, Pesticide use and safety practices among Greek tobacco farmers: a survey, Int. J. Environ. Health Res. 16 (2006) 339–348, https://doi.org/10.1080/09603120600869190.
[55] M.C.R. Alavanja, M.K. Ross, M.R. Bonner, Increased cancer burden among pesticide applicators and others due to pesticide exposure, CA Cancer J. Clin. 63 (2013) 120–142, https://doi.org/10.3322/caac.21170.
[56] Food and Agriculture Organization FAO, International Code of Conduct on the Distribution and Use of Pesticides: Guidelines for the Registration of Pesticides, 2010. http://www.who.int/whopes/resources/resources_2010/en/.
[57] Z.A. Imoro, J. Larbi, A.B. Duwiejuah, Pesticide availability and usage by farmers in the Northern Region of Ghana, J. Health Pollut. 9 (2019) 1–8, https://doi.org/10.5696/2156-9614-9.23.190906.
[58] E.E.K. Clarke, L.S. Levy, A. Spurgeon, I.A. Calvert, The problems associated with pesticide use by irrigation workers in Ghana, Occup. Med. (Chic. Ill.) 47 (1997) 301–308, https://doi.org/10.1093/occmed/47.5.301.
[59] K.N.D. Brice, P.A. Bi Fai, N.T. Norbert, M. Mbida, Environmental and human health assessment in relation to pesticide use by local farmers and the Cameroon Development Corporation (CDC), Fako Division, South-West Cameroon, Eur. Sci. J. ESJ 13 (2017) 454, https://doi.org/10.19044/esj.2017.v13n21p454.
[60] C.A. Damalas, G.K. Telidis, S.D. Thanos, Assessing farmers' practices on disposal of pesticide waste after use, Sci. Total Environ. 390 (2008) 341–345, https://doi.org/10.1016/j.scitotenv.2007.10.028.
[61] I.D. Haylamicheal, M.A. Dalvie, Disposal of obsolete pesticides, the case of Ethiopia, Environ. Int. 35 (2009) 667–673, https://doi.org/10.1016/j.envint.2008.11.004.
[62] A. Bagheri, N. Emami, M.S. Allahyari, C.A. Damalas, Pesticide handling practices, health risks, and determinants of safety behavior among Iranian apple farmers, Hum. Ecol. Risk Assess. Int. J. 24 (2018) 2209–2223, https://doi.org/10.1080/10807039.2018.1443265.