

Enhancing food Security through Agroforestry: A Case Study in Petit-Bondoukou, Nawa Region, Côte d'Ivoire

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Abstract Ensuring food security in tropical regions presents significant challenges due to the competition between cash crop cultivation and food crop production. This study focuses on Petit-Bondoukou, a key cocoa-producing zone in Côte d'Ivoire, investigating food diets and evaluating the potential of agroforestry systems to mitigate food insecurity. All cocoa farmers engage in agroforestry as a national strategy to combat cocoa swollen shoot disease through diversification. Three distinct agroforestry systems, involving various plant associations, were implemented by cocoa farmers. The research compared households practicing agroforestry with those not practicing it. The surveyed households commonly consumed cooked and processed roots, tubers, cereals, vegetables, meat, and pulses. Notably, pounded yam with okra sauce exhibited the highest dry matter content (94.66%), while guava and pounded yam with palm nut sauce displayed acidic pH values (4.13 and 4.61, respectively). Nutritional analyses revealed distinct attributes; rice and eggplant sauce had the lowest lipid content (2.90%), whereas rice with peanut sauce provided the highest protein rate (16.16%). Apart from fruits, all foods exceeded the recommended daily energy intake. Households practicing agroforestry relied on their farms for roots, tubers, and cereals, reducing the need to purchase food. Among households not practicing agroforestry, 80% experienced food shortages, compared to only 35% of households practicing agroforestry. Households practicing agroforestry had a higher intake of meat and pulses, with these pulses primarily sourced from their farms. Additionally, households practicing agroforestry exhibited higher consumption of vegetables. A higher percentage of households practicing agroforestry (78.6%) were identified as food secure compared to households not practicing agroforestry (38.9%). Moreover, households practicing agroforestry exhibited superior food consumption scores. This research provides insights into the role of agroforestry in enhancing food security in tropical regions.

Keywords: Cocoa agroforestry, Food availability, Food consumption, Food diets, Food security

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1. Introduction

Food insecurity, defined as "a lack of consistent access to enough food for every person to live an active, healthy life" [1], remains a pervasive issue in sub-Saharan Africa despite various programs implemented to address it [2]. In Côte d'Ivoire, the world's leading cocoa producer, 10.9% of households in rural areas were reported to be experiencing food insecurity [3]. Women-headed households were particularly vulnerable, with 15% experiencing food insecurity, compared to 12% of men-headed households [4]. However, food insecurity exacerbates malnutrition, which is a significant public health problem in Côte d'Ivoire. The country has one of the highest rates of childhood stunting worldwide (23%), serving as an indicator of chronic malnutrition. Rates of

emaciation and underweight were approximately 8% and 14%, respectively [5]. Moreover, malnutrition affects both urban and rural populations, with high rates found among children in cocoa-producing zones of Côte d'Ivoire, reaching 48.7% [4] and 39% [6].

Malnutrition is caused by nutritional deficiencies in proteins, energy, vitamins, and minerals [7]. It is also attributed to a lack of food diversification or limited food choices among populations [8]. In the cocoa zone, characterized since the 1960s by a cocoa mono-cropping system, the cultivation of food crops has been neglected. This has led to shortages of main foodstuffs in local markets [9]. However, historically, populations relied on products from the forest or developed multi-layered tree-crop systems in their fields to ensure access to fruits, vegetable leaves, spices, cash crops, and health products with high commercial value [10,11].

Food insecurity and malnutrition in rural Africa can be

addressed by popularizing diversified, multi-layered tree-crop systems that provide farmers with fruits, vegetable leaves, spices, cash, and health products with high commercial value [12,13]. Indeed, agroforestry in the tropics has many benefits, including household consumption of agroforestry products all year round, reducing the risk of food shortages, and income diversification that allows farmers to generate cash throughout the year by selling a wide array of fruits and nuts with high nutritional and commercial value [10,11,12,13,14]. Income from the sales of these fruits and nuts is used to purchase foodstuffs in periods of the year when the main income source from the sale of commodities is lacking. For example, in the humid forest zone of Africa, cocoa is the main cash crop and provides substantial income to farmers from September to January. During the rest of the year, farmers do not have enough income from cocoa to cover their daily needs. Processed cassava roots, also called ‘attiéké’ in Côte d’Ivoire, are widely consumed and traded in the country. While diversified agroforestry systems can provide year-round food to farmers and reduce the risk of food shortages and malnutrition in rural Africa, evidence on the effective contribution of agroforestry products or income generated by agroforestry in balancing diets or reducing food insecurity in rural Africa is currently lacking. Ongoing initiatives in Côte d’Ivoire aim to rebuild forest cover in agricultural landscapes using agroforestry techniques [15].

Since the 1960s, cocoa mono-cropping has been extensively practiced in Côte d’Ivoire following the introduction of high-yielding cocoa varieties. Farmer-driven efforts to restore forest cover in the country involve the establishment of diversified tree-crop systems. These initiatives align with actions undertaken by the Coffee and Cocoa Regulatory Board of Côte d’Ivoire to mitigate the spread of cocoa swollen shoot disease. This involves cutting down infected cocoa plants and rehabilitating the farms through a diversification approach. In the Nawa region, one of the major cocoa-producing areas of Côte d’Ivoire [16], cocoa farm rehabilitation includes the removal of infested cocoa plants. Indeed, the Nawa Region accounted for 8.7% of the 993,031 coffee and cocoa producers in Côte d’Ivoire in 2020 (Conseil du Café Cacao Côte d’Ivoire 2020). Subsequently, the cleared land is utilized for integrating food crops, fruit trees, and forest trees, with cocoa being planted one or two years later. The selected food crops comprise cassava and banana plantain (*Musa x paradisiaca* L., Musaceae), while exotic fruit species such as avocado (*Persea americana* (Mill.) (Lauraceae), guava (*Psidium guajava* L. (Myrtaceae), and orange (*Citrus sinensis* L., Rutaceae) trees are also incorporated. Additionally, indigenous forest trees such as Akpi (*Ricinodendron heudelotii* (Baill.) Pierre ex Heckel, Euphorbiaceae) and kplé (*Irvingia wombolu* Vermoeasen, Irvingiaceae), which produce kernels used as local spices and soup thickeners, are included [10,12,14,17].

However, the potential of the food, fruits, and nuts harvested from these agroforestry systems to alleviate food and nutritional insecurity in the region remains unknown. This study is a step towards recognizing the value of agroforestry for food and nutritional benefits. It aims to (i) assess the food diets, (ii) evaluate the impact of agroforestry on the food availability of households, and

(iii) examine the effects of agroforestry on the reduction of food insecurity in a cocoa-producing zone of Côte d’Ivoire.

2. Materials and Methods

2.1. Study Area

The study was conducted in Petit-Bondoukou, Nawa region, Côte d’Ivoire (Figure 1).

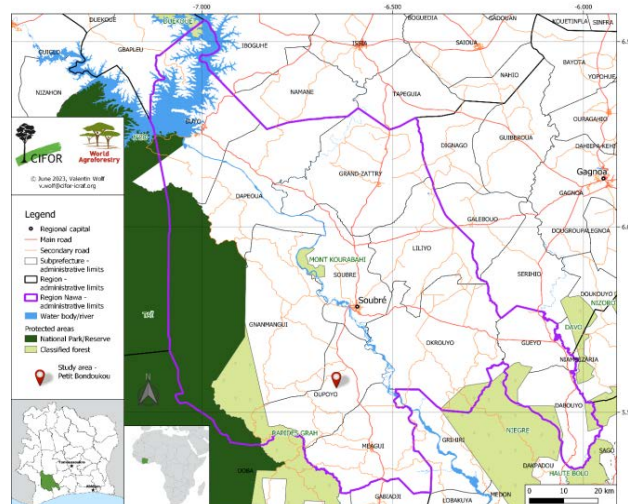


Figure 1. Localization of Petit-Bondoukou in the Nawa region, Côte d’Ivoire

2.2. Study Population

Initially, Petit-Bondoukou had a population of 245 cocoa producers in 2013 [18]. However, due to the outbreaks of cocoa swollen shoot disease, some cocoa farmers have shifted to trading, food crop production, or gardening, leading to a decrease in the number of cocoa producers. Additionally, farmers have introduced trees on cocoa farms to slow the spread of cocoa swollen shoot disease. The resulting cocoa agroforestry systems are cocoa-cassava-banana plantain, cocoa-avocado-akpi, and cocoa-avocado-akpi-guava. Cocoa plants are spaced by 3 m x 2 m, for a density of 1,666 cocoa plants per ha. Fruits trees and crops are integrated on cocoa farms without a specific density.

The sample size for households was calculated as follows [19]:

$$n = N \times P$$

where n is the sample size, N is the number of households, and P is the malnutrition prevalence in Petit-Bondoukou, which is 21.5%.

Approximately 53 cocoa producer households should have been interviewed, but only 40 of them were interviewed while they were less numerous in the locality. However, 40 non-cocoa producer households were added to the sample for comparison.

2.3. Survey

The survey took place from mid-September to mid-October 2021. Before the survey, a census was conducted

to determine the number of households, distinguishing between cocoa producers and non-cocoa producers. The survey itself utilized a questionnaire, gathering information on the most consumed foods over the last 7 days, the most frequently consumed food over the same period, types of foods consumed, and their frequency during the target period.

The questionnaire also covered the amounts of food consumed per household, the quantities of food purchased, the amounts of food produced by the household within their farming systems, the specific farming system practiced by the household (whether agroforestry or not), and the components of the agroforestry systems.

2.4. Assessment of the Food Diets

2.4.1. Food Material

The food material consisted of the food that housewives listed during interviews. The same housewives also cooked the food for the study. The food was weighed, and the number of people who ate the food was recorded.

2.4.2. Food Preparation

Pounded yam (Foutou) with okra sauce

Ingredients: Yam (*Dioscorea alata* L., Dioscoreaceae), fresh okra (*Abelmoschus esculentus* (L.) Moench; Malvaceae), smoked fish, onion, chili, salt, red palm (*Elaeis guineensis* Jacq., Arecaceae) oil.

Preparation:

- For the sauce: Fish was put to cook in water at low heat. Then finely grated fresh okra and a little red palm oil were added to the fish, and the whole was let simmer and then finely chopped onion (*Allium cepa* L., Amaryllidaceae), chili (*Capsicum frutescens* L., Solanaceae) and a pinch of salt were added. The whole was left to cook for 1 hour.
- For the pounded yam: Yam was cut, peeled and boiled for 40 minutes and let cool for a few minutes before pounding and a little water added to facilitate the formation of a ball.

Rice with peanut sauce

Ingredients: Rice (*Oryza sativa* L., Poaceae), peanut (*Arachis hypogaea* L., Fabaceae) paste, smoked fish, onion, chili, salt, tomato (*Solanum lycopersicum* L., Solanaceae) paste.

Preparation:

- For the sauce: Peanut paste was diluted in previously heated water and cooked for a few minutes. Then fish, tomato paste, finely chopped onion, chili, and a pinch of salt were added and the whole left to cook for 45 minutes.
- For the rice: The rice was cooked in water for 30 minutes.

Rice with eggplant sauce

Ingredients: Rice, African eggplant (*Solanum aethiopicum* L., Solanaceae), fresh tomato, smoked fish, onion, chili, salt.

Preparation:

- For the sauce: Eggplant, onion, and tomato were boiled in water and crushed using a mortar. The fish was cooked in water on low heat. Then eggplant-onion-tomato mixture was added to the fish and let

the whole simmered. The chili and a pinch of salt were added and the whole cooked for one hour.

- For the rice: The rice was cooked in water for 30 minutes.

Boiled yam with taro leaves sauce

Ingredients: Yam, taro (*Xanthosoma sagittifolium* (L.) Schott., Araceae) leaves, smoked fish, onion, tomato, chili, salt, red palm oil.

Preparation:

- For the sauce: Taro leaves were cooked with finely chopped onion and tomato. Then the mixture was crushed in a mortar and put on fire with red oil. Then the fish was crumbled and added to the taro leaves. Chili and a pinch of salt were added to the whole and cooked for 40 minutes.
- For the yams: yams were cut, peeled, and boiled for 40 minutes.

Placali with palm fruit sauce

Ingredients: Palm (*E. guineensis*) drupes, smoked fish, three onion bulbs, four to five akpi kernels, dry okra, chili, salt, cassava paste.

Preparation:

- For the sauce: Palm drupes were boiled in water for one hour. Then boiled palm drupes were crushed and mixed with water to extract juice. The extracted juice was filtered and put to cook on high heat. Then fish and two onion bulbs were added to the whole. The remaining onion was crushed in a mortar with akpi. Then dry okra, onion-akpi mixture, and a pinch of salt was incorporated into the sauce. The whole was cooked for an hour and a half.
- For the placali: the cassava paste was diluted in water, filtered, and left to settle. The supernatant water was poured out. The process was repeated a second time. The paste was then cooked over low heat, stirring continuously to prevent the formation of lumps. The mixture was left to cook until the paste thickened and became translucent.

The amount of food cooked for analysis depended on the declared household size and their daily consumption. Indeed, the following amounts of food were cooked for analysis: 5.653 kg of rice and eggplant sauce for 8 people, 3.055 kg of rice and peanut sauce for 4 people, 3.460 kg of foutou and okra sauce for 5 people, 2.591 kg of boiled yam with taro leaves sauce for 3 people, and 5.466 kg of placali and palm nut sauce for 8 people. Additionally, 408 g of avocado (for 5 persons) and 276 g of guava (for 8 persons) were used for food analysis.

2.4.3. Food Analysis

Prior to analysis, frozen foods were defrosted and mixed with a blender (CHOICE). For dry matter, pH, titratable acidity, and vitamin C determination, 100 mg of food was used. The rest of the food by recipe was oven-dried at 45°C for 72 hours, crushed using a blender (CHOICE), and used to determine ash, lipid, total carbohydrate, total soluble sugar, reducing sugar, phenolic compound, calcium, zinc, potassium, iron, magnesium, and protein content.

Dry matter, ash, lipid, and protein content were determined following AOAC methods [20]. Total carbohydrates were calculated according to FAO [21], and

food energy value was determined following Livesey and Elia [22]. Titratable acidity and pH were determined according to Nielsen [23]. Vitamin C was determined according to Tomohiro [24]. Total soluble sugars were analyzed using the phenol-sulphuric acid method [25], and reducing sugar was determined according to Bernfeld [26] method. Phenolic compounds were determined following McDonald et al. [27]. Calcium, zinc, potassium, magnesium, and iron were determined using an Atomic Absorption Spectrophotometer (type 20 VARIAN) at their specified wavelengths (422.7 nm, 213.9 nm, 766.5 nm, 285.2 nm, and 248.3 nm) [28].

2.5. Evaluation of the Impact of Agroforestry on Food Availability

The impact of agroforestry on food availability per household was assessed by determining the quantity and the type of food consumed by each household over the last 7 days prior to the interview. For this purpose, information was obtained from the responses to the questions posed to the interviewees. This included the average household consumption, the source of the food supply consumed during the seven days prior to the survey, i.e., the quantity of food purchased, the expenses incurred by households, and the quantity of food produced by the surveyed households during the seven days prior to the survey, for both households practicing agroforestry and those non practicing it.

2.6. Effects of Agroforestry on the Reduction of Food Insecurity

To assess the impact of agroforestry in mitigating food insecurity, we compared households practicing agroforestry with those not practicing it. Our analysis focused on various indicators, including food consumption score, reduced reliance on coping strategies, and factors influencing food security such as food shortage and the prevalence of food insecurity. The food consumption score, survival strategy index, and food insecurity determinant scale were calculated for this purpose. The food consumption score was determined using the method outlined by Kennedy et al. [30]. This score involved summing the frequency of consumption for each food group over a 7-day period and multiplying it by the weighting coefficient assigned to each food group. Specifically, the food consumption score took into account the 9 food groups consumed in the surveyed households over a week, with weighting coefficients defined by the World Food Programme for each category: 2 for cereals, tubers, and starchy foods; 3 for legumes; 1 for vegetables and fruits; 4 for meat and fish; 0.5 for sugar and oil; 4 for dairy products; and 0 for condiments. The sum of all the consumption scores for the food groups listed in the columns (those in which at least one food was consumed more during the last seven days; Table 1; [31]) was performed. This addition was carried out for each surveyed household, and the sum was considered as their food consumption score.

The Reduced Coping Strategy Index (rCSI) and the Household Food Insecurity Access Scale (HFIAS) were determined following the guidelines provided by USAID

[32]. The food insecurity determinant scale included assessing the annual duration of food shortage and the prevalence of food security.

Table 1. Food groups and weights in the calculation of the food consumption score

Types of foods	Food groups	Weights
Cereals: maize, millet, sorghum, rice, bread/donut, pasta Cassava, yam, plantain	Cereals, tuber and starchy foods (staple food)	2
Legumes: peanut, bean, cowpea, peas, lentils	Legumes	3
Vegetables: leaves	Vegetables	1
Fruits: guava, avocado, mango	Fruits	1
Meat: beef, fish, seafood, chicken, eggs, snails	Animal proteins	4
Milk/dairy products: yogurt	Dairy products	4
Sugar, honey	Sugar	0.5
Oils and fats	Oils	0.5
Condiments	Condiments	0

2.7. Statistical Analysis

Data was analyzed using R 4.1 software. A one-way ANOVA was used to compare the food security index of cocoa producers and non-cocoa producers. ANOVA was also used to compare the nutritional value indices of the most consumed foods. When a significant difference was observed, the Tukey test was applied at $P \leq 0.05$ for ranking.

3. Results and Discussion

3.1. Assessment of the Food Diets

3.1.1. Most Consumed Foods

The most food consumed in Petit-Bondoukou consisted of pounded yam locally called 'foutou' with okra (*A. esculentus*) sauce, boiled rice with peanut sauce, boiled rice with African eggplant sauce, boiled yam with taro leaves, boiled paste of cassava flour (placali) with palm sauce as main dishes, and guava and avocado as desserts. Table 2 presents the weight of each dish and the number of people who consumed it per household.

Table 2. Mass of the foods that were analyzed in a study aimed to assess the nutritional value of the most consumed foods in Petit-Bondoukou, Côte d'Ivoire

Parameters	Food mass (g)	Number of people who consumed the food
Rice with eggplant sauce	5653	8
Rice with peanut sauce	3055	4
Pounded yam with okra sauce	3460	5
Boiled yam with taro sauce	2591	3
Placali with palm nut sauce	5466	8
Avocado	408	5
Guava	276	8

Achieving Sustainable Development Goal 2, 'Zero Hunger,' is only possible if populations have access to nutrient-rich and diverse foods. In the studied locality, five types of foods and two fruits have been identified as the most consumed, reflecting the low-income level of the households under study, as food variety tends to evolve with income [32]. This low food diversity, also observed in Bangladesh [33], could be explained by low food and nutrition literacy [34]. Nonetheless, the low food diversity observed in our study could explain the malnutrition rates previously observed in cocoa-producing zones in West Africa [4,6,35]. Low food diversity negatively impacts dietary variety, which in turn affects health [36]. Efforts need to be made to increase food diversity and build capacities in food and nutrition literacy in cocoa-producing zones in West Africa. Such efforts would include the development of diversified food systems, such as agroforestry [10,12].

3.1.2. Biochemical Composition of the Most Consumed Foods

The physico-chemical characteristics of the foods are shown in Table 3. Significant differences ($P < 0.05$) were observed in the dry matter content among the foods. The foutou with okra sauce had the highest dry matter content ($94.66 \pm 37.47\%$), while guava had the lowest dry matter content ($89.33 \pm 30.65\%$). Guava and placali with palm nut sauce had the most acidic pH values, which were 4.1 ± 1.76 and 4.6 ± 1.53 , respectively. Rice with eggplant sauce had the lowest titratable acidity (0.33 ± 0.06 g/l), while guava had the highest titratable acidity (3.30 ± 0.97 g/l). Avocado had the highest ash content ($6.85 \pm 1.95\%$), while rice with eggplant sauce had the lowest ash content ($2.27 \pm 0.12\%$).

The fat, protein, total carbohydrate content, and energy value per 100g of foods showed significant differences among the tested foods (Table 4). The lipid content varied from $2.90 \pm 0.02\%$ to $51.16 \pm 17.47\%$, respectively, for rice with eggplant sauce and avocado. Rice with peanut sauce had the highest protein content ($16.16 \pm 0.10\%$), while placali with seed sauce had the lowest ($2.81 \pm 6.00\%$) protein content. The highest total carbohydrate content was observed in rice with peanut sauce ($78.07 \pm 0.17\%$), followed by foutou and okra sauce and guava,

respectively (Table 4), while the lowest total carbohydrate value was observed in rice with eggplant sauce ($30.89 \pm 0.11\%$). Avocado and placali with seed sauce had the highest energy values, with 605.74 ± 0.54 kcal/100g and 533.46 ± 0.39 kcal/100g, respectively. Guava had the lowest energy value (357.49 ± 1.47 kcal).

The food energy value per 100g was reported in terms of total weight per person and showed significant differences between treatments (Table 5). Boiled yam with taro leaves sauce, placali with palm nut sauce, and rice with peanut sauce provided more energy than the other consumed foods (Table 5). The energy value of fruits per person was found to be very low, with 503.97 ± 0.43 kcal for avocado and 121.99 ± 0.50 kcal for guava.

The mineral content of the consumed foods per 100g and per person varied significantly between treatments (Table 6). Rice with peanut sauce had the highest levels of sodium, calcium, and zinc (Table 6). Pounded yam with okra sauce had high levels of iron (5.06 mg/100g), calcium (6.86 mg/100g), and zinc (1.53 mg/100g). Guava had high levels of magnesium, calcium, and low levels of potassium (Table 6). Rice with eggplant sauce had the highest level of potassium (1.36 mg/100g), while placali with palm nut sauce had the lowest levels of iron and zinc (Table 6).

Our initial investigation focused on assessing food diets in a highly cocoa-producing zone where agroforestry is practiced in the study country. The food diets identified in this study mainly result from the cooking or transformation of root and tuber crops, meats, vegetables, and pulses. The absence of recommended daily standards and dietary reference intakes specific to Côte d'Ivoire complicates the assessment of the characteristics of the foods described in our study. Therefore, our comparisons were based on the daily reference values set by the European Union Commission [37]. The results of the present study reveal that the diet of different households is largely composed of products directly sourced from local food crops. In rural areas in tropical zones, agriculture is the primary activity, and even perennial crop producers have small plots for growing food crops for personal consumption or sale. Food crops serve as a readily available source of sustenance when food crop cultivation is prioritized [38].

Table 3.

	Rice with eggplant sauce	Rice with peanut sauce	Yam foutou with okra sauce	Yam with taro leaves	Placali with palm drupes sauce	<i>Persea americana</i> fruit flesh	<i>Psidium guajava</i> fruit
Dry matter content (%)	91.88 ± 0.20^c	91.77 ± 0.20^c	94.66 ± 37.47^a	93.33 ± 34.24^b	93.11 ± 32.51^b	94.33 ± 31.55^a	89.33 ± 30.65^d
Moisture content (%)	8.11 ± 0.20^b	8.23 ± 0.20^b	5.34 ± 3.11^d	6.67 ± 2.76^c	6.89 ± 2.58^c	5.67 ± 2.43^d	10.67 ± 2.84^a
pH	5.08 ± 0.02^d	5.73 ± 0.08^a	5.60 ± 2.21^b	5.77 ± 2.05^a	4.61 ± 1.53^e	5.37 ± 1.83^c	4.13 ± 1.76^f
Ash content (%)	2.27 ± 0.12^e	2.87 ± 0.10^d	5.44 ± 1.90^b	3.70 ± 1.66^c	3.77 ± 1.90^c	6.85 ± 1.95^a	3.82 ± 1.82^c
Titratable acidity (g/l)	0.33 ± 0.06^e	0.60 ± 0.01^c	0.50 ± 0.21^d	0.35 ± 0.18^e	0.63 ± 0.20^c	1.51 ± 0.43^b	3.30 ± 0.97^a

The means associated with different letters on the same line are significantly different from each other at the 5% threshold (Tukey test); eggplant: *Solanum aethiopicum*; taro: *Xanthosoma sagittifolium*; palm: *Elaeis guineensis*; peanut: *Arachis hypogaea*; rice: *Oryza sativa*; okra: *Abelmoschus esculentus*

Table 4.

Parameter	Rice with eggplant sauce	Rice with peanut sauce	Yam foutou with okra sauce	Boiled yam with taro leaves sauce	Placali with palm drupe sauce	<i>Persea americana</i> fruit flesh	<i>Psidium guayava</i> fruit
Proteins (%)	15.16 ± 0.01 ^b	16.16 ± 0.10 ^a	12.80 ± 6.07 ^c	5.12 ± 5.98 ^e	2.81 ± 6.00 ^g	5.42 ± 5.58 ^d	4.35 ± 5.30 ^f
Lipids (%)	2.90 ± 0.02 ^f	7.46 ± 0.01 ^d	5.09 ± 2.73 ^e	18.93 ± 6.57 ^c	35.22 ± 12.05 ^b	51.16 ± 17.47 ^a	3.09 ± 1.67 ^f
Total carbohydrates (%)	30.89 ± 0.11 ^e	78.073 ± 0.17 ^a	71.3 ± 28.15 ^b	65.28 ± 25.32 ^c	65.58 ± 23.48 ^c	51.30 ± 23.40 ^d	71.55 ± 24.03 ^b
Energy values (kcal/100g)	372.97 ± 0.50 ^f	392.92 ± 0.52 ^d	382.33 ± 0.03 ^e	453.17 ± 0.30 ^c	533.46 ± 0.39 ^b	605.74 ± 0.54 ^a	357.49 ± 1.47 ^g

The means associated with different letters on the same line are significantly different from each other at the 5% threshold (Tukey test); eggplant: *Solanum aethiopicum*; taro: *Xanthosoma sagittifolium*; palm: *Elaeis guineensis*; peanut: *Arachis hypogaea*; rice: *Oryza sativa*; okra: *Abelmoschus esculentus*

Table 5.

Parameter	Energy value of the food (kcal/100g)	Number of people who consumed the food	Total energy value (kcal)	Energy value per person (kcal)
Rice with eggplant sauce	372.97 ± 0.50 ^f	8	21083.80 ± 27.93 ^b	2635.47 ± 3.49 ^d
Rice with peanut sauce	392.92 ± 0.52 ^d	4	12082.19 ± 15.93 ^d	3020.55 ± 3.98 ^c
Pounded yam with okra sauce	382.33 ± 0.03 ^e	5	13228.62 ± 1.03 ^c	2645.72 ± 0.20 ^d
Boiled yam with taro sauce	453.17 ± 0.3 ^c	3	11741.63 ± 7.77 ^e	3913.88 ± 2.59 ^a
Placali with palm nut sauce	533.46 ± 0.39 ^b	8	29158.11 ± 21.28 ^a	3644.89 ± 2.66 ^b
<i>Persea americana</i> fruit	605.73 ± 0.54 ^a	5	2519.72 ± 2.15 ^f	504.11 ± 0.43 ^e

The means associated with different letters on the same column are significantly different from each other at the 5% threshold (Tukey test); eggplant: *Solanum aethiopicum*; taro: *Xanthosoma sagittifolium*; palm: *Elaeis guineensis*; peanut: *Arachis hypogaea*; rice: *Oryza sativa*; okra: *Abelmoschus esculentus*

Table 6.

	Sodium mg/100g	Magnesium mg/100g	Potassium mg/100g	Calcium mg/100g	Iron mg/100g	Zinc mg/100g
Rice with peanut sauce	1.0	1.6	1.1	6.7	0.44	1.54
Placali with palm nut sauce	0.7	0.9	1.1	6.6	0.35	0.84
Avocado	0.7	1.5	1.2	6.7	0.43	1.00
Rice with eggplant sauce	0.9	0.4	1.4	6.4	0.40	1.23
Guava	0.8	1.8	0.8	6.4	0.39	1.25
Pounded yam with okra sauce	0.8	1.4	1.1	6.9	5.06	1.53
Boiled yam with taro sauce	0.7	0.8	1	6.7	0.4	1.4

The moisture content of guava in this study was very high compared to the standard (<3.2%) according to the Codex Alimentarius [39]. This high moisture content can be an advantage for hydrating children who consume these fruits but could be detrimental in the perspective of fruit packaging for medium-term preservation, as a high moisture content in foods could cause the proliferation of microorganisms that can cause spoilage during packaging [40]. Rice-based foods, placali with palm nut sauce and boiled yam with taro leaves also exhibited high moisture content. This is normal because they were cooked with water. But this also indicates that precautions should be taken to reduce this humidity when storing these foods. Indeed, it very often happens in rural areas in Africa that the rest of the food that was eaten the day before is kept in the kitchen to be eaten in the morning after it has been reheated. These foods with high moisture content can be, for example, kept on the rack in the kitchen in order to reduce moisture content.

The pH is an indicator of the risk of proliferation of non-beneficial microorganisms to human health. The results of our study revealed that the pH of all the studied foods was acidic, with guava showing the highest acidity.

This result obtained on guava in our study is lower than those obtained earlier [41,42]. This difference could be explained by the difference in edapho-climatic conditions of the two study sites. However, this low pH value indicates that all the studied foods present a low risk of proliferation of microorganisms such as *Clostridium botulinum*, which is responsible for botulism. Similarly, the values of titratable acidity of the studied foods were found to be high, indicating the presence of beneficial organic acids for health in these foods.

Consuming foods that are low in lipids helps reduce the risk of obesity, high blood pressure, and other metabolic pathologies related to overweight [43]. Regular consumption of rice with eggplant sauce, guava and foutou with okra sauce, which are all low in lipid content, can help avoid pathologies related to overweight. However, avocado, placali with palm sauce, and boiled yam with taro leaves have the highest amounts of lipids and should be consumed in moderation to avoid metabolic diseases [44]. On the other hand, the investigated foods had lower protein content than the recommended daily allowances [37], indicating that other protein sources should be consumed by the studied population during the

day. The poor protein content in the studied foods may also explain the high malnutrition rates observed in children in cocoa-producing areas of Côte d'Ivoire [4,6]. Combining rice-based menus, which exhibited the highest protein contents in the present study, with protein-rich foods such as eggs, fish, and beans can help prevent certain diseases such as marasmus and correct malnutrition observed in children in cocoa-producing areas of Côte d'Ivoire.

Total carbohydrates and lipids play a crucial role in determining the energy value of foods. Foods that have high levels of these nutrients tend to be more calorie-dense [45,46]. Our study found that all the investigated foods, except for fruits, are high in calories because they provide more than the recommended daily energy intake of 2500 kcal for adult males and 2000 kcal for adult females [37]. However, the amounts of carbohydrates and lipids that people in Petit-Bondoukou consume are below the recommended dietary standard, which suggests that they need to find other sources of these nutrients. To achieve this, agroforestry systems in Petit-Bondoukou could be diversified with fruit tree species that provide additional carbohydrates and fat-producing tree species, such as *Tieghemella heckelii* (A. Chev.) Pierre ex Dubard (Sapotaceae) [14,47].

Consuming foods that are rich in minerals can help reduce the risk of cardiovascular disease and some types of cancer [48]. Foods that are high in ash content tend to contain the most minerals. As expected, avocado and pounded yam with okra sauce had the highest ash content, as fruits and vegetables are the main source of minerals [49]. By increasing the number of tree species in agroforestry systems in Petit-Bondoukou, people could diversify their fruit consumption and increase their intake of ashes.

3.2. Impacts of Agroforestry on Food Availability

In Petit-Bondoukou, households typically consumed processed and cooked roots, tubers, cereals, vegetables, meat, and pulses. Households practicing agroforestry

tended to purchase food, spending more money on it compared to households not practicing agroforestry.

Households practicing agroforestry had a higher intake of meat (5043.89 g per week) and pulses (4368.22 g per week), with these pulses primarily sourced from their fields (Table 7). On the other hand, they consumed more roots, tubers, and cereals compared to not practicing agroforestry, with the primary source of these being their own fields (32510.8 g per week). Additionally, households practicing agroforestry had a higher consumption of vegetables (3540.5 g per week) compared to households not practicing agroforestry (3144.8 g per week), with these vegetables typically purchased, obtained as gifts, but rarely sourced directly from their fields (Table 7).

Food availability is a fundamental aspect of food security, alongside food utilization, access, and stability over time. Our study reveals that households engaged in agroforestry tend to have greater food availability compared to those not involved in such practices. These findings align with previous research conducted by [51]. In the study area, staple foods primarily include root crops, tubers, and cereals, with cocoa producers consuming larger quantities of these items than non-cocoa counterparts. Notably, households practicing agroforestry often integrate cassava, yams, and plantains into their cocoa-based agroforestry systems for the preparation of foutou. Leveraging crop diversity strategically can play a vital role in mitigating food insecurity in rural tropical regions, reducing the duration of food shortages and enhancing overall food consumption.

The agroforestry systems examined in our study incorporate a diverse range of food crops and fruit trees, contributing to food availability year-round. Cocoa sales provide farmers with cash inflow from October to December (high production period) and January to July (low production period). Additionally, sales of processed cassava (attiéké) from cocoa agroforestry systems offer income throughout the year. This explains the shorter periods of food shortages experienced by households practicing agroforestry compared to those not involved in such practices, as observed in our study.

Table 7.

Food group	Quantity of food consumed per household (g/7 days)		Quantity of food purchased (g/ 7 days)		Expenses (West Africa CFA Francs)		Quantity of food providing from household own production (g/7 days)		Quantity obtained from gifts (g/7 days)	
	Households practicing agroforestry producers	Households non practicing agroforestry	Households practicing agroforestry producers	Households non practicing agroforestry	Households practicing agroforestry producers	Households non practicing agroforestry	Households practicing agroforestry producers	Households non practicing agroforestry	Households practicing agroforestry producers	Households non practicing agroforestry
Roots, tubers and cereals	6143.88	34014.42	2297.43	1734.93	918.59	992.02	3525.52	32510.81	320.93	00
Vegetables	3144.77	3540.52	1241.59	530.15	259.65	154.81	20.82	60.40	1882.36	2949.97
Meats	5043.89	3936.41	5043.89	3903.33	2143.06	1874.36	00	00	00	33.08
Oils	0.97	0.80	0.92	0.79	912.86	825.76	0.03	0.01	0.02	00
Sugar	341.9	866.83	282.07	700.33	400	505.56	18.18	00	41.65	166.5
Condiments	190.20	120.42	182.38	138.75	172.72	133.13	00	00	7.82	00
Pulses	4368.22	2042.15	1633.84	522.51	716.96	259.99	2493.26	1210.28	241.12	309.36
Overall mean	2747.69	6360.22	1526.02	1075.83	789.12	677.95	865.40	4825.93	356.27	494.13

Our survey highlights significant fluctuations in food availability throughout the year, characterized by periods of sufficiency and challenges. Specifically, households encounter food shortages, particularly in July, August, September, and October. During these months, most consumed food originates from sources other than their own production, indicating a period of food insecurity. In contrast, households not engaged in agroforestry experience shortages during different months, possibly due to limited diversification in their sources of production and income. For example, cocoa beans are primarily sold from September to January (cocoa harvesting season), providing cocoa producers with ample income for proper nutrition. Seasonal patterns in staple crops and vegetables also contribute to shortages when production is yet to commence.

3.3. Effects of Agroforestry on the Reduction of Food Insecurity

3.3.1. Food Consumption Score

Overall, the food consumption score (FCS) was considered acceptable for the households interviewed. Specifically, 85% of the households had an FCS greater than 45, indicating acceptable food consumption levels. Meanwhile, 3.75% of households had a moderately acceptable diet, as their FCS ranged between 35 and 45, and approximately 7.5% and 3.75%, respectively, had a borderline ($21 < \text{FCS} < 35$) and poor ($\text{FCS} < 21$) FCS. Households practicing agroforestry had a better FCS ($\chi^2 = 10.15$, $P = 0.02$) compared to those not practicing it. A total of 87.5% of households practicing agroforestry and 82.5% of households not practicing it had an acceptable FCS, with no household practicing agroforestry having a poor FCS, compared to 7.5% of households not practicing agroforestry (Table 8).

Table 8.

Food consumption score (FCS)	Households practicing agroforestry (%)	Households not practicing agroforestry (%)	Total percentage (%)
Poor ($\text{FCS} < 21$)	0 (n = 40)	7,5 (n = 40)	3.7 (n = 80)
Borderline ($21 < \text{FCS} < 35$)	10	5	7.5
Moderately acceptable ($35 < \text{FCS} < 45$)	2.5	5	3.7
Acceptable ($\text{FCS} > 45$)	87.5	82.5	85

The results of the Food Consumption Score (FCS) index in our study indicate that the majority of households across various categories demonstrate an acceptable level of food consumption in terms of both quantity and quality. However, it was observed that food variety was relatively low in the studied sites [52]. This phenomenon can be attributed to the daily consumption of cereals and tubers, as well as the high weighting coefficient of meat and fish in the FCS calculation. Consequently, households with limited and poor FCS scores tend to have a less diversified diet, leading to situations of food insecurity. The staple diet of these populations primarily consists of cereals (such as rice), tubers (including cassava and yam), and

bananas, which are consumed on a daily basis. Across Africa, especially in rural areas, cereals and tubers serve as the cornerstone of the diet, supplemented by the consumption of fish, vegetables, condiments, and oil. However, the consumption of milk and dairy products is less frequent. Locally available vegetables, such as eggplant, okra, tomato, and onion, are commonly utilized alongside oil and condiments (such as pepper, salt, and spices) in the preparation of sauces to accompany staple foods.

3.3.2. Reduced Coping Strategy Index

The majority (34%) of the interviewed households reported resorting to using less valued and less expensive foods as their primary coping strategy during periods of food shortage or lack of money to purchase food. The second most prevalent strategy was either reducing the number of daily meals or decreasing the portion sizes for adults (22% of the households interviewed). The final coping strategy involved sending household members to eat elsewhere (3%), reducing the food quantity per person during meals (12%), and borrowing food or seeking assistance from friends or relatives (9%) (Figure 2).

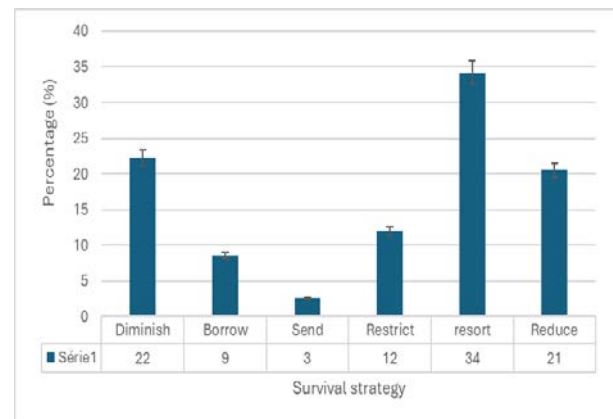


Figure 2. Reduced coping strategy index of Petit-Bondoukou, Côte d'Ivoire

The coping strategies identified in our study closely resemble those documented in South Africa in 2018 [53]. However, unlike the findings reported by [53], none of the interviewees in our study mentioned fasting for an entire day as a coping mechanism for food scarcity. This observation suggests that the level of food insecurity in cocoa-producing areas of Cote d'Ivoire may not be as severe. Nevertheless, it is advisable to enhance access to a wider variety of foods in the studied areas to mitigate any potential exacerbation of food insecurity.

3.3.3. Food Security Determinants Scale

Overall, 58% of households, including both households practicing agroforestry or not, experienced food shortages, while 42% did not. Among households not practicing agroforestry, 80% experienced food shortages, compared to only 35% of households practicing agroforestry (Figure 3).

Food shortages were more likely to occur for households not practicing agroforestry from February to October, while households practicing agroforestry were more likely to experience food shortages from July to October each year (Figure 4). However, for both groups, the peak of food shortages was observed in August (Figure 4).

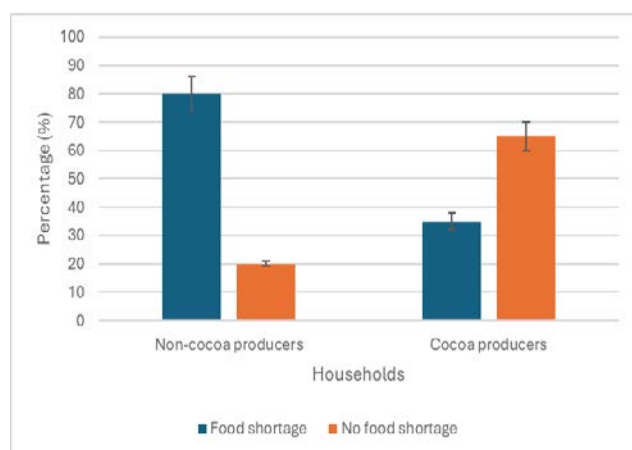


Figure 3. Food shortage periods for cocoa producers and non-cocoa producers in Petit-Bondoukou, Côte d'Ivoire

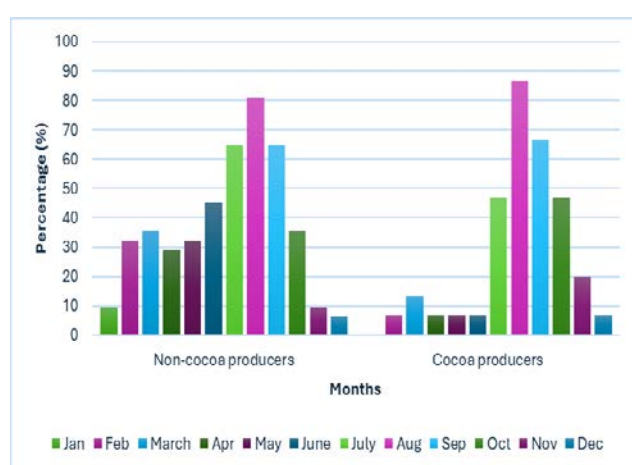


Figure 4. Annual distribution of household's food shortage period in Petit-Bondoukou, Côte d'Ivoire

To assess the overall level of household food insecurity, the Household Food Insecurity Access Prevalence (HFIAP) was calculated (Table 9). The average level of household food insecurity was $8.66\% \pm 1.2\%$. Based on the results of the Household Food Insecurity Access Scale (HFIAS) categories, a higher percentage of households practicing agroforestry (78.6%) were identified as food secure compared to households not practicing agroforestry (38.9%). Further analysis revealed that among households practicing agroforestry, 12.5% were categorized as moderately food insecure, 5.83% as moderately food insecure, and 3.05% as severely food insecure. In contrast, among households not practicing agroforestry, 28.65% were moderately food insecure, 16.49% were moderately food insecure, and 15.95% were severely food insecure (Figure 5).

The findings regarding the determinants of food insecurity align with data from the Food and Agriculture Organization (FAO) [30], indicating that households in the Bas-Sassandra region are not facing chronic food insecurity. The population, particularly households engaged in agroforestry practices, generally have access to safe and sufficient food, enabling them to sustain their households and lead healthy lives. This suggests that they can fulfill both their essential food and non-food needs without resorting to unconventional adaptation strategies.

However, households classified as having limited food security demonstrate only adequate food consumption and may struggle to afford certain essential non-food expenses without resorting to irreversible adaptation strategies. Those experiencing moderate food insecurity exhibit deficient food consumption or find it challenging to meet their minimum food needs without resorting to irreversible adaptation strategies. Lastly, households facing severe food insecurity have highly deficient food consumption or may experience significant losses in their livelihoods, resulting in substantial deficits in their food intake.

Table 9. Distribution of respondents based on Household Food Insecurity Access Prevalence (HFIAP) in Petit-Bondoukou, a top cocoa-producing zone in Côte d'Ivoire, from mid-September to mid-October 2021

Households not practicing agroforestry (HNPA)					
		Never	Rarely	Sometimes	Often
AXE 1	Q1	9	4	9	19
AXE 2	Q2	8	2	17	17
	Q3	8	1	7	24
	Q4	10	0	16	14
AXE 3	Q5	12	2	16	10
	Q6	15	4	13	8
	Q7	27	2	7	4
	Q8	26	5	4	5
	Q9	26	5	6	3
Households practicing agroforestry (HPA)					
		Never	Rarely	Sometimes	Often
Axe 1	Q1	30	1	4	5
Axe 2	Q2	30	2	3	5
	Q3	16	0	15	9
	Q4	30	2	5	3
Axe 3	Q5	30	1	5	4
	Q6	31	2	5	2
	Q7	37	0	2	1
	Q8	39	0	1	0
	Q9	39	0	1	0

Key	HNP	HPA
Food secure	39.73%	78.61%
Midly food secure	17.81%	5.83%
Moderately food insecure	26.30%	12.50%
Severely food insecure	16.16%	3.06%

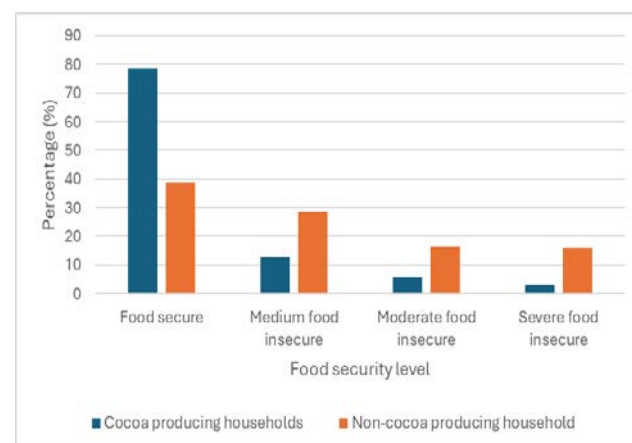


Figure 5. Household Food Insecurity Access Scale (HFIAS) category in Petit-Bondoukou, Côte d'Ivoire

4. Conclusion

In conclusion, our findings underscore the significance of sustainable agricultural practices, highlighting the crucial role of agroforestry systems in improving food availability and nutritional diversity. Effectively addressing nutritional gaps demands strategic planning, underscoring the importance of a variety of crops and tree species in fostering comprehensive diets. It is recommended to design and implement agroforestry systems that seamlessly integrate diverse crops and tree species, including those yielding fruits and nuts with both nutritional and commercial value. This approach is essential for mitigating food insecurity and reducing malnutrition rates in cocoa-producing areas.

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