



Impact of Crop Diversification on Household Food and Nutrition Security in Southern and Central Mali

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Many African countries, including Mali, depend on the production of a single or a limited range of crops for national food security. In Mali, this heavy reliance on a range of basic commodities or staple crops, or even just one, exacerbates multiple risks to agricultural production, rural livelihoods, and nutrition. With this in mind, the smart food campaign was initiated to strengthen the resilience and nutritional situation of households and peasant communities where the diet is mainly cereal-based and remains very undiversified and poor in essential micronutrients. As part of the campaign, our study aims to analyze the impact of agricultural diversification on food consumption and household nutritional security. The analysis uses survey data from 332 individuals randomly selected. Multinomial logistic regression and the Simpson diversity index were used to determine the index and estimate the determinants of crop diversification. The consumption score index weighted by consumption frequency and anthropometric indices (for children) were used to assess the nutritional status of households. The results show four types of strategies of diversification: 7.55% are cereals only, 5.66% combine millet–sorghum–groundnut, 41.51% combine millet–sorghum–groundnut–cowpea, and 45.28% combine millet–sorghum–groundnut–cowpea–maize. The estimation of the regression model shows that socioeconomic factors have a positive influence. With a consumption score index of 34 in the villages and 40.5 in Bamako, based on eight food groups, we find that the quality of food is insufficient in rural areas, but it is acceptable in the urban center of Bamako. Analysis of the nutritional status of children aged 6–48 months reveals that 30% of the surveyed population is in a situation of nutritional insecurity (all forms combined). To help improve crop diversification and the nutritional quality of foods, we suggest, among other things, subsidies and public spending to facilitate access to inputs that allow the acquisition of a wider range of inputs and services, intensification of nutrition awareness, and education programs to maximize the incentive to consume nutritious foods from self-production and market purchases. Finally, we propose to facilitate access to technologies promoting food diversification and improving food and nutritional security, particularly in rural areas.

Keywords: crop diversification, food consumption, nutritional security, smart-food, household, Mali

INTRODUCTION

The agricultural sector is emerging as the engine for growth and food security in Mali. The sector contributes up to 36% to the gross domestic product (GDP) and occupies 80% of the population (Maiga et al., 2019). Agricultural production varies by region, but the Southern and Central areas are generally the most productive, especially when it comes to cereals. The main cereals produced and consumed in the country are millet, sorghum, rice, and maize (Tounkara et al., 2019). Production metrics showed a sharp increase of those staple and cereal crops from year 2000, reflecting the potential for agriculture to achieve self-sufficiency in food production (World Bank, 2018; Kouressy et al., 2019). In contrast, the number of people facing chronic and persistent food insecurity and malnutrition has been steadily increasing in the past decade (Sanga et al., 2021). Segregated data showed that 54% of women 15–49 years of age with one child under 5 years suffer from anemia and that the national GDP in Mali is decreased by 2.7% due to vitamin and mineral deficiencies (Kennedy et al., 2009). FAO (1996) expressed that food insecurity exists when all human beings do not have, at all times, physical and economic access to sufficient, healthy, and nutritious food to enable them to meet their energy needs and food preferences to lead a healthy and active life. However, the notion of nutritional insecurity encompasses and goes beyond that of food insecurity. The prevalence of food insecurity and malnutrition is of concern especially when the availability and accessibility of nutritionally adequate foods are limited and/or uncertain. The consequences in Mali include low nutritional intake, the prevalence of stunting is of 27% for young children 0–23 months, and the perseverance of undernutrition among 18.5% women, particularly in rural areas (Konate et al., 2020).

Many drivers influence the linkage between agricultural productivity with food and nutrition security. Empirical evidence confirms the role of agriculture for the improvement of incomes and food, which provides two capital dimensions of food security: the availability and accessibility of food and reduction of malnutrition (FAO et al., 2021). Agricultural production in Mali is concentrated on few basic products, exacerbating the challenges of food insecurity, while the narrow staple production is reflected in food consumption with the dominant crops accounting for a significant portion of the caloric intake. Much of food produced locally is based on the proportion of crops in the different climatic zones (for example, rice and maize are cultivated in regions with high rainfall and irrigated areas, millet and sorghum in areas of medium and low precipitation). Moreover, since spatially distributed factors (climate, crops grown, infrastructure, market development, etc.) influence production or nutrition (Tefft et al., 2000), Joseph and Wodon (2008) saw in Mali important differences in the weight of the various cereals in the overall consumption basket

of the population, as well as differences between various types of households in their consumption patterns.

In the prospect of malnutrition alleviation, on the one hand, crop diversification has been promoted by different nutrition and food security interventions. Adjimoti and Kwadzo (2018) found that crop diversification has a positive effect on household food security status, and for Ijaz et al. (2019), it is a dynamic tool to ensure the food security in a sustainable way. It has great potential to strengthen the resilience and nutritional situation of households and farming communities (World Bank, 2018; Heumesser and Kray, 2019), and the diversity of crops grown through dietary diversity can improve household food security. The factors leading to diversification decisions are numerous, among which we can cite the following: an increase in farmers' incomes, reduction of the risks of food shortages and deficiencies, response to changing consumer demands or modification of policy government, the response to external shocks, and, more recently, as a consequence of global warming. In rural remote areas where household access to food depends largely on its production, crop diversification provides farmers with the different crops that they cannot access either because of the cost or because of the poor infrastructure constraints.

On the other hand, many approaches have concentrated on macroeconomic solutions and concepts of national food security. For instance, the availability of overall food stocks was emphasized, taking into account local production, imports, and exports and usually concentrating on staple foods. Planning along these lines did help to assure adequate national supplies but did not always fully address problems of dietary diversity, food quality and safety, post-harvest losses, processing and marketing, or access to food by all individuals and households (FAO, 1992). In this line, the concept of Smartfood mainstreaming “traditional” Smart Foods back as staples across Africa and Asia has been initiated. Smart Foods are food items that fulfill the criteria of being good for you, the planet, and the farmer. Sorghum and millet were selected as the first Smart Foods, and a participatory fun-filled approach was adopted to create awareness, to develop culturally acceptable products, and to bring about behavior change to improve adoption, dietary diversity, and nutritional status (Diama et al., 2020). In drylands, the smart food approach is innovating that millet and sorghum which are nutritious crops (Barikmo et al., 2007; Chande et al., 2021) can be better consumed through improved local dishes; thus, the household's daily energy requirements, particularly those of women and children, may be raised. As baseline research of such social marketing intervention of the smart food approach, we had the main concern for assessing how diversification of crops has positive effects on food consumption and the nutritional situation of households. In fact, the approach is providing a paradigm supporting the trends that Malian farmers, while often willing to try new crops, are typically loath to give up sorghum/millet cultivation since it represents the major part of their effort to provide self-sufficiency to their families (Foltz, 2010).

For this study, it has been postulated that the households and the consumers of millet and sorghum, identified and characterized in rural areas and particularly in the urban center

Abbreviations: FCS, food consumption score; GDP, gross domestic product; MLR, multinomial logistic regression; UE-APSAN-Mali, Enhancing Crop Productivity and Climate Resilience for Food and Nutrition Security; SDI, Simpson diversity index; S, strategy; WFP, World Food Program.

of Bamako, have different needs. Therefore, the study focuses on three main objectives: (1) evaluate the food consumption score in households and the nutritional situation among children; (2) estimate the determinants of crop diversification; and (3) evaluate the effect of crop diversification and consumption of Smart Foods and household nutritional security.

MATERIALS AND METHODS

Study Area Description

The study area concerned the regions of Kayes, Koulikoro, Sikasso, Ségou, and district of Bamako. The cercles of Kati (Bankoumana), Kita (Bendougouba), Dioila (Wakoro), Segou (Pelengana et Cinzana-gare), and Koutiala (M'pessoba et N'golonianasso) are taken into account in the regions (**Figure 1**). These are study areas of the UE-APSAN project (plus Bamako) with mandated and focus intervention on millet, sorghum, groundnut, and cowpea crop production and consumption analysis. The description of regions is presented as follows.

Bamako is the capital and the most urbanized city of Mali. With an important port on the Niger River and a commercial center radiating over the entire sub region, the city is also the main administrative center of the country and has 2,529,300 inhabitants in 2020 with a high urban growth rate. Bamako is administratively considered as “a district” and divided into six communes headed by elected mayors. Agriculture is mainly limited to vegetable gardening, fishing, and livestock which are poorly developed. The district of Bamako concentrates 70% of industrial companies. The tertiary sector is the most developed. Bamako is retained in surveys because most of Mali's agricultural production is transferred there and it is where the major consumer markets are located.

The Kati cercle is a territorial collectivity of Mali in the Koulikoro region. In the Koulikoro region, agriculture remains the main activity and employs more than 80% of the population. The cultivated crops are mainly cereals, which are used in the diet of the populations. Crops are millet, sorghum, maize, rice, fonio, and cowpea. These include also industrial or cash crops such as cotton, sesame, and groundnut.

The Kita cercle is a territorial collectivity of Mali in the Kayes region. It has 33 municipalities. Agriculture, trade, and livestock breeding are the main economic activities. The main cultivated crops are cereals, cotton, and groundnut. Livestock breeding represents income diversification activity (there is persistent existence of small herds of cattle or sheep/goats in almost every family).

The Dioila cercle is also in the region of Koulikoro. The cercle is traversed by three rivers—the Bagoé, the Banifing, and the Baoulé—and their multiple affluents. Likewise, in the cercle of Kati, agricultural activities are developed and practiced by the majority of the population. The agricultural system adopted in the cercle can be summed up in 1 year of cotton cultivation, followed by 2 years of cereal cultivation. The latter are sometimes replaced by legumes. Traditionally, this rotation was followed by a fallow period of several years, but pressure on good land now makes this practice disappear.

Segou located at 240 km from Bamako is mainly located in the Sahelian zone, with semiarid climate (average annual rainfall: 513 mm). Segou is traversed by Niger River (over 292 km) and the Bani River. The population is estimated at 2,336,255 inhabitants. Women represent 50.5% of the population. With its 127,000 ha of irrigated land, Segou strongly contributes to Mali's food security. Indeed, the Office of Niger (the largest hydraulic structure) represents about 60% of Mali's rice needs, which is equivalent to just under one million tons. However, Segou is not just a rice granary, because the region is also a major producer of maize, millet, and sorghum followed by groundnut and cowpeas and has a relatively large herd.

The Koutiala cercle is located in the Sikasso region and is characterized by Sudano-Sahelian climate. The Koutiala cercle has an economy essentially based on agro-pastoral care. It is the area of cotton cultivation, and this culture gives Koutiala the name of “capital of white gold” in Mali. Cotton production is supported by technical services, NGOs, etc., through agricultural credit, training, marketing, etc. The main cereal crops are millet, sorghum, maize, and rice. Other cash crops are cowpeas and groundnuts. The Koutiala cercle exports livestock to Burkina Faso and Côte d'Ivoire, in particular cattle, goats, and sheep.

Data Collection

The methodological approach initially consisted of collecting all the information available on household food and nutritional security. Subsequently, a survey was carried out to verify the hypotheses. The bibliographic review also enabled us to better define the theme on the one hand and to take stock of the results of research and studies relating to the subject on the other hand.

Within the framework of this study, the data collection related to secondary field data through tools including questionnaires which were administered to the surveyed population. The questionnaires were specific to the different categories of actors. Data collection took place over the period from March to April 2021 in the areas mentioned above. The data mainly concern agricultural production; food consumption (including Smart Food) and other household uses; anthropometric indices for children from 6 to 48 months; and information on micronutrient deficiencies.

Sampling

The sampling procedure relating to the collection of primary data retained in the framework of this study is random selection. Initially, following the coverage area of the UE-APSAN-Mali project, a total of 182 households were drawn randomly from the list of seven villages: Bankoumana, Bendougouba, Wakoro, Pelengana, Cinzana-gare, M'pessoba, and N'golonianasso. Additionally, we surveyed six mothers of children under 5 in each village. Then, a sample of 150 individuals was drawn using the random sampling method from six municipalities of the district of Bamako, including 110 households. **Table 1** describes the sampling of study.

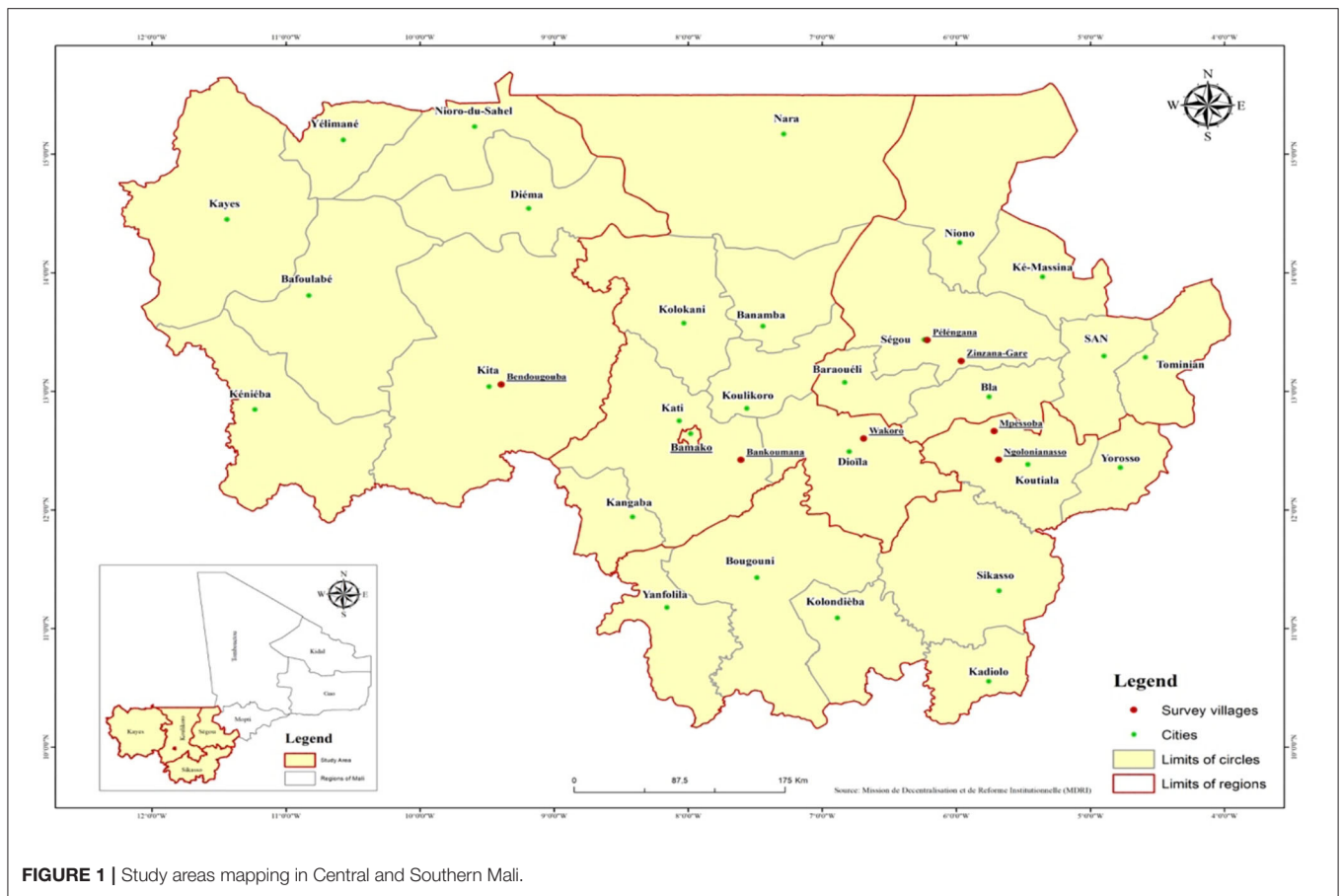


FIGURE 1 | Study areas mapping in Central and Southern Mali.

TABLE 1 | Description of the sampling size.

Categories	7 villages (Bankoumana, Bendougouba, Wakoro, Pelengana, Cinzana-gare, M'pessoba, and N'golonianasso)	6 urban municipalities (all of 6 municipalities of Bamako district)	Together
Children	42	30	72
Producers	53	–	53
Consumers	47	100	147
Transformers	10	10	20
Distributors	30	10	40
Totals	182	150	332

Data Analysis

Descriptive Statistics

Descriptive statistics were used to characterize respondents on the basis of age, education level, gender, and marital status. Percentages were used for estimating weight perception of the population.

The Simpson Diversity Index

Regarding the Simpson diversity index (SDI), it is between 0 and 1 where 0 denotes specialization and 1 extremely diverse. The

general formula of this index is as follows:

$$SDI = 1 - \frac{\sum Ni(Ni - 1)}{N(Ni - 1)}$$

Ni: number of individuals of the given species.

N: total number of individuals.

The SDI is a relative abundance index: it takes into account wealth (number of crops produced) and distribution (distribution of quantities produced). Its value increases when the number of species increases and/or when the quantities produced per species are close to each other. We chose to calculate it from the production in kilograms of dry matter.

Food Diversity Measurement

We estimated the likelihood effects of diversification strategies (the dependent variables) from the independent variable which is the total production of the farm. From a qualitative reminder of consumption and consumption frequency during the last 7 days, we calculated the score consumption of food households as a proxy for the coverage of needs micronutrients. This score was calculated according to the mathematical method named the Food Consumption Score (FCS). The FCS is inspired by the World Food Program (WFP), using the frequency of consumption of the eight food groups consumed during the last seven (07) days preceding the survey by households. Those eight food groups comprise cereals and tubers, legumes, vegetables, fruits, meats and fish, milk, sugar, and oil.

The FCS is calculated as follows:

$$FCS = A_{cereals}X_{cereals} + A_{legumes}X_{legumes} + A_{vegetables}X_{vegetables} + A_{fruits}X_{fruits} + A_{animals}X_{animals} + A_{sugar}X_{sugar} + A_{milk}X_{milk} + A_{oil}X_{oil}$$

with

AI = weight assigned to the food group

XI = number of days of consumption relative to each food group (≤ 7 days).

Thus, the conventional thresholds defined by the WFP to determine the three food consumption groups were used:

- Poor food consumption: FCS < 21 corresponds to a situation of severe food insecurity;
- Food consumption at the limit of acceptability, 21.5 < FCS < 35, which corresponds to a situation of moderate food insecurity;
- Acceptable food consumption: FCS > 35 which corresponds to a food security situation.

For the particular case of nutritional status of children under 5 years of age, we used children's height, weight, age, and brachial perimeter with Z-scores to estimate the nutritional status of children under 5. The Z-score is calculated as the following:

$$\frac{\text{(Measure - mean)}}{\text{standard deviation (of height, weight, age, and brachial perimeter)}}$$

From the World Health Organization's interpretation of z-score: <-3 z-scores: children in insecurity situation.

Multinomial Logistic Regression

In this study, multinomial logistic regression (MLR) was used. This method is suitable for the analysis of category-dependent variables when producers have only one choice among a set of diversification strategies (Greene, 2002). According to the theory of the random utility model (RUM), it is estimated that the producer opts to maximize his income by comparing the income generated by an alternative strategy. However, the income tended is a latent variable determined by the characteristics of the

agricultural exploitation and the error term.

$$\text{Thus, } U_{ij}^* = X\beta_{jj} + \varepsilon_{ij}$$

U_{ij} : Independent variable

$X\beta_{jj}$: Dependent variable

ε_{ij} : Error

It denotes the probability of choice of the producer whether to combine millet plus sorghum only (S1) or to combine millet, sorghum, and groundnut (S2); combine millet, sorghum, groundnuts, and cowpea (S3); or combine millet, sorghum, groundnut, cowpea, and maize (S4). According to Greene (2002), the model is given as the following:

$$P_{ij} = \frac{\text{Exp}(X_i \beta_i)}{\sum_{j=1}^4 \text{Exp}(X_i \beta_i)}$$

To solve the normalization problem, the model is written as follows:

$$P_{ij} = \frac{\text{Exp}(X_i \beta_i)}{1 + \sum_{j=1}^4 \text{Exp}(X_i \beta_i)}$$

Thus, the model estimates the coefficient by the maximum probability.

The explanations used for our analysis are as follows:

- X_1 : age of producers; X_2 : gender of producers; X_3 : education level;
- X_4 : household size; X_5 : possession work animals; X_6 : possession poultry;
- X_7 : total area sown; X_8 : the cost of agricultural inputs.

The MLR of the dependent variable diversification strategy on the explanatory variables made it possible to obtain the following results:

- The Chi² associated with the log ratio of our model has a probability of <5%, which means that the model is generally of good quality.
- The parameters for which the estimated coefficient is statistically significant at the 5% level are those in fluent adoption of a strategy of diversification of crops while the other variables do not affect or have less influential choice adoption of a crop diversification strategy.

Linear Regression

In this study, the likelihood effects of diversification strategies (the dependent variable) from the independent variable, which is the total production of the farm, were estimated. We applied this general equation to the n observations of Y and the corresponding values of X as follows:

$$Y_i = b_0 + b_1X_i + \varepsilon_i \text{ for } i = 1, \dots, n$$

For each individual i , the random variable ε_i represents the error made, that is to say the difference between the value of Y observed and the value $b_0 + b_1X_i$ given by the linear relation. Variables used for this analysis are diversification strategy (as dependent variable) and the global production (as independent variable).

RESULTS

Socioeconomic Characteristics and Production Patterns

The age of the investigated people ranges from 18 to over 60 for adults and from 6 to 48 months for those under 5 (Figure 2A). We therefore grouped the respondents into five age groups: the first <5 years old representing 24%; the second, 18–30 years old, 31%; the third, 31–50 years old, 32%; the fourth, 51–65 years old, which represents 12%; and only 1% which constitutes the last bracket (65 years and over). More than 60% are aged 50 or less, which indicates that the population of the study area is predominantly young and constitutes a labor force for agriculture. Admittedly, agricultural production activities involve very few women, but in our case the survey also concerned women who are sometimes well-imbued with the family food situation. As a result, participation share of women represents 43% against 57% for men (Figure 2B). Nevertheless, households are generally headed by men with no education in the majority or limited to primary school. Meanwhile, about a third (27%) of respondents are illiterate (15% of which reached higher education). According to the marital status, the married surveyed people are dominant in our study area with 89% against 11% for the unmarried (Figure 2D).

Within this population, analysis of the combination with a diversity index of 0.63 shows that the producers practice the diversification of crops of which 7.55% only make cereals, 5.66% combine millet–sorghum–groundnuts, 41.51% combine millet–sorghum–groundnut–cowpea, and 45.28% combine millet–sorghum–groundnut–cowpea–maize (Table 2). Overall, survey reveals that majority of farms practice mixed agriculture, and cereals are the staple crops intended for self-consumption. Livelihoods remain dependent to agricultural food productions and sale of agricultural products in rural areas.

Nutritional Situation of Households and Children

With consumers, Table 3 shows the contribution share of cereals and legumes, taken individually, in the daily menus in rural and

TABLE 2 | Different strategies of diversification crops (S corresponds to the name of strategy).

Diversification strategies	Frequencies	Percent	cum
S1 (2 cereals)	4	7.55	7.55
S2 (2 cereals; 1 legume)	3	5.66	13.21
S3 (2 cereals; 2 legumes)	22	41.51	54.72
S4 (3 cereals; 2 legumes)	24	45.28	100.00
Total	53		100.00

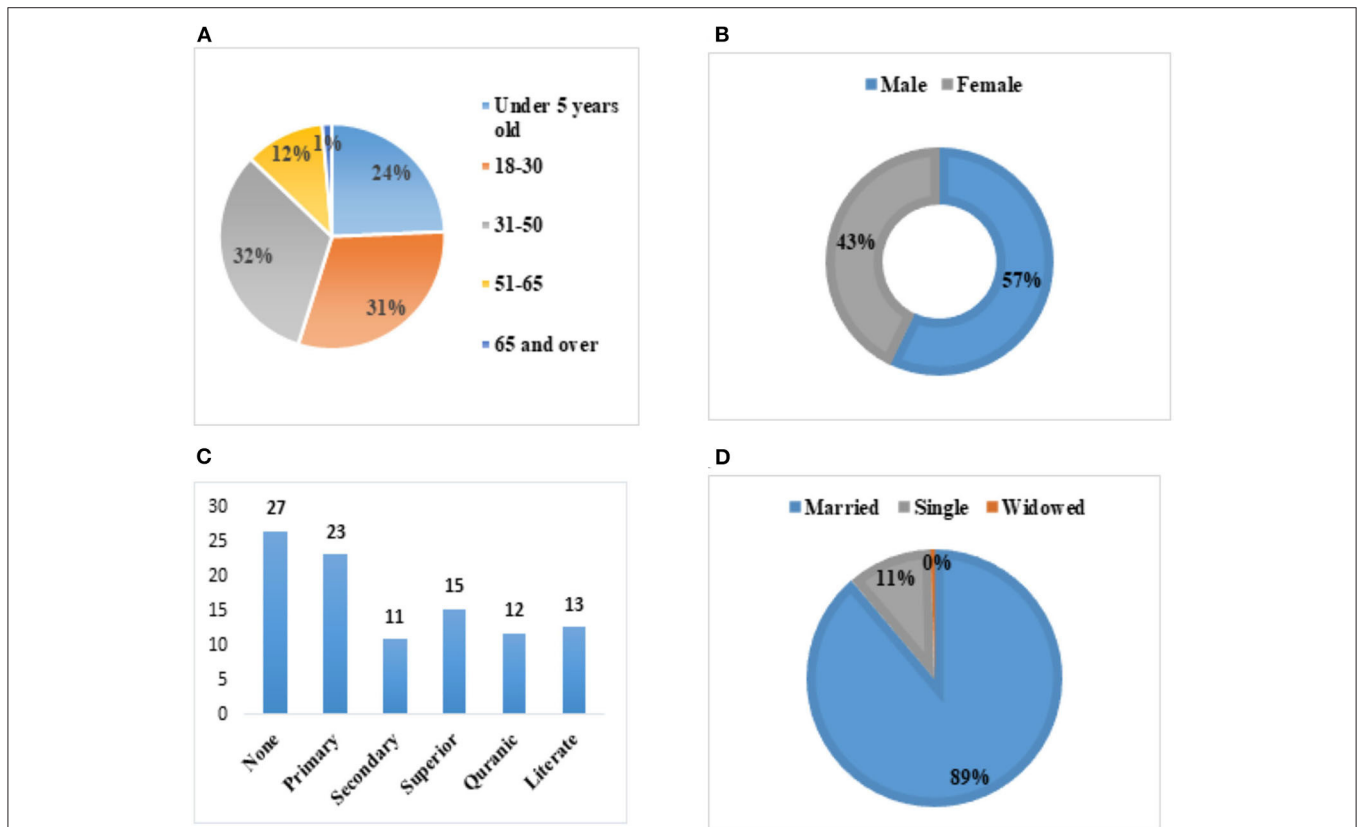


FIGURE 2 | Social characteristics of surveyed households. (A) Age group of respondents. (B) Gender of respondents. (C) Respondent’s education level (%). (D) Marital status of respondents.

TABLE 3 | Contribution of cereals and legumes in daily menus.

Frequencies (in %)	Rural environment					Urban				
	Mil	Sorghum	Groundnut	Cowpea	Rice	Mil	Sorghum	Groundnut	Cowpea	Rice
Daily	51	55	32	6	0	26	2	8	2	87
2–3 times/week	38	24	48	50	45	44	24	66	21	13
Once a week	11	21	21	44	55	17	15	20	43	0
Once/month	0	0	0	0	0	11	16	1	27	0
1–2 times/year	0	0	0	0	0	2	6	2	4	0
Never	0	0	0	0	0	0	37	2	2	0
Food source	Own production: 80%; Own production and donation: 20%					Purchase: 89% and donation: 11%				

urban households in the surveyed areas. With respect to rural environment, millet and sorghum contribute to 51 and 55% of daily household diets, respectively, followed by groundnut by 32%. While in urban areas and particularly in the urban center of Bamako, 26% for millet and 2% for sorghum are consumed in the daily diets of city dwellers. In the same city, it is reported that rice crop provides the major staple food, as it is consumed at least every day by 87% households. In parallel, FCS of 34 in rural areas was depicted against 40.5 in Bamako, underlining that quality of food is poorer in rural areas as compared to the urban areas (Figure 3). This allows also to classify the rural populations in moderate food insecurity and that the urban populations are in a food security.

Foods from targeted crops of this study come from purchase (89%) in urban areas and self-consumption (80%) in rural areas. Another contribution in the diet is provided by imported and processed products made of maize, millet, sorghum, groundnut, and cowpea. The analysis of consumer perception of millet and sorghum (Table 4) showed that millet and sorghum are highly valued by households because 90% of households claim that these two cereals are very healthy for human consumption and only 10% have less appreciation. Households highlighted that these crops are not only rich in micronutrients but also good for babies and pregnant women.

Surveys with processors of cereals and legumes show that processing options are undertaken and responding to traditional diets of Malian consumers. Processed products are cited to be as follows: flour for Tô, Couscous of Millet, Monicourou, Dêguê, Tiakry, Laro, Djouka, etc. These products are distributed by food stores and supermarkets, particularly in the urban center of Bamako.

Analysis of the nutritional status of children aged 6–48 months reveals that 30% of children are in a situation of nutritional insecurity (all forms combined) (Figure 4). However, it emerges from the analysis of dietary diversity and anthropometric indices of children that the FCS is 34 in rural areas and 40 in the urban center of Bamako (Table 5). In addition, children of educated mothers had a better nutritional situation than that of children of uneducated mothers (Figure 5).

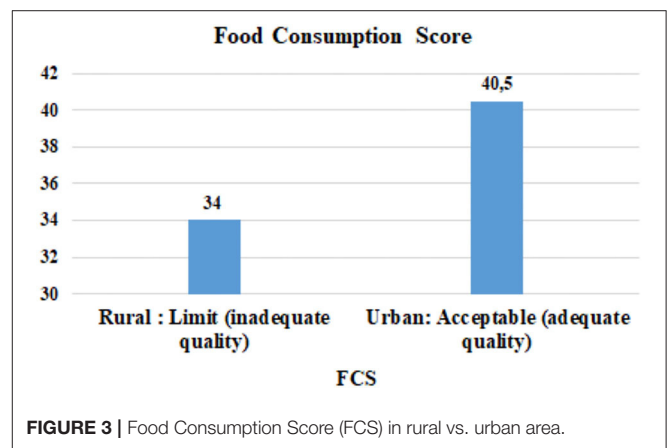


FIGURE 3 | Food Consumption Score (FCS) in rural vs. urban area.

TABLE 4 | Perception of millet and sorghum consumers.

Perception (in %)	Millet and sorghum
Very healthy and healthy	90
A little healthy	8
I do not know	2

Determinants and Effects of Crop Diversification and Its Importance in Production

The analysis of the determinants of choice of crop diversification strategies reveals that two (2) of the eight explanatory variables retained (age of producers, gender of producers, education level, household size, possession work animals, possession poultry, total area sown, and cost of agricultural inputs) are statistically significant at 5% (Table 6). These are the following:

- Level of education: the level of education influences the probability of choosing a diversification strategy, the more the level of education increases, and the more the propensity of the household to adopt S3 of diversification increase.
- Household size: this variable has a statistically significant surplus value at the 5% threshold. Thus, we can conclude that

this variable indicates a level of significance explaining the probability of choosing strategy S3 compared to strategies S1 and S2 if the size of the household increases.

The surplus or *p*-value of the explanatory variable (total production) is 0.013 (Table 7). This value represents the individual significance of the explanatory variables. In our case, it is below the 5% threshold, explaining that the adoption of crop diversification strategies has a positive effect on the overall production of the farm.

DISCUSSION

The findings of our study show wide farmer practices of crop diversification. These results are consistent with regional analyses across the Sahelian countries in West Africa (Félix et al., 2018; Abberton et al., 2021). Crop diversification is an important principle of nutrition sensitivity to improve dietary diversity and food production in farm. It is evidenced that diversification may be a route from agriculture to nutrition, as it can directly affect the amount and types of food available for consumption in smallholder households. Indeed, in our context, improving access and stock to food alone does not guarantee better nutritional outcomes as expressed by the FCS that lay down rural households under moderate food security. This diagnosis confirms the

conclusion of Youssouf (2017) that there is higher prevalence of food insecurity in rural areas compared to urban areas. Since sorghum and millet together account for 73% of the land area devoted to cereal production and 51% of the cereals produced in Mali (Foltz, 2010), the heavy reliance on a low range of commodities or staple crops, or even just one, exacerbates the multiple risks to rural livelihoods and nutrition arising from agricultural production which is threatened by various climate-related stressors and market volatility. In fact, Adams (1992) explained that the prevalence and severity of household food insecurity are strongly related to rainfall.

Overall consumer perception on diversification using foods made from millet, sorghum, groundnuts, and cowpeas aligns with the recognition that they can help to correct certain deficiencies and reduce certain diseases. Consumers of millet and sorghum are mostly in rural areas while urban areas are characterized by increased consumption and preference of rice in their diet. Kearney (2010) highlighted that the undergoing rapid transition in urban areas is experiencing nutritional transition in underdeveloped countries, and this is partly due to policies of trade liberalization over the past two decades with an increasing number of obesity and cardiovascular accident. Another valuable paradox to consider in the analysis, according to Bocoum et al. (2014), is that some poor households are managing to cover their caloric requirements by eating cheap calories and some non-poor households not doing so because they consume expensive calories and/or face constraints such as the obligation to share meals with visitors and high expenditure on healthcare or transportation.

For youth, our study shows that the prevalence of food insecurity is 30%, this result being superimposed on that of 26.6% as reported by Republique du Mali (2019); in fact, inadequate and insufficient nutrition, along with many other factors, contributes to poor nutritional status in children aged 6–48 months, from which nearly a third are with stunted growth. Children under 5 in urban areas had a better nutritional status compared to those in rural areas. Urban living is associated with better diet as an urban environment provides better monetary opportunity and food accessibility. However, other parameters such as access to healthcare and childcare practices and access to drinking water may influence nutritional results. Meanwhile, education of girls

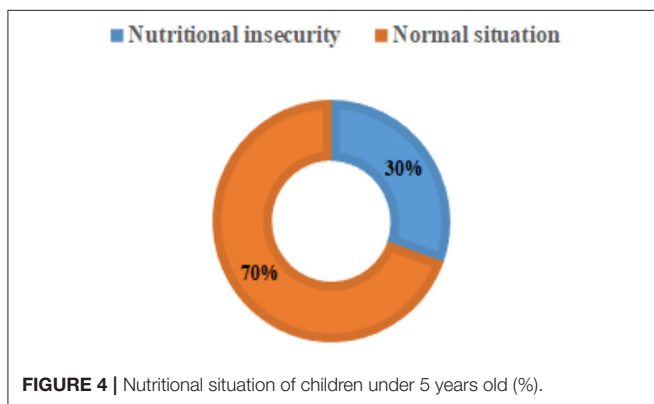


FIGURE 4 | Nutritional situation of children under 5 years old (%).

TABLE 5 | Food consumption score in rural and urban areas.

Food groups	Weighting	Villages		Bamako	
		frequency	Weighting × frequency	frequency	Weighting × frequency
Cereals and tubers	2	6	12	5	10
Legumes	3	3	9	2	6
Vegetables	1	2	2	3	3
Fruits	1	1	1	1	1
Meats and fish	4	1	4	2	8
Milk	4	1	4	2	8
Sugar	0.5	2	1	5	2.5
Oil	0.5	2	1	4	2
Totals			34		40.5

and women enables them to make more informed choices in matters of nutrition and health of their children (the higher the knowledge about the importance of a diversified diet, the better the nutritional status of children). Hirvonen (2016) supported that the difference in dietary diversity among children between rural and urban areas could be due to differences in parents' level of education, access to health services, and health between the two environments. As shown in our data, a high rate of illiteracy among women suggests a low level of knowledge on good feeding and care practices for young children. The survey reveals a low level of education, comparable to that reported by INSTAT AFRISTAT (2019) (34% for the whole country).

Multinomial logistic regression results underline socioeconomic factors that positively influence crop diversification. Notably, level of education, size of the household, and agricultural production per person positively influence the commitment of producers to the diversification of crops. Here again, having a certain level of education increases the probability for the producer to engage in the production of several crops (cereals and pulses) compared to producers only making cereals. This confirmed the findings of Idrisa et al. (2008) and Makombe et al. (2010). In fact, Mango et al. (2018) attributed that education can effectively improve prospects of the farming households to diversify their livelihoods through participation in off-farm formal employment activities as well as the access to and use of information while developing the capacity of farmers to enhance food security. Likewise, in cities,

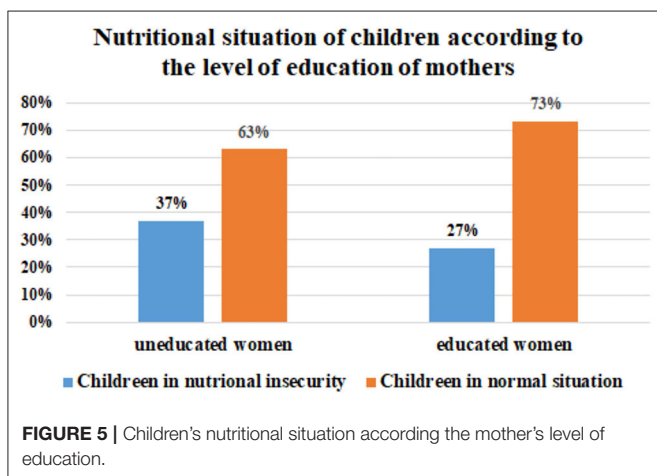


FIGURE 5 | Children's nutritional situation according the mother's level of education.

TABLE 7 | Variability of agricultural production when producers adopt crop diversification strategies.

Diversification strategies	Coef.	Std. err.	p > t
Total production	0.0000722	0.0000279	0.013
Number of obs. = 53			
$F_{(1,51)} = 6.70$			
Prob > F = 0.0125			
R-squared = 0.11			
Adj R-squared = 0.09			
Root MSE = 0.83			

TABLE 6 | Determinants of crop diversification using multinomial logistic regression results (S1 = cereals, S2 = 2, cereals, 1 legume, S3 = 2 cereals, 2 legumes, S4 = 3 cereals, 2 legumes).

Independent variables	Diversification strategies	Strategy (S1)			Strategy (S2)			Strategy (S3)		
		Coef.	Std. err.	p-values	Coef.	Std. err.	p-values	Coef.	Std. err.	p-values
Age of producers		0.48	2223.93	1.000	0.84	1692.24	1.000	0.029	0.03	0.39
Gender of producers		7.45	147292.1	1.000	14.87	66326.41	1.000	-22.44	25154.44	0.99
Education level		-7.57	19789.85	1.000	-6.56	24988.46	1.000	-1.40	0.54	0.01*
Household size		-0.16	1204.92	1.000	-0.57	2827.73	1.000	-0.11	0.053	0.04*
Possession work animals		-0.16	14309.25	1.000	0.64	1415.32	1.000	-0.036	0.034	0.29
Possession poultry		0.21	2212.73	1.000	-0.51	1472.27	1.000	0.048	0.063	0.57
Total area sown		-3.72	2212.73	1.000	-0.14	1125.93	1.000	0.048	0.063	0.45
Cost of agricultural inputs		0.00	0.37	0.999	-0.00	0.322	0.999	-0.00	8.46	0.12

Strategy (S4) (base outcome)

Number of obs. = 53

LR Chi² (24) = 59.64

Prob. > Chi² = 0.0001

Pseudo R² = 0.66

there are more heads of households with an acceptable level of education. The significance of household size is explained by the capacity of an agricultural household to undertake several agricultural activities. Household stratification in Mali according to the capacity to sustain a secure, adequate, and viable diet revealed the food-secure to be large and wealthy households with sufficient resources to diversify production and to invest in agriculture and social networks of exchange (Adams, 1992).

Our study limitation is that the producer sample size is relatively small compared to the population concerned in this study and could probably pose a problem of representativeness of our data. It will be recalled, however, that the main goal sought was to understand the mechanisms of crop diversification, which is one of the factors in increasing productivity and improving the living conditions of the Malian population, rather than having a statistical representativeness. In Mango et al. (2018), with a comparable sample of 271 individuals, the authors have shown that diversification of crops represent a viable option in smallholder agriculture and it can ensure the establishment of resilient farming systems that can significantly contribute to household food security. The two studies are in favor that the diversification of crops improves agricultural production but could have increased its availability for household consumption, for better dietary intake of protein and energy and consequently nutritional outcomes. In addition to this, diversification is done by some growers to mitigate the adverse effects of climate change on crop yields. The positive impact of the diversification of crops on the living conditions of small farmers encourages for the intensification and promotion of crop diversification by policy toward the fight against persistent threat of malnutrition and food insecurity. Since it is often the poorest, low-resource farmers who grow millet and sorghum, there are significant poverty benefits from better millet and sorghum technology (Foltz, 2010) with a consequence that small changes in the productivity of those lands can have large impacts on overall food security of the nation.

CONCLUSION

Crop diversification is practiced by majority of smallholder farmers surveyed, but households in both urban and rural areas consume a limited range of crops and children are nutritionally insecure. There is a potential for smart food crop initiatives to support malnutrition and food insecurity in both areas since households have a sound perception of nutritional assets of those crops in their daily diet. This approach will have to focus its intervention on awareness and education programs

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for maximizing the incentive to consume nutritious foods from self-production and market purchases. In terms of food policy, much effort has been established by the Malian government's flagship on Scaling Up Nutrition to underline advocacy actions for nutrition based on the results of analyses, policies, and laws. Our results suggest that such policies need to approach a sustainable and holistic manner of crop diversification by offering an enabling environment that considers the improvement of education; reduction of extreme poverty; human health; the boosting of agricultural production with higher access to inputs; increased access to agricultural market infrastructure and climate smart technologies, business, and agricultural extension services; and support of processors for making nutritious and healthy products available in the local market.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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