Journal of Energy and Natural Resource Management (JENRM), Vol. 10, No. 2, 48-61, 2025
Received: February 7, 2025; Revised: March 23, 2025; Accepted: March 24, 2025

Crop-raiding by forest elephants (*Loxodonta cyclotis*) around a West African national park: insights from a mixed method approach

Dominic Awukuvi[1,2]; Michael Asigbaase[1*]; Mercy Derkyi[1]

Abstract
Persistent annual raiding of crops by elephants is a significant threat to conservation efforts and harmonious human-elephant coexistence. The study analyzed the incidence of crop-raiding at Bia National Park to test the hypothesis that crops and elephant-related characteristics influence crop-raiding. It also assessed farmers' insight about elephant crop-raiding and strategies to control elephants. A mixed method was employed in this study: qualitative and quantitative data were obtained from official records, and questionnaire-led interviews of 90 farmers and 10 wildlife officials. Quantitative data were analyzed using General Linear Models, correlation, and Kruskal Wallis test while thematic analysis was used to analyze qualitative data. Between 2010 and 2020, 582 elephant crop-raiding cases involving 135 farms belonging to 93 farmers were recorded. The estimated cost of elephant crop-raiding per farmer per year ranged from US$100.00 to US$5,500.00, with a mean of US$668.78. Crop-related characteristics influenced the frequency of elephant crop raiding, while the actual size of farm damage was related to seasonality, and farm size. Farmer-based approaches to controlling elephant crop raiding were basically technical deterrent methods such as pepper boundaries, noise, fire and pepper grease. However, a potential for revenge killings exists. We concluded that elephants' crop raiding was influenced by crop-related, seasonality and behavioral factors. Potential for revengeful killing exists, thus there is a need to involve local communities whose livelihoods are directly affected by elephant crop raiding to co-create innovative elephant-friendly solutions to human-wildlife conflicts.

Keywords
Crop raiding; human-wildlife conflict; Bia National Park; Loxodonta cyclotis; pepper grease technology

[1]Department of Forest Science, School of Natural Resources, University of Energy and Natural Resources, Sunyani, Ghana
[2]Bia National Park, Bia National Park, P.O. Box, 30, Sefwi Essam
***Corresponding author:** Michael.asigbaase@uenr.edu.gh
DOI: 10.26796/jenrm.v10i2.279
Received: February 7, 2025; **Received in revised form:** March 23, 2025; **Accepted:** March 24, 2025; **Published:** April 30, 2024

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1. Introduction

Crop raiding by elephants (*Loxodonta cyclotis*) poses a significant challenge to human-elephant coexistence (Tchamba et al., 2014; Kiffner et al., 2021; Tiller et al., 2021), and it is a substantial driver of human-wildlife conflict (Mailu, 2010; Webber et al., 2011; Ladan, 2014; Massé, 2016; Mumby & Plotnik, 2018). Elephants range across large land areas to meet their reproductive and feeding needs; they forage on various grasses, shrubs, and tree parts (Graham et al., 2009). It is noted that about 70% of the range of elephants lies outside of the protected regions (Blanc et al., 2007). Crop raiding by elephants often occurs in areas close to protected areas and densely populated areas (Naha et al., 2020). For example, there are high incidences of elephant crop-raiding in farmlands adjacent to protected areas (Hoare, 2015; Megaze et al., 2017).

In Africa, elephant (*Loxodonta cyclotis*) crop raiding

has existed for centuries (Archabald & Naughton-Treves, 2001; Hoffmeir-Karimi & Schulte, 2015), and it persists in most national parks (e.g., Sam et al., 2005; Oppong et al., 2008; Webber et al., 2011; Tiller et al., 2021; Kiffner et al., 2021). Crop raiding by elephants (*Loxodonta cyclotis*) significantly impacts most farming communities' activities due to their consumption, trampling, and dung deposition on crops, resulting in crop destruction and food insecurity (Kagwa, 2011). It worsens the food insecurity situation of rural farmers due to the loss of food crops, the increased cost of farming due to crop protection measures, and its influence on crop selection, diversity, and farming patterns (Weinmann, 2018). Furthermore, crop-raiding by elephants in rural communities can limit access to proper education as students increasingly stay home to guard crops on family farms from elephants (Mackenzie & Ahabyona, 2012). Moreover, elephants' destruction of property and livestock poses a significant threat to farmers' general safety and standard of living. Crop raiding is not a new phenomenon; globally, it involves different species, including white-tailed deer (*Odocoileus virginianus*) in the USA and the Asian elephant *Elephas maximus* (Sillero-Zubiri & Switzer, 2001). That notwithstanding, elephant crop raiding mainly fosters animosity toward elephants and protected areas, erodes tolerance for elephants and impedes conservation efforts, as farmers in local communities may retaliate to the activities of the elephants by killing them when they come to raid their crops (Sitati et al., 2005; Gubbi et al., 2011; Mackenzie & Ahabyona, 2012; Benjaminsen et al., 2013). In this context, it is critical to understand the spatio-temporal patterns of crop raiding to develop innovative policies and strategies to address the problem.

The spatio-temporal distribution of elephants' crop raiding in agrospaces is influenced by multifaceted anthropogenic, environmental, ecological, and behavioural factors (Notter et al., 2010; Hema et al., 2017a,b; Mkilindi & Mbise, 2021). Sillero-Zubiri and Switzer (2001) reported several reasons for the predominant elephant crop cases globally, including changes in farming systems, encroachment of farming areas for farming, increased human and wildlife populations, urbanization, and improved education. Studies reveal that crop-raiding by elephants is due to crops' nutritious value and good taste (Osborn, 2004; Chiyo et al., 2005). According to EKanayaka et al. (2011), elephants may raid crops at all stages, from planting to harvesting. Still, the severity of the raiding depends on the quantity of the crop available, growth stage, preference, and nutritional value of the crop. For example, the differences in nutritional value between natural fodder and cultivated crops or the scarcity of natural fodder may influence the incidence of elephant crop-raiding in the dry season. Furthermore, some studies reported higher crop-raiding among male elephants than among female groups (e.g., Williams et al., 2001; Fernando et al., 2005; EKanayaka et al., 2011), while other studies reported the opposite (e.g., Sitati and Walpole, 2006). That notwithstanding, elephant crop raiding varies with seasonality (Chiyo & Cochrane, 2005; Jackson et al., 2008; Pastorini et al., 2010; Sitienei et al., 2014), climatic conditions (e.g., rainfall) (Webber et al., 2011) and time of day (Sukumar et al., 2003; Gunn et al., 2014; Graham et al., 2009). Understanding crop-raiding seasons and areas of occurrence would help wildlife managers focus on conflict hotspots, implement appropriate mitigation strategies, and safeguard human livelihoods (Gubbi, 2012; Acharya et al., 2016).

Many studies have been conducted on the elephant (*Loxodonta cyclotis*) crop-raiding from purely quantitative or qualitative approaches (e.g., Sam, 2000; Barnes et al., 2005; Oppong et al., 2008; Hoffmeir-Karimi & Schulte, 2015; Barnes et al., 2015), but rarely from a mixed method approach perspective. A mixed approach enables data triangulation and enhances complementarity, which helps understand socio-ecological issues. Besides, the effects of elephant (*Loxodonta cyclotis*) crop-raiding on communities around conservation areas in most parts of West Africa have not been fully understood because they are site-specific (e.g., Barnes et al., 2003, 2005; Boafo et al., 2004; Sam et al., 2005; Oppong et al., 2008; Webber et al., 2011; Kiffner et al., 2021). Crop raiding by elephants is a multifaceted problem that differs from community to community in the frequency of occurrence and severity (Hoare, 2001; Hoffmeier-Karimi & Schulte, 2015). Therefore, case studies are critical in understanding the immediate, ongoing, and future effects of crop raiding by elephants to develop comprehensive policies to address the issue. Furthermore, a critical question in human-elephant conflict has been: What drives elephant crop-raiding? Are the costs of crop-raiding linked to elephant group composition? Therefore, our objectives were to: (i) analyze the drivers and perceived drivers of elephant crop-raiding; (ii) analyze elephant crop-raiding cases recorded in the Bia National Park district from 2010-2020; (iii) assess farmers' insights on elephant crop-raiding and the types of crops raided by elephants and farmer-based elephant control strategies; and (iv) evaluate the effects of elephant (*Loxodonta cyclotis*) crop-raiding on the livelihood of local communities' members around the Bia National Park in Ghana. Consequently, we hypothesized that (i) actual damage size depends on farm and elephant group characteristics, crop quality and seasonality; (ii) frequency of crop raiding is related to crop type, crop quality and maturation stage; and (iii) estimated cost of elephant crop raiding varies across elephant group composition.

2. Materials and Methods

2.1 The study area

The study was conducted at Bia Wildlife Conservation Park in the Western North Region of Ghana (Fig. 1).

The Park was gazetted as a Wildlife Protected Area in 1974 by the Wildlife Reserves (Amendment) Regulations, 1974 LI 881, and other amendments. In 1983, the Park was designated a Biosphere Reserve. The Protected Area lies in southwest Ghana, on the border with Côte d'Ivoire. Bia Conservation Area covers a total landmass of 306 km2 and comprises Bia National Park (77.7 km^2) in the North and the adjoining Bia Resource Reserve (227.9 km^2) in the South. Sukusuku Forest Reserve and Bia Tawya Forest Reserve in the Western and Southern parts border the Park. The encroachment of Sukusuku and Bia Tawyer Forest Reserve for farming activities has led Bia Park into an ecological forest island in a sea of cocoa farms. The Park lies in transitional zones between the Moist Evergreen Forest and Moist Semi-deciduous Forest Zones. The area experiences bi-modal rainfall seasons in May-June (the primary season) and September-October (the minor season). The annual mean precipitation ranges from 1,500mm to 1,700 mm, and the mean yearly temperature ranges from 24.2 °C to 27.5 °C. In general, relative humidity is high and ranges between 90% at night and 75% in the afternoon. The high rainfall formation, coupled with fertile ochrosol soil, contributes to the biomass production of the Park.

Before gazetting the Reserve, the original faunal composition was diverse and complex. It had many elephants and primates, including chimpanzees and colobus, particularly Red Colobus. However, over three decades of excessive commercial and subsistence hunting, populations of several larger mammals (particularly canopy-dwelling primates), reptiles, and bird species have been severely reduced in numbers. The Park is characterized by a significantly large number of charismatic mammals, including forest elephants (*Loxodonta cyclotis*), leopards (*Panthera pardus*), bongos (*Tragelaphus eurycerus*), and yellow-backed druikers (*Cephalophus sylvicultor*). Six (6) primate species, such as the Western Chimpanzee (*Pan troglodytes verus*) and Geoffroys Pied Colubus (*Colobus vellerous*), have been recorded in the Park. The Miss Waldron's Red Colobus (*Piliocobus badius Waldronae*) is a highly endangered subspecies and is extinct in the Park. The Roloway Diana Monkey (*Cercopithecus diana roloway*) and White-naped Sooty Mangabey (*Cercocebus atys lunulatus*) were endemic to Ghana/Eastern Côte d'Ivoire but have not been reliably sighted for the last few years in Bia. The estimated population of *Loxodonta cyclotis* in the study area is 300-500 (BirdLife International, 2023). The Bia West District has a population of 88,939, comprising 51.4% males and 48.6% females. The fringe communities are located at a distance of 5-7 km from the Park boundaries. The main livelihood of the communities is hunting and rain-fed agriculture, which includes the cultivation of cash crops such as cassava, yam, cocoyam, banana, and plantains, as well as economic trees and shrubs such as citrus, cocoa, cola, coffee, cashew, and pawpaw. Farming of crops takes place all year round, resulting in all-year-round crop raiding by elephants. Crop raiding by elephants in the study area dates back to the 1970s, and it has worsened over time due to increased agricultural activities (Sam et al., 2005).

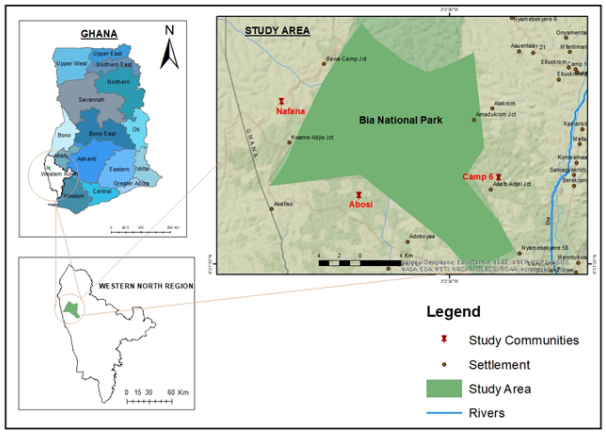

Figure 1. Map of the study area.)

2.2 Study design, sampling procedure, and data collection

The study employed a cross-sectional research design with a mixed approach involving qualitative and quantitative data collection methods to gather in-depth information (e.g. Mc Guinness, 2016). Data for the study were collected through local participant observation, questionnaire-led interviews, and document review. The mixed method approach provided the advantage of depth, synergistic data utilization and triangulation of the data, all of which enhances data robustness and strengthens the validity of the research (Mertens, 2009; Creswell and Plano Clark, 2011).

A simple random sampling technique was used to select three (3) communities near Bia National Park (Abosi, Nafana, and Camp 6) for the study. Ten (10) Wildlife officials at the Bia National Park were purposively selected while the snowball sampling technique was used to target farmers (90 farmers) affected by incidents of elephant crop raiding. The rationale was to ascertain their views on the types of crops raided by elephants, the seasons for occurrences of crop-raiding, and the effects of elephant crop-raiding on their livelihood. The data on the sample frame was obtained from the population of farmers' cooperative association info-sheets in the study communities.

2.2.1 Participant observation

The first author and a field assistant lived among selected communities and recorded their observations following standard procedures. The recorded observations included social settings, activities, norms, rituals, and events in a fieldwork diary. This information supplemented data

obtained via interviews and document reviews. Staying in the communities provided (i) contextual details on the impact of elephant-crop raiding, (ii) a broader understanding of the lived experiences of affected persons, (iii) opportunities for informal conversations that enriched the research, and (v) an avenue to discern and verify factual views from respondents (e.g. Galley et al. 2024).

2.2.2 Interviews and document reviews

Structured questionnaires-led interviews and document review provided quantitative data, whereas semi-structured questionnaire-led interviews provided qualitative data. Information solicited from the respondents included their socio-economic characteristics, types of crops raided and estimated costs, farmer-based elephant control strategies used, effects of crop raiding on their livelihood, drivers of elephant crop raiding, and their perceptions about the effectiveness of the pepper grease technology. In addition to the questionnaire data, we obtained official documented monthly incidences of crop raiding by elephants in Bia National Park from the local office. The information gathered included (i) the number and distribution of elephant crop-raiding cases recorded from 2010 to 2020 and (ii) the types of crops raided by elephants within the study period. These enabled us to assess the frequency of elephant crop-raiding cases recorded in the Bia National Park district from 2010-2020. Additionally, reviewing the monthly reports enabled the triangulation of the data by verifying the responses from both park officials and farmers.

2.3 Data processing and analysis

The data for the study were analyzed using the Statistical Package for Social Sciences (SPSS) version 22.0 programme and M.S. Excel software. The relationship between farm size and the estimated cost of elephant crop raiding (i.e. quantitative questionnaire dataset) was analyzed using Spearman rank correlation, and variation in estimated annual costs due to elephant crop raiding composition (based on the secondary dataset) was analyzed using the Kruskal Wallis test. The General Linear Model (GLM) was used to analyze the relationship between seasonality, crop, farm and elephant characteristics and the frequency of crop raiding and actual farm damage; this analysis was applied to the secondary dataset obtained from official records on crop raiding by elephants. We estimated each crop type's mean annual frequency of elephant raiding and related it to the mean yearly overall frequency of elephant crop raiding and actual farm damage. Relative citation frequency was used to analyze the types of crops raided by elephants, perceived drivers of elephant crop raiding, and farmer-based methods for controlling elephants; this analysis was applied to the questionnaire dataset. All qualitative data were content analyzed based on themes such as perceived drivers of elephant crop-raiding, perceived temporal patterns of crop raiding, farmer-based elephant control methods, and their effectiveness following after Braun and Clarke (2006). Our study followed both local (Ethics Committee of the University of Energy and Natural Resources) and international ethical standards (the Helsinki Declaration of 1975, as revised in 2000). The aims and risks associated with the study were made known to respondents so they could get their informed consent. The voluntary participation of the respondents was ensured. The study did not involve the collection specimens. In the context of the study, sex refers to biological or physical attributes (binary classification used: male/female), while gender reflects culturally constructed roles of males and females.

3. Results

3.1 Drivers of elephant crop raiding at the Bia National Park

The study found 582 reported elephant crop-raiding cases involving 135 farms belonging to 93 farmers from 2010–2020. Our results show that crop-related characteristics such as crop type, maturation stage, and quality were significant drivers of elephant crop raiding (Table 1). However, the magnitude of damage depends on seasonality, and farm size (Table 1). Similarly, Compaore et al. (2020) reported that elephant raids were directly related to some crops (e.g. millet and maize) and indirectly associated with others (e.g. beans). Additionally, the responses from farmers indicated that elephants had a preference for specific crops (Fig. 2), which is consistent with previous studies in Ghana (e.g. Oppong et al., 2008; Monney et al., 2010), Burkina Faso (Hema et al., 2018) and elsewhere (Osborn & Parker, 2003; Shaffer et al., 2019). Elephants' preference for certain crops is often related to their nutritional value and taste. Currently, the Western Region is the hub of cocoa production in Ghana; increased cocoa production and cocoa-driven habitat fragmentation possibly explain the elephant-crop raiding in the area.

The fact that elephant crop-raiding was directly related to rain seasons but indirectly to dry seasons is attributable to Ghana's major and minor rain seasons coinciding with the country's major and minor cocoa production periods. Similar to our study, several authors have shown that seasonality influences elephant crop-raiding (e.g. Chiyo & Cochrane, 2005; Jackson et al., 2008; Sitienei et al., 2014). Moreover, the views of farmers and wildlife officials that the highest incidences of elephant crop-raiding occur during the primary rainy season (i.e. July to October), while the lowest raiding occurs during the dry season (i.e. January to April, when cocoa fruiting decreased, and most food crops had been harvested) (Table 2), corroborated this notion. Additionally, studies have shown that elephant crop raiding mainly occurs during crop ripening and harvesting within the periphery of conservation areas (Chiyo et al., 2005; Sitienei et al., 2014; Parker & Osborn, 2001; Chiyo &

Table 1. Results of General Linear Models exploring the relation between selected predictors and elephant crop-raiding frequency and actual size of farm damage

	Estimate (95% CI)	T-value	P-value	Variance Inflation Factor (VIF)
Relationship between frequency elephant crop-raiding and crop type				
Intercept	15.95 (11.78, 20.12)	7.62	< 0.001	
Banana	-10.61 (-24.49, 3.27)	-1.52	0.132	2.25
Cassava	5.05 (-6.02, 16.12)	0.91	0.366	1.81
Cocoa	32.75 (21.68, 43.82)	5.9	< 0.001	1.81
Cocoyam	-10.57 (-22.77, 1.63)	-1.73	0.088	1.98
Maize	-7.07 (-19.27, 5.13)	-1.16	0.252	1.98
Other crops	-13.05 (-24.12, -1.98)	-2.35	0.022	1.81
Pineapple	-11.82 (-24.02, 0.38)	-1.93	0.057	1.98
Plantain	3.65 (-7.42, 14.72)	0.66	0.512	1.81
Yam	11.65 (0.58, 22.72)	2.1	0.039	
Relationship between frequency of elephant crop-raiding and crop quality				
Intercept	48.70 (19.80, 77.60)	3.49	0.002	
Good	79.80 (41.60, 118.10)	4.33	< 0.001	1.09
Average	-35.80 (-74.00, 2.50)	-1.94	0.065	1.09
Poor	-44.10 (-89.80, 1.60)	-2	0.058	
Relationship between frequency of elephant crop-raiding and crop maturation stage				
Intercept	44.73 (24.59, 64.87)	4.69	< 0.001	
Immature	-30.17 (-50.31, -10.03)	-3.16	0.006	1
Mature	30.17 (10.03, 50.31)	3.16	0.006	
Relationship between actual size of farm damage and seasonality, crop quality, farm size and elephant group size				
Intercept	1.66 (0.866, 2.453)	4.12	< 0.001	
Farm size ha	0.002 (0.001, 0.002)	4.93	< 0.001	1.08
Elephant group size	0.163 (0.119, 0.206)	7.43	< 0.001	1.13
Seasonality				
Dry	-0.311 (-0.799, 0.176)	-1.26	0.209	1.4
Major rain	0.504 (0.104, 0.903)	2.48	0.014	1.24
Minor rain	0.254 (-0.451, 0.959)	0.71	0.479	1.55
Short dry	-0.446 (-1.081, 0.188)	-1.38	0.167	
Crop quality				
Good	-0.230 (-0.894, 0.433)	-0.68	0.495	1.02
Average	0.230 (-0.433, 0.894)	0.68	0.495	
Poor	Not estimated			

Table 2. Perceived temporal dynamics of elephant crop-raiding and underlining drivers

Crop-Raiding Season	Underlying Driver	Extraction/Quotes	Relative citation frequency
August to November	Most food crops begin fruiting; the elephants obtain enough food to consume.	"When our crops start fruiting, it's like an invitation for the elephants. They know there's plenty to eat here." (Elder, male)	0.4
July to October	Rainy season makes most crops succulent, attracting elephants to raid them.	"The rains make everything green and juicy. The elephants just can't resist raiding our farms during this time." (Female farmer)	0.37
July to December	Cocoa season begins, and elephants are attracted to cocoa and other crops, leading to raids.	"Elephants love cocoa. Once they smell it, they come in groups and destroy not just cocoa but other crops too." (Elder, male cocoa farmer)	0.27
January to April	Cocoa fruiting decreases, and most food crops have been harvested and withered, reducing availability.	"By this time, there's hardly anything left on our farms, but they still come searching for what little remains." (Aged female cocoa farmer)	0.22
December to January	Dry season causes food in the reserve to become dry and scarce, pushing elephants to search for food outside.	"The dry season forces them out of the reserve. They come here looking for food, and we have no way to stop them." (Aged male farmer)	0.32

(Source: Field Data, 2021)

Cochrane, 2005; Pastorini et al., 2013). That notwithstanding, Weinmann (2018) reported higher crop-raiding in December and January and lower in September, while Osborn (2004) reported increased elephant crop-raiding from October to December. The disparity is likely due to differences in climatic conditions or seasonal patterns, the food resources available for elephants, and the management practices associated with wildlife conservation. Our results showed that the highest raiding was reported to occur at night, which is consistent with existing literature (Sukumar et al., 2003; Graham et al., 2009; Gunn et al., 2014). Contrary to Hema et al. (2018), elephants targeted larger farms; this disparity may be due to differences in crop type.

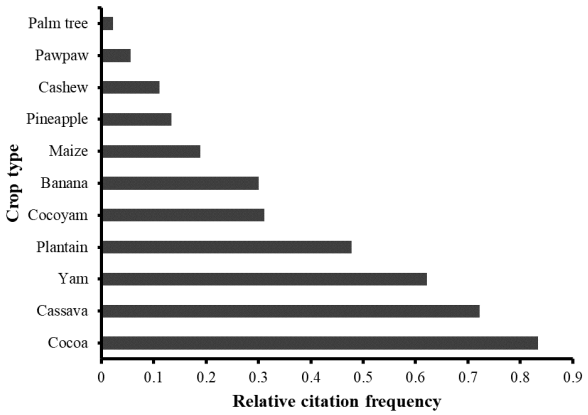

Figure 2. Perceived crop preference by elephants

3.2 Perceived drivers of elephant crop raiding

From the perspective of respondents, the relative citation index showed that food scarcity in the forest was the primary driver of elephant crop raiding in the study area; the other vital drivers were poaching, overpopulation, crop proximity to reserve and the location of farms near elephants' old paths (Table 3). These results imply that the key perceived drivers of elephant crop raiding were related to food and water resources, migration and elephant population management (Sitati et al., 2005; Hoare, 2012; Suba et al., 2017; Shaffer et al., 2019). Several authors (e.g. Sillero-Zubiri and Switzer, 2001; Osborn, 2004; Chiyo et al., 2005; Songer et al., 2016; Krishnan et al., 2019; Puyravaud et al., 2019; Naha et al., 2020) reported that the predominant elephant crop raiding cases that occur globally are due to changes in farming systems, the encroachment of conservation areas for farming, and an increase in human and wildlife populations due to urbanization and improved education. Specifically, crop diversity is an essential factor that attracts elephants to crop fields (Osborn & Parker, 2003; Graham et al., 2010). Crop fields with diverse vegetation cover are more likely to be raided by elephants than monoculture fields (e.g., Osborn and Parker, 2003; Shaffer et al., 2019) because elephants prefer to eat various plants. Additionally, mixed farming practices that involve planting crops near elephant corridors or other natural habitats increase the probability of elephant crop raiding. Elephants are known to follow traditional pathways that have been used for centuries. Studies have shown that crop fields located near old elephant pathways are more likely to be raided by elephants (Von Gerhardt et al., 2014). In some cases, elephants may raid crops simply because they are more accessible and abundant than natural food sources. For instance, in many forest areas, elephants have been known to raid cocoa and coffee plantations because they provide a reliable source of food (Monney et al., 2010; Dakwa et al., 2016). Similarly, the respondents in our study perceived food scarcity in the forest and crop availability as the predominant drivers of crop raiding by elephants (Table 3).

Elephants require large amounts of water to survive and will often travel long distances to access it or remain near water resources; hence, there is a significant correlation between water resources and elephant crop raiding (Ogada et al., 2003; Sitati et al., 2005; Shaffer et al., 2019); our respondents indicated that the proximity of farms to nearby water resources was a driver of elephant crop raiding. Therefore, it is evident that elephants raid varieties of crops; however, the type of crops they raid may differ due to the study location, seasons, and accessibility of the crops to elephants. Thus, as suggested by Kiffner et al. (2021), decreasing the proximity of farmland to National Conservation Areas may reduce the frequency of elephant crop-raiding cases.

Table 3. Perceived drivers of Elephant Crop Raiding at Bia National Park

Perceived driver		Extraction/Quotes	Relative citation frequency
Major Theme	**Sub-theme**		
Food and Water Resources	Proximity to Reserve	"The elephants come near our farms because we are too close to the reserve. They see our crops as easy food." (Elder, male farmer) "Farms expanding closer to the park increase the chances of human-elephant interactions, as elephants naturally explore nearby food sources." (Male wildlife officer)	0.34
	Nearby Water Resources	"During the dry season, they leave the forest and come here for water. We have no way of stopping them." (Aged female farmer) "In the dry season, elephants travel long distances to find water, and agricultural areas with water sources become key targets." (Male wildlife officer)	0.19
	Mixed Cropping	"Planting different crops doesn't stop them; they eat everything they find in their path." (Aged male farmer)	0.08
	Attractive Crops	"They love the plantains and maize. Once they smell them, they won't stop until they've eaten it all." (Female farmer)	0.03
	Availability of Diverse Crops	"The variety of crops we plant seems to invite them more. They destroy everything in one night." (Elder, male farmer)	0.28
	Food Scarcity in the Forest	"When the forest is dry and food is scarce, they come here looking for something to eat." (Aged male farmer) "Changes in forest vegetation, often due to logging and climate variability, reduce natural food availability, driving elephants toward farms." (Female wildlife officer)	0.79
Migration	Elephants' Old Path	"This land used to be part of their path. Now we farm here, but they still come through like it's theirs." (Male farmer) "Many farms are situated along historical elephant migration corridors, and despite land-use changes, elephants continue to use these routes." (Female wildlife officer)	0.14
Elephants' Population Management	Overpopulation	"The forest can no longer hold them; there are too many elephants, and they spill over to our farms." (Female farmer)	0.17
	Poaching	"Some people hunt them, but it only makes the elephants angrier and more aggressive towards us." (Female farmer) "Illegal hunting disrupts elephant herds, causing stress and erratic behaviour, which can result in more frequent and aggressive farm raids." (Male wildlife officer)	0.1

3.3 Elephant crop raiding cases in the Bia National Park district from 2010-2020

We found no consistent trend in elephant crop-raiding cases in the study area between 2010 and 2020, even though a steady rise was recorded from 2013-2015 (Fig. 3). According to the wildlife officials, the increase in cases recorded between 2013 and 2015 was attributable to the abundance of cultivated crops near the Park boundary and limited funds for management officials to purchase pepper grease (a mixture of pepper, dirty oil, and grease) to control elephant movement into farmland. This view is supported by existing literature, which indicates that elephants are opportunistic feeders and may raid crops when natural forage is scarce (Hoare, 2012). Moreover, the availability of crops near the Reserve boundary could have attracted elephants and led to an increase in crop-raiding incidents (Linkie et al., 2007; Graham et al., 2009; Seiler and Robbins, 2016; de la Torre et al, 2021). In the view of the wildlife officials we interviewed, the lowest number (20) of cases recorded in 2013 were due to the following reasons: (i) the Park was supported with materials from the District Assembly and some NGOs to train farmers on how to prevent the elephants from entering their farms through the use of pepper grease technology; (ii) volunteer groups were formed to patrol along the boundary to check crop-raiding activities, and (iii) a sensitization programme on elephant behaviours. This implies that the combination of innovative deterrent techniques (e.g. pepper grease), community engagement (through volunteer patrols), and educational initiatives (e.g. sensitization on elephant behaviours) may potentially reduce crop-raiding incidents by elephants (Gross et al., 2022).

About farmers, 81% primarily cultivated food or cash crops, and a few (19%) cultivated fruits and vegetables. Most of the farmers' farmlands were close to the park boundary (57%) and 66-82% stated that they knew about prevailing elephant crop-raiding incidences around the Bia Wildlife Conservation Park or had noticed elephant crop-raiding on their farms for over a year. Farmers indicated that elephants raided crops during the night (64%) and day (28%), while 18% were uncertain. Farmers (53%) had regular lived experience regular of elephant crop-raiding on their farms within a decade (Fig. 4). This is in line with Sillero-Zubiri and Switzer (2001), who asserted that crop-raiding by elephants is not a new phenomenon; it has been widely recognized since the beginning of agriculture.

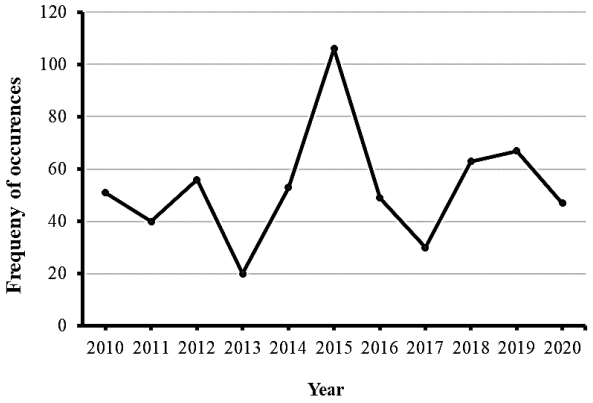

Figure 3. Trend of Elephant Crop Raiding Cases Recorded Per Year (2010-2020). (Source: Field Data, 2021).

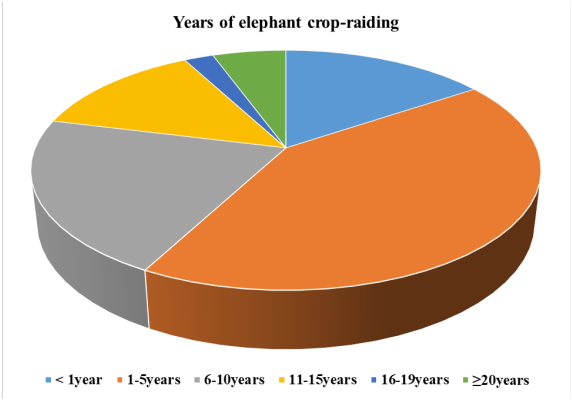

Figure 4. Longitudinal Experience of Farmers Facing Elephant Crop Raiding Events

3.4 Effects of crop raiding by elephants (*Loxodonta cyclotis*) on the livelihood of fringe communities

It was found that the average annual cost of elephant crop raiding per farmer was US$ 668.78; this value is relatively higher than the US$ 174.80- US$ 586.05 reported by Gnonlonfoun et al. (2019) in West Africa. The cost of crop raiding did not vary across elephant crop-raiding group compositions (Table 4) and it was unrelated to farm size. The respondents (97%) indicated that crop-raiding by elephants adversely affected the livelihood of local communities (Fig. 5); consistent with this, Kiffner et al. (2021) and Dickman (2010) postulated that crop-raiding by elephants poses a challenge to human livelihood and wildlife conservation. The findings revealed that crop-raiding by elephants on the livelihood of fringe communities brings hardship to family members, influences human-elephant conflicts, incurs additional costs on the construction of fences around farms and the hiring of labourers to guard the farm, and causes loss of interest in engaging in farming. Similarly, in Gabon and Indonesia, Terada et al. (2021) and Oelrichs et al. (2016) reported adverse effects of elephant crop raiding on the rural economy. The destruction of crops and loss of income generated from the sales of crops were reported as the predominant effects of elephant crop-raiding; this is similar to Wittemyer (2001), who reported that crop-raiding by elephants results in the destruction of farm products, impacting on the community's livelihood sources. Crop raiding by animals severely threatens subsistence farmers' economic stability and reduces income generated from the crops (Hedges & Gunaryadi, 2010; Mackenzie & Ahabyona, 2012; Sitienei et al., 2014).

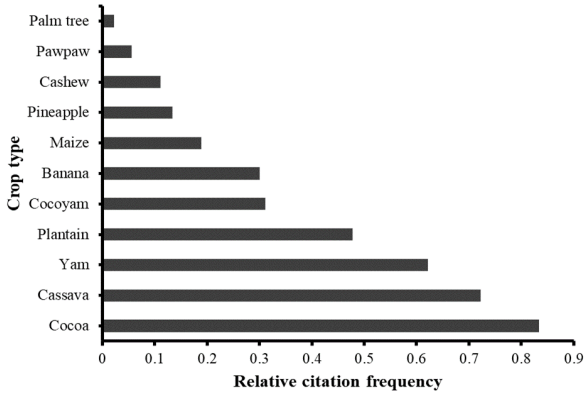

Figure 5. Effects of elephants (*Loxodonta cyclotis*) crop-raiding on the livelihood of community members. (Source: Field Data, 2021).

Table 4. Mean annual cost of elephant crop raiding

Composition	N	Mean (US$)	S.E. Mean	Min (US$)	Median (US$)	Max (US$)	K-W Ave Rank
Young only	11	555.5	190.4	200	350	2400	47.7
Adults only	16	707.9	207.9	100	450	3200	45.3
Old males only	17	667.6	285.2	80	300	5000	38.3
Both young and old	45	744.1	148.6	150	370	5500	46.8

3.5 Farmer-based elephant control methods and their effectiveness

Our results are similar to the findings of Gross et al. (2022), who reviewed the management of conflicts between elephants and humans in 12 African countries through qualitative expert interviews. The farmer-based strategies used by respondents to control elephant crop raiding were all technical deterrent methods such as acoustic (e.g., noise and bamboo blasting), visual (torches, fire), and olfactory (pepper grease, pepper boundaries) control methods (Fig. 5). Consistent with our results, studies in Mozambique (Shaffer, 2010), Indonesia (Hedges & Gunaryadi, 2010; Gunaryadi et al., 2017), Tanzania (Chang'a et al., 2016), and India (Davies et al., 2011; Gupta et al., 2013) reported similar deterrent methods as in our study. A few respondents considered killing the leader to control elephant crop raiding, indicating the need for community sensitization interventions to discourage revengeful killings and promote more humane elephant control strategies. Even though the farmers indicated that the pepper grease technology was effective (64 %), it was ranked the fifth-best elephant control method according to the relative citation frequency (Fig. 6). This is possible because farmers may need access to enough chilli peppers to make the grease or help to afford them. In addition, crushing and mixing the peppers can be time-consuming and labour-intensive, which may deter some farmers from using the method (Karidozo & Osborn, 2015; Chang'a et al., 2016). Moreover, pepper grease is not a long-lasting deterrent and needs to be reapplied regularly to be effective (Osborn & Parker, 2003; Karidozo & Osborn, 2015; Chang'a et al., 2016). Besides, heavy rains or high humidity can wash away or dilute the grease, making frequent reapplications necessary (Chang'a et al., 2016) and this limitation can reduce the practicality of the method, leading farmers to prefer more durable deterrents.

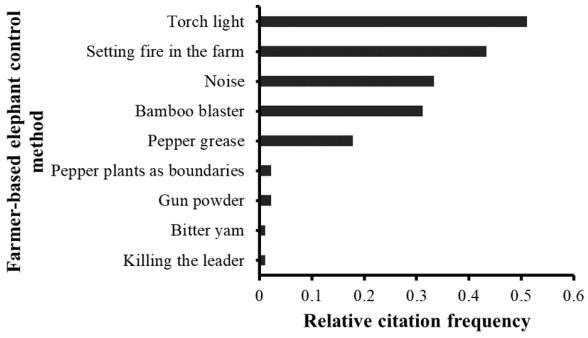

Figure 6. Farmer-based elephant control methods

3.6 Implications for conservation

Currently, the Western Region is a hub for cocoa production in Ghana, and recently, the Region has become a hotspot for gold extraction (Owusu-Nimo et al., 2018; Ghana Commercial Bank Strategy and Research Department, 2022). These two human activities can exacerbate human-wildlife conflicts and impede conservation efforts. Although the exact population of elephants in the subregion is unknown, rough estimates suggest their subregional population was 11489 ± 2 583 in 2015 (Website 1; Hema et el. 2017), and their estimated population in the Bia National Park was 300-500 (BirdLife International, 2023), highlighting the fact that elephants are under serious threat (Hema et el. 2017). Given the economic cost of elephant-crop raiding, increased raiding of crops by elephants may lead to revenge killings, an idea a few of the respondents suggested as a strategy to control elephants. Therefore, there is a need to involve local communities whose livelihoods are directly affected by elephant crop raiding to co-create innovative elephant-friendly solutions to human-wildlife conflicts (Hema et el. 2017). This will stimulate local communities' interest in the ideals of conversation and enhance elephant conservation in the sub-region. We propose collaborative and participatory research approaches among scientists, farmers, and wildlife managers to develop effective cropping technologies that reduce the attractiveness of cocoa, yam, and other preferred crops while maximizing their productivity and quality. Our study provides insights that can guide policymakers and interest groups in developing innovative policies for mitigating human-wildlife conflicts and their impacts on rural livelihoods and conservation efforts.

4. Conclusion and policy implications

Elephants target more extensive plantations and certain crops such as cocoa and yam and avoid others such as beans and garden eggs, highlighting the need for innovative strategies such as planting nonpreferred crops such as mangoes as a boundary crop around preferred ones. The

peak season for crop-raiding by elephants was from July to October, while the lowest was from January to April, indicating the need for effective management strategies. The primary reasons for elephants' crop-raiding were the food shortage within the Park and the cultivation of crops near the Park. The trend of crop-raiding by elephants between 2010 and 2020 showed variations each year, with 582 cases involving 135 farms belonging to 93 farmers being recorded. The highest number of cases was in 2015, with the least in 2013. Crop-raiding by elephants had a detrimental impact on the livelihood of fringe communities; the cost of elephant crop raiding per farmer per year ranged from US$ 100.00 to US$ 5,500.00 with a mean of US$ 668.78. It could cause human-elephant conflicts and undermine conservation efforts at Bia Park. It is highly recommended that comprehensive policies discouraging the cultivation of food crops close to the Park are implemented, coupled with the adoption of pepper grease technology, to significantly reduce elephant crop-raiding activities. Public education, farmer training programs, and promoting volunteer crop-raiding monitoring groups to patrol along the Park boundary to control crop-raiding activities are also highly recommended.

5. Acknowledgements

We are grateful to the wildlife officials and farmers who participated in the research. We appreciate the editor(s) and reviewers who helped shaped this manuscript.

6. Statements and Declarations

Ethical considerations: The study complied with both local (Ethics Committee of the Department of Forest Science, University of Energy and Natural Resources) and international ethical standards (the Helsinki Declaration of 1975, as revised in 2000). Respondents were informed about the purely academic nature of the research, and their consent was sought before they were engaged in the study.

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Consent to participate: Informed consent was obtained from all participants prior to their engagement. The voluntary participation of the respondents was ensured.

Consent to publish: Participants provided informed consent for the publication of results from the study. Conflict of interest statement: The Authors declare no conflict of interest.

Funding statement: No funding or grant was received for this study.

Data availability: All relevant data are contained in the main manuscript and the supplementary information files.

Authors' contribution statements: Conceptualization; M. A. and M. D. Methodology; M. D., D. A. and M. A. Formal analysis and investigation; M.A. and D.A. Writing – original draft preparation; D.A., M.A., and M.D. Writing - review and editing; M.D. and M.A.; Resources; D.A. Supervision; M.D. and M.A.

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