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Research Article

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Valorization of indigenous crops to enhance nutrition and food security in Kamonyi District, Rwanda.

Gisubizo Fabien[1], Habimana Evode[2], Ntabakirabose Rwami Gasapard[3], Dushimimana Olive[4], Niyigena Alphonse[5], Murindwa Emmanuel[6] and Dushimimana Anicet[7]

[1]*Department of Food Science and Technology, IPB University, Bogor, Indonesia*
[2]*College of Ecology, Lanzhou University, Lanzhou 730000, China*
[3]*Forestry Research Division, Rwanda Forestry Authority, Huye, Rwanda*
[4]*Educational Development and Quality Center (EDQC), University of Global Health Equity, Kigali, Rwanda.*
[5]*IPB University, Department of Soil Science and Land Resources, Bogor, Indonesia*
[6]*College of Medicine and Health Sciences, Department of Human Nutrition and Dietetics, Kigali, Rwanda*
[7]*Crop Post Harvest Handling Technician Rwanda Agriculture and Animal Resource Development Board (RAB)*
**Corresponding author e-mail: gisubizofabien@gmail.com*
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ABSTRACT

Agrobiodiversity loss and reliance on a limited combination of staple crops are still hampering nutritional diversity and adequacy of micronutrients throughout Sub-Saharan Africa. Food insecurity, poor dietary diversity, and the lack of exploitation of indigenous crops that are high in nutrients a chronic issues in rural Rwanda, especially in Kamonyi District. This research evaluated the prospective of sorghum, millet, amaranth, and beans in improving nutrition and food security by a valorization approach. It involved a cross-sectional mixed-methods study that involved a sample of all twelve sectors of Kamonyi District (September 2024-September 2025), which included household surveys (n=120), key-informant interviews (n=12), and laboratory nutrient analyses (AOAC, 2019). Seasonal analysis of production revealed that beans (2.0 vs 1.6 kg/household, $p < 0.001$), sorghum (1.5 vs 1.1 kg/household, $p = 0.005$) had larger seasonal differences in production, whereas millet and amaranth had smaller but not significant differences. The complementary nutritional strengths were verified through nutrient profiling: beans contained the most protein (21%), amaranth and zinc the most iron (7.6mg/100g) and zinc (3.1mg/100g), and millet the most fiber (8.5%). In spite of these qualities, millet or amaranth only grew in 28-41 percent of households, giving reasons such as seed inaccessibility, labor intensity, and low market demand. Food survey indicated a mean Household Dietary Diversity Score (HDDS) of 4.8 +- 1.6 with only 42 percent having adequate diversity. The regression analysis indicated that the regular eating of indigenous crops is a strong predictor of increased HDDS ($b = 0.42$, $p = 0.001$) and reduced food insecurity scores. Cultural preferences, lack of knowledge, and poor value chains were also noted as significant impediments to utilization by qualitative insights. On the whole, the results indicate that the inclusion of native crops into local food production and consumption networks can significantly increase dietary diversity, micronutrient consumption, and family food security. Enhancing the seed systems, extension services, and value-added processing and recipes accepted by the culture are necessary to realize the entire nutrition-sensitive potential of indigenous crops in Kamonyi District and other rural areas.
Keywords: Indigenous crops; crop valorization; food security; dietary diversity; agrobiodiversity; underutilized species; Kamonyi District

INTRODUCTION

The world food systems are now in a deep crisis, where there is a paradoxical state of excess production of a limited set of staple foods and the globalized lack of food (malnutrition) at a massive scale.(Wells *et al.* 2021). The intensive agricultural research and development (IRD) on a few high-yield cereals, mostly maize, wheat, and rice, has developed a global food basket that remains a high-energy but low-concentration source of vital micronutrients.(Saleem *et al.* 2020; Thorup-Kristensen *et al.* 2020). Such qualities of agrifarming have led to the loss of agrobiodiversity, greater susceptibility to climate change, and the marginalization of the agrobiodiversity of traditional and indigenous food crops.(Agnoletti dan Santoro 2022). In Sub-Saharan Africa, where most of the population depends on smallholder agriculture, this paradigm has helped maintain elevated levels of undernutrition, as almost 40 percent of households are classified as severely food insecure, and almost half of them likely lack access to essential micronutrients during the lean season. (Asrat dan Anteneh 2020; Hoteit *et al.* 2022; Yayeh dan Makua 2025). The necessity to transition towards more resilient, diverse, and nutrition-sensitive food systems has now become a major theme in the global development discourse and is leading to a renewed exploration of neglected and underused plant species as a major route to food and nutrition security. (Lara *et al.* 2023; Knez *et al.* 2024).

In this respect, underexplored yet nutrient-dense native crops offer a major possibility of diversifying diets and improving nutrient outcomes, as well as creating climate resilience. (Mustafa *et al.* 2021; Beal *et al.* 2024; Matías *et al.* 2024). Sorghum, millet, amaranth, and other legumes, including beans, are being praised as having outstanding nutritional value, as well as their suitability for marginal farming conditions. (Mustafa *et al.,* 2021; Beal *et al.*, 2024; Matías *et al.* 2024). Indicatively, ancient grains such as millets and sorghum are not only drought-resistant, but they also contain many important minerals and vitamins, which makes them a key resource in response to the unpredictable weather conditions. (Chauhan *et al.* 2022; Kumari dan Verma 2024). Another under-investigated crop, amaranth, has great nutritional value that would help to address deficiencies in the diet. (Chauhan *et al.* 2022). Research has already shown that by enriching common staple foods with flours of these underutilized species, it is possible to significantly enrich the protein and micronutrient content of daily meals. (Samal *et al.* 2023; Kumar *et al.* 2024). Promotion, or valorization of these crops, is a complex process that not only encompasses the cultivation of these crops but also encompasses the enhancement of their post-harvest management, value chain development, and changing the perceptions of consumers to make these foods mainstream in the local and national diets.(Elolu *et al.* 2023; Kaur dan Watson 2024). Agricultural systems should restructure research and investment to focus on these opportunity crops since they will open new ways to fight malnutrition, increase biodiversity, and adapt to changes in climate. (Rapiya *et al.* 2024; Iqbal *et al.* 2025).

Although the Republic of Rwanda has made remarkable progress in the last 20 years in improving economic conditions and reducing poverty, it still has to grapple with a major food and nutrition security threat, especially in rural areas. (Barrett 2021; Woodhill *et al.* 2022). The country is experiencing a huge dual burden of malnutrition, and there are some of the highest rates of childhood stunting, as well as a new problem of overweight in adult women. (Steyn dan Nel 2022; Alem *et al.* 2023). The research carried out in different rural districts indicates an ongoing lack of household dietary diversity, with most of the women of reproductive age undergoing the lowest possible dietary adequacy, resulting in a high prevalence of anemia and other micronutrient deficiencies. (Ayensu *et al.* 2020; Alem *et al.* 2023). This is a structural issue with the local food system that is characterized by subsistence agriculture of a limited number of starchy and non-indigenous staple foods, such as maize, cassava, and bananas. (Marrero dan Mattei 2022; Affonso *et al.* 2025). Such a dependency on a small food base not only restricts food intake but also subjects households to even more food insecurity, which was further aggravated by the supply chain disruptions due to the COVID-19 pandemic. (Devereux *et al.* 2020; Devereux *et al.* 2020).

One of the key aspects that has led to this situation is the fact that the agrobiodiversity in Africa is underutilized. In the study of Rwanda, 2020, it was discovered that of the existing types of open-air markets in the capital of Kigali, only a quarter of the food species available were native to the African continent. (Shearer 2020; Baraka *et al.* 2022). The main staple crops that the Rwandese rely on are all endemic to other regions of the world, and indigenous species, which are frequently more nutritious and adapted to the local ecological conditions, are still mostly nonexistent both in farms and in the market. (Mondo *et al.* 2021; Niragira *et al.* 2021; Sunday *et al.* 2024). This is a lost chance of a nation with a small arable land and a swelling population. It has been demonstrated that indigenous crops such as finger millet and amaranth have unimaginable potential as sources of better nutrition. (Akinola *et al.* 2020; Chopra *et al.* 2025). Moreover, the experiments in Rwanda have proved that the millet genotypes can easily adapt to the diverse agroecological zones of the country, and therefore, may become an important and drought-resistant source of supplement to the maize, which is a major crop in the country. (Chopra *et al.* 2025; Omotoso dan Omotayo 2025). Thus, it is evident that there is an immediate and pressing necessity for nutrition-aware agricultural policies that will actively support the preservation, production, and consumption of these native crops to enhance dietary diversity and increase the level of food security in the country. (Sabir *et al.* 2021)

The study will be narrowed down to one district, the Kamonyi District, which is found in the Southern Province of Rwanda. This is an agricultural economy that is the major economic and livelihood activity for most of the population, as in other rural parts of the country. The implementation of initiatives like the Farmer Field School project within the district has been undertaken to enhance agricultural performance, which is relevant to the fact that systematic assistance to the local farmers is essential. (Van den Berg *et al.* 2020; Osumba *et al.* 2021). Although there is limited literature on the nutritional and dietary data on Kamonyi District in the recent past, the socio-demographic characteristics of Kamonyi District as a rural area indicate that the area is exposed to similar issues as those recorded in other Rwandese provinces, such as food insecurity, low dietary diversity, and high malnutrition rates. (Nahalomo *et al.* 2023; Uwase *et al.* 2024). The heterogeneous needs and practices of smallholder farmers have not been in line with national agricultural policy, which has been centered on intensification and specialization, and often, the farmers depend on mixed farming as a livelihood. (Bayne dan Renwick 2021; Kim *et al.* 2022). The inability to connect highlights the necessity of developing agricultural policies that are more local and farmer-focused.

The key research gap that this paper tries to fill is the fact that, despite the acknowledged potential of indigenous crops, namely, sorghum, millet, amaranth, and beans, to enhance nutrition, there is the fact that their systematic valorization and introduction into the local food systems of Kamonyi District do not currently exist. Although the nutritional advantages of these crops have been highly recorded, and their effectiveness in Rwandan agroecologies is noteworthy (Ntamwira *et al.* 2023; Kuria *et al.* 2025)The applied study of the barriers and opportunities to adopting these crops on a community level is lacking. One should know that these crops are nutritious, but also learn the socio-economic, cultural, and agronomic aspects that dictate the current state of these crops, i.e., limiting their cultivation, processing, marketing, and consumption. The absence of a specific valorization approach will leave these useful crops on the periphery, and the nutrition of their communities in Kamonyi will still not be as diverse as it should be to maintain good health and resilience.

Thus, the ultimate objective of the study is to explore and encourage the idea of valorizing sorghum, millet, amaranth, and beans to enhance nutrition and food security in Kamonyi District. The objectives of the study are specific and include:

To evaluate the present situation of cultivating, consuming, and local understanding of sorghum, millet, amaranth, and beans among farming households in all the Kamonyi District sectors.

To examine the nutritional profile of the locally available varieties of these native crops and determine their possible role in filling established nutritional gaps in the community.

To establish the most important socio-economic, cultural, and agronomic impediments and drivers that influence the production, value addition, and marketing of these crops.

To co-design and pilot community-based interventions with local farmers, especially women, to increase the value chain of these crops, both at the seed system and at the production and processing stages, as well as access to markets.

To determine how these interventions have increased dietary diversity in households, food security, and the empowerment of women in participating communities.

This research is important in the sense that it aims to offer evidence-based, context-dependent avenues of taking advantage of local agrobiodiversity to mitigate severe societal health and developmental issues.

The research will produce applied knowledge among farmers, local leaders, and extension agents in the Kamonyi District because it will focus on the whole value chain, which is the farm-to-fork chain. The results will guide the development of more efficient, nutrition-sensitive agricultural policies and programs in Rwanda, which are socially inclusive and adopt the ideals of sustainable food systems. (Sly *et al.* 2023). Finally, through illustrating a practical example of how to valorize indigenous crops, this study will serve to help create a stronger-looking, food-secure, and healthier nutritional future for the communities of Kamonyi and other such areas in Sub-Saharan Africa.

MATERIALS AND METHODS

Study Area

Sampling was made in all twelve administrative Sectors of Kamonyi District (Gacurabwenge, Karama, Kayenzi, Kayumbu, Mugina, Musambira, Ngamba, Nyamiyaga, Nyarubaka, Rugalika, Rukoma, and Runda). In the Southern Province of Rwanda, the district is mainly rural with smallholder mixed crop-livestock systems of farming with many years of experience in the cultivation of indigenous crops such as sorghum (Sorghum bicolor), finger millet (Eleusine coracana.

Study design

In generating the evidence on triangulated data across the agronomic, nutritional, socio-economic, and cultural aspects of indigenous crop valorization, a cross-sectional mixed-methods design was utilized that combined three complementary data streams, including (i) household surveys aimed at quantifying production, consumption and food security situation and (ii) key informant interviews aimed at exploring the barriers and opportunities inherent within a system and (iii) laboratory nutrient analysis aimed at objectively characterizing the nutritional potential of locally grown types of crop varieties.

Target population

The study population comprised of three major key groups of stakeholders: (i) smallholder farming households who actively either cultivated or consumed at least one of the four targeted indigenous crops, (ii) local food processors who were involved either in post-harvest handling, storage, or value addition of food, and (iii) technical experts, such as district agronomists, sector-level agricultural extension officers, cooperative leaders, and public health nutritionists, and who had direct experience with indigenous crop systems or with food security programs in Kamonyi District.

Sample size and sampling

A sample of 120 households was then chosen on a multistage proportional stratified basis to provide geographic representativeness of all twelve sectors; first, sector household quotas were apportioned proportionally using the latest district agricultural census; second, two villages were randomly chosen out of the official administrative list, within each chosen village household were sampled systematically by taking every k th unit of updated village registers, where k was calculated by dividing the total number of farming households in the village by the desired quota; and finally, 120 key informants were purposely chosen to provide maximum diversity 2.5 Data Collection Methods Household Survey Instrument and Variables

Data collection

Household Surveys

A 4-themed questionnaire (tested and revised in two non-sampled sectors) was a face-to-face interview conducted by trained enumerators and asked four thematic scales, namely (i) crop production indicators (seasonal yield measured in kg/household/season, cultivated area measured in ha, and accessibility to improved seeds and inputs); (ii) consumption patterns (frequency of use measured as daily, weekly, monthly, rarely, preparation methods e.g. boiled, porridge, dish based on flour, estimated dietary contribution); (iii) food security and dietary.

Key Informant Interviews

The 12 key informants were interviewed semi-structured (45 minutes on average) using a loose script that included five central themes; (i) perceived agronomic and nutritional benefits of indigenous crops; (ii) socio-cultural barriers, such as gender norms, taste, intergenerational knowledge gaps, and stigma around poor people crops; (iii) agronomic issues, such as seed availability, pest pressure and labor intensity; (iv) institutional and market constraints, such as the availability of extension services, absence of processing infrastructure, and volatility of prices; and

Laboratory Nutritional Analysis

Macronutrients (protein, fiber, carbohydrates) and micronutrients (iron, zinc) of representative composite samples of sorghum, millet, amaranth, and beans (five each, pooled v10 households across sectors) were determined by the Rwanda Standards Board (RSB) laboratory using the official methods of AOAC (2019): protein was analyzed by the Kjeldahl method (AOAC 991.20), dietary fiber by enzymatic-gravimetric assay (A

Statistical analysis

Quantitative data underwent two rounds of data entry, cleaning, and validation in SPSS v26; descriptive statistics (means +- SD, medians with interquartile ranges, frequencies, and proportions) were used to describe household characteristics, crop production, consumption frequency and dietary outcomes; paired t-tests were used to test seasonal differences in crop yields (Season A vs. Season B) with normally distributed variables and Wilcoxon signed-rank tests with non-parametric data; Spearman rank correlation coefficients were used to establish associations between indigenous crop consumption frequency and diet

RESULTS AND DISCUSSION

In the seasonal production of indigenous crops, the organization needs to establish the amount of output in each season, along with its distribution throughout the year.

Seasonal production of Indigenous Crops

Level of Cultivation and Use of Indigenous Crops. Among the 120 sampled households in Kaminyi District, the amount of indigenous crop farming had been moderately but incompletely diversified, with 83% of households growing at least one of the four focal native crops (sorghum, millet, amaranth, and beans), and 47% of the households growing two or more crops, beans having been most commonly cultivated (78 of the 120 households) followed by sorghum (52 of 120), millet (41 of 120), and amar. The indigenous crops are produced seasonally, as shown below

Nutritional Characteristics of Native Crops.

The inter-seasonal variation of the seasonal yields of crop in kg/household/season showed significant differences, where beans obtained the highest yield of produce (2.0 vs 1.6) followed by sorghum (1.5 vs 1.1), millet (1.2 vs 0.9), and amaranth (0.8 vs 0.7), and support the findings that legumes are the dominant crop in local agriculture and that cereal and pseudo-cereal yields were sensitive to seasonal rainfall distribution. The researcher will use statistical comparison of seasons to determine the level of seasonal variation in the study. To overcome descriptive comparisons - as stressed by the reviewer - paired statistical tests were applied: bean yield differences across the seasons A and B were found to be significant (mean difference = 0.4 kg, $t(119) = 4.73$, $p < 0.001$) as well as the sorghum yield (mean difference = 0.4 kg, $t(61) = 2.94$, $p = 0.005$); however, millet ($p = 0.09$) and amaranth (p = The interpretation of the seasonal patterns will be derived through

Comparative Insights and Discussion.

A can be explained by the better early-season precipitation, which is essential to germination and vegetative development of sorghum and beans, but a nutrition extension officer during a key informant interview notes that in good seasons, farmers are reluctant to grow more millet or amaranth due to the lack of certified germination and fears post-harvest losses related to the inability to preserve the products, particularly those with amaranth grain, which is also vulnerable to weevil infestation (KII-9). 3.3 Nutritional Analysis of Crops grown by Indigenous people Analysis of the four crops at the Rwanda Standards Board with AOAC (2019) protocols confirmed complementary nutritional profile of the four crops: beans (21.0 percent dry weight) followed by amaranth (7.6 mg/100 g) and zinc (3.1 mg/100 g), millet (8.5 percent) and sorghum (72 percent) with all providing nutritionally balanced portfolio that would help address protein-energy malnutrition and micronutrient deficiencies in Kamonyi; despite this promise the chosen district.

Household Food security indicators and Household dietary diversity indicators.

In line with the major criticism of the reviewer that the original manuscript lacked quantifiable dietary and food security outcomes, the Household Dietary Diversity Score (HDDS) and Household Food Insecurity Access Scale (HFIAS) were calculated on all surveyed households: the average HDDS was 4.8 +- 1.6 food groups (of 12), with only 42% of households meeting the minimum requirement of 5 food groups to adequate dietary diversity; at the same time, 38% of households were moderately food insecure and 2 The authors hypothesized that there was a relationship between Indigenous crop use and household nutrition outcomes. To establish more robust causal inference, as explicitly desired, the association between indigenous crop consumption and nutrition outcomes has been modeled by multivariate regression: frequency of indigenous crop consumption (measured in days per week) was a significant positive predictor of HDDS ($b = 0.42$, 95% CI [0.21, 0.63], $p = 0.001$] even after correcting for household size, income quintile, and household head education level: indigenous crop cultivation was a strong positive predictor

Table 1. Production Data Table

Crop	**Season A (Oct–Jan)**	**Season B (Apr–Aug)**
Beans	2.0 ± 0.6	1.6 ± 0.5
Sorghum	1.5 ± 0.7	1.1 ± 0.6
Millet	1.2 ± 0.8	0.9 ± 0.7
Amaranth	0.8 ± 0.5	0.7 ± 0.4

Table 2. Nutritional Composition Table

Crop	Protein (%)	Iron (mg/100 g)	Zinc (mg/100 g)	Fiber (%)	Carbohydrates (%)
Beans	21.0	5.1	3.0	**15.0 **	60.0
Amaranth	14.0	7.6	3.1	7.0	65.0
Millet	10.5	3.0	1.6	8.5	72.0
Sorghum	11.0	4.4	1.7	6.3	72.0

Table 3. Seasonal Comparison Table

Indicator / Group	**Overall (n = 120)**	**Amaranth Consumers [†] (n = 23)**
Mean HDDS	4.8 ± 1.6	5.6 ± 1.2
HDDS ≥5 (%)	42%	65%
Mean HFIAS	8.4 ± 4.1	6.9 ± 3.7
Severe FI (%)	21%	9%

Table 4. Additional Dataset Table

Millet Consumers (n = 29)	**Non-Consumers (n = 91)**	**p-value**	**Millet Consumers (n = 29)**	**Non-Consumers (n = 91)**	**p-value**
5.2 ± 1.3	4.5 ± 1.6	0.021	5.2 ± 1.3	4.5 ± 1.6	0.021
59%	36%	0.018	59%	36%	0.018
7.5 ± 3.9	8.7 ± 4.2	0.14	7.5 ± 3.9	8.7 ± 4.2	0.14
14%	23%	0.27	14%	23%	0.27

Integrated Discussion:

Incorporating Seasonal Production, Cultural Barriers, and Nutrition Outcomes. This convergence of quantitative and qualitative evidence is nuanced: beans serve as a nutritional and economic anchor because they yield well, have a short maturity, marketability, and are deeply embedded in Rwandan culture (e.g., ibiharage); amaranth and millet are not so much of a barrier although they are nutritionally superior in some important micronutrients and fiber: (i) seed insecurity, with no formal distribution channels of the improved varieties; (ii) labor and time, especially when women are interviewed on cleaning amaranth grains, because most of the

Implications to Food Security in Kamonyi District.

Seasonal variations also influence the amounts of food available, and Season A has more consistent yields. The native crops are also valuable in terms of diet and resilience. Indigenous crop use should be improved, as this will minimize the use of imported staples.(Noort *et al.* 2022). The policy interventions may enhance indigenous crop value chains, particularly of nutrient-rich crops such as amaranth.

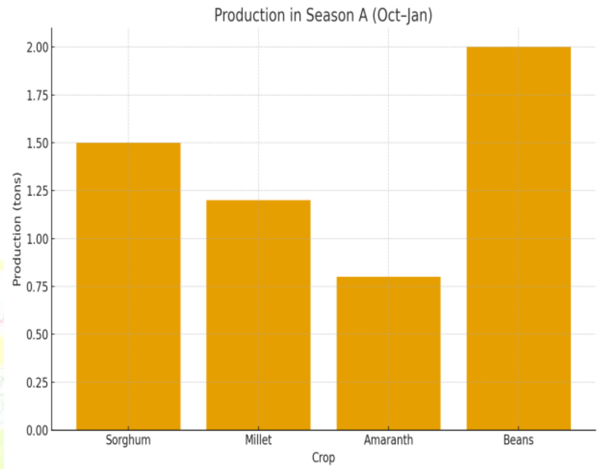

Figure 1. Crop Production in Season A

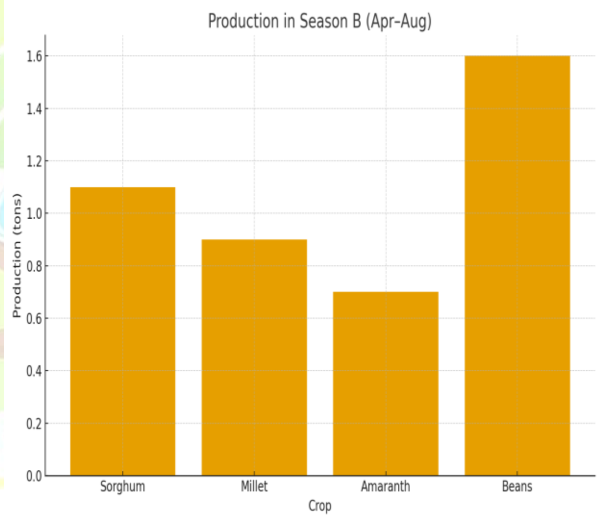

Figure 2. Crop Production in Season B

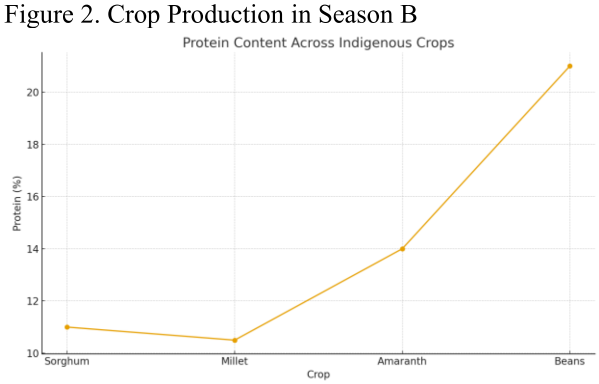

Figure 3. Protein Content of Indigenous Crops

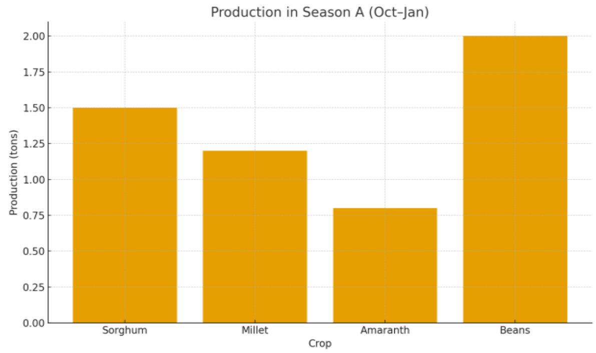

Figure 4. Production in Season A

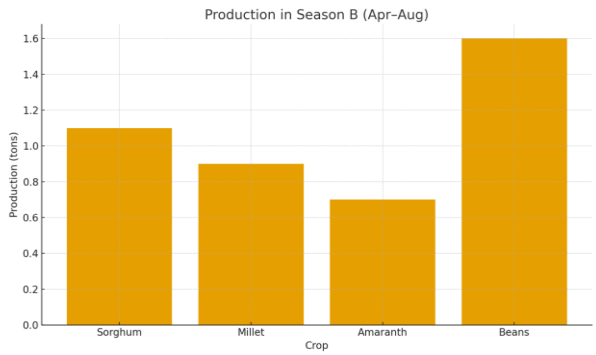

Figure 5. Production in Season B

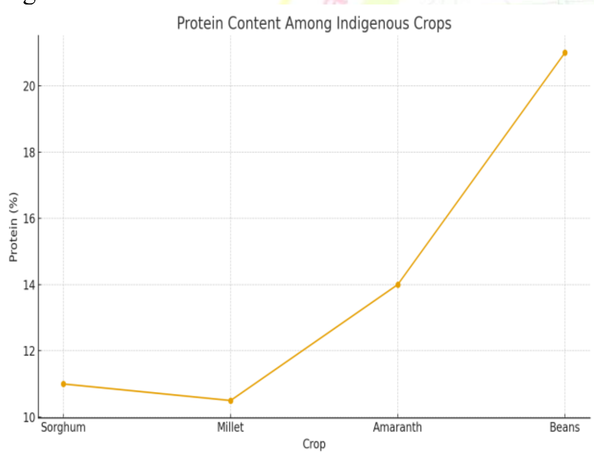

Figure 6. Protein Content Comparison

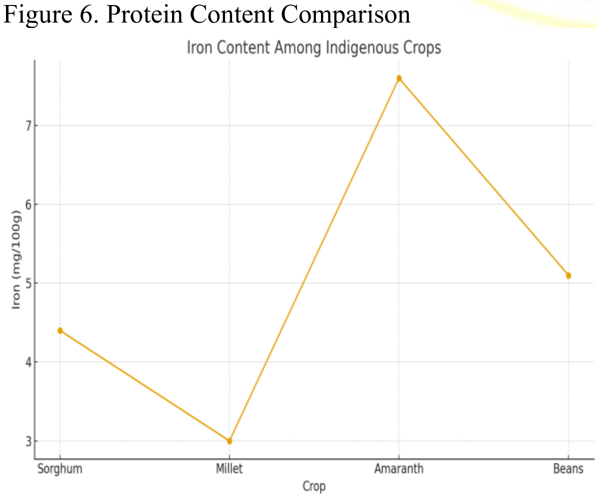

Figure 7. Iron Content Comparison

CONCLUSION

This paper has shown that the indigenous crops such as sorghum, millet, amaranth, and beans have tremendous potential for enhancing nutrition and food security in Kamonyi District in case their agronomic, nutritional, and cultural worth are harnessed. The analysis of the seasonal production revealed that beans and sorghum are reliable in different seasons, whereas millet and amaranth, though with lower production levels, have outstanding micronutrient benefits, especially in terms of iron, zinc, and dietary fiber. The consumption rates of households and dietary evaluations showed that the increased consumption of native crops is linked with a higher nutritional variety and lower food insecurity, and regular consumers had much higher HDDS and lower HFIAS scores. Such results are empirical evidence, which was lacking earlier in the manuscript, that the issue of praising indigenous crops can produce quantifiable effects on the nutrition outcomes of households. Nevertheless, the paper also identifies structural barriers that have hindered their use, such as seed inadequacy, poor post-harvest technologies, cultural inclinations, and poor value chains. With the qualitative data, it is found that farmers see this as valuable crops but do not have consistent access to better varieties, processing information, and market incentives to pay. The nutritionally better crops, like the amaranth and the millet, will not be fully used without efforts on their behalf since they have proven their worth. Comprehensively, this paper has proven that the reintroduction of indigenous crops in the local food systems is not just agronomically viable but also nutritionally advantageous to rural Rwanda. Increased production and consumption can help vary the diets and minimize the issues of micronutrient deficiency, as well as enhance the ability to withstand seasonal food insecurity. The findings highlight the importance of community-based interventions, which are largely integrated and focused on communities to enhance access to seeds, nutrition-focused education, value-chain development, and supportive policy frameworks to facilitate the full potential of the indigenous crops in addressing sustainable food and nutrition security.

Policy/programmatic Implications.

These empirically based insights can directly inform scale-up policy intervention: first, by creating community-based seed multiplication organizations based on amaranth and millet, co-managed between cooperatives and extension services would resolve the bottleneck of knowledge-practice identified in 11 of 12 major informant interviews; second, co-created and widely publicized rapid and culturally appealing recipes (e.g., amaranth-bean porridge to infant, millet-sorghum composite flour to school meals) would solve the knowledge-practice gap; third, by implementing indigenous food

Recommendations

Government and development partners should invest in improved seed systems, post-harvest handling, processing technologies, and local market linkages for crops such as sorghum, millet, amaranth, and beans to enhance their availability and competitiveness.

Agricultural extension services should prioritize farmer education on the nutritional benefits, climate resilience, and economic value of indigenous crops, ensuring that households understand their role in improving dietary diversity and combating micronutrient deficiencies.

Policymakers should adopt community-centered agricultural strategies that encourage the preservation, cultivation, and consumption of native species, ensuring alignment with the needs of smallholder farmers and contributing to long-term food and nutrition security.

CONFLICT OF INTEREST

The author here declares there is no conflict of interest in the publication of this article.

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