GLOBAL TRADE AND LOCAL FOOD SECURITY: MAPPING AND MONITORING COCOA EXPANSION AND ITS IMPACT ON HOUSEHOLD FOOD SECURITY IN THE BIA WEST DISTRICT, GHANA

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June, 2023

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ABSTRACT

The expansion of cocoa has become a threat to local food security and forest conservation in the cocoa-growing regions, especially in Ghana. Many reasons motivate farmers to engage in cocoa expansion, such as the desire to increase their household income, gain social status, ready market for cocoa beans, the profitable nature of the cocoa industry, and the attractiveness of government incentives towards cocoa farming. Nevertheless, discussions about cocoa research have dominated the literature and many international discussion forums. Yet, the research has not given much thought to cocoa expansion landuse types, its effects on household food diversity, and its associated variables.

The study downloaded Landsat images (1999, 2017, and 2022) and Sentinel 1 (SAR) images (2017 and 2022) and used them as input for a random forest machine learning model to perform the LULC classification. 200 household surveys were collected from 7 communities using a multi-sampling technique, which assessed household food security and its associated variables among the cocoa household heads in the study area. Ordinal logistic regression was employed to model the household and land use variables affecting the household food security of cocoa households.

The findings of this study revealed that cropland decreased from 1.86% to 0.93%, monoculture cocoa decreased from 40.1% to 31.8%, and agroforestry cocoa increased from 5.4% to 23.9% between 1999 and 2022. Through this study, it was discovered that among the households, 63% of the agroforestry cocoa households and 77% of the monoculture cocoa households had high and low dietary diversity status, respectively. This finding implies that monoculture cocoa households are food insecure, whilst agroforestry cocoa households are food secure. The top three most consumed food groups in monoculture cocoa households were roots/tubers (95.8%), vegetables (89.1%), oil/fat/butter (47.9%), whereas agroforestry cocoa households had vegetables (97.5%), roots/tubers (96.3%), local grains (95.1%) as their top three widely eaten food groups. Furthermore, only legumes (27.2%) food group was least consumed in agroforestry cocoa households, but fruits (12.6%), organic meat (12.6%), and milk product (2.5%) were the three least consumed food groups in monoculture cocoa households. In addition, 86.6% of the monoculture cocoa households indicated decreasing food production, whereas 70.4% of the agroforestry cocoa households noted increasing food production. Furthermore, only 9 out of the 15 investigated variables were key determinants of household dietary diversity status, namely, sex ($p < 0.005$), education ($p < 0.0912$), access to extension officers ($p < 0.0973$), age ($p < 0.0012$), dependency ratio ($p < 0.0386$), cocoa farming experience ($p < 0.000$), general food production trends ($p < 0.081$), agroforestry households ($p < 0.0001$), and food crop farming ($p < 0.0000$).

The study recommends that the cocoa households in the study area should be educated on the importance of consuming fruits, legumes, eggs, and milk products since they are rich in vitamins and protein. Government initiatives should be designed to reduce the rate of cocoa expansion in forest zones and inspire farmers to balance the production of food crops and cocoa.

Keywords: Food security; Cocoa expansion; Land use/cover; Agroforestry cocoa; Monoculture cocoa; Remote Sensing

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GDP	Gross Domestic Product
LULC	Land use Land cover
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NIR	Near Infrared
RF	Random Forest
SAR	Synthetic Aperture Radar
SWIR	Shortwave infrared

1. INTRODUCTION

1.1. Background to the study

Globally, cocoa is one of the many cash crops, which has been the mainstay and the driving force of the economy of many less-developed countries (Wessel & Quist-Wessel, 2015). However, the link between cash crops and local food security is still a difficult question, which is constrained by different local conditions (Hashmiu et al., 2022a). Over the years, there has been an increase in the amount of cocoa produced. For instance, the amount of cocoa produced worldwide has increased from 1.19 million metric tons in 1961 to 5.76 million metric tons in 2020, as well as the area harvested increased by 2.8 times, that is, from 4.4 million to 12.32 million between 1961 and 2020 (Food and Agriculture Organization, 2022).

Ghana is the second-largest producer of cocoa, which produced 18% of the world's production of beans in 2020 (Staritz et al., 2022). Cocoa farming is a source of income (Amoatey & Sulaiman, 2020; Franzen & Borgerhoff Mulder, 2007; Hashmiu et al., 2022a) and a source of sustenance for over 800,000 households (Kongor et al., 2018). In the cocoa areas of Ghana, the cocoa industry has employed more than 6,000,000 Ghanaians (Amponsah-Doku et al., 2021). This reduced poverty among farmers from 60.1% to 23.9% in 1991/1992 (Breisinger et al., 2008). Cocoa production contributed 13.3% to the GDP of Ghana (Asubonteng et al., 2018b). Ghana's cocoa exports climbed dramatically between 2010 and 2013, rising from 10.4% to 19.31% (Bangmarigu & Qineti, 2018).

Cocoa land use types (monoculture and agroforestry) expansion has been on the rise in Ghana's cocoa-growing districts (Asare et al., 2014). Monoculture cocoa involves only the cultivation of cocoa on a piece of land with few or no natural or planted trees. In contrast, agroforestry cocoa is the cultivation of cocoa within or among natural or planted trees (Ashiagbor et al., 2020). Most often, cocoa expansion threatens croplands and forests (Asubonteng et al., 2018b), with some farmers replacing food croplands with cocoa (Ajagun et al., 2022) and others encroaching on forest reserves to grow cocoa (Brobbey et al., 2020). However, this menace is posing threats to food security and forest conservation, especially in the forest ecological zones of Ghana (Ajagun et al., 2022). Food security has become a threat to human lives (Drammeh et al., 2019). Both local and global institutions, including the Food and Agriculture Organization and International Food Policy Research Institute, have made numerous attempts to define food security.

According to the International Food Policy Research Institute, "*food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*" (cited in Hashmiu et al., 2022a, p. 2). Availability, accessibility, utilization, and stability are the four facets of food security (Haini et al., 2022). Food availability means that people should at all times have adequate quantities of quality food to eat and maybe distributed through primary production, food outlets, or stores, whereas food accessibility is when everyone has access to food equitably, as well as resources to purchase and transport nutritious food (García-Díez et al., 2021; Lawlis et al., 2018; Mougeot et al., 1999). As opposed to that, food utilization refers to "*[t]he utilization of food based on knowledge and an understanding of an adequate diet to ensure a state of nutritional well-being and meet all human physiological needs. Food utilization takes into account clean water, sanitation, health care, cultural considerations, social environments and preparation, storage and cooking skills*" (Lawlis et al., 2018, p. 183). Food stability is achieved when all people have continuous access to sufficient and nourishing food at all times (García-Díez et al., 2021; Lawlis et al., 2018).

1.2. Problem statement

The Juaboso-Bia landscapes, in particular, have attracted spectacular attention as the recent cocoa expansion hotspot areas in the Western North Region of Ghana (Akrofi-Atitianti et al., 2018; Kuuwill et al., 2022). Most small-holder cocoa farmers are expanding their farm sizes to cultivate more cocoa due to some reasons, namely the desire to earn more income (Asare et al., 2014; Bangmarigu & Qineti, 2018) and several government programs benefit cocoa farming, including providing access to subsidized cocoa input (Asubonteng et al., 2018a), which is affecting croplands hence food diversity.

Benefoh et al. (2018) evaluated land use patterns and the pace of change in a structurally complex cocoa environment in Ghana with the use of both vegetation indices and a digital elevation model between 1986 and 2015. The study fused the vegetation indices and the digital elevation model to map and discriminate agroforestry cocoa and monoculture cocoa from different types of land cover classes. The study revealed that from 1986 to 2015, forest cover lost large portions to cocoa plantations and built-up. Also, the study disclosed that cocoa expansion happened in the open forest and rarely in closed forest areas.

Hashmiu et al. (2022a) examined the synergy between commercial and food crops to better understand the relationship between cash crop cultivation and household food security. According to the study, households that directly substituted food crops with cocoa plantations experienced less food insecurity than those that cultivated cocoa on non-food croplands. The study argued that this may sound counterintuitive, but it appears that the practice of using cocoa to directly substitute food crops in the study area is a sign of better access to land and self-produced food at the home level and is, thus, less associated with household food insecurity. The study also showed that household food security cannot be ensured by income from cocoa alone, but rather, provided farmers with the means to reinvest their earnings in cashew planting and boost food crop production.

Most of the research on the expansion of cocoa made a general conclusion that the extension displaces croplands (Ajagun et al., 2022; Asare et al., 2014; Ashiagbor et al., 2020; Hashmiu et al., 2022a), hence affecting food security. However, these studies measured food security based on the availability and accessibility aspects of food security without paying attention to the diversity aspect. Dietary diversity (quality) shows a good link with the pillars of food security and provides an easy way to assess food security than the recent emphasis on dietary quantity, which creates a gap in the literature (Rashid et al., 2006; Taruvinga et al., 2013). Different remote sensing datasets and techniques have been applied to map different LULC classes.

A few studies (Abu et al., 2021; Ashiagbor et al., 2020; Erasmi & Twele, 2009), have utilized a multi-temporal stack of optical images and SAR data to map and distinguish cash crops, such as cocoa types from other landcover classes in the tropics. Monthly optical images capture all phenological stages during a year, and SAR data is reported to have the ability to penetrate clouds and woody materials to help distinguish features (Le et al., 2016; Rignot et al., 1994). Thus, evidence on the combination of optical satellite images and Sentinel-1, which could help improve cocoa mapping accuracies is inadequate in the literature (Ashiagbor et al., 2020; Erasmi & Twele, 2009).

Moreover, most of the studies that looked at the relationships between cocoa and food security status, such as Ajagun et al. (2021), Anderman et al. (2014b), and Hashmiu et al. (2022b) did not categorize cocoa landuse types into monoculture and agroforestry to specify which cocoa land use type is positively or negatively affecting household food security. It is important to distinguish the relationship between cocoa land use types and food security since monoculture cocoa and agroforestry cocoa have different impacts on household food security (Niether et al., 2020).

Thus, it is essential for this study to analyze the spatio-temporal dynamics of cocoa expansion and how that expansion has affected household dietary diversity, as well as its associated variables in the Bia West District.

1.3. Justification/ Significance of the study

Food insecurity is a global concern (Drammeh et al., 2019; Mougeot et al., 1999), and its impacts affect both farmers and non-farmers, especially those living in sub-Sahara Africa (Clover, 2003; Ringler et al., 2010). Food insecurity has led to several complications, such as undernourishment (Lal, 2020), and death (Drammeh et al., 2019), hence it is important to undertake this study because of the following reasons.

The results from the agroforestry cocoa, monoculture cocoa, cropland, built-up/bare land, open forest, and closed forest classes change over the years, impacts of monoculture and agroforestry cocoa expansion on household dietary diversity, and household dietary diversity determinants will fill in the gaps in the literature. Additionally, it will support cocoa management methods that will ensure the sustainability of cocoa landscapes by monitoring monoculture and agroforestry cocoa expansion. Moreover, it will enhance agricultural intervention programs to address food insecurity in cocoa landscapes.

1.4. Research objectives

1.4.1. Main objective

The overarching objective is to monitor cocoa expansion, its impact, and associated variables influencing household food security.

1.4.2. Specific objectives

1. To analyze agroforestry cocoa, monoculture cocoa, cropland, built-up/bare land, open forest, and closed forest classes change from 2000 to 2022 in the Bia West district.

2. To investigate the effect of monoculture and agroforestry cocoa expansion on the variety of diets consumed by cocoa farmers' households in the Bia West district 2022 farming season, as well as their food production trends and shortage/ unavailability experiences.

3. To identify key household and landuse variables influencing cocoa farmers' household dietary diversity status in the Bia West district.

1.5. Research questions

1. Which LULC types have significantly changed between 2000 and 2022 in the Bia West district?

2. What effects does monoculture cocoa and agroforestry cocoa expansion have on the variety of diets consumed by cocoa farmers' households in the Bia West district 2022 farming season, as well as their food production trends and shortage/ unavailability experiences?

3. Which household and land use variables are statistically significant in influencing the variety of diets consumed in cocoa farmers' households in the Bia West district?

1.6. Hypothesis

H1: There is a positive relationship between agroforestry cocoa households and high dietary diversity status.

H2: There is a negative relationship between monoculture cocoa households and high dietary diversity status.

2. LITERATURE REVIEW

2.1. Cash crop and food security relationship

Rubhara et al. (2020) analyzed how food security is impacted by cash crops and revealed that there is a positive relationship between cash crops and household dietary diversity. This means that the incomes cash crop farmers gained are used to purchase different food groups, which in the long run improves their dietary diversity.

Anderman et al. (2014a) examined the relationships between cash crops and food security dimensions, namely accessibility, availability, and utilization. The study discovered that there is a negative relationship between cash crop production and food utilization, especially with the diet diversity score metric. The study noted that there were some changes in the food groups. For instance, some households ate more white tubers and fruits, but remarkably fewer vegetables, which shows that the quality of their diets has reduced with higher levels of cocoa and oil palm production. Hashmiu et al. (2022a) found that cocoa farming had a good relationship with food security and household crop income because of their interdependencies. In other words, cocoa farming promotes household food security. Nonetheless, their study pointed out that food security cannot be ensured by the distribution and level of income from cocoa alone. The study's findings suggested that the incomes earned by smallholder cocoa farmers from the sales of cocoa aided them to reinvest in cashew farming and diversify food crop production. This pathway guaranteed regular circulation of money, reduced reliance on the market for local foods, and boosted annual crop income.

Does the expansion of cash crops, such as cocoa (monoculture and agroforestry) guarantee household dietary diversity? This question about the relationship between cocoa (monoculture and agroforestry) and dietary diversity remains unclear in the literature.

2.1.1. Agroforestry cocoa, monoculture cocoa, and food security

Niether et al. (2020) findings from the meta-analysis of cocoa agroforestry and monocultures argued that the total system of cocoa yields was roughly ten times greater in agroforestry systems than in monocultures, which helped to increase food security and diversify earnings. Also, Jacobi (2016) study revealed that through the sustainable use of resources, application of traditional knowledge, and diversification of food production, cocoa agroforestry systems in Bolivia contribute to local food security and food sovereignty.

Schneider et al. (2017) suggested that cocoa agroforestry has a higher likelihood to increase local food security when compared to monocultures because their studies showed that the total yields of all harvested goods increased dramatically in agroforestry than monocultures households. The full-sun/ monoculture cocoa plantation nature makes food production quite difficult, which affects the household food security of such cocoa farmers (Schneider et al., 2017). Kuyah et al. (2019a) argued that agroforestry can help improve local food security since agroforestry has good ecological conditions, such as infiltration rates, soil quality, nutrients, and carbon and water content, which ensure high crop yields.

2.2. Application of remote sensing in mapping cash crop expansion, LULC, and food security

Asubonteng et al. (2018b) evaluated the consequences of palm oil and cocoa farming on the structure and size of land-cover transition in a varied topography of the Eastern Region of Ghana. Remote sensing data employed in their studies were Landsat images from a temporal period between 1986 and 2015. The classes were cocoa, palm oil, forest, food crops, water, build-up/bare, and other tree crops. The maximum likelihood classification algorithm was used. Key respondent interviews, Google Earth data, and field data were used to validate the accuracy of the classification, as well as intensity analysis was used to analyze the change matrix. Evidence from their studies revealed that the classes in the landscape have undergone major transitions from 1986 to 2015. For instance, forests and food crops drastically decreased, whilst cocoa and palm oil increased over the years. The intensity analysis demonstrated that cocoa gains and losses from oil palm land, food cropland, and other tree crops, whilst food cropland gains from built-up/bare, water, and cocoa. The study argued that cocoa and palm oil are increasing in the study landscapes at the cost of food crop production and forests, thus posing a threat to food security in these areas (Asubonteng et al., 2018b). The study further recommended that future research should investigate and quantity the configuration of the changing LULC and how these changes affect households' food security and livelihoods.

Ajagun et al. (2022) study sought to examine how and why farmers switch from cropland to cocoa. Earth Observation data namely Sentinel 2 with an RF classification algorithm was applied to produce land cover maps for 1986, 1999, and 2017 identifying areas where food croplands have been lost to cocoa production. The accuracy of the various land cover maps was verified by using surveys, focus group discussions, and field data. The variables that led to the changing of cropland to cocoa farming have been investigated using logistic regression. The area's LULC was divided into four categories in this study. The study discovered that from 1986 to 1999, acreage for cropland significantly dwindled and lost 0.36% (4.92 km^2). Nevertheless, cropland further lost 1.76% (24.04 km^2) between 1999 and 2017. While cropland was statistically reducing significantly, cocoa land was statistically increasing greatly. In other words, cocoa production was expanding at the expense of cropland. This is affecting food security in the communities in the district. The findings suggested that farmers' quest to maximize profit, stabilize their land tenure, and lack of place in off-reserve landscapes all contribute to the changing of food cropland to cocoa (Ajagun et al., 2022). On the other hand, the study investigated only the availability and accessibility aspects of food security without exploring how the cocoa (monoculture and agroforestry) expansion is affecting household food diversity. Thus, knowledge of the effect of cocoa expansion types on household food diversity in the Juaboso-Bia cocoa landscapes remains a gap in the literature.

Using a deep learning approach, Kalischek et al. (2022) examined cocoa mapping in Ghana and Côte d'Ivoire with high-resolution satellite imagery. The study used Sentinel-2 images between 2018 and 2021. In the end, 9 bands were used as input for the neural network. The researchers had over 100,000 GPS ground-truth data from non-profit organizations and other data providers. The study used 80% of the ground truth for training, and to prevent biases due to spatial linkage between neighboring farms, the researchers randomly crop out large connected regions as validation zones (20%). The study revealed that forest cover has reduced drastically, that is 37% and 13% in protected areas in Côte d'Ivoire and Ghana, respectively due to cocoa cultivation. On the other hand, this paper did not employ SAR as an extra input to feed the neural network. SAR data could have helped reduce the misclassification problems, especially in the tropics since it can penetrate through clouds to detect physical properties (Reiche et al., 2015). Again, this study is constrained by the analysis period, which does not account for the changes in LULC classes for the years before 2018.

Dada and Hahn (2020) used Landsat images from 2000, 2002, 2014, and 2015 to analyze the temporal changes in the cocoa plantation in Nigeria. Findings from their study showed that cocoa plantation has increased across the investigated years at the expense of other land cover classes. The study contended that the expansion of cocoa plantations will increase the foreign exchange earnings of Nigeria, hence improving their food security.

Erasmi and Twele (2009) argued that cloud cover in tropical areas makes it difficult to map land cover using optical satellites; as a result, alternate data sources must be considered. The study applied both optical and SAR data, namely Landsat EM+ and Envisat-ASAR satellite sensors to map cocoa and rice in a tropical environment, particularly Central Sulawesi, Indonesia. The study's findings supported prior research on the general potential and benefits of multi-temporal SAR data compared to mono-temporal SAR-based mapping. Another finding suggested that when compared to typical, co-polarized time series of ASAR data, cross-polarized data from Envisat-ASAR did not produce a notably better map of tropical land cover. However, the study's overall finding emphasized the usefulness of combining optical and radar satellite data for mapping LULC, such as cocoa and rice in tropical areas.

2.3. Change detection techniques in land use/cover mapping

Many studies have examined changes in LULC, especially in the cocoa mapping (Akinyemi, 2013; Asubonteng et al., 2018b; Dada & Hahn, 2020; Loh et al., 2022). Change detection techniques may include post-classification, trend forecast-based, and land change modelers.

Ajagun et al. (2022) adduced that the post-classification change detection method is effective because it quantifies, provides changes, displays details on the distribution of the changes, and provides the percentages of other land cover classes that share in each land cover class separately. For instance, Dada and Hahn (2020) employed a post-classification change detection method to analyze cocoa plantation change from 2000 to 2015 in Ondo State, Nigeria. The study revealed that cocoa plantations had gradually gained more land size than the other land cover types over the years. Nevertheless, Peterson et al. (2004) emphasized that post-classification change detection method accuracy is directly influenced by the LULC classification result.

Chen et al. (2018) argued that phenological variations and interference issues may cause false changes to be produced by conventional bi-temporal change detection methods using remotely sensed imagery. So, their study created the Trend Forecast-based Change Detection Approach employing time-series metrics collected from Landsat to get rid of phenologically-induced pseudo changes. To explain the trend and temporal patterns of crops through time, a multi-harmonic model was used. The change detection was performed between 2014 and 2015 using 25 stacked Landsat EM+ and Operational Land Imager images. The findings showed that Trend Forecast-based Change Detection was more accurate than conventional approaches at detecting actual changes, with an overall accuracy of 95.79% and a Kappa coefficient of 0.751. However, one criticism of this model is that Landsat's limited clear observations and 16-day temporal resolution can both be significant barriers to its broad adoption. Additionally, the robustness of this approach needs to be verified in various regions due to the variations in croplands' characteristics between countries (Chen et al., 2018).

Saha et al. (2022) explored the LULC classes in the Sub-Himalayan North Bengal between 1991 and 2021, together with the dynamics of those changes, and forecast LULC changes by 2050. The study estimated the Spatio-temporal land use/cover changes from 2021 to 2050, and the land change modeler under the multi-layer perceptron neural network Markov Chain model was used. The paper found that by 2050, agricultural land would be left with 24%, and built-up and tea plantations would increase significantly in the study area. The model's validity was checked using Pearson's chi-squared test, which revealed no discernible differences between simulated and real classified maps.

2.4. Determinants of household food security status

Oluyole and Taiwo (2016) investigated the socioeconomic determinants that affect food security in households that grow cocoa. The findings from this study suggested that, besides large household sizes providing labor on the farm, it poses a risk to food security, particularly if it contains a lot of young children and older people. Again, the study revealed that there were six major variables influencing the area of study's food security situation, for example, the age of the household head may positively or negatively impact a household's availability of food.

Previous studies found that the household head's age, sex, education, household size, non-agricultural income, dependence ratio, yearly cocoa yield, own food production, access to extension officers, agroforestry practice, cocoa farming experience, and social group membership are the common important variables that impact households' food security (Aidoo et al., 2013; Ajagun et al., 2021; Asefach & Nigatu, 2007; Bogale & Shimelis, 2009; Cordero-Ahiman et al., 2021; Dei Antwi et al., 2018; Felker-Kantor & Wood, 2012; Heim & Paksi, 2019; Ingutia & Sumelius, 2022; Isabirye et al., 2020; Jacobi et al., 2015; Kuyah et al., 2019b; Niether et al., 2020; Powell et al., 2017; Sambo et al., 2022; Sekhampu, 2013; Silvestri et al., 2015; Taylor, 2017). Aidoo et al. (2013) argued that their findings aligned with previous findings suggesting that credit access, farm size, and income from off-farm are directly related to household food security. Nonetheless, the variables that affect household dietary diversity have not received much research attention (Rashid et al., 2006; Taruvinga et al., 2013).

2.5. Conceptual framework

There are several ways to conceptualize the issue of how local household dietary diversity may be impacted by cocoa expansion types, for instance, by understanding the features and determinants of a household dietary diversity state. As illustrated in Figure 2.1 below, the elements involved in this concept are; production, income, consumption, and resources (Nyariki & Wiggins, 1997; Taylor, 2017).

In this hypothetical situation, cocoa households utilize their human resources, physical resources, and lands for monoculture cocoa and agroforestry cocoa production in the Bia West district. Households that engage in agroforestry cocoa can cultivate food crops alongside their cocoa trees, whereas monoculture cocoa households only produce cocoa without having other economic trees on their farms. Agroforestry cocoa households generally get higher income as a result of higher yields (Niether et al., 2020). Some of the income is then used to purchase more food to complement their food production, improving their consumption and enhancing their dietary diversity status over time. Contrarily, monoculture cocoa households usually obtain lower income due to lower yields (Andres et al., 2016; Niether et al., 2020), which they are not able to buy sufficient food from the market to supplement their food production, which to some extent affects their dietary diversity status.

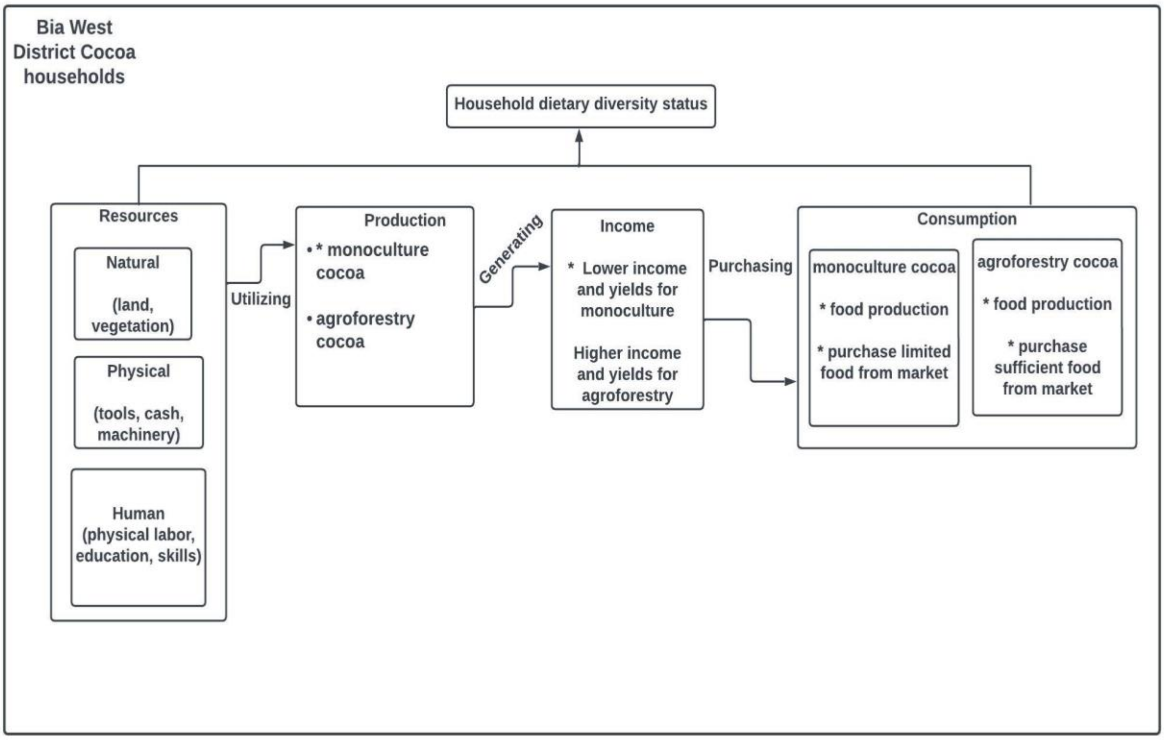

Figure 2.1: Conceptual diagram of cocoa landuse types and household dietary diversity

Source: Adapted (Taylor, 2017)

3. METHODOLOGY

3.1. Study area description

Bia West District is one of the districts in the newly created region, the Western North Region of Ghana. This district was created out of the existing Bia district in 2012 using Legislative Instrument 2014, with Essam-Dabiso as its capital (Ghana Statistical Service, 2014). The district's geographic coordinate is 6º 29' 2.4" N, 3º 4' 58.8" W, and it is bordered to the north and east by Bia East District, to the south by Juaboso District, and the west by La Cote d'Ivoire (Ghana Statistical Service, 2014) (see Figure 3.1). The district is located in the wet semi-equatorial climate zone. The district's average yearly temperature and rainfall ranges are 25.5°C to 26.5°C and 1,250mm to 2,000mm, respectively (Ghana Statistical Service, 2014). The two main wet and dry seasons alternate in the region: April through October is the wet season, and November through March is the dry season. Numerous dietary staples and economic crops are favored by the climate, for instance, the district is among the top leading producers of cocoa in the country (Ghana Statistical Service, 2014). There are two forest reserves, including Bia North and Bia South, where the north is a protected reserve while the south is a productive reserve (Ghana Statistical Service, 2014). According to Ghana Forestry Commission (2021), cocoa production is the largest landuse type in the district. Bia West is one of the most populated districts in the Western North Region of Ghana, with a 2010 population size of 88,939, which comprised 51.4% (45,717) of males and 48.6% (43,222) of females (Ghana Statistical Service, 2014). 78.2% of the district's households participate in agriculture.

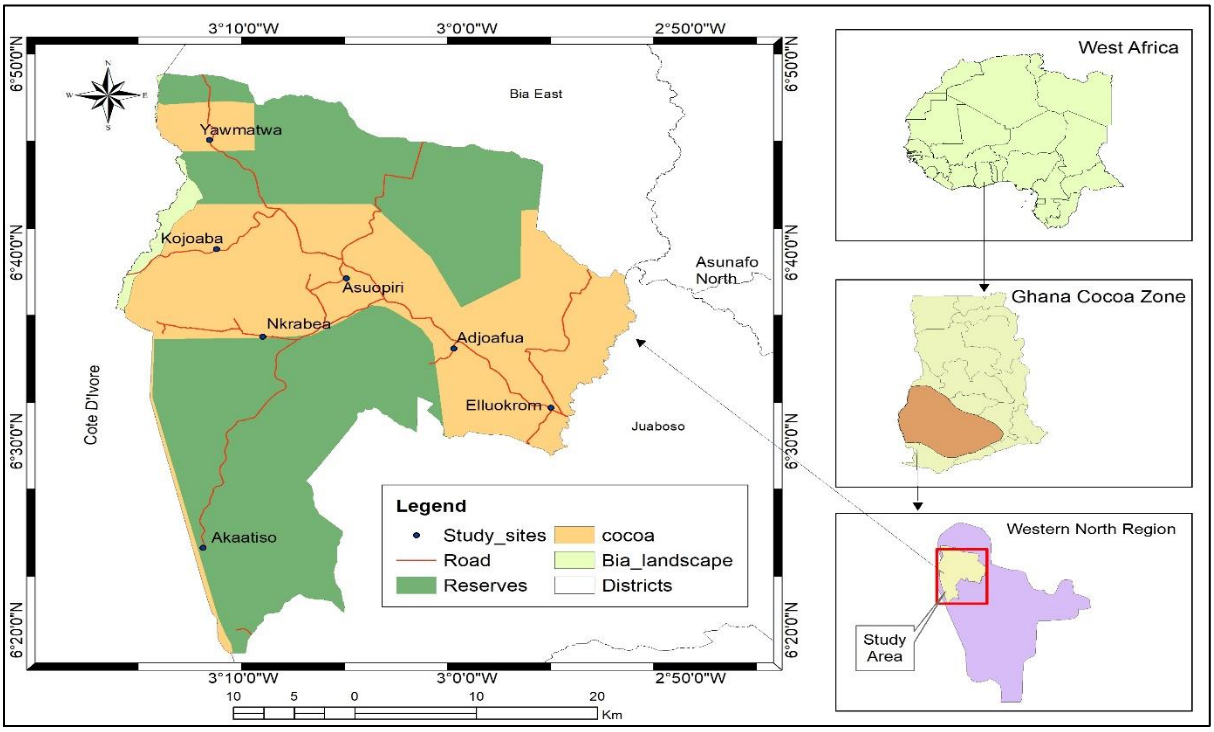

Figure 3.1: A landuse map of Bia West District

Source: Shapefiles from UG RSGIS Lab

3.2. Data source and collection

This thesis used two types of data: remote sensing classified LULC maps and food security indicators derived from the household survey.

3.2.1. Primary data collection methods: survey, sample size, sampling method, ground truth

The application of survey questionnaires can help specify models and determine the type of correlations between various variables and also provides an impartial social reality that guarantees the authenticity and trustworthiness of research findings (Teye, 2012). Therefore, this study used a survey.

According to Ghana Statistical Service (2014), the district's entire number of households that are now working in agriculture is 15,491. A statistical method from Miller and Brewer (2003) was used to determine the sample size for this study. The formula is $n = (N / 1+N(a)^2)$, where **'N'** = sample frame, **'n'** = sample size, and **'a'** = confidence interval Miller and Brewer (2003). This research's confidence interval will be 95%, with a 5% margin of error. Because, unlike the physical sciences, where assurance is of a high caliber, this research works with people as subjects whose truthfulness of the information is vulnerable to prejudices. Therefore, **N= 15,491**, **a= (5%)** putting into the formula **$n = 15{,}491/(1 + 15{,}491 (0.05)^2) = 390$**. This research surveyed only **200** out of 390 households due to resource limitations.

With the sampling method, this study applied a multi-stage sampling technique to collect the questionnaire data. It has been applied extensively in research, such as by Ajagun et al. (2021) and Wongnaa et al. (2021) to collect survey data. For instance, a stratified sampling technique was used in the first phase of the sampling process to divide the Bia West district into four groups: the north, south, east, and west wings. A stratified sampling technique ensures adequate representation of all groupings (Springer & Mcclure, 1988). For the second phase of the sampling technique, a purposive sampling technique was employed to select seven communities for the survey data collection, which was based on the number of households and road accessibility. The third and final phase of the sampling technique was the Snow-Ball technique to select cocoa-producing household heads for the semi-structured interviews. The snowball technique is based on networking and referral (Parker et al., 2019). See Table 3.1 in the appendices for the names of the selected communities, and the number of household surveys conducted per community.

For the remote sensing ground truth data, see Table 3.2 for the number of samples for the years 1999, 2017, and 2022, which were collected from fieldwork conducted in 2023 and Ajagun et al. (2021).

Table 3.2: LULC samples for 1999, 2017, and 2022

LULC classes	**Number of samples**		
	1999	**2017**	**2022**
Agroforestry cocoa	200	218	98
Monoculture cocoa	500	578	100
Cropland	20	22	23
Open forest	45	500	51
Closed forest	1500	1900	26
Built-up/bare	500	600	65
Others	177	15	16

3.2.2. Remote sensing data

Landsat and Sentinel 1 (SAR) data were used in this study. The Landsat program has released several missions, ranging from Landsat 1 to 8 (Loveland & Dwyer, 2012) and now Landsat 9 (Masek et al., 2020). Landsat has a field of vision with a swath of 185 km as opposed to other satellites, such as Aster and commercial systems (Hansen & Loveland, 2012; Williams et al., 2006). The Landsat missions have spatial resolution ranging from 15m to 60m, and a temporal resolution of a 16-day orbital repeat (Williams et al., 2006; Wulder et al., 2019). The Landsat program offers the opportunity for a thorough examination of the Earth's surface, and also improves the effectiveness of monitoring the Earth's surface, for example, LULC mapping, crop mapping, forest mapping, and other natural resources management (Wulder et al., 2019). However, Landsat images are hindered by cloud cover in tropical areas, such as the Bia West district (with a lot of cloud cover), which limits its sole application in mapping LULC, hence there is the need to combine it with SAR data.

Sentinel-1 is part of the Copernicus Space Component, which comes with a constellation of 2 satellites, namely A and B with each having on board C-band SAR ensuring ERS and ENVISAT SAR data continuity (Geudtner et al., 2014; Torres et al., 2017). Sentinel-l satellites are meant to endure 7 years while utilizing 12-year-old consumables. The Sentinel-1 satellite is in a nearly polar (dawn-dusk), sun-synchronized orbit at a height of 693 km (Geudtner & Torres, 2012). Four distinct imaging modes with varying resolution and coverage are supported by the Sentinel-1 SAR instrument's active phased array antenna: Interferometric Wide Swath (1W), Extra Wide Swath (EW), Strip-Map (SM), and Wave (WV) (Geudtner & Torres, 2012). Sentinel-1 synthetic aperture radar (SAR) is very essential in mapping landcover (Geudtner et al., 2014) in the tropics, where cloud cover usually limits optical satellite imagery, such as Landsat (Erasmi & Twele, 2009; Reiche et al., 2015). See Table 3.3 for the data management plan in the appendices.

3.3. Data source and collection

3.3.1. LULC classification

Multispectral satellite images were downloaded from the United State Geological Survey (USGS) at (https://earthexplorer.usgs.gov/). The Bia West district covered 2 tiles, namely 055 and 056. In order to provide a sufficient window of time to monitor changes in the landscape, the study selected the years 1999, 2017, and 2022, particularly, the year 2017 was selected due to the availability of training samples for the study area, which was obtained from Ajagun et al. (2021). For each year, a single-date image, such as 07-02-1999, 25-12-2017, and 21-01-2022 was downloaded based on the availability of less than 10% cloud-cover satellite images over the study's period. Preprocessing steps, for example, atmospheric correction, layer stacking, and mosaicking were performed on the Landsat images in ArcGIS 10.8. Also, preprocessed SAR images for 2017 and 2022 covering the spatial extent of the study area were downloaded from the Google Earth Engine. The spectral bands utilized, included blue, green, red, near-infrared, short-wave infrared 1, short-wave infrared 2, VV, and VH, because this band combination is good for monitoring forests, crops, and other land use/cover (Wang et al., 2018). Also, NDVI and NDWI were calculated and added to the model since it is good for vegetation analysis (Ashiagbor et al., 2020). For instance, red and blue bands have low reflectance for vegetation due to high chlorophyll absorption; NIR has a high reflectance for vegetation; and SWIR has low reflectance for vegetation cover because of high water content absorption (Ashiagbor et al., 2020; Wang et al., 2018). Again, the Landsat 2017 and 2022 images were stacked with SAR 2017 and 2022 images to help discriminate agroforestry cocoa from other trees, and also to address the cloud cover limitation in the tropics, following (Erasmi & Twele, 2009; Reiche et al., 2015). The fusion was done by resampling Landsat and SAR spatial resolutions to 5 meters to capture small farms. In the same way, the Landsat 1999 was resampled to 5 meters spatial resolution. The LULC classes included open forest, closed forest, monoculture cocoa, agroforestry cocoa, built-up/bare land, cropland, and others (see Table 3.4 and Figure 3.2 in the appendices).

RF machine learning algorithm was employed to perform the classification because it ensures higher classification accuracy (Belgiu & Drăguţ, 2016; Breiman, 2001). RF was used to perform 1999, 2017, and 2022 LULC classifications. The ground truth data was divided into training and validation sets by using a stratified random split. The samples were split into 70% for training and 30% for validation. The variables utilized in the models for the various years can be found in Table 3.5 in the appendices. The hyper-parameter tuning was done manually by testing different parameters for the geometry (mtry) and the number of trees (ntree) until getting the best parameters that produced the least error, for instance, the best parameters for ntree and mtry were 1000 and 5, respectively. The study modified an available RF code to perform the classification in R Studio 4.2.2.

3.3.1.1. Assessment of LULC classification

The classified images were assessed to check their accuracy with the ground-truth data. Following Tassi et al. (2021), this study employed 30% of the ground truth for validating the RF algorithm for 1999, 2017, and 2022 classification accuracy. Overall, producer, and user accuracies, as well as kappa statistics were calculated from the confusion matrix.

3.3.1.2. LULC change detection

This study performed a post-classification change detection method (Al-doski et al., 2013) to detect spatial changes in the LULC that occurred from 1999 to 2022 in the Bia West district.

3.3.2. Effects of cocoa expansion types on cocoa farmers' household dietary diversity

Dietary diversity is broadening the range of foods available within and between dietary groups, allowing for adequate consumption of vital nutrients that can support optimum health (Ruel, 2003; Taruvinga et al., 2013). One of the direct outcome indicators used frequently in developing nations that measure food security and nutrition based on broad 12 food types is the Household Dietary Diversity Score (HDDs) (Al-Zabir et al., 2021; Dei Antwi et al., 2018; Taruvinga et al., 2013). Therefore, this study utilized the household dietary diversity score to assess the effect of cocoa expansion types (monoculture and agroforestry) on household dietary diversity, following Al-Zabir et al. (2021) and Taruvinga et al. (2013). These dietary groups are set standards for Africa (Rubhara et al., 2020).

The local food of the study participants was incorporated into the food categories. The 12 food categories that were used to classify the food items that monoculture and agroforestry cocoa households reported having consumed over the previous 24 hours to create a score for the food security status of that household: (A) cereals; (B) roots and tuber; (C) vegetables; (D) fruits; (E) organic meats; (F) eggs; (G) fish and other seafood; (H) legumes: nuts and seeds; (I) cheese, milk, and other milk product; (J) oil and fat; (K) sugar or honey; (L) spices, condiments, coffee, tea or beverages (Al-Zabir et al., 2021; Rubhara et al., 2020). If monoculture or agroforestry cocoa household members ate any food items from that specific food category, the household would receive one (1) for that food group, otherwise zero (0).

Thus, HDDs = Total (A+B+C+D+E+F+G+H+I+J+K+L). The HDDs range between 0 and 12. The dietary diversity status of cocoa (monoculture and agroforestry) households would differ since resources are not distributed equally among them.

3.3.3. Variables influencing household dietary diversity status

A regression model is needed to determine the relationship between key household and landuse variables that influence household dietary diversity status. Ordinal logistic regression is suitable for analyzing a dependent variable with more than two ordered categories (Sambo et al., 2022). Following Cordero-Ahiman et al. (2021) and Isabirye et al. (2020), therefore this study used the ordinal logistic regression model to analyze the variables impacting household dietary diversity status.

In this instance, the dependent variable had three dietary diversity categories (LDD, MDD, and HDD). The HDD was selected as the reference group with a categorical number of 3, LDD with a categorical number of 1, and MDD with a categorical value of 2. Using Cameron and Trivedi (2005), expressed econometrically, the logistic probability model as:

Logit (Pi) = $\ln \left(Pi / 1 - Pi \right) = \alpha + \beta i Xi + \varepsilon i$……………….. (1)

Where; $\ln \left(Pi / 1 - Pi \right)$ is the logit for dietary diversity categories, Pi = the moderate dietary diversity, $1 - Pi$ is the probability of a household to be either classified as a low or high dietary diversity, Xi = explanatory variables, α & β = regression parameters to be estimated, and εi = error term. A household's chance of falling into one dietary diversity category juxtaposed to the other must fall between zero and one ($0 \leq Pi \leq 1$).

Based on the reviewed determinants of food security, this study came up with the following variables (see Table 3.6) and computed them in the univariate, bivariate, and multivariate levels to test which ones are statistically significant in influencing household dietary diversity status of cocoa households.

Table 3.6: Variables influencing cocoa households' dietary diversity status

Explanatory Variables	**Measurement**
1. Age	years
2. Sex	Male = 1; Female = 0
3. Marital status	Married=1;Single=2; Divorced=3; Widow/Widower=4
4. Education	Primary=1;JHS/Form-4=2; SSS/O/A level= 3; Tertiary=4; No formal education =5
5. Household size	number
6. Dependent ratio	number
7. Cocoa cooperative	Yes = 1; No = 0
8. Cocoa farm age	Years
9 Cocoa farming experience	10-30 =1; 31-50 =2; above 50 =3
10. Agroforestry cocoa size	acres
11. Monoculture cocoa size	acres
12. Agroforestry households	Yes = 1; No = 0
13. Monoculture households	Yes = 1; No = 0
14. Household total income	GH¢
15. Access to extension officers	Yes = 1; No = 0
16. Food crop farming	Yes = 1; No = 0
17. General food production trends	Decreasing = 1; Increasing =2; Not noticeable = 3

Source: (Agwu et al., 2014; Aidoo et al., 2013; Bogale & Shimelis, 2009; Dei Antwi et al., 2018; Maharjan & Joshi, 2011)

The survey questions and the ordinal logistic regression were examined using Scientific Statistical Package for Social Sciences (SPSS 27) and R Studio. All the elaborated processes above are simplified in Figure 3.3 below. See the appendices for the ethical considerations statement.

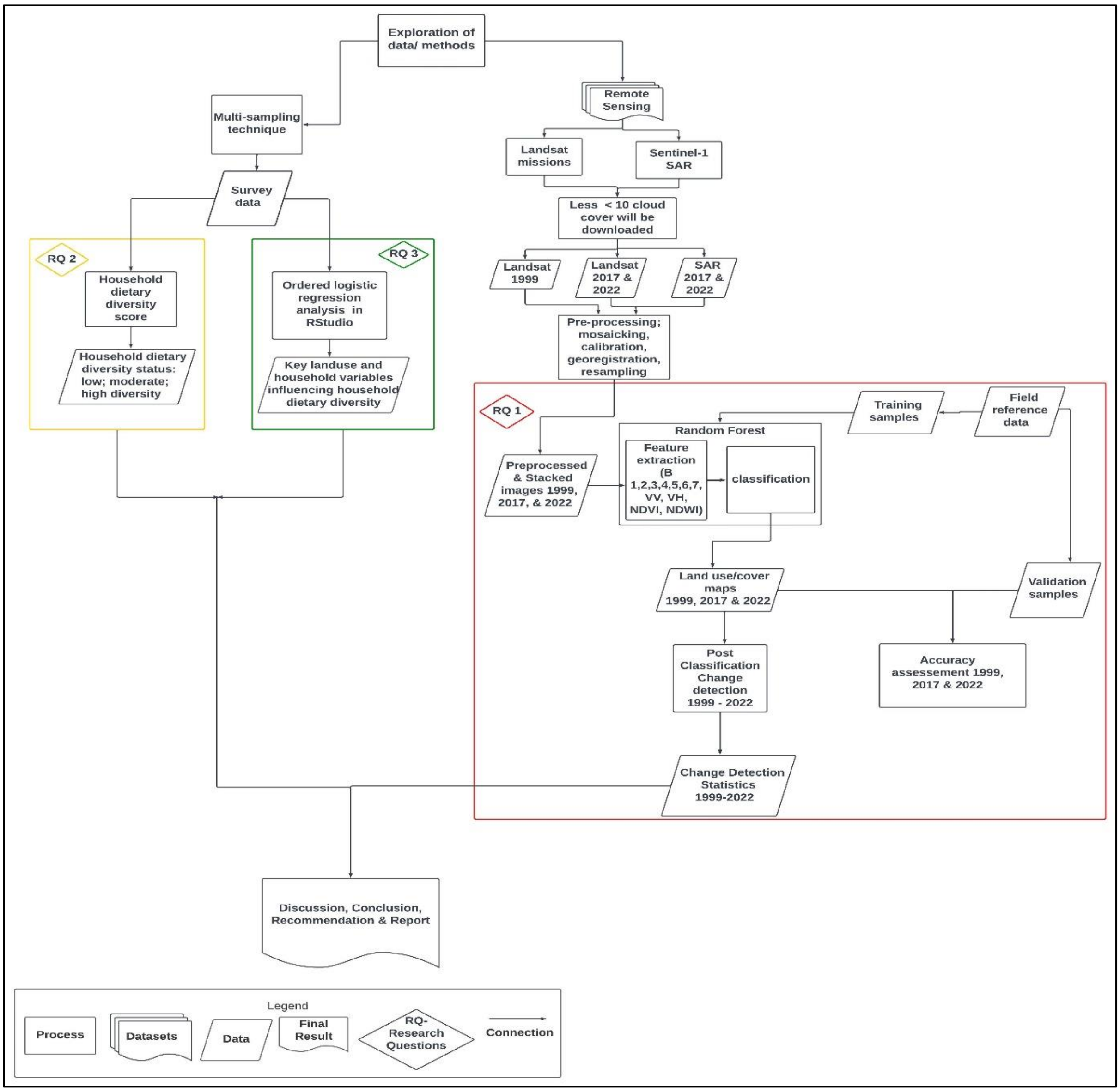

Figure 3.3: Methodological flowchart

Source: Author's construct

4. RESULTS

4.1. Demographic and socio-economic characteristics of the respondents

This section presented the background features of the respondents, including data on the respondent's age, sex, marital status, educational level, household size, dependency ratio, cocoa cooperative membership, as well as household cocoa landuse type. A total of 200 semi-structured interviews were conducted among cocoa households. The respondent rate of data collected was very high as a total of 200 questionnaires were received and valid for analysis, which represented a high percentage of 100 % of the estimated sample size. A summary of the analysis of the respondents' demographic background is presented in Table 4.1. 60.5% of the respondents who took part in the study were men, which constituted the majority, while females constituted the minority which is 39.5%, according to their sex distribution. The survey also looked into the respondents' academic histories. According to the analysis's findings, 10% of people were primary school dropouts, 26.5% have completed junior high or form 4, 13.5% were senior high school or O/ A level graduates, 17.5% had tertiary education, and 32.5% had no stated formal education. The majority of participants, according to the analysis, have no formal schooling. Also, the results the showed that majority which is 74% of the respondents were married, followed by 15%, and then 7% widows/widowers and divorced, respectively. In addition, 4% of respondents were single. A little over 78% indicated that they were part of cocoa cooperatives and 93% of the households engaged in food crop farming.

Table 4.1: Socio-demographic characteristics of participants

Variable	Category	Frequency	Percentage
Sex	Male	79	39.5
	Female	121	60.5
Level of Education	Primary	20	10.0
	JHS/Form 4	53	26.5
	SSS/O/A level	27	13.5
	Tertiary	35	17.5
	No Formal Education	65	32.5
Marital Status	Single	8	4.0
	Married	148	74.0
	Divorced	14	7.0
	Widow/widower	30	15.0
Dependency Ratio	1-2	72	36.0
	3-4	99	49.5
	5-6	29	14.5
Cocoa Cooperative	Yes	157	78.5
	No	43	21.5
Food crop farming	Yes	186	93.0
	No	14	7.0
	Total	200	100

Source: Field Work, 2023 Sample Frame (N) 200

As presented in the cocoa household landuse characteristics in Table 4.2, 81 cocoa households which represented 40.5% indicated that they engaged in agroforestry cocoa, whereas 119 of the cocoa households represented 59.5% engaged in monoculture cocoa. 88% and 81.5% of the agroforestry and monoculture cocoa households were noted to have engaged in cocoa expansion and cropland conversion, respectively over the years.

Table 4.2: Cocoa household land use characteristics

Variables	Category	Frequency	Percentage (%)
Agroforestry cocoa household	Yes	81	40.5
	No	119	59.5
Cocoa expansion	No	24	12.0
	Yes	176	88.0
Cropland conversion	No	37	18.5
	Yes	163	81.5

Source: Field Work, 2023 Sample Frame (N) 200

4.2. LULC changes in the Bia West District from 1999 to 2022

4.2.1. LULC classification for 1999, 2017, and 2022

Cocoa production played an integral role in the LULC of the studied region's landscape. The LULC classes that were incorporated into the RF algorithm to perform the classification for the years 1999, 2017, and 2022 are shown in Figure 4.1.

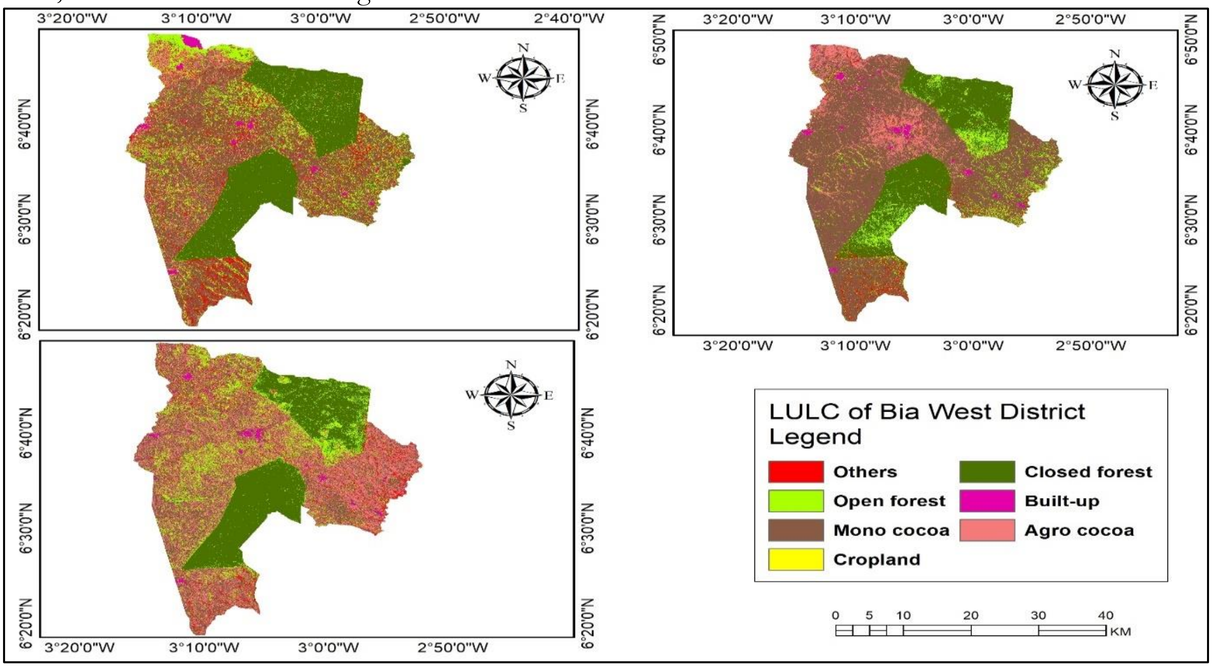

Figure 4.1: LULC classification map for 1999, 2017, and 2022

The User accuracy and the Producer accuracy for the individual LULC classes as well as the kappa score for each of the studied years are presented in Table 4.3. The Overall accuracy for 1999, 2017, and 2022 were approximately 81%, 90%, and 92%, respectively. The 1999, 2017, and 2022 uncertainty levels were 0.19, 0.11, and 0.1, respectively.

Table 4.3: Summary of the LULC maps classification accuracy for 1999, 2017, and 2022

LULC classes	**1999**		**2017**		**2022**	
	Producer Accuracy (%)	User Accuracy (%)	Producer Accuracy (%)	User Accuracy (%)	Producer Accuracy (%)	User Accuracy (%)
Open Forest	83.3	71.7	99	92	91.4	85.7
Closed Forest	83.9	86.8	90	97.3	95	98
Cropland	73	68.5	65	70	94	72.4
Built-up/ Bareland	82	89.5	81	86	85.7	90.7
Agro Cocoa	80.3	85.7	90	79	95.4	89.3
Mono Cocoa	82.2	76.5	77	85	85	90.4
Others	84.1	70.8	80	68	77.4	85
Overall Accuracy	0.81		0.89		0.90	
Kappa Statistics	0.75		0.85		0.88	
Uncertainty	0.19		0.11		0.1	

4.2.2. LULC change detection analysis

4.2.2.1. LULC change detection statistics for 1999, 2017, and 2022

All of the LULC classes had experienced substantial changes in land size during the previous 23 years, as shown in Figure 4.2 and Table 4.4. From 27.43 km^2 (2.14%) in 1999 to 30 km^2 (2.34%) in 2017, built-up/bare land increased. In 2022, it continued to grow steadily, reaching 32.59 km^2 (2.54%). Furthermore, open forest declined from 185.21 km^2 (14.48%) to 99.11 km^2 (7.72%) from 1999 to 2017, and it eventually increased to 179.60 km^2 (13.99%) in 2022.

Table 4.4: LULC change detection statistics for 1999, 2017, and 2022 in km^2

LULC classes	**1999 (km^2)**	**2017 (km^2)**	**2022 (km^2)**
Open Forest	185.21	99.11	179.60
Closed Forest	351.19	316.67	303.04
Cropland	23.85	13.26	12.53
Built-up/ Bareland	27.43	30.00	32.59
Agro Cocoa	69.12	116.00	307.41
Mono Cocoa	514.04	683.82	407.27
Others	108.50	24.62	46.03

The closed forests initially occupied about 351 km² (27.45%) of the studied region's landscape. In 2017, this number dropped to about 316.7 km² (24.67%), and then to 303 km² (23.60%) in 2022. Similarly, the cropland landuse type has undergone significant changes between 1999 and 2017, going from 23.74 km² (1.86%) to 13.27 km² (1.03%) and further decreased to 12.53 km² (0.93%) in 2022. In addition, throughout the same period, agroforestry cocoa gently climbed from 69.12 km² (5.38%) to 116 km² (9.04%), and then to 307.4 km² (23.94%) in 2022.

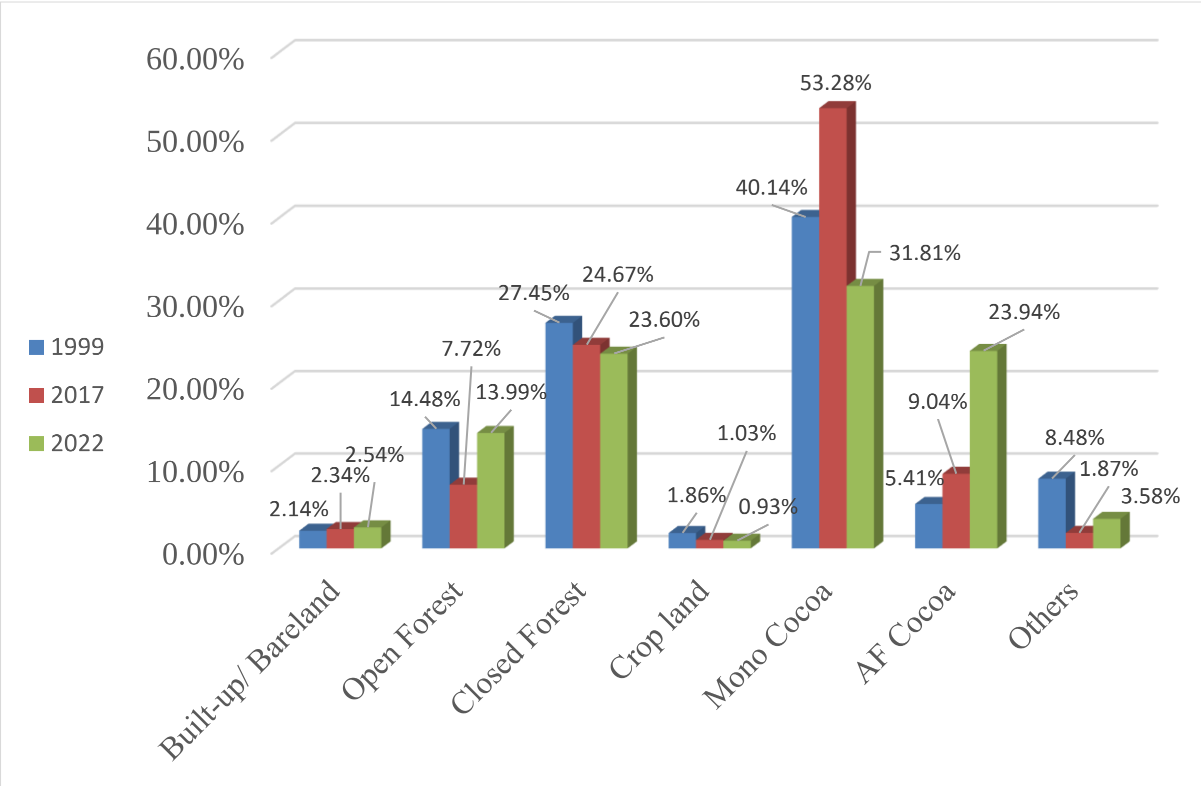

Figure 4.2: Percentage coverage of LULC classes in the Bia West District for 1999, 2017 and 2022

Similar to open forests and conversely to cropland, other classes also decreased from 108.50 km² (8.48%) to 24.62 km² (1.87%) from 1999 to 2017. It ultimately increased to 46.03 km² (3.58%). Monoculture cocoa expanded from 514 km² (40.14%) to 683.8 km² (52.28%) between 1999 and 2017. Consequently, monoculture cocoa reduced to 407.27 km² (31.81%) in 2022.

4.2.2.2. LULC classes transition matrix between 1999 and 2022

This section reported on the LULC classes' change matrix over the years. Cropland significantly loss about 10.5 km² and 0.74 km² between 1999 and 2017, and between 2017 and 2022, respectively to mostly monoculture cocoa.

Table 4.5: LULC classes transition between 1999 and 2022 in km²

	2017 Class							
1999 Class	Agro cocoa	Built-up	Closed forest	Cropland	Mono cocoa	Open forest	Others	**Total**
Agro cocoa	10.60	2.80	2.07	1.73	49.31	1.77	0.85	69.12

Built-up/ Bareland	4.99	9.24	0.34	1.39	15.93	0.33	0.37	27.43
Closed forest	2.55	0.09	274.00	0.09	15.72	54.28	4.46	351.19
Cropland	2.68	1.68	2.21	0.54	14.77	1.57	0.29	23.74
Mono cocoa	52.74	8.97	14.91	4.91	401.86	21.46	9.19	514.04
Open forest	30.53	3.99	16.60	2.99	114.28	11.99	4.82	185.21
Others	11.91	3.24	6.54	1.61	72.82	7.71	4.67	108.50
Total	116.00	30.00	316.67	13.27	684.68	99.11	24.64	1284.37
Image difference	46.88	2.57	-34.52	-10.47	170.64	-86.09	-83.86	
2017 Class	**2022 Class**							
Agro cocoa	33.19	0.96	2.69	1.41	37.66	12.61	7.42	116.00
Built-up/ Bareland	1.44	15.42	0.01	0.69	8.04	3.49	0.90	30.00
Closed forest	7.12	0.17	256.09	1.23	10.99	35.46	5.54	316.59
Cropland	1.67	1.82	0.04	0.41	6.49	2.25	0.59	13.27
Mono cocoa	263.06	8.94	0.82	8.21	322.89	84.27	16.32	684.52
Open forest	14.52	0.06	40.08	0.45	14.74	18.41	10.80	99.11
Others	6.41	0.05	3.32	0.11	4.46	3.09	7.16	24.62
Total	307.41	32.59	303.04	12.53	407.27	179.60	46.03	1284.06
Image difference	191.41	2.59	-13.55	-0.74	-277.25	77.49	21.41	

In addition, agroforestry cocoa obtained a total of 238.29 km² from other classes, such as monoculture cocoa, and cropland within the change detection periods. Inversely, monoculture cocoa gained 170.64 km² between 1999 and 2017, and loss 277.25 km² from 2017 to 2022 to classes, mainly to agroforestry cocoa. Between the period of 1999 to 2022, closed forest and open forest extent loss 48.15 km² and 8.61 km², respectively primarily to monoculture cocoa, others, and agroforestry cocoa.

4.3. Effects of cocoa land use types expansion on the cocoa households' food security

4.3.1. Monoculture cocoa households' dietary diversity status

This section presented results from the household dietary diversity assessment conducted in the study area based on the monoculture cocoa households' recall of food groups consumed in the past 24 hours. According to Figure 4.3, the dietary diversity survey revealed that out of the 119 monoculture cocoa households interviewed, the following food groups were ordinarily consumed the most: roots/tubers 114 (95.8%), vegetables 106 (89.1%), oil/fat/butter 57 (47.9%), seafood 53 (44.5%), local grains 52 (43.7%), and eggs 40 (33.6%).

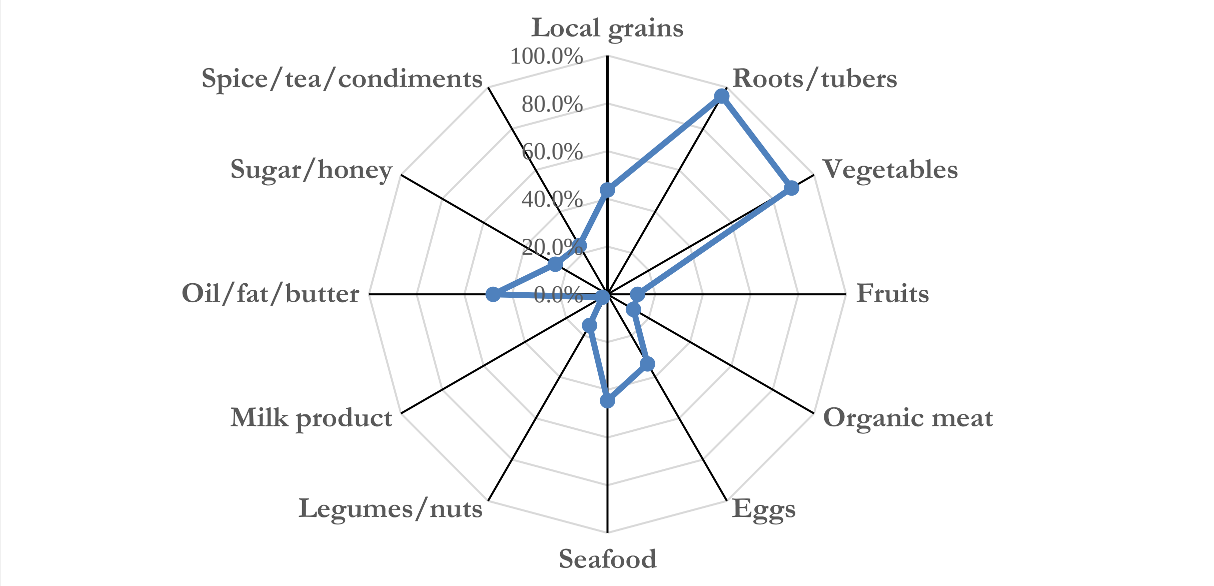

Figure 4.3: Reported dietary diversity from the monoculture cocoa households

Also, the radar summary of the reported eaten food groups indicated that sugar/honey 30 (25.2%), spices/tea/condiments 28 (23.5%), legumes/nuts 18 (15.1%), fruits 15 (12.6%), organic meat 15 (12.6%), and milk product 3 (2.5%) were the least food groups consumed by monoculture cocoa households.

Furthermore, the dietary diversity status, which is shown in the pie chart below (Figure 4.4) revealed that 4 (3%) out of the 119 monoculture cocoa households had high dietary diversity and 24 (20%) obtained moderate dietary diversity status. The majority of the monoculture cocoa households 91 (77%) in the study area fell within the low dietary diversity status.

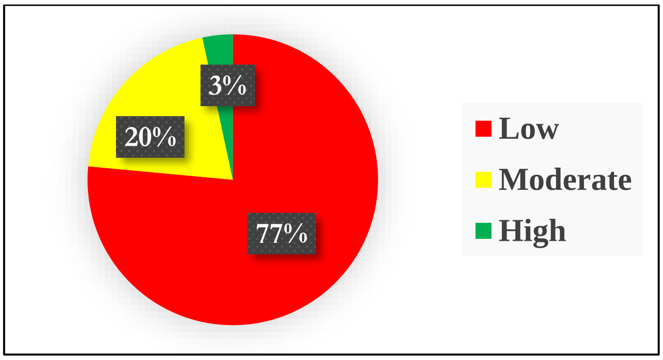

Figure 4.4: Monoculture cocoa households' dietary diversity status

4.3.2. Monoculture cocoa households' food production trends and food shortage/ unavailability periods

Figure 4.5 showed that, over the past 5 to 10 years, monoculture cocoa households indicated their food production trends as follows: increasing 4 (3.4%), not noticeable 12 (10.1%), and decreasing 103 (86.5%). This suggested that the absolute majority of the monoculture cocoa households were plagued with food insecurity. Again, the heads of the monoculture cocoa households were questioned regarding the sources of their staple foods, including self-production, the market, both (self-production and market), and other sources.

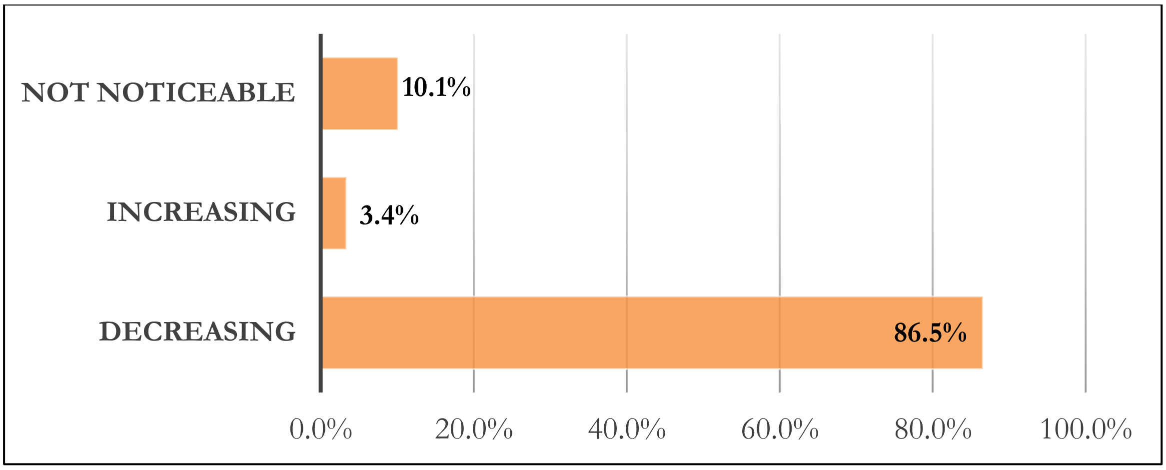

Figure 4.5: Monoculture cocoa households' food production trends

33.6% of them said they grow their food, 8.4% said they purchase it from the market, 57.1% said they both grow and purchase their food from the market, and 0.8% said others. When asked how far they walk to acquire their food from the market, 88.9% said it takes less than 30 minutes, 9.9% said they buy from nearby communities, and 1.2% said others.

4.3.3. Monoculture cocoa households' food shortage/ unavailability periods

In addition, concerning the food shortage/unavailability experiences, 8 (7%) out of the 119 monoculture cocoa households expressed no food shortage/unavailability experience, whilst 111 (93%) confirmed that they indeed experienced food shortages/unavailability (Figure 4.6). The monoculture cocoa farmers stated that they face food shortages/unavailability in certain months of the year. Regarding the food shortage/unavailability months in Figure 4.7, the following months were reported to be the severe food shortage/unavailability seasons: June 83 (74.8%), July 82 (73.9%), May 68 (61.3%), April 65 (58.6%), March 61 (55.0%), February 58 (52.3%), and January 57 (51.4%).

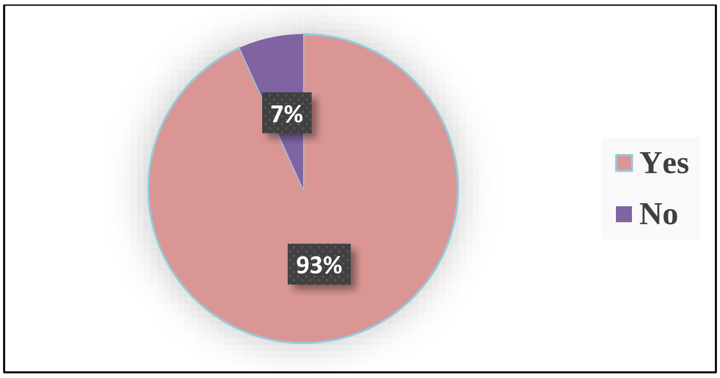

Figure 4.6: Monoculture cocoa households' food shortage/unavailability experience

The less severe food shortage/unavailability periods reported by the monoculture farmers were December 32 (28.8%), August 29 (26.1%), September 28 (25.2%), November 9 (8.1%), and October 7 (6.3%).

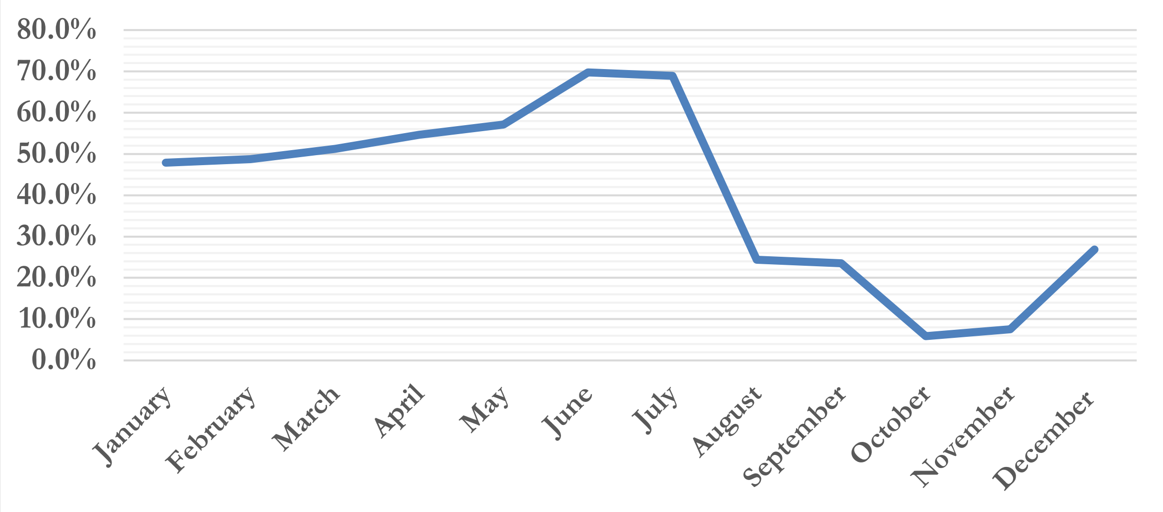

Figure 4.7: Monoculture cocoa households' food shortage/unavailability months

4.3.4. Agroforestry cocoa households' dietary diversity status

The agroforestry cocoa farmers in the study area were engaged in a series of interviews to assess their household dietary diversity. The radar summary graph illustrates the distribution of their recorded food groups (Figure 4.8). With reference to Figure 4.8, 11 of the food groups were highly consumed by the agroforestry cocoa households in the past 24 hours, including vegetables 79 (97.5%), roots/tubers 78 (96.3%), local grains 77 (95.1%), oil/fat/butter 76 (93.8%), seafood 74 (91.4%),

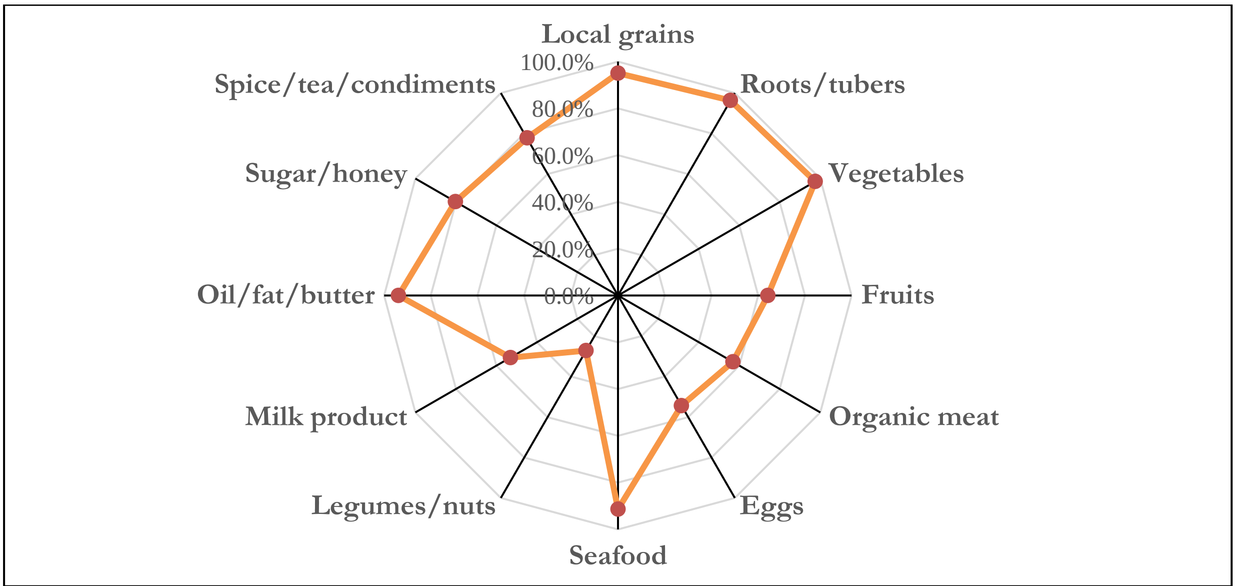

Figure 4.8: Reported dietary diversity from the agroforestry cocoa households

sugar/honey 65 (80.2%), spices/tea/condiments 63 (77.8%), fruits 52 (64.2%), organic meat 46 (56.8%), eggs 44 (54.3%), and milk products 43 (53.1%). On the other hand, only the legume/nut food group 22 (27.2%) was the least consumed by the agroforestry cocoa households in the study area.

With regards to the agroforestry cocoa household dietary diversity status classification (Figure 4.9), 2 (2%) out of 81 agroforestry cocoa households interviewed in the study area scored low dietary diversity as compared to moderate dietary diversity 28 (35%). The majority of the agroforestry cocoa households 51 (63%) scored high dietary diversity status.

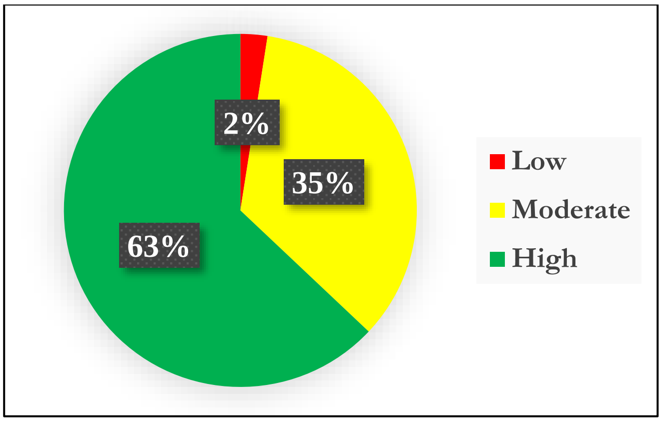

Figure 4.9: Agroforestry cocoa households' dietary diversity status

4.3.5. Agroforestry cocoa households' food production trends

According to Figure 4.10, the majority of the agroforestry cocoa households, which is 57 (70.4%) indicated that over the past 5 to 10 years, their household food production has been increasing, while 17 (21.0%) indicated decreasing food production. 7 (8.6%) of the agroforestry farmers mentioned that they did not notice any increment or decrement; in other words, no changes in their food production. A variety of staple food sources, including self-production, the market, both (self-production and market), and other sources, were asked of the heads of the agroforestry cocoa households.

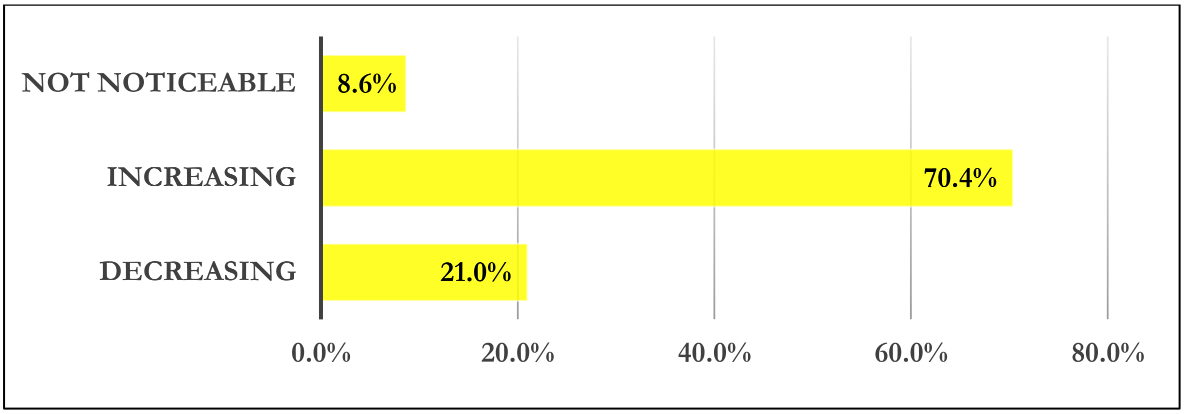

Figure 4.10: Agroforestry cocoa households' food production trend

Among them, 6.2% claimed to cultivate their food, 2.5% claimed to purchase it at the market, 91.4% claimed to both grow and purchase their food at the market, and no household said other. 50% of the respondents who were asked how far they had to walk to the market to get their food claimed it took less than 30 minutes, 50% said they bought it from the nearby communities, and none of the households stated other.

4.3.6. Agroforestry cocoa households' food shortage/ unavailability periods

Although, most of the agroforestry cocoa households 45 (56%) claimed that they had no food shortage/unavailability experiences, about 36 (44%) of the other agroforestry cocoa farmers shared their thoughts that they faced food shortages/ unavailability (Figure 4.11).

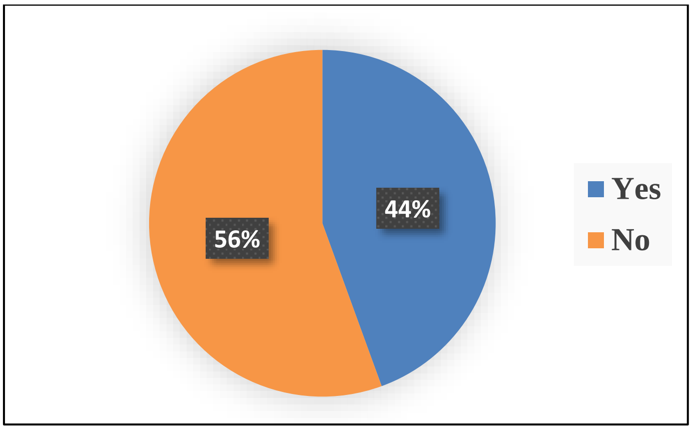

Figure 4.11: Agroforestry cocoa households' food shortage/ unavailability experience

The reported food shortage/unavailability months by the agroforestry cocoa households in the study area were as follows (Figure 4.11): July 22 (61.1%), June 22 (61.1%), March 14 (38.9%), April 13 (36.1%), February 13 (36.1%), May 11 (30.6%), January 11 (30.6%), December 10 (27.8%), August 5 (13.9%), September 1 (2.8%), October 1 (2.8%), and November 1 (2.8%).

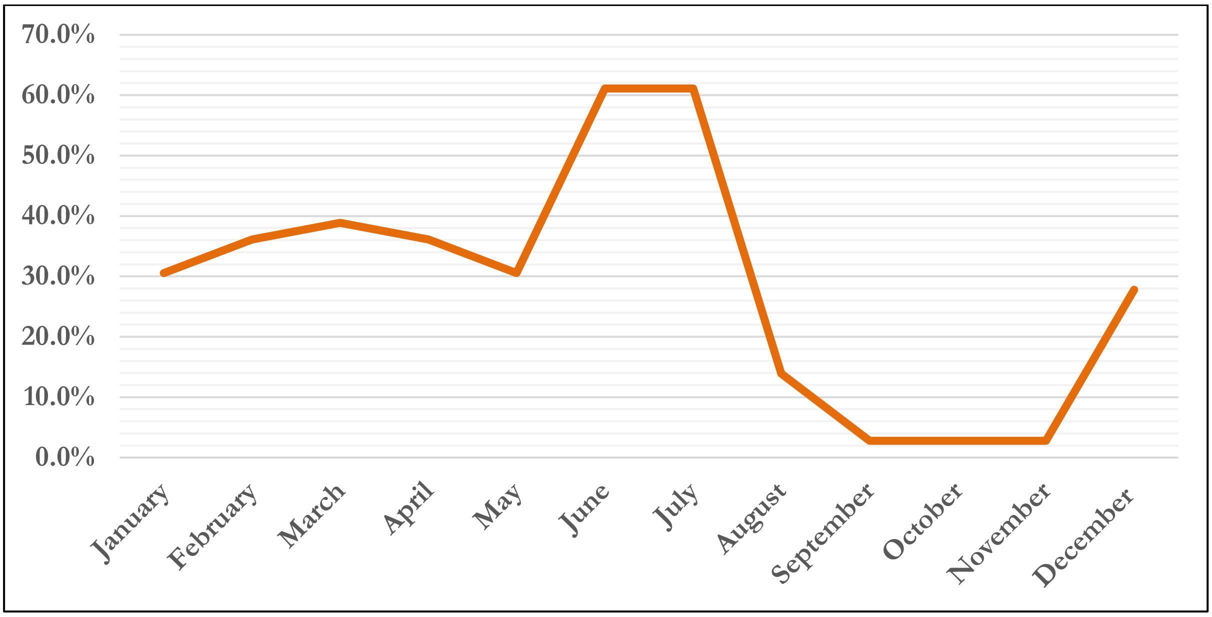

Figure 4.12: Agroforestry cocoa households' food shortage/ unavailability months

4.4. Variables influencing cocoa households' dietary diversity status

The estimated land use and socio-economic variables that affect cocoa household dietary diversity were analyzed and presented in this section. The summary statistics of all the variables employed in the ordinal logistic model in R studio are illustrated in Table 4.6 in the appendices. After checking multicollinearity among the independent variables, these variables, including monoculture households, cocoa income, and agroforestry size, were found to be highly correlated, and thus were excluded from the final model. The variables that were incorporated into the multivariate level analysis are presented in Table 4.7.

As can be seen in Table 4.7, the ordinal logistic model fit was determined to have a pseudo-R2 of 0.547, which means that more variation was explained by the model. The model and null were compared in a final likelihood ratio test, which produced a significant chi-square of 17 (232.2) and a p-value of 0.007. This demonstrated that the final model performed better than the null.

Table 4.7: Determinants of household dietary diversity

Explanatory Variables	**Determinants of Household Dietary Diversity**		**Odd Ratio (OR)**
	Threshold: Low Dietary Diversity (LDD) Moderate Dietary Diversity (MDD)		
	B	**Sig (p-value)**	
1. Sex (Ref = Male) Female	-1.8637	0.001***	0.155098
2. Age	0.1314	0.0012***	1.140424
3. Education	0.2538	0.0912*	1.288914
4. Marital status	-0.0941	0.6844	0.910192
5. Household size	-0.1055	0.3076	0.899874
6. Dependency ratio	-0.5180	0.0386**	0.595711
7. Cocoa cooperative	0.2138	0.7001	1.238375
8. Cocoa farming experience	0.0103	0.009***	1.010353
9. Cocoa farm age	-0.0655	0.1600	0.936599
10. Agroforestry households	5.9014	0.0001***	365.5489
11. Total household income	0.0328	0.9193	1.033344
12. Food crop farming	4.1606	0.0000***	64.10998
13. General food production trends	1.9145	0.0000***	6.783546
14. Access to Extension Officers	1.4326	0.0973*	4.189578
15. Monoculture cocoa size	0.1240	0.2112	1.132016
a. Base Category	High Dietary Diversity (HDD)		
b. No. of Observation	200		
c. – 2 Log Likelihood	96.17		
d. Likelihood Ratio LR Chi-Square (17)	232.2		
e. LR Chi-Square (p-value)	0.007		
f. Nagelkerke (Pseudo) R2	0.78		
g. AIC	226.3412		
h. BIC	282.3274		

Significance level: ***$p < 0.001$ (1%), **$p < 0.05$ (5%), *$p < 0.1$ (10%)

Source: Field Work, 2023

A total of 15 variables were predicted to have had statistical significance to determine household dietary diversity status; only 9 variables were determinants of household dietary diversity status. These 9 variables consisted of sex, dependency ratio, agroforestry households, education, cocoa farming experience, food crop farming, general food production trend, access to extension officers, and age. Among these variables, some had significant levels of 1%, 5%, and 10% with household dietary diversity status. According to the model results, there was a 10% significant level of relationship between education, access to extension officers, and household dietary diversity status. Also, the results revealed that there was a 5% significant level of association between dependency ratio and household dietary diversity status, whereas there was a 1% significance of p-value between sex, age, cocoa farming experience, agroforestry cocoa households, food crop farming, general food production trend, and household dietary diversity status. Marital status, cocoa cooperative, household size, cocoa farm age, total household income, and monoculture cocoa size were not statistically significant in influencing household dietary diversity status.

Regarding the base category (moderate dietary diversity), the model found that there existed a positive relationship (positive coefficient) between high dietary diversity status and these household and landuse variables, including age, education, cocoa farming experience, agroforestry cocoa households, food crop farming, and general food production trend (Table 4.8). Also, there was a negative association (negative coefficients) between dependency ratio, sex, and high dietary diversity.

This indicates that for every increase in a unit of the above variables of a household, there is a high chance of that household obtaining a low or high dietary diversity status. These variables and their associations with the household dietary diversity status are thoroughly examined in the discussion chapter.

5. DISCUSSION

5.1. Monitoring and mapping cocoa land use types expansion in the Bia West District

This study implemented the RF algorithm to map agroforestry cocoa, monoculture cocoa, open forest, closed forest, built-up/bare lands, and other landcover types in a cocoa landscape from 1999 to 2022 using both Landsat images and Sentinel 1 images. This present research classified cocoa landuse types into agroforestry and monoculture, which was not done in previous studies by Ajagun et al. (2021) and Asubonteng et al. (2018a). This research filled a gap in the literature by mapping and identifying various cocoa land use types within the study area (tropical region) using the RF algorithm in conjunction with the stacked Landsat and SAR data. The evaluated overall accuracies for the classified LULC maps (Table 4.3) increased from 1999 to 2022 than those reported by Ajagun et al. (2021) and Asubonteng et al. (2018a). This is probably because of the combination of Landsat, SAR, NDVI, and NDWI, which enabled the RF model to generate higher accuracies. The 1999 classified LULC map had a lower accuracy compared to 2017 and 2022. This is partially due to the 1999 image's poor atmospheric conditions, lack of SAR, and lack of independent reference data; as a result, some verified ground truth from 2017 and ground truth collected with local farmers' assistance were utilized to improvise. Because cropland is a small class and is typically planted under cocoa, it could have been misclassified, which is why its user and producer accuracies for the examined years were comparatively lower than those of the other classes in the study area. Similarly, closed forests outperformed the other classes, which may have been partially influenced by the closed forests' higher density of tree canopy than the other classes. Furthermore, the user accuracy of agroforestry cocoa in 1999 was greater than that of monoculture cocoa in 1999, suggesting that some trees may have been mistakenly classified as agroforestry cocoa. The estimated uncertainty account for the sampling irregularities that were present during the collection of reference data (Asubonteng et al., 2018a).

In 1999, cropland accounted for 1.86% of the area. This is partly because food crops, such as plantain, cocoyam, and cassava are intercropped on cocoa plantations, specifically to support the growth or establishment of old and new cocoa plantations (Amfo & Ali, 2020; Aneani et al., 2011). That percentage dropped significantly to 1.03% by 2017, and subsequently to 0.93% in 2022. According to Table 4.5, 163 households (81.5%) stated that they had converted all or parts of their croplands to cocoa plantations over the previous 2 decades of which the majority were from monoculture cocoa households, validating the LULC classification/change detection analysis (Figure 4.1, Figure 4.2, Table 4.4 and Table 4.5,) findings that cropland has decreased over the years in the study area. This finding that 81.5% of the cocoa households have converted all or parts of their croplands to cocoa plantations was akin to and somewhat higher than the percentage (80.01%) that Ajagun et al. (2021) obtained in a parallel study that was carried out in the Juaboso District, Western North Region of Ghana. This implies that more cocoa farmers converted their croplands for cocoa expansion in the Bia West District than in the Juaboso District, which may be due to the lack of available land. According to Quaye et al. (2014), the inaccessibility of new land makes it difficult for cocoa farmers to increase their output, forcing them to convert some or all of their croplands to cocoa cultivation. Plantain, cocoyam, cassava, yam, fruits, vegetables, maize, and rice are among the crops said to have been replaced with cocoa plantations by both monoculture and agroforestry houses.

Agroforestry and monoculture cocoa production together occupied the highest portion of the studied region's landscape, accounting for 45.55%, 62.33%, and 55.75% of it in 1999, 2017, and 2022, respectively (Table 4.4). As evident in Table 4.4 and Table 4.5, between 2017 and 2022, the area of monoculture cocoa lost about 276.6 km^2, whereas the area of agroforestry cocoa gained 191.4 km^2 within the same time frame. The farmers' increased understanding of the value of agroforestry cocoa farming in maintaining household food security may help partially explain the increasing scale of agroforestry cocoa farms in the study area (Jacobi et al., 2015; Kuyah et al., 2019b; Schneider et al., 2017). Also, due to their direct sun exposure, monoculture cocoa trees may have been affected by the detrimental effects of climate change, causing some of them to perish eventually (Andres et al., 2016; Jacobi et al., 2015; Niether et al., 2020).

Moreover, as shown in Table 4.2, 88.0% (176) of the cocoa households in the Bia West District expressed that they had engaged in cocoa expansion over the last 22 years. The cocoa expansion over the years can be attributed to the area's suitability for cocoa growing, the social prestige associated with cocoa farming, the fact that cocoa farms are assets that can be transferred to future generations, and numerous government incentives for cocoa farming, like mass cocoa spraying, and fixed market prices for cocoa (Ajagun et al., 2021; Asubonteng et al., 2018a; Deans et al., 2018; Michel-Dounias et al., 2015). The farmers disclosed that the cocoa expansion took place in one or a combination of these areas; off-reserve forests, cropland, and fallow land. None of the farmers had cocoa farms in the protected areas or closed forests, supporting the conclusion by Benefoh et al. (2018) that cocoa production is far less common in closed forests than it is in open forests.

5.2. Impact of cocoa land use types expansion on household food security

5.2.1. Analysis of household dietary diversity among cocoa households

The household dietary diversity assessment of the food groups reported to have been consumed by the monoculture and agroforestry cocoa households in the Bia West district in the past 24 hours is significantly different. This is influenced by variables, such as household income, income from cocoa, food production, the cocoa farming experience of the household head, dependency ratio, and cocoa landuse type, according to the findings from this study and other studies (Asefach & Nigatu, 2007; Cordero-Ahiman et al., 2021; Isabirye et al., 2020; Sekhampu, 2013).

The most commonly consumed foods in both agroforestry and monoculture cocoa households are roots/tubers, vegetables, and oil/fat/butter, which are the general staple food eaten throughout the Western North Region of Ghana (Ajagun et al., 2021; Ghana Statistical Service, 2014). This result conforms to the findings by Taruvinga et al. (2013) and Ochieng et al. (2017), who found that oils/fats, vegetables, and roots/tubers were among the main diets eaten by rural households in Nyandeni district, South Africa and Tanzania (Bahi District and Mbarali District), respectively. A similar finding was observed by Isabirye et al. (2020), who argued that fats and oils are highly consumed by rural households in Eastern Uganda, partly due to their cheap price. It is not a good dietary habit for 66.5% of cocoa households in the Bia West District to be consuming too much unhealthy fats and oil since it could lead to obesity and other health complications (Chandler, 2018).

In contrast to studies, namely Heim and Paksi (2019), Sambo et al. (2022), and Taruvinga et al. (2013), who revealed that vegetables as a food group are barely eaten among rural farmer households in Namibia and South Africa, this study found it to be the second highest consumed in the study area. This may be elaborated partly by their richness in vitamins and minerals (Hernandez, 2018), and their accessibility (Sambo et al., 2022) since the majority of the cocoa households in the study region cultivate it. Vegetables are key ingredients in ensuring quality dietary diversity (Ochieng et al., 2017).

The following food groups, such as local grains, seafood, sugar/honey, and spices/condiments were the next somewhat highly consumed food groups by the cocoa households. This finding is inconsistent with the findings reported by Jebessa et al. (2019), Sambo et al. (2022), Heim and Paksi (2019), and Megbowon and Mushunje (2018), who concluded that the top three food groups highly consumed by rural households were local grains/cereals, sugar/honey, and spices/condiments. Also, Ochieng et al. (2017) found that the spices/condiments food group is among the top food groups eaten by rural households, which was contrary to this present study's findings. In addition, this study revealed that seafood was consumed by a relatively good number of the respondents (44.5%) than the reported figures by Mekuria et al. (2017) 0.2%, and Ochieng et al. (2017) less than 16%. Cereals/ local grains happened not to be part of the top three food groups because the majority of the cocoa households rarely cultivated grains, such as maize, rice, and millet in the study area.

The least-consumed food groups by the cocoa households in the study area were eggs, fruits, organic meat, milk products, and legumes/nuts. The findings of Mekuria et al. (2017) in West-North Ethiopia and Sinyolo et al. (2021) in South Africa concurred with the findings of the present study on the least consumed food groups. This suggests that the low consumption of these food groups in the study area could be a result of a lack of education among the cocoa household heads, particularly, the household heads without formal education may not know the relevance of balance-diet (Megbowon & Mushunje, 2018). The high price of these food groups and the fact that the farmers might not have enough money to buy them given their poor incomes could be another contributing factor (Ruel et al., 2004). Due to their infrequent consumption of meat, legumes (beans), milk products, and eggs, the findings also demonstrate that certain cocoa households are protein-deficient (Sambo et al., 2022).

Concerning the general dietary diversity status distribution among the cocoa households in the Bia West district, the findings indicated that most of the cocoa households were in the low dietary diversity category. It was also revealed from the analysis that the majority of the households that had high dietary diversity obtained their food from both self-production and the market. Sibhatu and Qaim (2018) findings confirmed that households that get their staple food from self- and market-produced sources have a higher chance of obtaining high dietary diversity. This finding is consistent with earlier studies, which revealed that low dietary diversity dominated in many rural communities as against high and moderate dietary diversity (Cheteni et al., 2020; Heim & Paksi, 2019; Isabirye et al., 2020). Contrary to the findings of this study, Megbowon and Mushunje (2018) discovered that 61.7% of the respondents had high dietary diversity in the Eastern Cape Province of South Africa. Also, Sambo et al. (2022), Taruvinga et al. (2013), Mekuria et al. (2017), Shisana et al. (2014), and Mango et al. (2014) studies unveiled that moderate dietary diversity was persistent in their study areas, which were not aligned with this present study's findings. The prevalence of low dietary diversity in the study area implies that the majority of cocoa households are highly vulnerable and severely undernourished since they do not have good quality dietary diversity.

5.2.2. Food production trends among cocoa households

The food production trends over the past 5-10 years were quite different among the monoculture and agroforestry cocoa households. A high proportion of both monoculture and agroforestry cocoa households (60%) indicated a decreasing food production as against an increase (30.5%). The findings from this present study suggest that the study area is not food secure because there is a significant reduction in the amount of food production. This could be attributed to cocoa expansion, which has displaced many croplands in the study region (Ajagun et al., 2021; Akrofi-Atitianti et al., 2018; Kuuwill et al., 2022). The findings conform to the findings by Dei Antwi et al. (2018), who found that the majority of cocoa households (67%) were food insecure in the Wassa-Amenfi West District, Western North Region of Ghana. Similarly, this finding corroborated that of Oluyole and Taiwo (2016), who indicated that 57% of the cocoa households in Ondo State, Nigeria were food insecure. However, the result from this study was inconsistent with the findings by Taylor (2017), who claimed that 73% of the cocoa households in the Ashanti Region, Ghana were food secure.

5.2.3. Food shortage/ unavailability periods among cocoa households

The monoculture and agroforestry cocoa households in the study area had comparable food shortage/ unavailability months. The months of June, July, May, April, March, February, and January, respectively, saw the highest percentage of families in the study's monoculture and agroforestry households suffer food shortages/ unavailability. April to September is the rainy season and also the beginning of the farming season where food is cultivated, however, from December to March is the dry season and the peak period for foodstuff in the study area (Ghana Statistical Service, 2014). During the peak seasons, food prices rise, making it more difficult for low-income households to buy enough food to feed their families (Rademacher-Schulz et al., 2014), especially during rainy and dry seasons in the study area. This may leave such cocoa households with no option but to consume low-quality diets, mainly made up of high-starchy foods, such as cassava and yam (Ochieng et al., 2017). Moreover, Kiewisch (2015) disclosed that households in cocoa-growing villages in Ghana have food shortages during the rainy season, notably between July and September, as the basic crops like cassava run out. In addition, Kiewisch (2015) pointed out that these households struggle to pay for their daily dietary needs because the proceeds from cocoa sales run out in the same time frame before the subsequent harvest.

5.3. Determinants of household dietary diversity status

The findings from Table 4.7 suggest that the sex of the household head had a direct impact on the household dietary diversity at 1% significance. The model predicts that as the proportion of female-headed households rises, there is a 0.155 less likelihood that their nutritional diversity will be high in comparison to their male-headed counterparts. The primary reason for this is that cocoa female household heads typically have high levels of poverty as well as fewer opportunities to engage in activities that generate revenue because they have more responsibilities related to home maintenance and child-rearing as well as high (Dei Antwi et al., 2018). Other studies, such as Powell et al. (2017) and Felker-Kantor and Wood (2012) found corresponding findings that male-headed households are more food secure than female-headed households in Tanzania and Brazil, respectively. In contrast to previous findings, Silvestri et al. (2015) revealed that households with female heads may not experience more acute food insecurity than those with male heads.

In addition, the model results revealed that the dependency ratio had a significant negative association at 5% significance with high dietary diversity. The higher the dependency ratio, the lower the chance of that household having high dietary diversity. The observed data implies that the larger the dependency ratio, the more burden befall the household head to provide the nutritional needs of his or her household, thus there is a 0.596 lower probability of that household scoring a high dietary diversity status. This evidence was similar to the findings by Asefach and Nigatu (2007), Bogale and Shimelis (2009), and Dei Antwi et al. (2018), who remarked that a larger dependency ratio decreases household food diversity. This is partly because people are more aware of and comprehend the advantages of the dependency ratio (Sambo et al., 2022; Sekhampu, 2013). For instance, Taylor (2017) revealed that cocoa households with larger dependency ratios may harm the household food security status since the household number outweighs the available food resources.

As the study predicted that the cocoa farming experience significantly influences the household dietary diversity status, the model results confirm that this variable had a positive correlation with high dietary diversity at a 1% significant level. This effect suggests that an increase in the cocoa farming experience of the household heads would have a positive influence on the households' level of household dietary diversity. Thus, the household dietary diversity status would increase by an odd ratio of 1.010 for every year that a household head's cocoa farming experience increased. This outcome conforms to Ajagun et al. (2021) findings, which indicated that the household head's expertise in cocoa farming is particularly important for the production of cocoa since higher levels of experience lead to greatly improved cocoa farming techniques, which in turn increase yields and food security.

Moreover, findings from this study show a positive correlation at a 1% significant level between age and high dietary diversity, indicating that the higher the age of the household head, the more likely the household head attains a high level of dietary diversity. There would be a positive impact on such households' dietary diversity by an odd ratio of 1.140. This evidence corroborated the findings by Dei Antwi et al. (2018) Sambo et al. (2022), and Heim and Paksi (2019), who disclosed that an increase in the age of the household head would increase the household's food security in Ghana, South Africa, and Namibia, respectively. Nevertheless, according to Aidoo et al. (2013), older household heads experience food insecurity because their output declines as they age.

According to the model's results, there was a positive statistically significant correlation between high dietary diversity and access to extension officers at a 10% significant level. This implies that the more households have access to extension officers, the higher the chance of achieving a highly diverse range of dietary patterns with an improvement in dietary diversity by 4.189 than households that do not have access to extension officers. This is because when households have access to extension officers, it enhances those households' cocoa farming experiences; hence increasing their household food security in the long run. These findings agree with the findings of Ingutia and Sumelius (2022), who pointed out that access to extension service help increase rural farming households' food security in Kenya.

Furthermore, as expected, there was a positive correlation between education and high dietary diversity at a 10% significant level. A unit increase in the level of education of the household head increases the household dietary diversity. This implies that as more household heads advance in education, there is a 1.288 greater chance of those household heads obtaining high dietary diversity as compared to household heads with low levels or no formal education. How knowledgeable the household head is on the food groups required for human growth and development may depend on how much schooling they have; thus knowing about these food varieties ultimately influences dietary decisions that improve the quality of the food ingested by family members (Cordero-Ahiman et al., 2021; Dei Antwi et al., 2018). The evidence was similar to that of Isabirye et al. (2020) in Ghana and Sambo et al. (2022) in South Africa, and Cordero-Ahiman et al. (2021) in Ecuador.

The model results revealed that agroforestry cocoa households had a significant positive association with high dietary diversity at 1%. The more households shift to agroforestry cocoa farming, the higher the chance for those households having a high dietary diversity as against monoculture cocoa households. The observed data implies that with every rise in the unit of agroforestry cocoa households, there is a 365.548 higher likelihood of having a high dietary diversity. This variable was expected to have been positive since agroforestry or shaded cocoa plays a great socio-economic and ecological role in the cocoa landscape, and helps increase yield (Niether et al., 2020) ensuring local food security of cocoa households (Schneider et al., 2017). For example, Kuyah et al. (2019b) found that the good nature of the agroforestry cocoa ecosystem helped safeguard the local food security of agroforestry cocoa households in comparison to monoculture or full-sun cocoa households. Similarly, Jacobi (2016) study discovered that the agroforestry system ensured local food security in Bolivia.

Moreover, findings from this study show a strong positive correlation between food crop farming and high dietary diversity with a p-value of 0.000 (1%), indicating that households that grow food crops are more likely to have a high dietary diversity. There will be a 64.109 greater chance of such households having a high dietary diversity for every unit increase in the number of household heads cultivating food crops. In the same vein, concerning the model results, the coefficient between general food production trends and high dietary diversity was positive and significant at 1 % (p-value: 0.000). This means that households that experience an increase in their food production stand a 6.783 higher likelihood of having high nutritional diversity compared to those with a decline in their food production. Taylor (2017) confirmed that cocoa households that grow food crops in addition to cocoa are food-secured or obtain higher dietary diversity than households that do not. Silvestri et al. (2015) postulated that households that produce more of their basic foods to guarantee there is always food available reduce their vulnerability to seasonal food insecurity.

Total cocoa income, marital status, cocoa cooperative, cocoa farm age, monoculture cocoa size, and household size were not significant with high dietary diversity, which was in line with some other studies (Ajagun et al., 2021; Silvestri et al., 2015).

5.4. Reflection on stakeholders’ roles in guaranteeing sustainable cocoa landscape and food and nutrition security in the Bia West District

In Ghana's forest belt, cocoa production has dominated agricultural land use due to its economic importance to the majority of smallholder farmers (Ajagun et al., 2021; Ashiagbor et al., 2020). Despite this, the majority of cocoa farmers remain mired in poverty and unable to provide for their daily food and nutritional needs due in large part to the meager money earned from cocoa sales, which is a result of the government's low cocoa pricing (Ajagun et al., 2021). Additionally, the Bia West District's cocoa farmers are struggling with the negative effects that climate change is having on their cocoa crops, which has also contributed to food insecurity in the majority of cocoa landscapes. Consequently, the local cocoa farmers are expanding their cocoa plantations widely at the expense of secondary forests and agricultural lands to boost their household earnings and, to a greater extent, their food security (Ajagun et al., 2021; Asubonteng et al., 2018a).

The involvement of stakeholders cannot be disregarded, even while farmers have been at the vanguard of food production and eventually the realization of food security. Although the government of Ghana has implemented policies, such as subsidizing farm inputs and fertilizers to cocoa farmers, along with its flagship program "Planting for food and jobs," the government must effectively intensify awareness programs on the need for cocoa farmers to engage in crop diversification to reduce their reliance on only cocoa income and ensure their food and nut security. Again, local farmers should have access to seeds for climate-resilient cocoa varieties and other food crops for free or at substantial discounts, and cocoa prices should be raised. Additionally, to solve issues related to intensification and encourage land sparing in the area, the government, through the Bia West area land use planning department, should closely monitor and efficiently implement the spatial planning regulations. Moreover, SVN and Tropenbos Ghana, among other private partners, are once more urged to continue educating and enlightening the local cocoa farmers about the value of agroforestry cocoa production and working with them to acknowledge the local spatial plans. Finally, both the government and private sector players should roll out incentives to encourage farmers to switch to agroforestry cocoa production and minimize farmland conversion. This will ultimately increase farmers' cocoa yields, ensuring their food security and maintaining a sustainable cocoa landscape without expanding their cocoa farms.

6. LIMITATIONS, CONCLUSION, AND RECOMMENDATIONS

6.1. Limitations

Just like any other research, this present study encountered a few challenges, particularly with the remote sensing dataset, ground truth, and household survey data collection. It was quite cumbersome downloading cloud-free Landsat images from the USGS. Moreover, some of the farmers did not agree for their households and farm coordinates to be taken by handheld GPS because of failure to meet their exorbitant demands. The study had to change some of the study sites largely due to security reasons. Regardless, these challenges did not influence the analysis of this thesis.

6.2. Conclusion

The study successfully combined Landsat and SAR images with the RF technique to map and distinguish agroforestry and monoculture cocoa land use and other land covers. Food security questions, such as household dietary diversity score, food shortage, and production trends were asked of the farmers and analyzed to determine the food security status of the monoculture and agroforestry cocoa households, and by extension the whole study area. It was hypothesized by this study that there is a positive relationship between agroforestry cocoa households and high dietary diversity status, as well as a negative relationship between monoculture cocoa households and high dietary diversity status. Thus, this study accepts that there is a positive relationship between agroforestry cocoa households and high dietary diversity status (2.39 coefficient), and a negative relationship between monoculture cocoa households and high dietary diversity status (-2.39 coefficient) since the Chi-Square test had a p-value of 0.001.

The study unveiled that cocoa production has been increasing over the years at the expense of croplands and off-reserve forests primarily. According to the LULC change detection, monoculture cocoa replaced more croplands than agroforestry cocoa. Through this research, it was found that the amount of closed forest had considerably declined over the previous 23 years, as well as monoculture cocoa decreased between 2017 and 2022.

It was found that agroforestry cocoa households had a higher dietary diversity status compared to monoculture cocoa households. The results disclosed that fruits, organic meat, eggs, legumes, and milk products were barely consumed as against roots/tubers, vegetables, and oil/fat/butter in the monoculture cocoa households compared to agroforestry cocoa households. The findings suggested that food production has been increasing in agroforestry households more than in monoculture households. Moreover, June and July were the 2 months both the monoculture and agroforestry cocoa households experienced high food shortages/unavailability.

The results showed that 9 variables had a significant relationship with household dietary diversity. Agroforestry cocoa households, food crop farming, sex, age, cocoa farming experience, and general food production trends were revealed to have had a highly significant association at 1% with high dietary diversity status. Among these variables, only sex (female-headed households) had a negative relationship with high dietary diversity at a 1% significant relationship.

6.3. Recommendations

This study suggests that farmers in the study region need to periodically be informed and made aware of the relevance of consuming fruits, legumes, and dairy products. Also, farmers ought to be motivated to switch to shaded cocoa and adopt sustainable cocoa-producing practices to protect the forest. Future studies might examine and quantify the consequences of increasing cocoa production on the ecosystem's functioning, as well as assess the effectiveness of government policies toward ensuring the food and nutritional security of cocoa households.

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7. APPENDICES

Table 3.1: Names and number of household surveys per the selected communities

No	Towns/ Communities	Study area group	No. of household survey
1	Asuopiri	North	17
2	Yawmatwa		47
3	Elluokrom	East	11
4	Adjoafua		23
5	Kojoaba	West	23
6	Nkrabea		25
7	Akaatiso	South	54
	Total		**200**

Source: (Ghana Statistical Service, 2014)

Table 3.3: Data Management Plan

Data collection

Name of Data	Primary / Secondary	Availability	Data format	Temporal resolution	Contains personal data (No/Yes)	Source	Software
Landsat 2000, 2015 & 2022	Secondary	Free	Raster	30 meters	No	USGS	Envi 5.6 Arcmap 10.8
Sentinel-1 2015 & 2022	Secondary	Free	Raster	5 meters	No	Copernicus	Google Earth Engine
Survey	Primary	Free	Text	-	Yes	-	Kobo collect/ survey paper
Bia West	Secondary	Free	Vector	-	No	The	ArcMap

shapefile and other shapefiles						University of Ghana RSGIS Lab	
Ground truth	Primary	Free	Vector	-	No	Author	Hand-held GPS

Organization and documentation of data

Data Organization: 1. How will you organize your data during the project? 2. What can you tell about the quality of the data?	There was the main folder for the research with different sub-folders, such as thesis write-up, datasets (downloaded, pre-processed), survey data, and analysis. Good

Processing your data

Versioning: 1. What would be your strategy concerning versioning your data files during the project? 2. How can different versions of a data file be distinguished?	Different data files had different versioning folders. Using date created, names, and version number.

Storage and sharing

Data storage: 1. Where would the data be stored? 2. Any backup storage? 3. Any strategy to prevent unauthorized access to data during research?	The data was stored on my laptop. Yes, on my UT Google Drive. Password was set on the data. View-only option for external users.

Table 3.4: Description of land use/cover classes

Land use refers to the socioeconomic usage of a piece of land, whereas land cover refers to the visible surface of a piece of land.

LULC Classes	**Description**
Open Forest	This constituted secondary and plantation forest cover, usually found outside the protected areas and forest reserves.
Closed Forest	This constituted only primary forest cover. This is found in the protected areas and forest reserves.
Built-up/bare land	urban, commercial, and industrial areas. Playgrounds and truck terminals. Portions of the ground or bare rocks are not covered with vegetation. There are apparent

	desolate patches within and surrounding built-up areas. Terrains cleared in anticipation of development or cultivation make up this category.
Monoculture cocoa	The land is allocated for the cultivation of only cocoa with no planted trees within. This is also known as full-sun cocoa.
Agroforestry cocoa	This cocoa landuse is also known as shaded cocoa, which refers to cocoa fields that contain both natural and planted trees.
Cropland	The land is allocated for growing staple food crops, such as maize, plantain, cassava, yam, and cocoyam.
Other tree crops	It included palm trees, etc

Source: (Adamu et al., 2021; Ashiagbor et al., 2020)

Figure 3.2: Pictures showing the different classes mapped

Source: (Google Earth, 2022; Fieldwork, 2023)

Table 3.5: Input variables of the implemented RF model for 1999, 2017, and 2022

1999	2017	2022
Blue	Blue	Blue
Green	Green	Green
Red	Red	Red
NIR	NIR	NIR
SWIR	SWIR 1	SWIR 1
NDVI	SWIR 2	SWIR 2

NDWI	NDVI	NDVI
	NDWI	NDWI

Table 4.6: Summary statistics of the variables used in the ordinal logistic regression model

Variables		Frequency	Mean	Std. Deviation
Household dietary diversity	Low Dietary Diversity (0-4)	93	2.33	1.296
	Moderate Dietary Diversity (5-8)	52		
	High Dietary Diversity (9-12)	55		
Sex	Female	79	0.61	0.490
	Male	121		
Age	between 25 and 45	44	1.98	0.645
	between 46 and 66	117		
	above 67	39		
Education	Primary	20	3.36	1.421
	JHS/Form 4	53		
	SSS/O or A level	27		
	Tertiary	35		
	No formal education	65		
Marital status	Married	148	1.63	1.131
	Single	8		
	Divorced	14		
	Widow/widower	30		
Household size	between 1 and 5	55	1.96	0.715
	between 6 and 10	98		
	above 10	47		
Dependency ratio	between 1 and 2	72	1.79	0.679
	between 3 and 4	99		

	between 5 and 6	29		
Cocoa cooperative	No	43	0.79	0.412
	Yes	157		
Cocoa farming experience	between 10 and 30	135	1.37	0.570
	between 31 and 50	56		
	above 50	9		
Extension officers	No	26	0.87	0.337
	Yes	174		
Agroforestry cocoa households	No	119	0.41	0.429
	Yes	81		
Monoculture cocoa households	No	81	0.60	0.429
	Yes	119		
Total household income	less than 10,000	105	1.82	0.918
	Between 10,000 and 30,000	26		
	Above 30,000	69		
Food crop farming	No	14	0.93	0.256
	Yes	186		
General food production trends (5-10 years)	Decreasing	120	1.50	0.665
	Increasing	61		
	Not noticeable	19		
Income from cocoa			40016.00	56069.977
Agroforestry cocoa acres			5.10	7.821
Monoculture cocoa acres			4.02	4.427
Cocoa farm age			30.49	11.121

Source: Field Work, 2023 Sample Frame (N) 200