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Contribution of Access to Bio-Fortified Bean in Improving Eating Habits in Burundi

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Abstract

Burundi faces alarming food insecurity, affecting 41.2% of the population, with a prevalence of malnutrition reaching 55.9%. Micronutrient deficiencies, particularly iron and zinc, affect children and women of reproductive age. In response to this situation, bio-fortified beans, rich in proteins and essential micronutrients, are presented as a solution to improve household eating habits. However, although several initiatives have been put in place to encourage this crop, their real impact on the diet of Burundian households remains poorly documented. This study aims to assess the impact of bio-fortified beans on dietary diversity and household food security by comparing them to conventional beans. To do this, we conducted a study in 2024 in four provinces of Burundi: Gitega, Ngozi, Muyinga, and Kirundo, chosen because of their high bean production and the presence of farmers adopting bio-fortified beans. A sample of 384 smallholder farmers was selected using a voluntary sampling method. To analyze household dietary habits, the study used several food security indicators, including the Food Consumption Score (FCS), the Household Dietary Diversity Score (HDDS), and the consumption of foods rich in iron and protein. The statistical analysis is based on a multinomial logistic regression model, allowing the identification of factors associated with FCS and HDDS. We found that the HDDS is high (61%) for households growing bio-fortified beans, compared to 41% for those consuming conventional beans. The majority of households (78%) growing bio-fortified beans have an acceptable FCS compared to 57% for conventional beans. Daily consumption of iron-rich foods is 20.4% of households growing bio-fortified beans, and daily consumption of protein-rich foods is 73.5% of households consuming bio-fortified beans compared to only 20% of those consuming unimproved conventional beans. The gender of the household head, the number of active individuals, agricultural supervision, cultivated area, trade, handicrafts, and membership in an agricultural cooperative significantly improve diversity and food security. The household head's gender, the number of active individuals in the household, agricultural supervision, agricultural labor, and the level of education of the household head significantly improved the household food consumption score. This study shows that better dissemination of this crop, accompanied by technical and organizational support, is essential to maximize its impact on nutrition and food resilience in Burundi.

Keywords

Bio-Fortified Beans, Eating Habits, Food Security, Burundi

1. Introduction

Located in East Africa, Burundi faces major challenges in terms of food security and nutrition. Indeed, food insecurity affects 41.2% of the population, while the prevalence of malnutrition reaches 55.9% [1]. According to the World Food Programme (WFP), one in ten people in Burundi faces food insecurity, and rates of acute and chronic malnutrition remain worrying, especially among children under five [2].

The problem of food quality is more pronounced than that of insufficient food quantity. According to IPC [3], 55% of households sometimes consume protein-rich foods, while 4% have never consumed them. Furthermore, the prevalence of global acute malnutrition among children under 5 years of age is 4.8%, below the 5% recommended by WHO. There is also a sharp decline in the proportion of children under five years with a minimum acceptable diet, from 28.5% in 2018 to 13.5% in 2022 [4].

In addition, as in other developing countries, micronutrient malnutrition, due to deficiencies in essential nutrients such as iron and zinc, is a widespread problem in Burundi. According to UNICEF [4], nearly 60% of Burundian children suffer from iron deficiency, which has serious consequences for their physical and cognitive development [5]. The comparison of the results of the 2010 EDSB-II and the EDSB-III reveals an increase in the prevalence of anemia in children aged 6 to 59 months from 45% to 61% [6]. Pregnant and lactating women are also particularly vulnerable to these deficiencies, which can harm maternal and child health. Between 2010 and 2016-2017, the prevalence of anemia among women aged 15-49 increased significantly, from 19% to 39%. This increase is observed for all forms of anemia, with the prevalence of mild anemia increasing from 15% to 29% and that of moderate anemia from 3% to 10% [6]. According to the strategic nutrition plan of the Republic of Burundi [7], 47% of the population is deficient in zinc. Deficiency in these two micronutrients is widespread in the country and has significant consequences for the intellectual and physical development of many individuals. This situation raises the need for adequate iron and zinc intake.

Thus, malnutrition is decreasing, yet micronutrient deficiency (hidden hunger) is increasing and causing ravages in all stages of the population, especially among women and children. This indicates that more efforts are concentrated on quantity than on the quality of food [5]. These challenges can be overcome through biofortification, a process that enriches crops with essential micronutrients by boosting their mineral content and enhancing their bioavailability in the edible portions [8]. It has been demonstrated that biofortification offers a powerful and sustainable solution to hidden hunger by enhancing vital macro (amino acid such as lysine and tryptophan) and micronutrients (such as Iron, Zinc, and provitamin A) directly in edible parts of maize [9]-[10] and rice [5]-[11]. Since beans are already a staple crop in the country, their biofortification aimed to increase their content of essential nutrients, such as iron and zinc [12]. Therefore, bio-fortified beans appear to be a potential solution to improve nutritional security in Burundi.

Biofortification is defined by the World Health Organization as a sustainable method of enriching staple foods to improve the nutritional quality of diets [5]-[9] [10]. Studies show that introducing bio-fortified beans into diets can significantly reduce iron and zinc deficiencies, especially in vulnerable populations, such as children and pregnant women [13]. In addition, promoting these varieties can also help diversify crops and strengthen the resilience of food systems to climate challenges [14]. Since 1997, twelve bio-fortified bean cultivars have been introduced in Burundi to combat nutritional deficiencies [15]. In addition to nutritional improvement, the introduction of beans aimed to increase yields and diversify income sources [16], which can help improve dietary diversification. In our country, several actions are often implemented to improve the quantity and quality of a crop. However, these initiatives are frequently accompanied by a lack of monitoring and evaluation of their impact. In this context, it is genuine to ask how access to bio-fortified beans influences eating habits (such as diversification and food consumption) in Burundi. This study, therefore, aims to examine the impact of the introduction of bio-fortified beans on household dietary habits and the factors determining these habits. As a research gap to the existing literature, it lies in understanding how access to bio-fortified beans influences behavioral changes in food consumption and dietary diversification patterns, as well as long-term nutritional outcomes among different population groups in Burundi.

2. Materials and Methods

2.1. Study Area and Sampling Procedure

The study was carried out in 2024 in the Northern and Central regions of Burundi and covered four provinces, namely Muyinga, Kirundo, Ngozi, and Gitega. The provinces were chosen because of the large-scale bean farming operations and the possession of fortified organic bean pilot farmers. A voluntary sampling procedure was used to recruit the respondents. A statistical formula by Rea & Parker

[17], which takes into account the confidence level, margin of error, and estimated proportion in the population, was used to determine the sample size. Using this formula, a sample of 384 smallholder farmers was found and distributed in the study area as follows: Muyinga (113), Kirundo (55), Ngozi (115), and Gitega (107). The study focused mainly on smallholder farmers to understand the place of biofortified beans in diets and their contribution to improving food security and the nutritional situation of the Burundian population. The inclusion factors for participants were the possession of one or more pieces of agricultural land and the practice of agriculture; otherwise, the participant was rejected.

2.2. Food Security Indicators

Food security assessment is based on several indicators. Each pillar of food security has its indicators. However, the most commonly used indicators are food accessibility indicators, namely the household food consumption score [18] and the household dietary diversity score [19]. In our study, alongside these two indicators, we also calculated the content of nutrients such as protein and iron.

- **Food Consumption Score (FCS):** The computation of a household's Food Consumption Score is based on a seven-day recall before the survey. The calculation of the score takes into account 8 standard food groups, which are weighted according to their nutritional values. The following table shows the different groups and their respective weightings.

Food groups	Meat, fish and eggs	Milk and dairy products	Pulses	Staples	Vegetables	Fruit	Oil	Sugar
• Weightings	• 4	• 4	• 3	• 2	• 1	• 1	• 0.5	• 0.5

The score is found by summing up the products of the consumption frequencies of the food groups and the respective weights. Two standard thresholds are then defined to analyze the FCS. A value less than or equal to 21 of FCS indicates that the household has "poor food consumption", whereas a value between 21.5 and 35 indicates that the household has "borderline food consumption", and any score greater than 35.5 indicates that the household has "acceptable food consumption" [20].

- **Household Dietary Diversity Score (HDDS):** The Household Dietary Diversity Score takes into account 12 food groups proposed by FANTA [21] which are cereals, roots and tubers, vegetables, fruits, meat, eggs, fish and seafood, pulses/legumes/nuts, milk and dairy products, oil/fats, sweets, and condiments. The score is found by adding all the groups according to whether the household took the foods of this group in the last 24 hours preceding the survey. Two standard thresholds are also defined. A household that took three or fewer food groups is considered to have low dietary diversity, while the one that took 4 or 5 groups is considered to have average dietary diversity, and the one that took 6 or more food groups is observed to have high dietary diversity [19].
- **Consumption of Nutrient-Rich Foods:** The nutrients considered for the case

of our study are proteins and iron. The food groups considered to assess the consumption of households rich in proteins are 6 in number, which are as follows: legumes, dairy products, meat, offal, fish, and eggs. As for foods rich in iron, the groups considered are: meat, offal, and fish. For both nutrients, three thresholds are defined to assess the consumption score of nutrient-rich foods [20]:

- 0 time: Never consumed;
- 1 to 6 times: Often consumed;
- 7 and up: Still consumed.

2.3. Multinomial Logistic Model

Regression, for our study, concerns the analysis of factors associated with household food diversity and consumption. Both being ordinal qualitative variables (with more than two modalities), the choice of the model is directly limited to the multinomial (polytomous) logistic model, which treats multinomial dependent variables [22] [23]. The multinomial logistic regression model is the natural generalization of the two-category situation to a situation based on $K-1$ different logistic relations. If we take the last (K-th) category as a base category, the model then indicates that the probability of falling into group K given the set of predictor values X satisfies the following relationship:

$$Y=\log\left(\frac{\pi_k(X)}{\pi_K(X)}\right)=\sum_{i=0}^{p}\sum_{k=1}^{K-1}\beta_{ik}X_i \quad (1)$$

with: Y: indicator of household eating habits (FCS or HDDS); X: all explanatory variables for household eating habits.

For model adequacy, we performed the Wald test, which is a way to test whether the particular explanatory variables included in a statistical model are significant and non-zero [24]. For each explanatory variable in the model, there will be an associated parameter. The Wald test is one of the many ways used to test whether the parameters associated with a group of explanatory variables are zero. If for an explanatory variable in the model, or a group of explanatory variables, the Wald test is significant, this implies that the parameters associated with these variables are not zero, and these variables should be included in the model.

3. Presentation of Results

This section concerns analyzing and presenting the results of descriptive statistics and multinomial logistic models.

3.1. Descriptive Statistics

3.1.1. Consumption of Beans

In Burundi, beans are among the staple food crops [25]. In the study area, all households consume beans. The main source of beans consumed is the stock for self-consumption made from the household's harvests. If this stock is finished, households get supplies from local markets. Table 1 illustrates the proportions of the stock of self-consumed beans to the quantity produced and consumed, as well as the test for comparing the means of these proportions.

The results of Table 1 indicate that the share of bean stock intended for self-consumption is, on average, 63.86% of the total bean production of a household. In the total quantity of beans consumed annually (quantity of stock of self-consumed beans + quantity of purchased beans), the proportion of stock of self-consumed beans is 77.067%. The average difference of 13.206% (representing the share of purchases in the quantity of beans consumed) is statistically significant. This shows that the volume of purchased beans occupies an important part in households' eating habits. These results are supported by Kataliko and his collaborators [26], who pointed out that beans are globally considered the most important legume, constituting a staple food in many developing countries.

Table 1. Proportions of self-consumed bean stock compared to the quantity consumed and produced.

Variable	Obs	Mean	Std. Dev.	[95% Conf. Interval]		t	p-value
Share of self-consumption stock compared to the quantity of beans consumed	389	77.067	21.843	74.889	79.244		
Share of self-consumed stock to the quantity of beans produced	389	63.860	32.243	60.646	67.074		
Difference	389	13.206	39.728	9.246	17.167	6.556	0.000

3.1.2. Household Bean Purchasing and Selling Behavior

Households are economic agents producing goods and services intended for the market. Among the goods that households offer on the market are beans. Half of the households in the study area (50.26%) sell their harvest. However, the majority of the latter (36.41%) later returned to stock up on beans on the market, which means that they did not sell the surplus of their harvest; rather, it was just getting the needs that they don't produce in their households. The average production of beans sold is 597.1 kg, while the average of beans purchased during a year is 51.02 kg. Table 2 below illustrates the comparison test of these two averages.

Table 2. Comparison test of the mean quantity of beans sold and purchased per household.

Variables	Obs	Mean	Std. Dev.	[95% Conf. Interval]		t	p-value
Quantity sold (1)	196	597.076	1321.135	410.966	783.187		
Quantity purchased (2)	310	51.019	64.047	43.862	58.177		
Net sale		546.057		398.447	693.667	7.268	0.000

The results show that the net sale (mean difference between the purchased and sold quantity) is 546.057 kg of the bean and varies between 398.447 kg and 693.667 kg at the 95% threshold. The significant value of the test of equality of means indicates that this difference is statistically significant. Therefore, the mean of the beans sold exceeds that of the beans purchased. It should be noted that all households purchasing beans from the market only buy conventional beans because of their relatively low market consumer price compared to the price of bio-fortified beans. The results are in agreement with those of ACED [27], which states that consumers are not willing to pay higher prices.

3.1.3. Description of Bean Production in Households

The majority of households (98.97%) grow conventional beans and produce an average of 564.4 kg. The proportion of households growing bio-fortified beans is 12.56%, and they produce an average of 946.4 kg. Table 3 shows the comparison of these averages.

Table 3. Description of bean production in households.

Variable	Obs	Mean	Std. Dev.	[95% Conf. Interval]		t	p-value
Bean conv. (1)	390	564.387	1156.467	449.254	679.521		
Bio-fortified bean (2)	49	946.388	1838.662	418.263	1474.513		
Difference (1)-(2)		−382.001		−754.284	−9.717	−2.016	0.044

The results in Table 3 indicate that the difference between the two means is 382 kg. The significant value of the student test for comparison of means indicates that the two means are statistically different. The average production of bio-fortified beans exceeds the average production of conventional beans. These results are supported by those found by the African Union [28], which states that bio-fortification is a modern agricultural technique, providing a crop with a highly profitable intervention, thus contributing to the improvement of welfare and economic development.

3.1.4. Descriptions of the HDDS and FCS Food Security Indicators

Considering the category of bean grown by the household, we found that households that grew bio-fortified beans have a higher dietary diversity score and a good FCS compared to other households growing other categories. Table 4 illustrates these two indicators of household food accessibility concerning the practice of bean cultivation.

According to the results shown in Table 4, 44% of households are in the high dietary diversity score category. This suggests that the diet is rich and varied, with a balanced consumption of foods from many food groups. This score is associated with a more balanced diet, providing a wide range of nutrients essential for health. Then, 39% of households are in the medium dietary diversity score class. This indicates a relatively varied diet, but one which sometimes remains limited in certain food groups. Finally, 17% of households have a low dietary diversity score. This means that the diet is not very varied, which can lead to nutritional deficiencies or imbalances. The results also demonstrate the importance of bio-fortified beans in improving household food security. The majority of households (61%) that practice bio-fortified bean cultivation have a higher dietary diversity score. Those who have a low dietary diversity score are very few (9%) compared to households that practice other categories of beans. These results are supported by the work of Ruel and her collaborators [29] and Sharma [30], who say that biofortification is a nutrition-sensitive and cost-effective agricultural intervention compared to other actions aimed at improving household dietary diversity.

Regarding the FCS, the results in **Table 4** show that households practicing the cultivation of bio-fortified beans have a high acceptable consumption score rate (78%) compared to other households practicing other categories of beans. These results also show that among households that practice bio-fortified bean cultivation, a small proportion of 4% have a poor consumption score compared to other households producing other categories of beans. The most vulnerable households are those that practice unimproved conventional bean cultivation due to the low yield of this category of beans [31].

Table 4. Description of household FCS and HDDS.

	Types of Beans		
HDDS	Bio-fortified bean	Conventional bean	**Total**
High	61%	41%	**44%**
Medium	33%	41%	**39%**
Low	6%	18%	**17%**
FCS			
Acceptable	73%	57%	**59%**
Borderline	14%	21%	**20%**
Poor	12%	22%	**21%**

3.1.5. Analysis of the Content of Useful Nutrients (Iron and Proteins)

Iron and protein are among the useful nutrients that play essential roles in the optimal functioning of the human body. Iron is an essential mineral that is involved in several crucial biological functions, including oxygen transport, immune system function, growth, and development (in children and pregnant women). Proteins, on the other hand, are macromolecules made up of amino acids, and they perform many essential functions in the human body, such as tissue building and repair, enzyme and hormonal functions, immune system support, nutrient and molecule transport, muscle mass maintenance, and fluid and electrolyte balance, and so on [30] [31].

1) Prevalence of consumption of iron-rich foods

The calculation of this indicator is based on the consumption of iron-rich foods, which are foods of group 8 (Offal), group 9 (Meat), and group 11 (Fish and other seafood) [32]. Thus, **Figure 1** illustrates the distribution of the proportions of consumption of iron-rich foods.

Based on the results of **Figure 1**, we note that half (50.1%) of households sometimes consume iron-rich foods and that 39.4% never eat foods containing iron. It should be noted that the proportion of households that consume iron-rich foods every day is around 10%. These results differ from those found in the study of the Global Analysis of Vulnerability, Food Security, and Nutrition in Burundi [33]. The convincing reason for this discrepancy is the increasing global and food inflation, even during the harvest period [34].

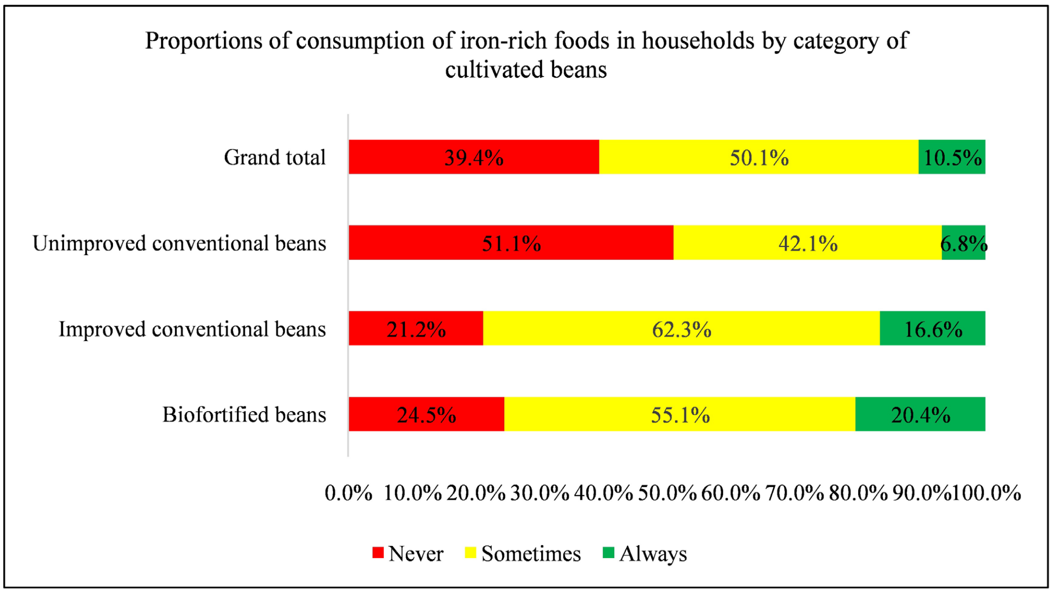

Figure 1. Proportions of consumption of iron-rich foods in households according to the category of cultivated beans.

Considering the category of beans grown on the farm, the practice of bio-fortified beans has an added value in improving food security. The above chart illustrates the proportions of iron-rich food consumption according to the category of bean grown. Households that practice bio-fortified bean cultivation have a high rate (20.4%) of those who consume iron-rich foods every day compared to households practicing other categories of beans. These households have a lower risk of facing iron deficiency diseases. However, households that practice unimproved conventional beans have a high risk of catching iron deficiency diseases because half (50.1%) of them never consume iron-rich foods. The reason for this state of affairs is the low agricultural yields of this bean, which do not allow them to earn sufficient income to be able to buy meat, with its price becoming increasingly expensive.

2) Prevalence of consumption of protein-rich foods

This indicator shows the frequency of consumption of protein-rich foods by a household. Based on a 7-day recall of a household's food consumption, the prevalence of protein-rich foods consumption is calculated by considering foods such as legumes, offal, meat, fish and other dairy products, eggs, milk, and dairy products. **Figure 2** illustrates the frequency of consumption of protein-rich foods by gender of the household head in the study area.

The results of **Figure 2** prove that 53.2% of households consume protein-rich foods. In addition, households that sometimes consume protein-containing foods represent 33.8%, while households that never consume protein amount to 13%. Considering the category of bean grown, households that adopted improved conventional bean and bio-fortified bean frequently consume protein-rich foods compared to households growing unimproved conventional beans. The majority of households that cultivate improved conventional beans (74.2%) and bio-fortified beans (73.5%) consume protein-rich foods daily. This indicates that they are not exposed to protein deficiency diseases such as Kwashiorkor and Marasmus. For households that concentrate on unimproved conventional beans, the proportion of those who never eat protein-rich foods is high (20%) compared to other households. The latter have a high risk of being affected by protein deficiency diseases.

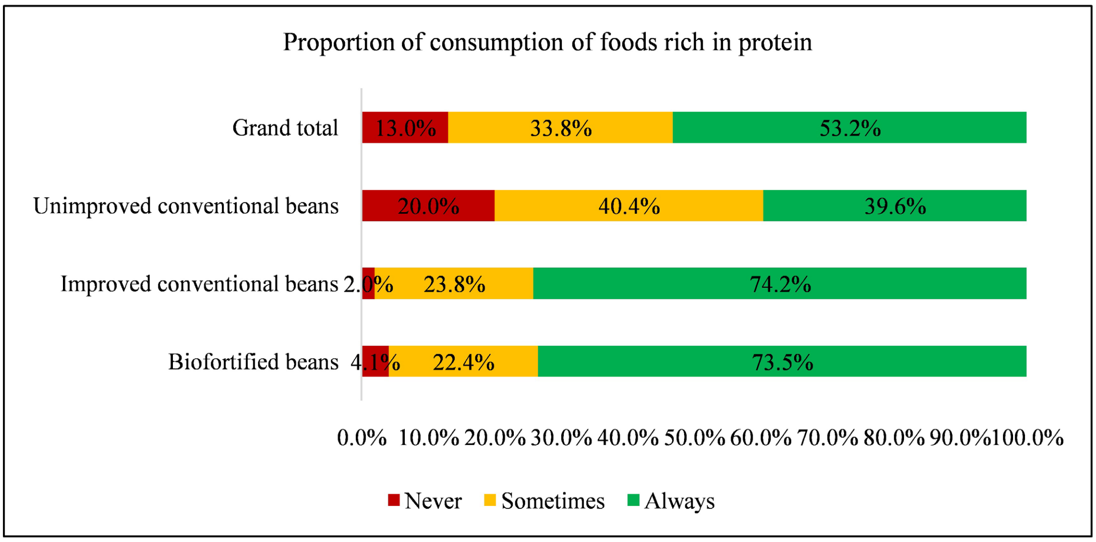

Figure 2. Proportion of consumption of foods rich in protein.

3.2. Description of Factors Likely to Influence HDDS and FCS

3.2.1. Categorical Variables

According to the results of **Table 5**, the majority of households are headed by men (71.03%) with an age between 35 and 65 years for 58.97% of cases. Young adult heads of households and the elderly are poorly represented. Marital status shows that most heads of households are monogamous married (80.26%). Widowers represent around 10%, with very small portions of divorced and single households. As for education, most heads of households are literate. However, heads of households with a primary level dominate (48.72%). They total, with those with a secondary level, more than half of the sample. Only a small fraction of households is represented by university graduates (2.31%). As a result, most households included in the study are mainly farmers (79.74%). Few are employees or traders. Secondary household activities are mainly dominated by livestock farming, trade and the sale of labor. In the same vein, more than half of the households emphasize that they have the necessary labor for their farm (57.95%). As for the types of beans, most households grow conventional beans (87.44%) while households that are satisfied with bio-fortified beans cover 12.56% of the sample. Furthermore, most of the households surveyed are not part of an agricultural production cooperative (77.69%). The majority do not benefit from agronomic supervision (67.23%). Only less than half of the households do. Farms are generally occupied by crops for two seasons during the growing year (72.82%). Households that cultivate for three seasons represent less than a fifth (17.95%). Finally, the majority of households own domestic animals (71.28%).

Table 5. Description of categorical variables.

Variables	Modalities	Count	(%)	Variables	Modalities	Count	(%)
Gender of head of household	Female	113	28.97	Provision of the necessary workforce for the operation	Yes	226	57.95
	Male	277	71.03		No	164	42.05
Age of head of household	18 - 35 years old	138	35.38	Bean cultivation	Bio-fortified bean	49	12.56
	35 - 65 years old	230	58.97		Conventional bean	341	87.44
	Over 65 years old	22	5.64				
Marital status	Bachelor	11	2.82	Be part of an agricultural production cooperative (group)	Yes	87	22.31
	Divorced	21	5.38		No	303	77.69
	Monogamous married	313	80.26	Benefit from agronomic supervision	Yes	117	32.77
	Polygamous	1	0.26		No	240	67.23
	Free union	2	0.51	Crop seasons of occupation by crops	A season	36	9.23
	Widower	42	10.77		Two seasons	284	72.82
Education level of the head of household	Uneducated	60	15.38		Three seasons	70	17.95
	Literacy	45	11.54	Ownership of domestic animals			
	College	27	6.92		Yes	278	71.28
	Primary/fundamental	189	48.72		No	112	28.72
	Secondary/post-fundamental	59	15.13				
	University	9	2.31				
Main activity of the head of household	Agriculture	311	79.74	Secondary activity of the head of household	Jobless	114	29.23
	Employee	38	9.74		Agriculture	107	27.44
	Trade	17	4.36		Breeder	58	14.87
	Sale of labor	10	2.56		Trade	52	13.33
	Breeder	7	0.77		Sale of labor	27	6.92
	Craftsmanship	3	0.51		Craftsmanship	15	3.85
	Jobless	2	0.51		Employee	10	2.56
	Other	2	1.79		Other	7	1.79

3.2.2. Quantitative Variables

Based on the results of Table 6, the average number of people per household is 5.1. The average variation in size from one household to another is 2.26. The median size is within the confidence interval of the average size. Consequently, the number of dependents in the household is around 5.1 for most households. Then, the average number of active people per household is 2.95. The average arable area per household is 92.95 areas, with an average variation of 128.25 areas from one household to another. The median area (40 areas) is excluded from the confidence interval of the average area, which shows that the area per household is lower than the average area for the majority of households. Finally, the average income per household is 460,873 BIF, with an average difference of 1,000,000 BIF between one household and another. The median income (559,080 BIF) shows that the majority of households have an income below the average income.

Table 6. Description of quantitative variables.

Variables	Mean (95% CI)	Standard deviation	Median
Household size	5.1 (4.87 5.32)	2.26	5
People active in the household	2.95 (2.75 3.14)	1.90	2
Area	92.25 (78.90 105.60)	128.25	40
Household income	460,873 (360,889 2,608,578)	1,000,000	559,080

3.3. Presentation of the Models' Results

To decide the variables that will be part of the general model, it is imperative to cross each explanatory variable with the dependent variable, the FCS, and the HDDS. With this step, the independent variables to be taken into the general model must have a single significance level lower than 0.2. The results obtained are shown in Table 7 below.

Table 7. Selecting model variables.

	HDDS	FCS		HDDS	FCS
Variables	P-value	P-value	Variables	P-value	P-value
Age	0.8527	0.2812	Agriculture	0.0031	0.1282
Sex	0.0347	0.0000	M_CooperAgri	0.0695	0.0000
Sit_Matri	0.5466	0.2158	Management	0.0000	0.0012
N_Education	0.1584	0.1374	Trade	0.0033	0.1992
T_household	0.1816	0.0001	Craftsmanship	0.1944	0.1776
N_Actives	0.0012	0.0000	Official	0.0034	0.0686
AP	0.0057	0.1447	Seasons	0.0585	0.1344
Act_Secondary	0.7306	0.0028	Breeding	0.0040	0.0494
Income	0.0000	0.0000	Bean	0.0089	0.0874
Mo	0.0012	0.0022	Area	0.0291	0.0182

According to the results of Table 7, variables such as age and the marital status (Sit_Matri) are to be excluded from all models (p-value > 0.2), but keep the second activity of the head of the household for the FCS. Therefore, the general model will concern variables such as, Sex (gender), Level of education, size of the household, number of active people in the household, main activity of the head of the household: Agriculture, crafts, trade, civil servant, household income, belonging to an agricultural production cooperative, agronomic supervision, Seasons, Livestock, Types of beans. The results are detailed in the steps below.

3.3.1. Model Selection Using Information Criterion

With the results of the full model, the variables considered jointly explain the FCS and HDDS as well (p-value < 0.001). However, not all the model's variables are significant. It is, therefore, necessary to proceed by the models in stages until reaching the saturated model where all the variables are significant. Then, we chose the right model using the AIC and BIC criteria before we made the diagnosis. The best model for FCS is the 8^{th}, which has a value of AIC = 557.104 and BIC = 633.858. The 7^{th} model for the HDDS is chosen with an AIC value of 654.746 and a BIC value of 731.176. The diagnosis and interpretations, consequently, focus on these two models.

3.3.2. Diagnosis of the Best Selected Models

1) Adequacy of the FCS model

The adequacy of the model is highlighted by the Wald test. This test allows us to know if the coefficients of the model are statistically different from zero with H0: coefficients = 0 and Ha: there is at least one coefficient different from zero. The level of significance associated with the test (p-value < 0.001) allows us to confirm that there are at least coefficients of the model that are different from zero. Hence, the chosen model is adequate.

The results in Table 8 indicate that the factors considered exert a highly significant influence on the food consumption score, with a threshold of 1% (p-value < 0.01). Their combined contribution amounts to 59.63% (Pseudo R^2 = 0.596).

Furthermore, gender, number of employed people, education level, labor availability, access to agricultural supervision, and household income influence the food consumption score (p-value < 0.05). In contrast, farming and civil servant status result in a smaller variation in the score (0.05 < p-value < 0.1). Furthermore, crafts, trade, and land area do not show a statistically significant relationship with the food consumption score (p-value > 0.05). Thus, households headed by men are 5.25 times more likely to have an acceptable food consumption score and 2.87 times more likely to have a borderline score rather than a poor food consumption score, compared to households headed by women. Furthermore, each additional working person in the household increases the probability of obtaining an acceptable score by 1.45 times and a borderline score by 1.30 times, compared to a poor score.

Table 8. Determinants of FCS in the study area.

		Bivariate analysis		Multivariate analysis	
	Factors	RRR (95% CI)	p-value	RRR (95% CI)	p-value
	Base: Poor				
Acceptable	Sex				
	Male	3.65 (2.12 6.26)	0.000	5.25 (2.22 12.39)	0.000
	N-active	1.45 (1.19 1.75)	0.000	1.35 (1.06 1.72)	0.014
	Agriculture	0.55 (0.27 1.12)	0.099	1.02 (0.19 5.46)	0.975
	Trade	1.64 (0.76 3.56)	0.208	0.67 (0.07 6.21)	0.727
	Craftsmanship	0.57 (0.29 1.12)	0.103	1.23 (0.48 3.11)	0.659
	Official	2.14 (0.79 5.74)	0.130	0.38 (0.08 1.82)	0.227
	Mo	3.58 (2.11 6.08)	0.000	2.40 (1.20 4.79)	0.013
	Area	1.001 (0.99 1.01)	0.235	1.001(0.99 1.004)	0.433
	Management	4.21 (2.16 8.21)	0.000	2.27 (1.26 7.059)	0.013
	Income	1	0.000	1	0.083
	N_Education				
	Uneducated	0.85 (0.35 2.06)	0.719	1.16 (0.38 3.57)	0.786
	Primary	3.48 (1.63 7.45)	0.001	2.94 (1.09 7.92)	0.033
	College	4.46 (1.28 15.56)	0.019	6.55 (1.60 40.54)	0.043
	Secondary or higher	4.98 (1.78 13.94)	0.002	5.49 (1.11 26.93)	0.036
Limit	Sex				
	Man	1.90 (0.99 3.62)	0.050	2.87 (1.29 6.37)	0.010
	N-active	1.29 (1.02 1.59)	0.029	1.30 (0.98 1.68)	0.048
	Agriculture	0.62 (0.27 1.43)	0.262	0.94 (0.15 5.78)	0.953
	Trade	1.29 (0.50 3.32)	0.590	1.35 (0.12 14.22)	0.798
	Craftsmanship	0.66 (0.28 1.52)	0.327	0.71 (0.24 2.12)	0.549
	Official	0.81 (0.21 3.14)	0.761	0.18 (0.27 1.22)	0.080
	Mo	1.22 (0.65 2.31)	0.537	1.45 (0.66 3.17)	0.788
	Area	1.001 (0.99 1.004)	0.506	1.002 (0.99 1.005)	0.254
	Management	1.03 (0.43 2.46)	0.946	0.86 (0.30 2.49)	0.789
	Income	1 (0.99 1)	0.902	0.99 (0.99 1)	0.550
	N_Education				
	Uneducated	1.82 (0.64 5.20)	0.263	1.84 (0.55 6.10)	0.317
	Primary	2.62 (0.99 6.90)	0.051	2.79 (0.91 8.53)	0.071
	College	1.06 (0.16 7.06)	0.950	2.24 (0.23 21.27)	0.481
	Secondary or higher	3.34 (0.94 11.84)	0.062	7.44 (1.28 43.19)	0.025

Prob > Chi^2 = 0.000 Pseudo R^2 = 0.596.

Similarly, compared to literate household heads, those with a primary education provide their household with 3.48 times more chances of having an acceptable score and 2.79 times more chances of having a borderline score rather than a poor score. For household heads with a secondary education, this probability increases to 6.55 times for an acceptable score. Similarly, households whose heads have attained secondary education or higher are 5.49 times more likely to obtain an acceptable score and 7.44 times more likely to obtain a borderline score rather than a poor score. However, no significant difference is observed between households whose heads are literate and those whose heads have never attended school (p-value > 0.05).

Similarly, compared to households lacking sufficient labor, those with sufficient labor are 3.58 times more likely to obtain an acceptable food consumption score rather than a poor score. Furthermore, households receiving agricultural support are 4.21 times more likely to obtain an acceptable score compared to those without support. However, support does not appear to influence the probability of obtaining a borderline score (p-value > 0.05). Finally, an increase in income is accompanied by an improvement in the food consumption score.

2) HDDS model adequacy

The Wald test allows the model adequacy to be highlighted. Indeed, this test helps to know if the coefficients of the model are statistically different from zero with H0: coefficients = 0 and Ha: there is at least one coefficient different from zero. The level of significance associated with the test (p-value < 0.001) confirms that there are at least coefficients of the model that are different from zero. Thus, the chosen model is adequate.

Based on the results of **Table 9**, we note that the variables considered have a highly significant influence on the household dietary diversity score at the level of 1% (p-value < 0.001). Their joint contribution amounts to 56.38% (Pseudo R^2 = 0.5638).

Furthermore, certain factors such as the number of working people, agriculture, trade, civil servant status, access to agricultural supervision, growing seasons, income, and type of beans grown have a statistically significant influence on the household dietary diversity score (p-value < 0.05). In contrast, crafts, cultivated area, and membership in an agricultural cooperative have a weaker relationship with this score (0.05 < p-value < 0.1). Furthermore, each additional working person in the household increases the likelihood of a high dietary diversity score by 1.33 times and of a medium score by 1.31 times compared to a low score.

Regarding occupational status, farming households are 77% and 66% less likely to obtain a high and medium dietary diversity score, respectively. In contrast, households of artisans are 2.65 times more likely to have a medium score than a low score. Similarly, households of traders are 5.69 times more likely to have a high score and 3.47 times more likely to have a medium score than a low score. As for households of civil servants, they are 10.75 times more likely to obtain a high score and 5.95 times more likely to obtain a medium score than a low score.

Table 9. Determinants of HDDS in the study area.

	Factors	Bivariate analysis RRR (95% CI)	Bivariate analysis p-value	Multivariate analysis RRR (95% CI)	Multivariate analysis p-value
	Base: Low				
High	N_actives	1.33 (1.09 1.62)	0.004	1.32 (1.05 1.65)	0.017
	Agriculture	0.23 (0.08 0.62)	0.003	0.74 (0.14 3.87)	0.730
	Craftsmanship	1.26 (0.51 3.11)	0.614	2.36 (0.75 7.37)	0.138
	Trade	5.48 (1.62 18.51)	0.006	5.69 (1.27 25.46)	0.023
	Official	10.75 (1.42 81.23)	0.021	1.79 (0.09 33.87)	0.696
	Area	1.00 (0.99 1.01)	0.684	0.99 (0.99 1.00)	0.055
	M_CoopAgri	1.57 (0.78 3.14)	0.202	0.41 (0.15 1.08)	0.071
	Management	5.78 (2.61 12.86)	0.000	6.18 (2.12 17.95)	0.001
	Seasons				
	Three seasons	8.44 (2.52 28.31)	0.001	4.95 (0.89 27.43)	0.067
	A season	1.14 (0.41 3.17)	0.796	0.87 (0.22 3.55)	0.857
	Breeding	2.65 (1.43 4.91)	0.002	1.65 (0.75 3.65)	0.209
	Income	1	0.004	0.99 (0.99 1)	0.055
	Bean				
	Bio-fortified	4.53 (1.33 15.41)	0.015	2.04 (0.54 7.59)	0.287
Medium	N_actives	1.25 (1.03 1.53)	0.025	1.32 (1.05 1.65)	0.015
	Agriculture	0.34 (0.130 0.92)	0.034	1.00 (0.19 5.22)	0.993
	Craftsmanship	1.78 (0.73 4.32)	0.203	2.65 (0.86 8.14)	0.088
	Trade	3.47 (1.00 12.04)	0.050	4.13 (0.90 18.89)	0.067
	Official	5.95 (0.76 46.45)	0.089	1.92 (0.09 37.44)	0.666
	Area	0.99 (0.99 1.00)	0.120	0.99 (0.99 1.00)	0.055
	M_CoopAgri	0.86 (0.41 1.79)	0.688	0.41 (0.15 1.08)	0.071
	Management	2.52 (1.11 5.74)	0.027	4.47 (1.51 13.24)	0.007
	Three seasons	3.03 (0.86 10.67)	0.084	3.94 (0.86 17.98)	0.076
	A season	1.36 (0.507 3.62)	0.543	0.87 (0.22 3.54)	0.854
	Breeding	1 (0.99 1)	0.979	0.99 (0.99 1)	0.636
	Income	1 (0.99 1)	0.979	0.99 (0.99 1)	0.636
	Bean				
	Bio-fortified	2.42 (0.68 8.59)	0.173	1.78 (0.46 6.79)	0.397

Prob > Chi^2 = 0.000 Pseudo R^2 = 0.5638.

The area under crops has a slight influence on the dietary diversity score. Furthermore, households that are members of agricultural cooperatives are less likely to obtain a high or average score than those that are not members.

Households that benefit from agricultural support are 6.18 times more likely to have a high dietary diversity score and 4.47 times more likely to have a medium score than those who don't benefit from it. Furthermore, households that farm their land for three seasons are 8.44 times more likely to have a high score and 3.94 times more likely to have a medium score than those who farm for only two seasons. However, no statistically significant difference is observed between households that farm for two seasons and those that farm for a single season (p-value > 0.05).

Increasing income favors a higher dietary diversity score. Finally, households growing bio-fortified beans are 4.53 times more likely to obtain a high score than those growing conventional beans. However, regardless of the bean variety cultivated, the average dietary diversity score remains statistically unchanged (p-value > 0.05).

3.4. Discussion of Results

The food consumption score, an indicator of household dietary habits, directly reflects their food security status. A high score indicates a more balanced and varied diet, while a low score often indicates a more restricted diet, which can lead to nutritional deficiencies. According to the results of our study, families in which both parents are still married (those headed by a man) generally enjoy better nutrition than other households. This is explained by the increased opportunity to diversify income sources, better family organization, and greater social and financial stability, which can lead to more robust food education [35] [36]. Furthermore, our results also show that households that have benefited from agricultural support are significantly more likely to have a varied diet and better nutritional quality. This situation is explained by the adoption of agricultural technologies, the dissemination of which to rural households not only contributes to improving their diet but also to increasing their agricultural productivity [37]. On the other hand, agricultural supervision plays a crucial role in improving the performance of farmers and in strengthening farmers' capacities to adopt these innovative technologies [38]. In addition, membership in organizations' social networks promotes the adoption of these agricultural technologies [39], which directly improves household food security [40]. Furthermore, our results show that households with a large number of assets and access to sufficient labor to carry out their activities are more likely to obtain higher scores in terms of dietary diversity and consumption compared to households that do not have these resources. This situation is explained by the fact that family labor, as well as additional labor, plays a key role in increasing household income, which has a direct impact on improving their food situation through a diversified diet [41]. Indeed, there is a positive and strong relationship between improving household food security and increasing the number of assets and additional labor within the household [42]. Finally, a significant number of assets within the household significantly increases the chances of achieving a food security situation [43]. Our results also reveal that households with the ability to cultivate during three seasons and sufficient arable land are more likely to achieve a higher dietary diversity score. This is explained, on the one hand, by their ability to access a wide range of food products available throughout the year, given that the production of these foods is not uniform across seasons [44]. On the other hand, having sufficient arable land leads to an increase in agricultural income, which improves the household's dietary diversity [45]. Furthermore, households with high agricultural income are more likely to achieve an acceptable dietary diversity score compared to those with low agricultural income [46].

Finally, the results highlight that households where the head of household has a higher level of education are more likely to achieve a higher food consumption score compared to uneducated households. Indeed, a higher level of education facilitates access to food and nutrition information, strengthens food security, promotes obtaining better-paid employment, and provides solid social capital, all of which contribute to escaping food insecurity [47]. Similarly, households engaged in income-generating activities, such as crafts and trade, are more likely to achieve an average dietary diversity score. This is explained by the fact that increasing non-farm income promotes a more balanced distribution of resources, thus enabling households to better meet their needs and better cope with food insecurity [48].

4. Conclusion

The study demonstrates that bio-fortified beans have significant potential to improve the dietary habits of Burundian households, a country where malnutrition is aggravated by socio-economic and climatic factors. Enriched with iron and zinc, bio-fortified beans constitute a sustainable solution to combat nutritional deficiencies, particularly among the most vulnerable populations, such as children under five and pregnant women. The results of the bivariate analysis indicate that the development of this crop significantly improves the HDDS and FCS compared to households practicing conventional bean cultivation. In addition to FCS and HDDS, they also record higher consumption of foods rich in essential nutrients such as iron and protein. However, its impact is absorbed by other determinants of dietary habits in the multiple regression models. The gender of the head of household, the number of active individuals in a household, and agricultural supervision are the factors that positively influence household dietary habits. In addition to these latter factors, the FCS is positively influenced by labor and education levels. In contrast, the HDDS is positively influenced by the agricultural area owned by the household, trade, crafts, and participation in a farming cooperative. Thus, to effectively improve household eating habits, the adoption of bio-fortified bean cultivation should be accompanied by the agricultural extension and adoption of new agricultural technologies and increased agricultural investment expenditure.

Policy Implications

Policies should focus on strengthening household stability by supporting family cohesion programs and encouraging income diversification to improve food security. Expanding agricultural support through financial aid, training, and cooperative networks can enhance productivity and dietary diversity. Ensuring facility access to land, labor, and information will help stabilize food availability. Education and nutrition awareness campaigns, especially for women, can lead to long-term improvements in food security. Additionally, promoting non-farm income opportunities and strengthening social protection programs, such as market access improvements, will further enhance household resilience.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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