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New challenges and future perspectives in nutrition and sustainable diets in Africa

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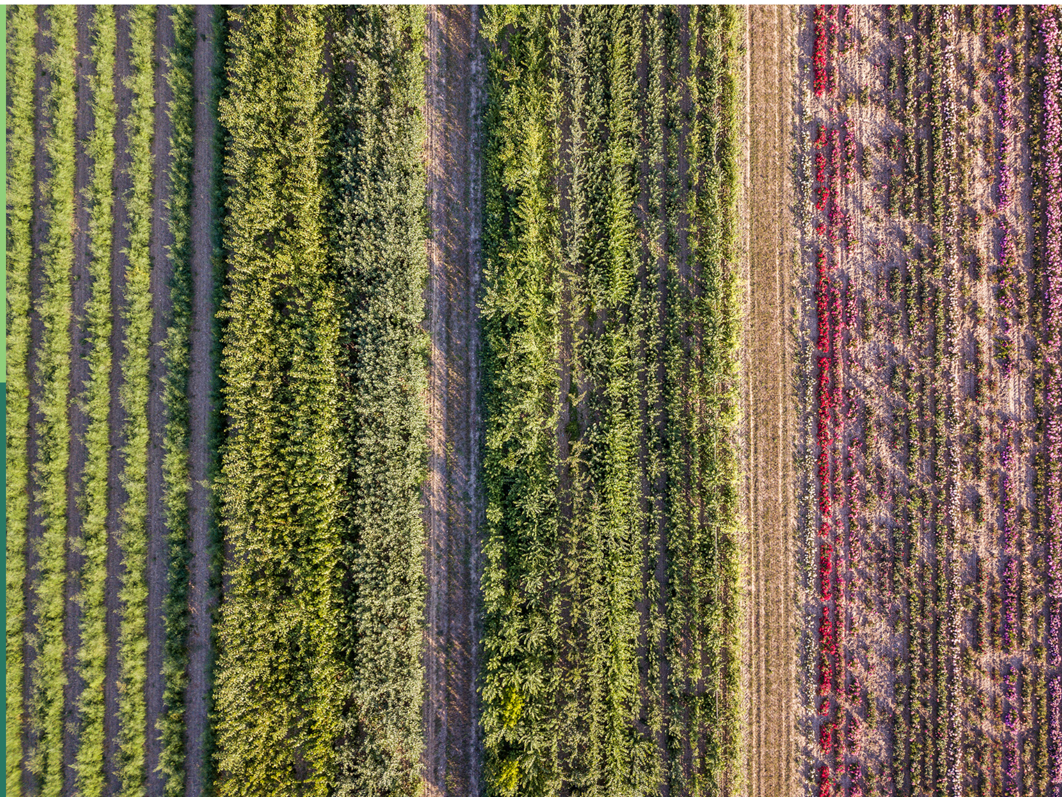

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New challenges and future perspectives in nutrition and sustainable diets in Africa

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Table of contents

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Editorial: New challenges and future perspectives in nutrition and sustainable diets in Africa

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Editorial on the Research Topic
New challenges and future perspectives in nutrition and sustainable diets in Africa

Although African countries may produce or import enough food to provide adequate average energy per person per day, energy alone does not ensure nourished individuals. A lack of diversified diets year-round and high intakes of low cost, poor nutrition value staple foods contribute to prevailing malnutrition in all its forms. Africa is confronted with the triple burden of malnutrition; it is also faced with the triple challenges of poverty, inequality and unemployment. Food affordability and access are unevenly distributed and gaps are widening even further. Increased food and fuel prices, the COVID-19 pandemic, population growth and the state of the global economy, as well as climate change, are challenges that increase the risk of food insecurity, threatening attaining nutritious and sustainable diets (FAO et al., 2021).

In many African countries, large proportions of the population rely on agriculture not only for their food, but also for their livelihoods. Transforming agricultural and food system is thus a necessary solution for addressing the double-triple challenge. To accomplish this, there is an urgent need for a far greater focus on food systems and how to make these deliver the strategic goals of the African agriculture and food security agenda - namely economic opportunities, poverty alleviation and shared prosperity. The EAT-Lancet proposed a universal healthy diet to mitigate environmental changes (Willett et al., 2019). However, such a diet needs to be adapted to take African dietary challenges of an already malnourished population into account (Tuomisto, 2019). These diets are already plant-based with a lack of animal sourced foods to provide the necessary micronutrients. This will require targeted approaches to ensure that innovation includes the use of indigenous African knowledge systems, protecting biodiversity and embracing modern sciences as enabling factors for building a knowledge economy (FAO and Alliance of Bioversity International and CIAT, 2021). There is a close linkage between food security and societal stability; however, global food security is threatened by the vulnerability of our agriculture and food systems including animal and plant health and environmental stresses. These threats are aggravated by climate change, the globalization of agriculture, and an over-reliance on non-sustainable inputs.

Fifteen quality papers, nine research articles, two reviews, two perspective articles, one systematic review, and one policy and pro-active review article are published in this Research Topic. Big data and smart-tech solutions are rapidly moving into agriculture and nutrition, offering high potential for unprecedented innovation. The potential to harness twenty-first century technologies is regarded as a fundamental tool for change. The capacity to analyse and draw meaningful insights from big data through the lens of agriculture and food systems is an area in need of attention. Food and agriculture policies have the potential to influence every stakeholder involved in the food system, thereby shaping the accessibility and affordability of nutritious diets (FAO et al., 2022). Articles include the application of science, innovation and policy in the advancement toward sustainable food systems and achieving the sustainable development goals (SDGs) by 2030 (Sachs et al., 2023).

Research that intends to have an impact on food security and nutrition in Africa, needs to have an overarching vision to enable and catalyze the transformation of Africa's agriculture and food systems. The focus of the discussion by Pretorius et al. was on approaches for higher education institutions in Africa to deliver sustainable solutions at scale and encourage collaborative actions to directly transform Africa's agriculture and food systems. Information and Communications Technology (ICT) and Big Data were identified as key enablers that can ensure relevant research with appropriate translation into practice while maintaining quality and excellence. High-quality food composition data are indispensable in many nutrition-related activities for improved decision making. With a focus on Africa, Pretorius et al. deliberates on current challenges in nutrition, while discussing new advances in food composition activities. Opportunities (such as the Internet of Things (IoT), wearable devices, natural language processing (NLP) and other machine learning techniques) to improve existing resources must be more actively explored and supported. The use of machine learning algorithms was explored by Gebeye et al. to identify important predictors of Micronutrient (MN) deficiencies, leading to childhood morbidity and mortality, among children aged 6–23 months in Ethiopia. The Random Forest algorithm outperformed other Machine Learning algorithms in predicting child MN deficiency. Umwali et al. demonstrated that a minimum acceptable diet was a good stunting predictor, with the child's gender, consumption of animal sourced foods, child underweight status and income type being other stunting risk factors. In studying the diet quality of HIV exposed children aged between 6 and 18 months in Ghana, Folson et al. highlighted the need for nutrition programs to educate HIV exposed children's caregivers on optimal feeding practices and stresses the importance of continued breastfeeding as well as dietary diversity.

After studying food and nutrition security policies, strategies and programs in Ghana, Kenya and South Africa, Sibanda et al. identified several gaps that must be addressed to ensure adequate food and nutrition security. This finding was supported by Vermeulen et al. who found that the rising cost of basic healthy eating prevents 40% of households in South Africa and Kenya from being able to afford basic healthy eating when considering current income distribution data. Bwanaisa and Hendriks concluded that without a significant change in the incomes of the poor, access to a nutritious diet is impossible in Malawi. A radical re-benchmarking exercise is necessary if the country intends to make progress on reducing undernutrition, while several policy interventions could support improved access to affordable and nutritious meals.

Even though the African continent contains more than 400 traditional crop species, Munialo et al.'s study found that only a few crops (n = 15) were commonly researched, with maize being the most intensively researched crop. High crop diversity has been associated with improved dietary quality and quantity. Nkwonta et al. highlights the potential of neglected and underutilized species from Uganda and Nigeria to alleviate food and nutrition insecurity due to their abundance and high nutritional value. The nutrient composition of Bambara groundnut (BGN), an underutilized, indigenous crop grown and consumed in sub-Saharan Africa was studied by Veldsman et al.. This study confirm that this traditional legume can together with other commonly consumed plant-based foods (e.g., maize) form a complete protein, contributing to increased protein intake and alleviating the burden of protein-energy malnutrition. Adeosun et al. reported that to achieve an increase in diverse foods and the integration of fruits and vegetables into informal ready-to-eat food vending in Nigeria requires a change in food norms and promoting sensitization to the importance of diverse diets through training initiatives. Despite limited consumer awareness Wangithi et al. found that consumers across income groups in Kenya are willing to pay more for vitamin A enriched (biofortified) orange-fleshed sweet potato (OFSP) products. Significant determinants of willingness to pay were found. Kapulu et al. reported that wealth status and income utilization are determinants of the dietary diversity of women from farming households in Zambia rather than agricultural diversification using soybean farming as an example.

Essilfie et al. concluded that in Ghana the fruit and vegetable industry remain one of the most promising agricultural sectors, mainly owing to the heightened knowledge of the health benefits linked to their consumption. However, food safety is of ultimate concern due to the association of foodborne hazards. The study, therefore, recommends establishing a traceability system as well as appropriate measures and standards for hygienic practices.

With an African focus, we trust that this Research Topic will assist in understanding new challenges and future perspectives on nutrition and sustainable diets.

Author contributions

HS: Funding acquisition, Project administration, Writing – original draft. YG: Writing – review & editing. GE: Writing – review & editing.

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Determinants of stunting in children aged between 6–23 months in Musanze region, Rwanda

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Under-nutrition causes approximately half of all deaths in young children every year globally which is exacerbated by the multiple malnutrition burden. Infant and young child feeding practices pose immediate effects on the nutrition status of under 2 years aged children and greatly influence the survival of a child. This study aimed at determining the implication of the infant and young child feeding practices in evaluating stunting in young children among other stunting risk factors. Analytical cross-section study was carried out in Musanze, a district of Rwanda and involved 241 mothers having children aged between 6 and 23 months. Data was collected using a validated semi-structured questionnaire with observations and check list guides. Chi-square test and logistic regressions were used to determine the associations and risk factors of various variables. The results show that minimum meal frequency (MMF) was attained at 83% rate, minimum dietary diversity (MDD) at 57%, minimum acceptable diet (MAD) at 53% with consumption of iron rich foods at 29%. Stunting prevalence was 28%. The MAD had a significant ($p = 0.021$) association with height-for-age Z-score of a child and was found to be the stunting's predictor. The child's sex, consumption of animal sourced foods, child underweight status and income type were revealed as other stunting risk factors. A holistic approach that promotes infant and young child feeding practices and complementary feeding in particular can contribute to the alleviation of the stunting burden in Rwanda. Further, other associated factors that influence child nutrition status should be taken into consideration by the policy decision makers and development partners when developing food and nutrition sensitive programs and interventions.

KEYWORDS

infant and young child feeding practices, nutritional status, stunting, risk factors, minimum acceptable diet

Introduction

Recently, the world's hunger situation has been threatened by the ravages of COVID-19 pandemic, conflict, and climate change and last year the projections by the Food and Agriculture Organization of the United Nations (FAO) reported 657 million people will be undernourished in 2030 which is nearly 30 million more than if the pandemic had not happened (1). Food insecurity is complex challenge in most global South countries and it has been reported that about 81% percent of all households in Rwanda are food secure with 39% out of this being considered marginally food secure and 19% percent are food insecure whereby out of these, 1.7% are severely food insecure (2). The Global Hunger Index (GHI) Scores by 2021 in the GHI rank placed Rwanda at 26.4 which is a serious state with 35.2% of the population being undernourished, and a high prevalence of stunting for children under 5 years at 33.1% (3). Malnutrition is recognized as a major universal concern that has various forms and can affect anyone in the world at certain point in life, despite of one's age, sex, wealth or geographical area (4). Although all people can suffer from malnutrition, young children are among the most affected (5). Undernutrition is estimated to be associated with 2.7 million child deaths annually or 45% of all child deaths (4).

The first 2 years of a child's life are particularly important, as optimal nutrition during this period lowers morbidity and mortality, reduces the risk of chronic disease, and fosters better overall development. Infant and young child feeding (IYCF) practices possess immediate effects on the nutritional status of under 2 years aged children and greatly influence the survival of a child (6). WHO (7) recognizes promoting proper IYCF practices as being one of the most successful interventions in ameliorating the health of a child and reports that potential growth and development are attained when children are fed properly especially those in the critical window of 0 and 24 months of age (8). IYCF indicators such as exclusive breastfeeding, minimum meal frequency (MMF), minimum dietary diversity (MAD) and minimum acceptable diet (MAD) have been largely associated with nutritional status outcome of children (9, 10). After analyzing statistics on IYCF practices globally, UNICEF (8) emphasized on the urgent development of programs in this area and specially showed considerable need for improving how children in complementary feeding period (6–23 months) are fed. The statistics were showing that feeding children aged 6–23 with WHO recommended minimum meal frequency (MMF), minimum dietary diversity (MDD) and minimum acceptable diet (MAD) were done at 51, 25, and 16% rate, respectively.

Few children receive nutritionally adequate and safe complementary foods; in many countries less than a fourth of infants 6–23 months of age meet the criteria of dietary diversity and feeding frequency that are appropriate for their age (7). Over 820,000 children's lives could be saved every year among children under 5 years, if all children 0–23 months were optimally breastfed (11).

The current Demographic Health Survey (DHS) aggregated statistics in Rwanda for under 5 years children is 33.1% for stunting levels and wasting at 1.1% (12) with the stunting levels for 6–8 months, 9–11 months, 12–17 months, and 18–23 months reported at 18.2, 21.3, 41.6 and 49.4%, respectively. In Rwanda, only 22 % (12) children of age between 6 to 23 months adhere to the infant young child feeding practices in terms of minimum acceptable diet, despite the high stunting prevalence that is very high (stunting ≥30%) according WHO threshold (13). Few children receive nutritionally adequate and safe complementary foods; in many countries less than a fourth of infants 6–23 months of age meet the criteria of dietary diversity and feeding frequency that are appropriate for their age (7). Breastfeeding improves IQ, school attendance, and is associated with higher income in adult life but only 37% of children younger than 6 months of age are exclusively breastfed in low-income and middle-income countries (14). Dewey and Begum (15) have reported that being stunted is a risk factor for reduced survival, childhood and adult health, and reduces the capacity of learning and production. Therefore, improving child development and reducing health costs through breastfeeding results in economic gains for individual families as well as at the national level. It is against this background that this study sought to find out whether IYCF practices play role in determining the stunting level in Rwanda.

Materials and methods

Study design and setting

The study was conducted in Northern Province of Rwanda, in the District of Musanze. A cross-sectional study design was used for data collection in the study sites. The study took place at nine health centers purposively selected from 16 health centers found in Musanze District. The district was purposely chosen since it is food secure district and yet has a high stunting prevalence of 38%. The study targeted the mothers having children aged of 6–23 months from which 241 mothers fulfilling all the study inclusion criteria participated in the study.

Sample size determination

The sample size was calculated using the formula of Fischer et al. (16) where the prevalence of infant and young child feeding practices in Rwanda (18%) was used as p-value. The sample size was calculated using formula of Fischer et al. (16) as follows:

$$n = z^2pq/d^2$$

Where

n= the desired sample size when population is >10,000

z= the standard normal deviation which is 1.96 at 95 % confidence interval

p= prevalence of IYCF practices 18 %, (Demographic and Health Survey (2014/15)

q=1-p=1-0.18=0.82

d= the degree of accuracy desired set at 5 % (0.05)

Therefore;

$n=1.96^2 * 0.18 * 0.82 = 227/0.05^2$

5.5 % attrition=227/0.945=241 (attrition = 14)

Therefore, the total sample size =241.

Sampling procedure

The sampling schema is shown in Figure 1. Musanze District was sampled purposely for the study as it has a high stunting prevalence of 37.8 % despite being 80% food secure according to CARI index (17). The district is divided in 15 sectors with 16 health centers. The data were collected in 9 health centers purposively selected based on the ones having higher cases of acute malnutrition. The health centers were Nyakinama, Nyange, Kimonyi, Kinigi, Rwaza, Karwasa, Muhoza, Gataraga and Musanze. The study participants were the mothers having children aged between 6 and 23 months who had visited the health center at the time of data collection. Systematic random sampling was used to select 27 mothers from each of the nine health centers.

Inclusion criteria

All mothers having children of 6–23 months old who had attended the selected nine Health Centers and who gave consent.

Exclusion criteria

The children who had severe or critical illness or referral cases were excluded from the study.

Data collection tool and procedure

Data collection

Quantitative research method was used in the study. By using a semi-structured questionnaire, the information on socio demographic and socioeconomic characteristics were collected; age, sex, education level of the mothers, household size, marital status, household occupation, income, land ownership, and wealth category. The information was obtained by face-to-face interviews with the mothers of the children under the study and data were analyzed using the descriptive statistics. Observational study was also employed during the interviews. Further, a pre-tested semi-structured questionnaire was used to collect data on maternal nutrition knowledge, IYCF practices, nutrition information network and anthropometric measurements. The questionnaire was administered to the mothers and each response given was filled well in its respective section.

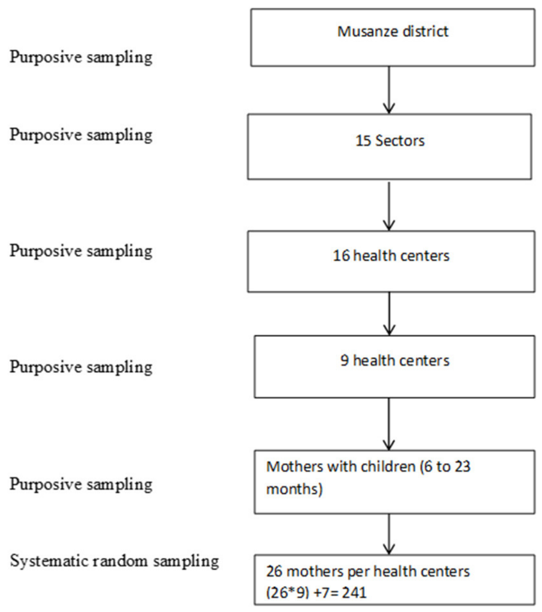

FIGURE 1
Sampling schema of the study.

In Rwanda, all households are classified into categories called "Ubudehe," which is a social stratification programme depending on income among households, thus reflecting their economic status. The study used the classification done into 2015 where the population was put into 4 Ubudehe categories based on the resources and assets owned by households as well as the ability of sustaining their livelihoods. The categories are the first (poorest), second, third and fourth (richest) Ubudehe categories (18, 19). In this study, these categories are referred as wealth categories. During the data collection, every mother under the study was asked the category in which her household had been classified and the answer was recorded.

Twenty-four hour dietary recall

In order to capture all the foods, beverages and the frequency at which children were fed in 24 h preceding the interview, a 24-h dietary recall questionnaire was used which collected data on the time of the food consumption, the name and ingredients of the dish followed by the corresponding quantities.

Anthropometric measurement

The anthropometric measurements were taken referring to WHO (20) recommended guidelines for measuring weight and height (length) of under 2 years children. For height, the UNICEF height board was used to measure the length of the child and read to the nearest 0.1 cm. In the first place, the mother helped to take off the excess clothes and shoes of the child prior to measuring. Then, the height board was horizontally placed on a flat and leveled surface and the height (length) was obtained by the child lying on it straight with feet together, knees straight, heels and buttocks in contact with the board, the shoulders relaxed, arms straight at the sides and the shoulder blades touching the length board. The measurements were taken twice from which an average length was calculated. For the weight, an electronic SECA scale was used to measure the weight of the child. The scale was placed on flat and stable surface and checked for accuracy and verified using an object of known weight before every weighing session. Children only remained with lightweight clothes (without jackets, socks and shoes). The measurements were taken twice from which an average weight was calculated and reported to the nearest 0.1 kg.

Data quality control

Pretesting of study tools

The questionnaire was pre-tested on 20 mothers in a selected pilot health facility before commencing actual data collection to ensure familiarization of the field assistants with the questionnaire, equipment, obtaining consent, checking on its validity and find out if it would respond to objectives of the study.

Recruitment and training of field assistants and enumerators

The recruitment of field assistants and enumerators was advertised verbally within the study district. The criteria for recruitment consisted of good conduct and reliability, attainment of college education, having basic nutritional knowledge, experience in data collection, and preferably being a resident of the study area. The shortlisted candidates were interviewed. The training took 4 days and the covered subjects included the study objectives, the use of survey equipment, interviewing techniques, anthropometric measurements, and filling the questionnaire. The whole team went through the questionnaire to understand its contents for uniformity in interpretation of the questions. They were trained as well on good behavior and courtesy while interacting with and interviewing the participants.

Weight scale assurance, and length quality assurance mechanism

The scale was placed on flat and stable surface and checked for accuracy and verified using an object of known weight before every weighing session. Children only remained with lightweight clothes (without jackets, socks and shoes). For the length quality assurance, the height board was horizontally placed on a flat and leveled surface and the height (length) was obtained by the child lying on it straight with feet together, knees straight, heels and buttocks in contact with the board, the shoulders relaxed, arms straight at the sides and the shoulder blades touching the length board. For both anthropometries, length and weight, measurements were taken twice from which an average length was calculated.

Ethical consideration

Ethical clearance certificate was sought from Rwanda National Ethics Committee (reference no. 681/RNEC/2019) as well as a written approval from Musanze district administration. The informed consent was also sought from health centers administration and the study participants were interviewed after signing the informed consent form.

Assessment of infant and young child feeding practices of children aged 6–23 months

The assessed infant and young child feeding practices' indicators include minimum meal frequency (MMF), Minimum dietary diversity (MDD) and Minimum acceptable diet (MAD). The tools used were developed following the guidelines recommended by FAO (21). The tools included a semi-structured questionnaire composed of questions reflecting on the pre-mentioned indicators; a seven food-groups dietary diversity checklist as well as a 24-h dietary recall questionnaire where the mothers indicated all foods and drinks the child consumed 24 h before the start of the survey. The MMF was calculated based on the number of meals (solid, semi-solid or soft foods) fed to the child during the 24 h preceding the interview. The criteria for meeting the MMF recommended by WHO vary depending on the age and the breastfeeding status of the child (22). Among the breastfed children, receiving at least two meals (when aged of 6–8 months) or at least three meals (when aged of 9–23 months) were the conditions to achieve the MMF. Regardless of the age, the non-breastfed children had to be fed at least four times the previous day to be classified as having met the MMF. The recommended MDD was calculated referring to WHO/UNICEF (22) guidelines. A seven food groups checklist was used to determine the individual dietary diversity score (IDDS) reflecting the number of food groups a child was fed from 1 day before the interview. The food groups on the checklist were grains, roots and tubers; legumes and nuts; dairy products; flesh foods; eggs; vitamin A fruits and vegetables and other vegetables and fruits. The conditions for meeting MDD differ for breastfed children and non-breastfed children (22). Consequently, being fed from four food groups or more was a criterion to achieve the MMD among breastfed children whereas the consumption of at least four food groups, without including the milk feeds, was a condition for non-breastfed children. Children met the MAD when they had achieved at the same time the MMF and MDD 24 h before the survey. The consumption of at least 2 milk feeds was an added condition to non-breastfed children for them to achieve the MAD (22).

Data processing and analysis

Nutritional status of children

By using height/ length boards and electronic SECA scales as tools and referring to WHO guidelines, two anthropometric data were taken, namely, height (length) and weight, for children of 6 to 23 months of age (23). The nutritional status was assessed by determining the three nutrition indicators namely; stunting, wasting and underweight. A Height-for-age Z-score (HAZ), weigh-for-height Z-score (WHZ) and weight-for-age Z-score (WAZ) that fell under a minus two standard deviation (SD) indicated the state of stunting, wasting and underweight, respectively.

Data analysis

Statistical Package for Social Science (SPSS) software version 20.0 was used for data entry, cleaning, and analysis with different statistical tests whereas anthropometric data were analyzed using Emergency Nutrition Assessment software (ENA for Smart 2014, https://smartmethodology.org/wp-content/uploads/2014/11/ENA-Manual.pdf) to determine different nutritional status of children. Descriptive statistics were used for socio-demographic and economic, maternal knowledge, feeding practices and nutritional status data analysis. Chi-square and the independent *t*-test were used to determine the association between different IYCF practices and nutritional status of children. Binary logistics regression model was used to determine factors influencing stunting.

Results

Socio-demographic profile of participant households

The socio-demographic and socio-economic profiles of the study participants are showed in Table 1. The findings show that the mean household size was 4.7 (SD = 1.8) with a minimum of two (1) members. The mean age of the index children was 11.8 months (SD = 4.5). The mean age of the mothers was 29 years with the oldest interviewed mother being 50 years old. Most of the mothers (56.4%) have attained primary school education with 27% attending secondary school and only 4.1 % attended University. Nearly 12.4% of mothers had no formal education. The study revealed that farming and casual labor were the two predominant sources of income of the households, 38 and 37%, respectively. The households that were found to possess land for food production were 68% whereas 32% of the households did not produce food. The results on the household's classification into wealth categories indicated that majority of the respondents were in the second wealth category (54%). The study found that only a few respondents (17%) were in the first wealth category whereas 30% were in the third wealth category. It is noteworthy that no household was found to be in the fourth wealth category, the richest category. The mean nutrition knowledge score was found to be 71.03 (15.06 SD) and the majority (72%) of the mothers had a high (score ≥70% score) knowledge score whereas 28% had a low (score <70%) knowledge score.

Socio-economics characteristics of households

Majority of the mothers (49%) were farmers, 21% casual labors, 9% business women while 17% were unemployed (Table 1). On the other hand, the predominant occupation of the heads of households was casual labor (39%), followed by farming (37%), salaried job (13%) and business (9%). Out 32 the salaried households head, 72% were from the third wealth category. Furthermore, the study revealed that farming and casual labor were the two predominant sources of income of the households, 38 and 37%, respectively. The households that were found to possess land for food production were 68% whereas 32% of the households did not produce food (Table 2). The total household income for the month preceding the survey was below 10,000 Rwandan francs for the majority of the households (46%). Out of households which earned more than fifty thousand Rwandan francs, 61% were from third wealth category and only 2% from first wealth category.

Child feeding practices among mothers

The results show that most of the children (79%) were fed at least 3 times the day before the survey whereas 2.5% did not consume any solid or semi solid food 1 day before the survey (Table 3). The mean IDDS score for all

TABLE 1 Sociodemographic and socio-economic profile of households ($n = 241$).

Variable	Pooled $n = 241$		1st wealth category $n = 40$		2nd wealth category $n = 130$		3rd wealth category $n = 71$		Chi2	p-Value
	Freq	%	Freq	%	Freq	%	Freq	%		
Marital status of mothers									18.33	0.005***
Married	206	85.5	29	72.5	113	87	64	90		
Single	22	9.1	5	12.5	12	9	5	7		
Separated	3	1.2	3	7.5	0		0			
Widowed	10	4.2	3	7.5	5	4	2	3		
Education of mothers									49.31	0.000***
No formal education	30	12.4	12	30	12	9.2	6	8.5		
Some primary	69	28.6	21	52.5	32	24.6	16	22.5		
Completed primary	67	27.8	2	5	44	33.8	21	29.6		
Some secondary	37	15.4	22	12.5	10	16.9	37	14.1		
Completed secondary	28	11.6	0		18	13.8	10	14.1		
University/college	10	4.1	0		2	1.5	8	11.3		
Number of under five children per HH									4.745	0.314
1	161	66.8	23	57.5	91	70.0	47	66.2		
2	76	31.5	15	37.5	38	29.2	23	32.4		
3	4	1.7	2	5.0	1	0.8	1	1.4		
Sex of index child									1.227	0.541
Male	115	47.7	16	40	65	50	34	47.9		
Female	126	52.3	24	60	65	50	37	52.1		
Religion of HH									19.85	0.001***
Catholic	127	52.7	10	25	82	63.1	35	49.3		
Protestant	112	46.5	29	72.5	48	36.9	35	49.3		
Muslim	2	0.8	1	2.5	0	0.0	1	1.4		

***Represents significance at 1% level.

TABLE 2 Socio-economic characteristics of household members across their wealth categories.

Variable	Pooled $n=$ 241		1st category $n=40$		2nd category $n=$ 130		3rd category $n=71$		Chi2	p-Value
	Freq	%	Freq	%	Freq	%	Freq	%		
Occupation of mothers									37.601	0.000***
Salaried job	9	3.7	0		1	0.8	8	11.3		
Farmer	117	48.5	15	37.5	70	53.8	32	45.1		
Business	21	8.7	2	5	9	6.9	10	14.1		
Casual labor	50	20.7	18	45	24	18.5	8	11.3		
Crop/animal sales	2	0.8	0	0	1	0.8	1	1.4		
Housewife	1	0.4	0	0	1	0.8	0			
Unemployed	41	17	5	12.5	24	18.5	12	16.9		
Occupation of HHH									43.537	0.000***
Salaried job	32	13.3	1	2.5	8	6.2	23	32.4		
Farmer	89	36.9	13	32.5	53	40.8	23	32.4		
Business	21	8.7	1	2.5	13	10.0	7	9.9		
Casual labor	94	39	24	60	54	41.5	16	22.5		
Crop/animal sales	1	0.4	0	0.0	0	0.0	1	1.4		
Unemployed	4	1.7	1	2.5	2	1.5	1	1.4		
Major source of income of the HH									47.030	0.000***
Salaried job	30	12.4	1.0	2.5	6	4.6	23	32.4		
Farmer	92	38.2	13.0	32.5	55	42.3	24	33.8		
Business	21	8.7	3.0	7.5	11	8.5	7	9.9		
Casual labor	89	36.9	22.0	55.0	53	40.8	14	19.7		
Casual trade	7	2.9	0.0	0.0	4	3.1	3	4.2		
Remittance/gift	2	0.8	1.0	2.5	1	0.8	0	0.0		
Total HH income in the last month (Rwf)									29.415	0.000***
<10,000	110	45.6	25	62.5	63	48.5	22	31.0		
10,000–20,000	45	18.7	7	17.5	28	21.5	10	14.1		
20,000–30,000	18	7.5	4	10.0	9	6.9	5	7.0		
30,000–50,000	29	12.0	3	7.5	16	12.3	10	14.1		
50,000 and above	39	16.2	1	2.5	14	10.8	24	33.8		
HH access to the land for food production									0.584	0.747
Yes	163	67.6	25	62.5	89	68.5	49	69		
No	78	32.4	15	37.5	41	31.5	22	31		

***Represents significance at 1% level.

children was found to be 3.5 (1.25 SD) and the majority had the medium dietary diversity score (4–6 score), followed by the low dietary score (43%) (≤3 score). The proportions of 241 children under the study who achieved the MMF, MDD and MAD were 83%, 57 and 53%, respectively. The consumption of the animal sourced foods was at 28% rate (Table 3).

Nutritional status of children

Almost 28% of 241 children measured were stunted where 9% and 19% were severely and moderately stunted, respectively (Table 4). The male children had higher stunting rate than their female counterparts, 40 and 17%, respectively. Global acute malnutrition (wasting) prevalence was 2% where 1% of male

TABLE 3 Distribution of children (6–23 months) by the feeding practices ($n = 241$).

Feeding practices	Frequency	Percent
Individual dietary diversity score (IDDS)		
High dietary diversity (≥6 score)	9	3.7
Medium dietary diversity (4–5 score)	128	53.1
Low dietary diversity (≤3 score)	104	43.2
Meal frequency		
0 meal	6	2.5
1 meal	11	4.6
2 meals	34	14.1
3+ meals	190	78.8
Consumption of iron rich foods		
Yes	70	29
No	171	71
Consumption of animal sources foods		
Yes	68	28.2
No	173	71.8
Meeting minimum meal frequency		
Yes	199	82.6
No	42	17.4
Meeting minimum dietary diversity		
Yes	137	56.8
No	104	43.2
Meeting minimum acceptable diet		
Yes	128	53.1
No	113	46.9

TABLE 4 Distribution of children by their nutritional status ($n = 241$).

	Males (%)	Females (%)	All (%)
Stunting*			
Overall	40	16.7	27.8
Moderate	25.2	13.5	19.1
Severe	14.8	3.2	8.7
Wasting			
Global	0.9	2.4	1.7
Moderate	0.9	1.6	1.2
Severe	0	0.8	0.4
Underweight			
Overall	8.7	2.4	5.4
Moderate	6.1	2.4	4.1
Severe	2.6	0	1.2

*Stunting, wasting, underweight = <-2 Z score; Moderate = -3<Z score<-2; Severe =<-3 Z score and/or oedema for wasting.

children were wasted against 2% of female children. Out of 241 children under this study, 95% had a good nutrition status in terms of underweight, whereas the prevalence of moderate and severe underweight was found to be 4 and 1%, respectively.

Using Chi-square test, the study revealed that the majority of children who met the IYCF practices had a good nutritional status (Table 5). The results show that 74, 73, 76 and 63% of children who met MMF, MDD, MAD and consumption of iron-rich foods, respectively, were not stunted. Moreover, 2, 3, 3 and 1% of children with recommended MMF, MDD, MAD and iron-rich food consumption, respectively, were wasted. Lastly, 6, 3, 8 and 10% who achieved MMF, MDD, MAD and consumption of iron-rich foods respectively, were underweight. However, when the significance tests were conducted between the above IYCF practices and different forms of malnutrition, the associations were found to be no significant at 95% Confidence Interval (Table 6). Nevertheless, the study revealed that the MAD has a statistically significant ($p = 0.021$) association with height-for-age Z-score (HAZ) of a child. The results of an independent sample t-test show a significant difference between the HAZ mean (−1 SD) of children who met the MAD and the HAZ mean (−1.5 SD) of those who did not (Table 6).

Determinants of stunting

The determinants of stunting were identified by using the multiple logistic regression analysis. The results showed that the factors that predict stunting are MAD, income type, sex of the child, consumption of animal sourced foods and underweight status (Table 7). The findings revealed that there was a significant ($p = 0.009$) negative relationship between the child meeting the MAD and stunting. The household income type (farming) ($p = 0.021$), child underweight ($p = 0.000$) were found to have a significant negative relationship with stunting whereas the sex (male) of a child ($p = 0.003$) and consumption of animal sourced foods ($p = 0.047$) had a significant positive relationship with stunting.

Discussion

The proportion of children who met the IYCF indicators are higher compared to the 2014-2015 RDHS report showing that in Northern Province, the rate of meeting the MMF, MDD and MAD was 54, 34 and 22%, respectively (24). This could be attributed to two main factors which are food security and maternal nutrition knowledge level in Musanze district. The 2018 Rwanda Comprehensive Food Security and Vulnerability Analysis (CFSVA) report indicates that, in Musanze district, the food security rate (by CARI index) has increased from 80% in 2015 to 88.5% in 2018. Additionally, many mothers (72%) demonstrated to have a high level of knowledge on feeding practices and 95% of respondents had been exposed to the nutrition education from different sources such as health centers, CHWs and community gatherings (groups). This is supported by a study conducted in Indonesia where the diet of children whose mothers had been exposed to nutrition

TABLE 5 Association of IYCF practices with nutritional status of children.

IYCF practices	Pooled $n = 241$	Stunting			Wasting			Underweight		
		Yes	No	χ^2	Yes	No	χ^2	Yes	No	χ^2
MMF (yes)	199	26%	74%	0.20	2%	98%	0.35	6%	94%	0.34
MDD (yes)	137	28%	73%	0.98	3%	97%	0.07	3%	97%	0.13
MAD (yes)	128	24%	76%	0.18	3%	97%	0.05	8%	92%	0.08
Consumption of iron-rich foods (yes)	70	37%	63%	0.13	1%	99%	0.64	10%	90%	0.16

χ^2: Chi-square (p-value).

TABLE 6 Independent *t*-test between HAZ score and MAD.

Variable	Did the child meet MAD?		Std. Error difference	t-value	*p*-Value
	No	Yes			
HAZ score	−1.49331	−1.05326	0.189599	−2.321	0.021*

* Represents $p < 0.05$.

information improved in terms of meeting MAD (25). Similar findings were observed in one of the studies done in Ethiopia where Berra and young (26) found that maternal knowledge on complementary feeding is one of the key determinants of suboptimal complementary feeding practices and is positively associated with meeting MMF and MAD among children aged between 6 and 23 months.

The stunting rate in this study is lower as compared to 38% rate reported in 2014-2015 RDHS report. This decrease could be explained by the time factor where the prevalence might have decreased as the years passed. The RDHS (2014-2015) report indicates the trend of malnutrition decreasing over the years where the stunting rate dropped from 51% in 2005 to 44% in 2010, then to 38% in 2015 (24). Those improvements may be attributable to the great effort done by the government of Rwanda through different strategies and programmes such as multisector participation and consensus around Rwanda's First National Nutrition Summit (2009), and Second National Nutrition Summit (2011), National Multi-Sector Strategy to Eliminate Malnutrition (2010), behavior change communication (including mass media), home food fortification by using micronutrient powders and First 1,000 Days Community Based Food and Nutrition Programs (24, 27) among many others.

In addition, the reduced stunting prevalence in the present study could be because larger proportion of children in the study met the MMF, MDD and MAD as compared to the children in 2014-2015 RDHS report as elaborated in the preceding paragraphs. This is supported by several researches that linked the nutritional status of children and child feeding practices. While assessing the association of IYCF indicators and stunting by reviewing the DHS data of different countries, Jones et al. (9) found that the odds of being stunted were significantly lower among the children (6–23 months) who had achieved the MAD (in Zimbabwe) and those who had met the MDD (in India). In Bangladesh, India, Zambia and Ethiopia, meeting the MAD was found to be associated with a higher Height-for-age Z-Score and there was a positive association between MDD and HAZ in those same countries except Ethiopia (9).

Concerning stunting determinants, the MAD was found to influence stunting negatively and significantly, implying that children who achieve the MAD are less likely to be stunted. Since meeting the MAD reflects the consumption of a significant number of meals and more diversified foods, children who meet this IYCF indicator are more likely to meet adequate nutrients required for child optimal development and growth (11), hence the prevention of stunting. This study is consistent with Jones et al. (9) who found that in Zimbabwe, the odds of being stunted were significantly lower among the children (6–23 months) who had achieved the MAD.

Though the root causes have not yet been clearly established, a considerable number of studies have asserted that male children are more likely to be undernourished than female children. The examples of these studies include Medhin et al. (28), Wamani et al. (29), Bork and Diallo (30), Mya et al. (31) and Sultana et al. (32). Also, this study linked stunting with the child's sex by finding that being a male child is associated with a higher chance of being stunted than a female child. Though, the reason behind this finding was not in the scope of this study, some researchers, such as Wells (33), claim that natural selection might be the cause of male children being more prone to infectious diseases and malnutrition in early stage of life as compared to girls. Moreover, Bork and Diallo (30) while conducting a study in rural Senegal, found that male children are introduced to early complementary feedings

TABLE 7 Determinants of stunting among children aged of 6–23 months.

Variable	Coefficient (B)	Standard error	Sig.
Income type (Farming HH = 1)	−0.946	0.411	0.021*
MAD (yes = 1)	−1.385	0.527	0.009*
Higher Education of the mother (yes = 1)	−0.659	0.426	0.122
Iron-rich foods consumption (yes = 1)	0.787	0.472	0.095
Age of the mother (above 35 years = 1)	−0.017	0.400	0.967
Consumption of animal sourced food (yes = 1)	−1.109	0.558	0.047*
HH Wealth category (2^{nd} or higher = 1)	−0.165	0.462	0.721
Maternal nutrition knowledge (high = 1)	0.194	0.388	0.617
Meal frequency of a child	−0.005	0.195	0.982
IDDS of a child	0.468	0.258	0.070
Access to land (yes = 1)	0.752	0.423	0.075
Sex of a child (male = 1)	1.026	0.346	0.003*
Underweight status (yes = 1)	3.184	0.870	0.000*
Constant	−2.590	0.862	0.003

Dependent variable: Stunting.
*Prediction is significant.

(before age of 6 months) which might be detrimental to their height status, probably resulting in having poorer nutrition status as compared to female children. According to Michaelsen et al. (34), introducing the complementary food before age of 6 months results in increased child morbidity and interferes with the bioavailability of breastmilk nutrients, hence gaining the potential weight and height by a child is likely reduced.

The consumption of animal sourced foods was another factor revealed by this study to negatively influence the stunting, implying that children who consume animal sourced foods are less likely to be stunted. This could be attributed to the fact that animal sourced foods such as meat, fish, eggs and dairy products are scientifically proven to contain high quality protein which according to Headey et al. (35), has been linked to the child growth by several nutritional researchers. Consequently, Dewey (36) recommends the daily inclusion of animal sourced foods in the complementary food for the child's insurance of meeting all nutrient needs. The present study's finding is in line with the research conducted in 46 countries (Asia, Africa, and Latino America) that concluded that the consumption of foods from animal origin is strongly associated with child growth, especially the milk products and fish (35). The similar results were found by Krasevec et al. (10) in study conducted in low-and middle-income countries.

Underweight was found to be significantly and positively associated to stunting. This implies that a child who is underweight has a bigger chance to become stunted. This finding was not surprising because stunting is defined as low height for age whereas underweight stands for low weight for age (4). Therefore, factors that can interfere with the child's optimal growth by affecting the weight, can easily affect the height as well. This is upheld by WHO (4) stating that an underweight person can suffer from stunting, wasting or both concurrently. The present finding is in consistent with Ngwira et al. (37) who found a significant association between underweight and stunting among under five children in Malawi.

Farming as major source of household income was found to be negatively associated with stunting, implying that in Musanze district, children belonging to households that farm as their main source of income are less likely to be stunted. This could be because farming increases the availability of and access to food items which in turn improves food and nutrition security of the households, thus the likelihood to reduce malnutrition. Moreover, the present study shows that 100% of households farming as major source of income own the land for crops production and according to 2018 Rwanda CFSVA report, land ownership among the agricultural households contributed to food security and more severe food insecurity was observed in households who did not own land as compared to those who owned land (2). A study done in India asserted a relationship between household food security and child undernutrition by finding that children from severely food insecure households have higher chances of suffering from severe stunting and underweight (38). The similar findings were as well found by Ali et al. (39).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Ethical clearance certificate was sought from Rwanda National Ethics Committee (reference no. 681/RNEC/2019) as well as a written approval from Musanze district administration. The informed consent was also sought from health centers administration and the study participants were interviewed after signing the informed consent form. The patients/participants provided their written informed consent to participate in this study.

Author contributions

NU and CK were involved in the conceptualization of the study. CK and DK were involved in general supervision of the study and project administration and assisted in the study proposal write up, ethical approval process follow up, survey tools development, data collection, and analysis methodology. All authors contributed in writing the original draft preparation, reviewing and editing, and read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Dietary diversity of women from soybean and non-soybean farming households in rural Zambia

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Introduction: Soybean farming in Zambia is promoted to increase farm productivity and diversification away from maize, and improve cash income and livelihoods for farmers. However, the impact of soybean farming on women's dietary intake is not clear. This study compares the dietary diversity of women from soybean (S) and non-soybean (NS) farming households as a pathway to understanding policy efficacy.

Methods: A cross-sectional survey involving 268 women of reproductive age from 401 rural households was conducted in two soybean-producing districts of Central Province, Zambia. Data from a qualitative 7-day food frequency questionnaire (FFQ) was used to calculate dietary diversity scores (DDS), women's dietary diversity scores (WDDS-10) and assess dietary patterns. Information on household sociodemographic and agricultural characteristics was used to explore determinants of dietary diversity.

Results: Results show there were no significant differences in the mean DDS (S: 10.3 ± 2.4; NS:10.3 ± 2.6) and WDDS-10 (S:6.27 ± 1.55; NS:6.27 ± 1.57) of women from soybean and non-soybean farming households. Both cohorts had similar dietary patterns, plant-based food groups with additional fats and oils. Agricultural diversity was not associated with dietary diversity. Household wealth status was the most important determinant of dietary diversity, as women from wealthier households were more likely to have higher DDS ($\beta = 0.262$, 95% CI = 0.26 to 0.70, $P < 0.001$) and WDDS-10 ($\beta = 0.222$, 95% CI = 0.08 to 0.37, $P < 0.003$) compared to those from poorer households. Women from households that spent more on food had a higher DDS ($\beta = 0.182$, 95% CI = 0.002 to 0.07), but not WDDS-10 ($\beta = 0.120$, 95% CI = −0.01 to 0.03); for every additional dollar spent on food in the past 7 days, the DDS increased by 0.18. Meanwhile, soyabean farming was not statistically associated with higher wealth.

Conclusions: Policymakers and promoters of agricultural diversification and nutrition-sensitive agriculture need to consider how women can benefit directly or indirectly from soybean farming or other interventions aimed at smallholder farmers.

KEYWORDS

soy, dietary diversity, Zambia, food system, women, farm production diversity, wealth status, nutrition-sensitive agriculture

1. Introduction

The United Nations Sustainable Development Goal Two (SDG2) has led to ambitious efforts to transform the food system into one that promotes sustainable development and meets the increased demand for food and nutrients from a rapidly growing population. Increasing policy prominence specifically points to efforts to end hunger, address food insecurity, improve nutrition, and promote sustainable agriculture by 2030 (Nkomoki et al., 2019; Atukunda et al., 2021). In response, national governments have promoted investments in agriculture around internationally linked value chains such as soybean, which are presented as great pathways through which farmers can benefit economically (Manda et al., 2019).

In the past two decades, Zambia has been under growing pressure to improve agricultural productivity to meet the food and nutrition needs of a rapidly growing population (FAO, 2017). This has highlighted the importance of agribusiness and foreign investments in value addition and processing (Mdee et al., 2020), underpinned by different smallholder coordination arrangements (Manda et al., 2018b). However, like other sub-Saharan Africa (SSA) countries, Zambia has a problem of limited agricultural diversity and productivity, with a dominance of maize (Mwanamwenge and Cook, 2019; Kapulu et al., 2020). Driven by increased multinational investment and policy support from the government, in the last two decades, soybean has increased contributions to the national-level supply of key dietary nutrients such as energy, protein, iron, zinc and calcium (Kapulu et al., 2022); however, the effect that soybean growing has on household-level diet quality is not well-understood. Historically, agricultural policies promoted maize production, neglecting crop diversification—only now are these emerging (Kapulu et al., 2022). Consequently, diets have predominantly remained poorly diversified, limiting the availability of macro and micronutrients (Joy et al., 2014; Kapulu et al., 2022), increasing the risk of dietary deficiencies and associated poor health outcomes (Afshin et al., 2019).

In Zambia, women and children are the most affected by undernutrition and micronutrient deficiencies (Doocy and Burnham, 2006; Zambia Statistics Agency, 2019), especially in rural areas (NFNC, 2014; Grech et al., 2018). Despite being important actors in the food system, population data shows that 30% and 14% of women were anemic and vitamin A deficient, respectively (Zambia Statistics Agency, 2019). Among children under 5 years of age, 58% were anemic, 35% stunted, 4% wasted and 12% underweight (Zambia Statistics Agency, 2019). Diversifying agriculture and other forms of nutrition-sensitive agricultural interventions, could be strategies that address nutritional deficiencies among rural households by increasing their access to a range of nutrient-dense foods such as fruits, vegetables, legumes, dairy and eggs (Jones et al., 2014; Mofya-Mukuka and Hichaambwa, 2018). A nationally representative survey in Malawi revealed a strong association between greater farm production diversity with increased consumption of legumes, vegetables and fruits (Jones et al., 2014). In the case of Zambia, the government and its stakeholders have promoted dietary diversity from the assumption that more diverse diets increase the likelihood of achieving caloric and micronutrient adequacy and improved nutritional outcomes (Sibhatu et al., 2022). The proposed pathways through which agriculture contributes to dietary diversity or diet quality include on-farm production and diversification, increased income from agriculture and higher expenditure on food. As an example, on-farm production diversification can be promoted through tax incentives for inputs required to grow healthier foods, improved access to farming advice, seeds and markets, and gendered agricultural empowerment (Ruel et al., 2018; Kaltenbrun et al., 2020; Sharma et al., 2021).

Zambia has developed policies toward agricultural expansion and sustainable intensification (Manda et al., 2019) and diversification of diets away from maize (Mwanamwenge and Harris, 2017). Using data from the 2015 Rural Agricultural Livelihoods Survey (RALS) longitudinal survey, Nkonde et al. (2021) explored household factors contributing to household dietary diversity scores in 7,934 households with children under 5 years in rural Zambia. The study showed that having male household heads, receiving extension advice on diversification, use of productivity enhancing inputs, practicing conservation tillage, education of mothers, amongst others, were significantly associated with households having a diversified diet and being more food secure (defined as having more than 6 months of adequate food provisions). However, the association between agricultural diversification and household dietary diversity score and adequate food provision were not statistically significant.

Soybean is a crop promoted among small-scale farmers to improve agricultural diversity and incomes. The increase is largely driven by expansions in the livestock and edible oil sectors, resulting in growing farmer participation in its production (Sitko et al., 2018). For instance, between 2006 and 2019, soybean production has increased from 57815MT to 281389MT representing a 320% increase (FAOSTAT, 2020). However, much emphasis has been placed on income from soybean production and biodiversity impacts (Manda et al., 2017; Sitko et al., 2018; Nuhu et al., 2021), as opposed to nutritional implications. Moreover, we did not find studies that explore the relationship between participation in soybean farming and nutrition outcomes in households with women of reproductive age.

The overall objective of this paper is to evaluate whether soybean farming contributes to dietary diversity of women in rural Zambia. The specific objectives were (i) to calculate and compare the dietary diversity of women from soybean and non-soybean farming households; (ii) to assess the dietary patterns in those households; and (iii) to determine what sociodemographic and agricultural factors are associated with dietary diversity.

2. Methods

2.1. Description of the study area

Zambia country has ten provinces and a population of 18 million (CSO et al., 2019). Nearly 1.5 million people live in the Central Province, and almost 75% of the households are in rural settings, from which 90% depend on agriculture for their livelihood. The province has a 56% poverty prevalence rate, while 54% of

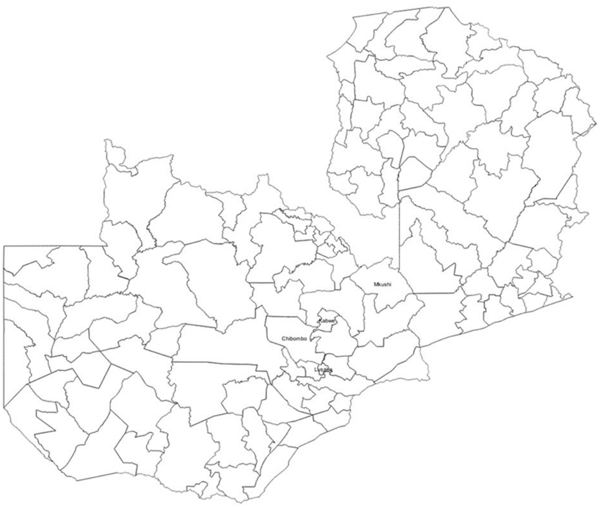

FIGURE 1
District map of Zambia showing the main study areas Chibombo and Mkushi districts, respectively.

under-five children were in 2016 wasted, 11% are underweight, and 6% are stunted (CSO, 2016). Malnutrition severity levels range from medium to high (CSO, 2013, 2016). The province accounts for 43% of the area under soybean in Zambia, including 46% of the annual soybean production of 450 000MT (ZAMSTATS, 2020).

The study was conducted in two districts of the Central Province, specifically, Mkushi and Chibombo districts (Figure 1). Chibombo district is located south of Central Province near Lusaka and Kabwe—urbanized cities. The district has an estimated population of 294 000 and an annual growth rate of 2% (CSO et al., 2019). By contrast, Mkushi district is located further north of Central Province, away from major cities and has a population of about 149 000 with a 4% annual growth rate, the highest in the province (CSO et al., 2019). Both districts have a combination of subsistence and commercial farming settlements. However, 85% of farmers are smallscale (CSO, 2016). The few commercial farms occupy the more fertile lands near main trade routes with access to developed infrastructure (MAL-GRZ, 2016). These commercial farms cultivate maize seed, wheat and soybean (grain and seed). In contrast to large scale farming, smallscale agriculture occurs in more remote areas with less developed infrastructure and is characterized by poor soils (MAL-GRZ, 2016, 2018). Maize grain, groundnuts, and pulses such as common beans and cowpeas are grown for subsistence, with some households cultivating cash crops such as soybean, tobacco and cotton.

Marketing arrangements for smallscale agriculture in the two districts differ. In Mkushi, the farmers mainly depend on government-controlled markets, while Chibombo has a combination of government and other gateways to commodity markets in nearby urban towns (MAL-GRZ, 2016, 2018). Also, Chibombo hosts Mount Meru Limited, a multinational edible oil processing company that provides access to ready soybean markets and out-grower schemes for smallscale farmers located near the plant. Likewise, other multinational cotton ginneries located in Kabwe and Chibombo offer opportunities for cotton out-grower schemes to smallscale farmers (MAL-GRZ, 2018). In addition, Lusaka hosts well-established grain processing industries for livestock feed, food and edible oils that provide additional soybean markets for farmers in Chibombo (Samboko et al., 2018). Finally, compared to Mkushi, farmers in Chibombo have better access to agricultural advisory services, including government and NGO extension (MAL-GRZ, 2018).

2.2. Ethical considerations

Before undertaking the survey, ethical approval was obtained from ethics committees at the University of Leeds (Ref No. MEEC 18-009) and in Zambia by ERES (Ref No. 2019-Apr-008). In addition, the Zambian government granted clearance to conduct the household survey. During the survey, verbal consent was given by participants in the presence of a witness, normally a local leader, or a government official.

2.3. Data collection

Data collection was conducted over 10 days in May 2019. Five days were spent in each district. This period coincides with the primary harvest season for most crops such as soybean, maize, cassava and groundnuts. The interviews were conducted in three commonly spoken local languages: Bemba, Tonga, and Nyanja. At each household, an adult male or female (in most cases, the head of household) was the primary respondent. The dietary assessment considered responses from women only. Before data collection, questionnaire pre-testing involving 20 households was conducted in Chikumbi agricultural camp, Chibombo district, to ensure the questions were interpreted as intended before conducting the survey. Following the pre-test, the questionnaire was adjusted by rephrasing or including additional terms to some questions. Data were captured electronically on a tablet using a web-based open data kit (ODK) application. Interviews lasted between 50 and 90 min. The data was verified and uploaded to a server at the end of each interview.

2.4. Study sample

The sample comprised 401 respondents of which 268 women of childbearing age (15–49 years) completed the dietary assessment questions. The women were randomly selected using a multistage cluster selection process involving: (1) purposive selection of the two districts (Mkushi and Chibombo) based on soybean market linkages; (2) stratified random selection of four target agricultural camps[1] based on access to soybean markets; (3) selection of agricultural zones and determining the number of households for enumeration using probability proportional to size without

1 A camp is an official government geographical area delineated into zones for administrative purposes comprising agricultural households. The number of households per camp can range from 300 to 3000.

TABLE 1 The number of households and agricultural camps surveyed.

District	Camp	Number of zones sampled	Number of households surveyed
Chibombo	Kalola	3	100
	Nanswinsa	2	100
Mkushi	Ilume	3	100
	Nkolonga	2	100

replacing sampling; (4) simple random sampling of households for enumeration in each zone. As a result, 100 households were selected for enumeration from each respective camp in the two districts (Table 1).

Ten trained enumerators collected sociodemographic data, including household assets, family size, education status, market distance, and amount spent on food in the past seven days. Agricultural data included land ownership, size of agricultural land, ownership of livestock, and the number of crops cultivated in the past 12 months. Dietary data were collected using a list-based 7-day food frequency questionnaire (FFQ) without portion size estimation. The FFQ was adapted and modified from previous studies conducted in Ethiopia, Tanzania, and Zambia by including other foods commonly eaten in Zambia (WFP, 2008; Ambikapathi et al., 2019; Madzorera et al., 2021).

2.5. Study variables

2.5.1. Wealth status

An asset-based index was constructed using principal component analysis in the Statistical Package for Social Sciences (SPSS) to determine the wealth status of each household (Vyas and Kumaranayake, 2006; Rutstein, 2008). The following variables considered to be determinants of wealth included in the analysis were the type of material used for house walls and floors, primary lighting source, cooking energy source, type of roofing material, ownership of land, livestock, farm and household assets such as tractor, plows, TV, radio, mobile phones. These are reliable determinants of the household wealth status used to overcome bias challenges in self-reporting wealth by participants, especially in rural settings (Morris et al., 2000; Doocy and Burnham, 2006; Rutstein, 2008). All the variables were converted to binary format [yes (1) or no (0)] except for those already collected as continuous variables. The binary recoding indicated whether they were present or absent from a household.

Eigenvalues for each principal component indicated the percentage variation explained in the original data (Vyas and Kumaranayake, 2006). For example, the first component with a 26.4% variance explained in the original data was used to determine individual households' wealth status. Next, the wealth score values were added to the data as a variable for each household to create a new variable. Finally, this new variable indicating a wealth score was used to generate five quintiles representing a wealth index, ranging from 1 being the poorest to 5 the richest.

2.5.2. Farm production diversity score

The FPDS is a simple unweighted count of the number of food crops, plants and livestock species produced and kept on the farm (Sibhatu et al., 2015). The respondents were asked questions on the type of crops produced and livestock species raised on the farm in the last 12 months. The FPDS was calculated from a generated list of crop and livestock species categorized based on the FAO classification (FAO, 1994), including (1) cereals; (2) tubers; (3) pulses; (4) nuts and seeds; (5) vegetables; (6) fruits; (7) cattle; (8) poultry; (9) goats and sheep; (10) pigs; (11) rabbits and guinea pigs. Although farm productivity (total species count on-farm) is a determinant of wealth status (Jones et al., 2014), from a nutrition standpoint, it was necessary to group the species based on their nutritional contribution (Sibhatu and Qaim, 2018a). This approach was taken to avoid double-counting, especially crops (e.g., wheat and maize) with similar nutritional profiles and adding crop and animal species such as tobacco and donkeys, which are not consumed in Zambia. In the end, the FPDS was developed as a continuous variable ranging from 1 to 11.

2.5.3. Dietary diversity indicators

Dietary diversity is a valuable indicator of household and individual access to different foods and a proxy indicator of nutrient adequacy in the diet for individuals (Arimond et al., 2010; FAO FHI360, 2016; FAO, 2018).

A 7-day FFQ was used to collect information on habitual dietary intake. The dietary information was used to calculate dietary diversity score (DDS) and women's dietary diversity score (WDDS-10).

The DDS was calculated by adding the number of food groups reported consumed in the past 7-days based on 20 binary questions included in FFQ. These are based on an FAO classification of food groups commonly consumed in rural settings of low- and middle-income countries (FAO, 2018). The food groups were predefined as (1) cereals; (2) roots and tubers; (3) pulses; (4) nuts and seeds; (5) dark green vegetables; (6) vitamin A-rich vegetables; (7) other vegetables; (8) vitamin A-rich fruits; (9) other fruits; (10) red palm oil; (11) dairy; (12) meat and poultry; (13) organ meat (i.e., liver, heart, intestines or kidney); (14) eggs; (15) fish and seafood; (16) oils and fats; (17) savory and fried snacks; (18) sweets, confectionery and sweetened beverages; (19) condiments; (20) other beverages (e.g., tea, coffee and alcohol). A score of 1 (if consumed) or 0 (if not consumed) was assigned, to give a maximum score of 20.

The WDDS-10 was calculated using the 7 days binary FFQ data using 10 food groups. The 10 food groups (FAO FHI360, 2016) were aggregated from the list of 20 predefined lists described above and included the following: (1) cereals, roots and tubers; (2) pulses; (3) nuts and seeds; (4) dark green vegetables; (5) vitamin A-rich fruits and vegetables; (6) other vegetables; (7) other fruits; (8) dairy; (9)meat, poultry and fish; (10) eggs. A score of 1 (if consumed) or 0 (if not consumed) was assigned (FAO, 2018). Women who reported consuming at least five or more different food groups in the previous 7 days were expected to have a higher likelihood of achieving micronutrient adequacy compared to those who consumed food from fewer than five food groups (FAO FHI360, 2016; FAO, 2018).

Minimum dietary diversity (MDD-W) for women of reproductive age (MDD-W) is a dichotomous indicator used to establish the prevalence of women in a given population who achieve minimum dietary diversity (FAO FHI360, 2016) in this case among soybean and non-soybean farmers. The MDD-W is determined from 10 food groups used to estimate WDDS-10 and has a cut-off point of 5 (FAO, 2018). A value of 1 was assigned when a woman consumed at least 5 different food groups in the previous 7 days and 0 when otherwise.

2.6. Data analysis

Statistical Package for Social Sciences (SPSS) version 25 was used for all statistical analyses (Field, 2009). The normality of the data was checked using the Kolmogorov-Smirnov and Shapiro-Wilk tests, respectively. The variables representing the household, farming, women, and dietary characteristics were summarized as mean standard deviation (SD) or standard error (SE) were appropriate. Summary statistics were used to assess the composition of diets for soybean and non-soybean farmers. Analysis of variance (ANOVA) with Brown-Forsythe robust test was used to test the hypotheses that growing soybean increases mean DDS and WDDS-10, respectively. Bivariate analysis (at $P<0.05$ significance level) was conducted to explore for covariates under household (i.e., sociodemographic) and farming (i.e., agricultural) characteristics. In addition, variables were identified as potential confounders based on literature. This included district, farming system, women's education, women's age, gender of household head, education of household head, and age of household head.

A stepwise ordinary least square (OLS) multivariate regression model that included wealth status, household size, nearest market distance, and amount spent on food as explanatory variables and DDS and WDDS-10 as continuous variable outcomes to assess whether sociodemographic factors were predictors of women's dietary diversity. In addition, the model was adjusted for the district, farming system, women's education, women's age, gender of household head, education of household head, and age of household head. Further, a second model assessed the association between agricultural factors, including FPDS and women's dietary diversity. The OLS multivariate regression model included FPDS, the crop area cultivated under soybean, the proportion of crops grown consumed, and the proportion of crops harvested sold as explanatory variables with DDS and WDDS-10 as outcomes. The model was adjusted for confounder as above alongside wealth status. The model outputs included β-coefficients, 95% confidence intervals (CIs), and *P*-value for each explanatory variable.

3. Results

3.1. Characteristics of the study participants

The characteristics of study participants from the two farming systems [soybean (S) and non-soybean (NS) farmers] and at the district level (Chibombo and Mkushi) for soybean farming households only are shown in Table 2.

3.1.1. Household characteristics

More than 80% of the head of households in the farming systems were male. The average family size was six people per household. The level of education among household heads was moderately low, with many (61%) having attended school only up to the primary level. Chibombo had a higher proportion (44.2%) of households ranked as "poorest and poor" than the 35.7% from Mkushi. The primary source of income was from on-farm activities, comprising mainly crop production with some livestock keeping.

3.1.2. Farming characteristics

Households in the survey had access to an average of 5.0 ha of land, while an average of 3.1 ha was used for agriculture in the preceding 12 months. More than 80% owned the land. The mean (±SD) number of crops grown was 3.0 ± 0.15 and 2.1 ± 0.08 for the two farming systems. A further look at the soybean farmers at district levels showed that the mean (±SD) number of crops grown were 3.0 ± 0.16 in Chibombo and 3.1 ± 0.19 in Mkushi. Maize, soybean, beans, sweet potatoes and tomatoes were the most common crops grown. Many households owned livestock, especially chickens and goats, with a few having cattle and pigs. The mean (±SD) FPDS was statistically significantly different for the two farming systems 5.4 ± 0.26 and 3.6 ± 0.13 ($P < 0.001$) for soybean and non-soybean farms, respectively, and for districts, 4.3 ± 0.25 and 5.9 ± 0.25 ($P < 0.001$) Mkushi and Chibombo, respectively.

3.1.3. Women's characteristics

The mean age for women was 33 years. About 50% of the women attended school up to the primary, but only 20% completed secondary and tertiary levels. More than 80% of the women were married.

3.2. Effect of soybean farming on dietary diversity indicators

3.2.1. Diet diversity score

The mean DDS for women from soybean and non-soybean farming households are shown in Table 3. Analysis of variance (ANOVA) with Brown-Forsythe robust test was used to determine if soybean growing affected mean DDS. The results show that the mean (±SD) DDS between soybean (10.3 ± 2.4) and non-soybean (10.3 ± 2.6) farmers did not differ significantly ($P = 0.909$). Further analysis of soybean farming households showed that the mean (±SD) DDS of women from Chibombo district (10.2 ± 2.3) did not differ significantly ($P = 0.629$) from those from Mkushi district (10.5 ± 2.8) (Table 3).

3.2.2. Women's diet diversity score based on 10 food groups

The WDDS-10 for women from soybean and non-soybean farming households are shown in Table 3. The results show that the mean (±SD) WDDS-10 of women from soybean (6.27 ± 1.55) and non-soybean (6.27 ± 1.57) farming households did

TABLE 2 Demographic, agricultural and dietary characteristics of the sampled households and women according to the farming system and district.

Characteristics	Farming system		District	
	Soybean households	Non-soybean households	Chibombo (soybean households)	Mkushi (soybean households)
Household characteristics (*n*)	110	291	73	37
Gender of household head (%)				
Male	84.5	81.4	87.7	78.4
Female	15.5	18.6	12.3	21.6
Average family size ± SD	6.9 ± 2.6	6.7 ± 2.5	7.0 ± 2.9	6.8 ± 2.4
Education level of household head (%)				
No formal education	1.8	4.8	27	0
Primary school incomplete	40.9	36.8	43.8	35.1
Primary school complete	20.0	23.7	19.2	21.6
Secondary school incomplete	24.6	21.3	24.7	24.3
Secondary school complete	11.8	10.3	9.6	16.2
Tertiary education	0.9	3.1	0	2.7
Wealth status (%)				
Poorest	15.5	21.6	19.2	8.1
Poorer	14.5	22.0	15.1	13.5
Middle	23.6	18.9	27.4	16.2
Richer	19.1	20.3	16.4	24.3
Richest	27.3	17.2	21.9	37.8
Mean number of income sources ± SD	1.9 ± 1.1	1.7 ± 0.9	1.8 ± 0.1	1.8 ± 0.1
Farming characteristics				
Mean total accessible land (ha) ± SE	6.1 ± 0.9	4.1 ± 0.6	6.4 ± 0.7	9.8 ± 3.3
Mean total agricultural land (ha) ± SE	3.8 ± 0.4	2.6 ± 0.3	5.0 ± 0.5	3.2 ± 0.6
Own land (%)	93.6	86.3	94.5	91.9
Own livestock (%)	91.8	77.7	98.6	78.4
Mean number of crops grown ± SE	3.0 ± 0.2	2.1 ± 0.1	3.0 ± 0.2	3.1 ± 0.2
Mean number of livestock species kept ± SE	2.4 ± 0.2	1.5 ± 0.1	2.9 ± 0.2	1.2 ± 0.2
Mean number of food crops grown ± SE	2.8 ± 0.2	2.0 ± 0.1	2.7 ± 0.1	3.1 ± 0.2
Mean farm production diversity score (FPDS) ± SE	5.4 ± 0.3	3.6 ± 0.1	5.9 ± 0.3	4.3 ± 0.3
Women's characteristics (*n*)	66	202	45	22
Mean age (years) ± SD	32.8 ± 9.8	33.7 ± 10.1	33.6 ± 1.7	33.2 ± 1.8
Education level (%)				
No formal education	6.3	5.6	4.4	9.1
Primary school incomplete	42.9	51.0	46.7	36.4
Primary school complete	17.5	20.4	17.8	22.7
Secondary school incomplete	22.2	18.4	20.0	9.1
Secondary school complete	11.1	4.6	11.1	7.0
Dietary characteristics				
Mean dietary diversity score (DDS) ± SD	10.3 ± 2.4	10.3 ± 2.6	10.2 ± 2.3	10.5 ± 2.8
Mean women's dietary diversity score (WDDS-10) ± SD	6.3 ± 1.6	6.3 ± 1.6	6.2 ± 1.7	6.4 ± 1.3
Mean amount spent on food last 7 days $USD ± SD	9.7 ± 0.8	9.4 ± 0.5	8.1 ± 1.0	12.9 ± 1.6

TABLE 3 Mean ±SD dietary diversity scores (DDS) and women's dietary diversity scores (WDDS-10) categorized according to the farming system and district.

Indicator	Farming system				District			
	Soybean	Non-soybean	*N*	*p*-value	Chibombo (soybean only)	Mkushi (soybean only)	*N*	*p*-value
DDS ± SD	10.27 ± 2.41	10.23 ± 2.59	268	0.909	10.16 ± 2.26	10.47 ± 2.76	66	0.629
WDDS-—10 ± SD	6.27 ± 1.56	6.27 ± 1.57	268	0.981	6.21 ± 1.70	6.39 ± 1.30	66	0.636

The results of ANOVA with the Brown-Forsythe robust test are shown at a 95% significance level.

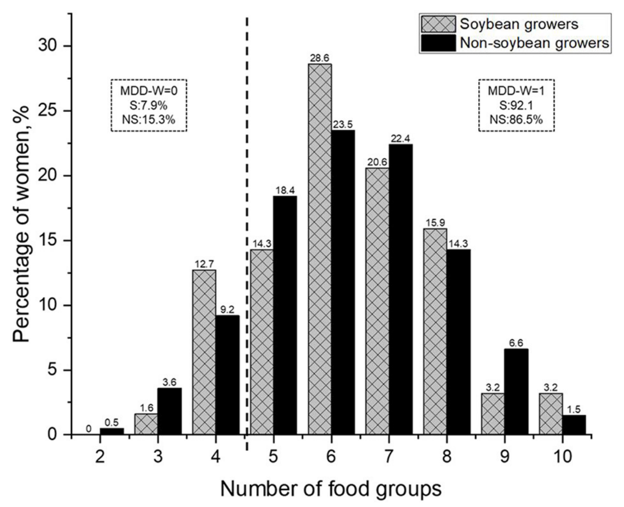

FIGURE 2
Percentage of women achieving different women's dietary diversity scores (WDDS-10) and prevalence of the minimum dietary diversity for women of reproductive age (MDD-W) among soybean (S) and non-soybean farmers (NS). MDD-W = 1 if the women consumed at least five or more different food groups during the past seven days and 0 otherwise. The dotted line denotes a cut-off point for MDD-W. *N* = 268.

not differ significantly ($P = 0.981$). Further analysis of soybean growing households district showed that the mean (±SD) WDDS-10 of women from Chibombo district (6.2 ± 1.7) did not differ significantly ($P = 0.636$) with those from Mkushi district (6.4 ± 1.3) (Table 3).

3.2.3. Minimum dietary diversity

The WDDS-10 calculated from food groups consumed in the previous seven days and the proportion of women who achieved the minimum dietary diversity (MDD-W) were further investigated (Figure 2). More than 86% of women from soybean and non-soybean households achieved the MDD-W (i.e., WDDS-10 ≥ 5), while 14% of women did not achieve MDD-W (i.e., WDDS-10 < 5). In this case, the diet comprised of plant-based foods primarily. For example, those who consumed two food groups tended to eat cereals and dark green vegetables. Those who consumed three food groups consumed starchy roots in addition to cereals and dark green vegetables. Only a few reported eating eggs (13%) and fish (38%). As the WDDS-10 increased, the diets comprised mostly starchy roots, dark green vegetables, and other vegetables with other food groups such as pulses, eggs, fish, dairy, organ meat, and meat. Likewise, when the district is considered, over 86 women from soybean farming households in Chibombo and Mkushi achieved an MDD score of 1, consuming >5 food groups daily (Supplementary Figure 1).

3.3. Composition of the diets

Figure 3 shows the percentage of households from which women reported consuming a food group in the past seven days. The results confirm the observations with WDDS-10 of a general dominance of plant-based food groups in the diets. Cereals are consumed by more than 95% of households. Nearly 90% reported consuming dark green vegetables and other vegetables, while pulses, roots and tubers, and nuts and seeds were consumed by over 60% of the households. About 50% of the households reported consuming animal products such as fish, eggs, meat, and poultry in the past seven days. A few households reported consuming other food groups such as fruits, dairy, and vitamin A-rich foods. Notably, 20.9% of women from non-soybean farming households said they consumed snacks in the past seven days compared to 77.8% from soybean farming households, while 50.5% from non-soybean farming households consumed sugary foods against 43.1% soybean farming households. Likewise, 86.7% non-soybean farming households said they consumed condiments in the past 7 days compared to 77.8% from soybean farming households.

Further analysis of dietary patterns among women from soybean-farming households in the two districts revealed that women ate mostly similar foods (Supplementary Figure 2). More than 90% of the women from both districts reported consuming cereals, dark green vegetables, and other vegetables. Notably, the consumption of vitamin A rich fruits, other fruits, dairy, and vitamin A rich vegetables ranged from 6 to 35% in the two districts. However, over 80% reported consuming roots and tubers in Mkushi compared to 65% from Chibombo. Likewise, 80% consumed pulses in Mkushi against 50% in Chibombo, and 84% of the women in Mkushi ate fish compared to 50% from Chibombo. A possible explanation to this is that Mkushi compared to Chibombo has several rivers and streams. In contrast, nuts and seeds were consumed more in Chibombo (91%) than Mkushi (50%). Organ meat (15.0 vs. 3.8%), including meat and poultry (65.2 vs. 34.6%), were also reported to have been eaten more by women from Chibombo than Mkushi, respectively. On the other hand, oils and

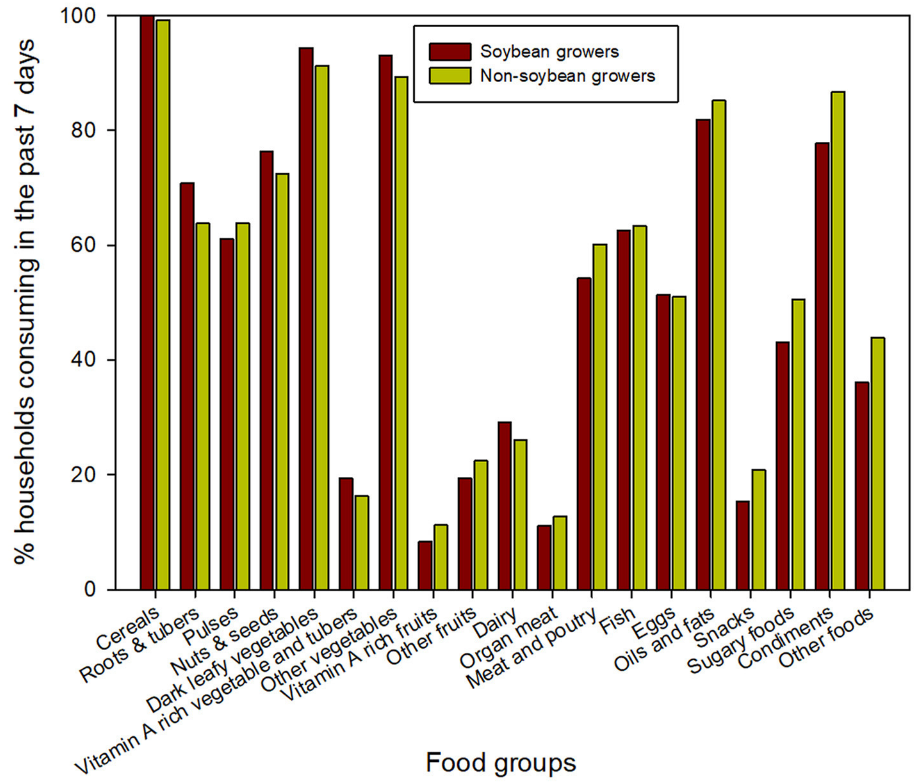

FIGURE 3
Percentage of women from households who reported consuming a food group in the past 7 days.

TABLE 4 Multivariate regression analysis of the relationship between dietary diversity scores (DDS) and women's dietary diversity scores (WDDS-10) and agricultural factors.

Variable	DDS				WDDS-10			
	Adjusted[a] β	95% CI		*p*-value	Adjusted[a] β	95% CI		*p*-value
Farm production diversity score unweighted	0.069	−0.255	0.196	0.334	0.090	−0.104	0.189	0.222
Proportion of crop area cultivated under soya	0.048	−1.582	3.913	0.647	0.061	−0.964	2.602	0.575
Proportion of crop harvested consumed	−0.011	−0.902	2.299	0.856	0.008	−0.809	1.269	0.903
Proportion of crop harvested sold	0.141	0.070	3.680	0.036	0.087	−0.626	1.717	0.214

Data are presented as β, 95% confidence intervals, p-value and were analyzed by multivariate regression analysis.
[a]Adjusted for district, farming system, women's education, wealth status, women's age, gender of household head, education of household head, and age of household head.

fats were equally eaten by 87% of the women in Chibombo against 73% from Mkushi.

3.4. Factors related with women's dietary diversity

3.4.1. Agricultural factors associated with women's dietary diversity

Table 4 shows the results of a multivariate regression analysis of the relationship between selected household agricultural characteristics with DDS and WDDS-10. The analysis was adjusted for district, farming system, women's education, women's age, gender of household head, education of household head, age of household head and wealth status (see Supplementary Table 3 for unadjusted model outputs). DDS and WDDS-10 were not statistically significantly associated with farming diversity indicator FPDS ($P = 0.334$; $P = 0.222$), proportion of crop area cultivated under soybean ($P = 0.647$; $P = 0.575$), and proportion of crops grown consumed ($P = 0.856$; $P = 0.903$). Notably, the regression analysis shows that the higher proportion of crop harvested sold was associated with greater DDS (β = 0.141, 95% CI = 0.70–3.60) but this was not the case with WDDS-10 (β = 0.087, 95% CI = −0.626 to 1.717). For every kilogram of crop harvested that was sold, DDS increased by 0.141.

TABLE 5 Multivariate regression analysis of the relationship between dietary diversity scores (DDS) and women's dietary diversity scores (WDDS-10) and sociodemographic factors.

Variable	DDS				WDDS-10			
	Adjusted[a] β	95% CI		*p*-value	Adjusted[a] β	95% CI		*p*-value
Wealth status	0.305	0.274	0.727	<0.001	0.230	0.080	0.373	<0.001
Household size	0.106	−0.101	0.150	0.102	0.125	−0.037	0.125	0.056
Nearest market distance (km)	0.094	−0.005	0.021	0.138	0.115	−0.001	0.015	0.075
Amount spent on food last 7 days (USD)	0.182	0.002	0.069	0.003	0.120	−0.010	0.033	0.055

Data are presented as β, 95% confidence intervals, p-value and were analyzed by multivariate regression analysis.
[a] Adjusted for district, farming system, women's education, women's age, gender of household head, education of household head, and age of household head.

3.4.2. Sociodemographic factors associated with of women's dietary diversity

Table 5 shows the results of a multivariate regression analysis of the relationship of DDS and WDDS-10 with sociodemographic variables, including wealth status, household size, nearest market distance, and amount spent on food in the past seven days. The analysis was adjusted for district, farming system, women's education, women's age, gender of household head, education of household head, age of household head and wealth status (see Supplementary Table 4 for unadjusted model outputs). Wealth status and amount spent on food in the past 7 days showed a significant positive relationship with women's dietary diversity. Wealth status was associated with higher DDS ($\beta = 0.305$, 95% CI = 0.27–0.73) and WDDS-10 ($\beta = 0.230$, 95% CI = 0.08–0.37). The results indicate that each unit increase in women's wealth status increased the DDS and WDDS-10 by 0.31 and 0.23, respectively. Women from households that spent more on food in the past seven days were associated with a higher DDS ($\beta = 0.182$, 95% CI = 0.002–0.07), but not WDDS-10 ($\beta = 0.120$, 95% CI = −0.01 to 0.03). This means that for every additional dollar spent on food in the past 7 days, the DDS increased by 0.18. By contrast, household size and distance to the nearest market were not associated with greater increase in DDS ($\beta = 0.106$, 95% CI = −0.101 to 0.15; $\beta = 0.094$, 95% CI = −0.005 to 0.021) and WDDS-10 ($\beta = 0.125$, 95% CI = −0.037 to 0.125; $\beta = 0.115$, 95% CI = −0.001 to 0.015).

4. Discussion

Here we advance the literature by comparing the dietary diversity of women from soybean and non-soybean households from rural Zambia. Overall, we report no significant difference in DDS and WDDS-10 between the two groups. We explored factors associated with dietary diversity and report that household wealth status is the most important determinant of women's diet diversity as an indicator of diet quality. Our findings suggest that dietary diversity is mediated by socioeconomic factors such as household wealth.

4.1. Effect of soybean farming on women's diets

As in other African countries, soybean in Zambia has been promoted to encourage crop diversification away from maize (a leading food and income security crop), improve cash income to farmers and nutritional security (Giller et al., 2011; Manda et al., 2017; Mubichi, 2017). However, the study finds little evidence suggesting that growing soybean resulted in higher diet diversity directly. Farmers are more motivated to grow the crop for sale than household consumption. This could be attributed to the focus of soybean promotional messages as a cash crop rather than food crop. Soybean production and processing (mostly into livestock feeds and edible oils) has increased exponentially in the past two decades. Exports for soybean products such as oilcake/meal enabled by rapid growth in livestock sectors in the Southern African region, seem to drive increased investment in industrial processing of soy (Meyer et al., 2019; Mulenga et al., 2020). Likewise, a recent study using FAO food balance sheets shows that soybean has increased contributions to the national supply dietary nutrients such a calcium, protein, energy, iron at national-level in Zambia (Kapulu et al., 2022). However, the findings from this study show that the quality of diets assessed *via* DDS and WDDS-10 of women from soybean farming households did not differ from that of non-soybean farming households. The findings demonstrate that soybean farming was not associated directly with more diverse diets. This likely because soybean is processed into oils and livestock feeds, rather than directly consumed. In this cohort, there is low consumption of animal source foods among soybean and non-soybean farming women, suggesting that there is little contribution coming from soybean as animal-feed to the diets of women. Our findings confirm what previous studies show regarding low household-level utilization of soybean for food in SSA. Therefore, there is a need to train farmers in domestic processing for soybean for food to encourage its consumption and utilization—an important enabler (Chianu et al., 2009; Wilson et al., 2021). However, this needs to go alongside interventions such as behavioral change communication focusing on consuming nutritious foods, especially the locally available ones such as eggs and fruits. Nutrition-sensitive agriculture (NSA) programmes focused on women's training in processing their produce have resulted in increased intake of nutritious foods and improved diet diversity (Gondwe et al., 2017).

This study revealed that women from soybean-growing households residing in Chibombo with better proximity to soybean and food markets, including major cities such as Lusaka and Kabwe, achieved similar diet scores compared to those living in Mkushi. This suggests that location did not seem to affect dietary diversity across differently linked to urban cities. Both districts are in rural settings, which could be a function of the diversity of food markets in such settings. For instance, a study involving 600 households conducted in Cameroon and Ghana suggests that households living in urban cities with better access to food markets were more likely to have higher DDS than those from peri-urban (agricultural) cities (Bahadur et al., 2018). Moreover, the women from the two districts had similar consumption patterns (Supplementary Figure 2). Previous reports suggest that in rural Zambian settings, the diets do not differ much, comprising mostly nshima (a thick porridge) made from maize or cassava alongside dark green leafy vegetables, which is consistent with results from this study (Caswell et al., 2018). However, a further look at the dietary composition from results of this study suggest that dietary transitions is slowly occurring among rural households as consumption of sugar and snacks is on the rise (Kapulu et al., 2022). Notably, Chibombo women consumed more meat, poultry, oil, and fats than Mkushi. This could be attributed proximity to edible oil processing plants for the women located in Chibombo.

4.2. Agricultural diversification and women's diets

The present study results showed no relationship between the proportion of crops harvested consumed with DDS and WDDS-10 (Table 3). The farms were not diversified enough with food crops to affect the diet diversity of the women. Another possible explanation for this is that soybean and many other cash crops (e.g., tobacco, groundnuts) have been promoted to increase agricultural incomes (Kumar et al., 2018). However, studies from Zambia report that direct consumption of soybean from their own produce is low due to processing constraints among smallscale farmers (Lubungu et al., 2013; Alamu et al., 2018). This is due to a lack of knowledge of soybean processing techniques such as cooking and baking (from soy-flour) for home consumption (Lubungu et al., 2013). Likewise, a survey conducted among smallholder farmers in Ghana revealed that many farmers consider soybean more of a cash crop than a food crop (Mbanya, 2011). Thus, many smallscale farmers prefer selling most of their harvest, improving their incomes (Meyer et al., 2018).

In Zambia, soybean productivity among smallscale farmers is below 1 ton/ha and is characterized by high transactional costs (Sitko et al., 2018). Farmers also have poor access to inputs and markets offering higher soybean prices (Mbanya, 2011; Asodina et al., 2020). Besides, the scale is too small to provide an adequate income to diversify the food they can purchase. Moreover, smallscale farmers tend to over-specialize when market demand for especially cash crops increases, impacting agricultural and diet diversity, respectively (Mofya-Mukuka and Hichaambwa, 2018). Recent reports from Zambia show that increasing soybean productivity and better market access seems important if smallscale farmers are to realize dietary benefits from soybean production (Nuhu et al., 2021). The study measured resultant welfare benefits from growing soybean on smallscale farmer incomes and household food security. Generally low productivity soybean and limited access to land among smallscale farmers compared to commercial farmers, affected household food security and incomes. This suggests that, while policy interventions in Zambian agriculture have focused on improving agricultural diversity, e.g., promoting soybean and emphasizing increasing rural incomes (Manda et al., 2019), there is a need to improve their access to land and increase productivity. Smallscale farmer production systems are not diverse and thus farming has little to no effect on dietary diversity.

Furthermore, results showed no relationship between FPDS (a proxy indicator of agricultural diversity) and DDS and WDDS (Table 3). In this study, most of the households in the two farming systems and districts had low diversity, and they grew less than three food crops and kept fewer than two livestock species (see Table 2). The pathway linking production diversity with women's diets is complex (Sibhatu and Qaim, 2018a; Madzorera et al., 2021). For example, contributions from farm production diversity to dietary diversity will most likely be diminished if households predominantly grow crops or keep livestock for sale and not consumption. Unlike our study, a previous rural agricultural household survey by Nkonde et al. (2021) used a 24-h recall to investigate the link between agricultural diversification and household diet diversity scores (DDS) among 7,934 households with under 5-year-old children across all 10 provinces of Zambia. They did not find a relationship between agricultural diversification and household diet diversity scores (Sibhatu and Qaim, 2018b; Sibhatu, 2019). In all these studies, better market access mediated the effects of production diversity on dietary diversity. Improved market access can improve farmer incomes from sales, which improves diets when spent on nutritious foods. Provided the markets are well-functioning and have stable supply (available) and affordable nutritious foods (Manda et al., 2018a).

Several factors that seem to mediate the relationship between diversification and diets are reported in the studies (Sibhatu et al., 2015; Sibhatu and Qaim, 2018a; Madzorera et al., 2021). These include consumption of own produce, food prices, food market availability, geographical location, and income from sales. However, while agricultural diversification can improve smallholder incomes (Jones, 2017), the results of this study show a weak association. Agricultural diversification alone, we argue, is not enough, and that there are equally important determinants of the quality and diversity of diets. It can be argued that from a nutrition-sensitive perspective, interventions such as soybean farming are not yet providing the farmers with better access to affordable markets with nutritious foods (Madzorera et al., 2021). This can be achieved with much emphasis on increasing farm income from soybean sales, investment in micro-level processing as well as sensitization on the role and importance of crop diversification more generally and soya bean expansion specifically.

4.3. Sociodemographic factors and women's diets

The sociodemographic factors revealed that household wealth was the strongest predictor of DDS and WDDS-10 among agricultural households. For example, every increase in wealth status (i.e., from poorest to poorer or middle to rich) resulted in a 0.26 (95% CI 0.25–0.7) and 0.22 (95% CI 0.08–0.37) unit increase in DDS and WDDS, respectively (Table 4). These findings are aligned with previous research in Zambia by Mofya-Mukuka et al. (2017) that used 24-h recall panel data collected from two surveys in all 10 provinces. The study involving 8839 households also found that household wealth status increased household diet diversity scores by 18 percentage points (Mofya-Mukuka et al., 2017). Further, the present study results show that women's dietary diversity (DDS and WDDS-10) improved in households with wealth status ranked middle, rich and richest, respectively. Conversely, women in poor and poorest ranked households had low diet diversity regardless of farming system and district.

Considering that the districts in this study are rural, poverty levels are high (CSO, 2016), with limited infrastructure and inadequate institutional support for market engagement. This could potentially be the reason this study did not find difference in diets between soybean and non-soybean households. A recent study shows that farmers who cultivated <5 ha soybean (i.e., smallscale) did not receive sufficient economic returns to reduce poverty, despite a wider growing market demand and soybean prices (Nkonde et al., 2021). Limited market connectivity could be another important factor.

Another key finding in this study was a positive relationship between the proportion of crops harvested and sold with DDS. The regression model was adjusted for district (Chibombo and Mkushi), farming system (soybean and non-soybean) and wealth status. It is plausible that women from households that allocated more money toward food achieved more diverse diets. A panel study in Zambia confirmed this, finding a positive association between land under soybean and increased incomes from sales with diet diversity (Nkonde et al., 2021).

This study found that the amount of money spent on food was positively associated with DDS and WDDS-10. The finding agrees with previous studies that report increased effects of income from agriculture on diet diversity (Mofya-Mukuka and Hichaambwa, 2018; Some and Jones, 2018; Mulenga et al., 2021). This study demonstrates that although crops like soybean have been promoted as cash crops, this may not always impact diet diversity if incomes earned are not sufficient. Policy measures that provide income social safety nets especially for the poor are required, including tax incentives on nutritious foods to increase availability.

Nevertheless, this was not the case for farmers who did not receive sufficient economic returns from soybean growing on <5 ha of soybean. Smallscale soybean production is characterized by low productivity. Their yields and land area were insufficient to improve their wealth despite growing market demand and soybean prices (Nkonde et al., 2021). In the case of the present study, farmers involved in soybean need to earn enough income from crop sales for soybean to improve diets *via* the income pathway.

Therefore, while the Zambian government has promoted soybean to improve rural incomes, the results from this study show that improving diet diversity among rural farming households involves complex socioeconomic factors. Some of these notable factors include food market availability, the proportion of harvest retained for consumption, the amount spent on food, household-level decision-making dynamics, women empowerment, education, and incomes from sales (Wineman, 2016; Gondwe et al., 2017; Rosenberg et al., 2018; Sauer et al., 2018; Mulenga et al., 2021). For example, women play an important role in making decisions about food purchases (Bellon et al., 2016). However, women are at a higher risk of achieving low diet diversity, especially if they are less empowered and come from low-income or poor households (Harris-Fry et al., 2015; Madzorera et al., 2021). Since poor women may find it difficult to purchase enough food, including nutritious ones, to feed the entire household, they might prioritize meeting the food needs of other family members (e.g., children and men) over their own (Chakona and Shackleton, 2017). Therefore, a better understanding of such household dynamics is needed if interventions such as soybean farming are to achieve food security and desired nutrition outcomes for women.

5. Implications of the study

Economic imperatives, specifically attractive soybean prices driven by increased market demand, seem to be the Government basis for encouraging farmers to participate in soybean production in Zambia. The framing of soybean promotional messages among smallscale farmers are primarily for income rather than food. Evidence from this study support the hypothesis that farmers may be growing soybean for markets to earn higher incomes and not for direct food consumption or healthy food purchases. This research suggested limited evidence of soybean utilization for food among smallscale farmers. There is a need to sensitize smallscale farmers, especially women, on the nutritional benefits of soybean consumption and household-level processing technologies. Future studies should further explore opportunities and barriers for household-level soybean utilization among smallholder farmers.

This study also found an important difference between households in different wealth quintiles regardless of the farming system (soybean or non-soybean). Smallscale farmers rely on market functionality to grow their incomes and access nutritious foods. Results underpin the argument that the functionality of markets such as for soybean for farmers located both nearer and further away from cities and main roads could raise challenges including price exploitation. As with other crop value chains, this increases transactional costs on the part of smallscale farmers and undermines incomes, perpetuating the poverty trap (see Manda, 2022). The policy drive to expand soybean production has not considered the dynamics among smallscale farmers; instead, as the case has been with maize, the approach is more holistic than targeted. The implication is that because most of these farmers depend on agriculture as their main livelihood activity, they may not generate sufficient incomes (in this case, soybean farming) to enable them to move out of poverty and simultaneously meet their food needs (Mdee et al., 2020). Most smallscale farmers have access to small portions of land on which they also grow other staples. Furthermore, smallscale soybean farming is characterized by low productivity and poor market functionality. The farmers are not likely to earn sufficient incomes from soybean growing until these improve (Nkonde et al., 2021). The income pathway should be complemented with additional interventions to influence income use, for example, nutrition education and women empowerment for increased decision-making on how income from agriculture including soybean production, and non-agriculture sources are used to purchase nutrient-dense food.

5.1. Limitations of study

For the first time, a study in Zambia focuses explicitly on assessing how soybean farming is associated with diet quality. However, the study has several limitations. First, the FFQ did not specifically ask questions about the consumption of soybean-based foods. Soybean was included in the FFQ as a food item under oil crops alongside other crops such as groundnuts and sunflower. Consequently, a limitation of this study is that it might not be possible to ascertain a single direct contribution to diet scores from soybean alone. In this case, dietary assessment methods that use an open 24 h recall would be fittingly relevant to assess the consumption of soybean. Therefore, caution should be applied when interpreting the results, as FFQ are good for estimating dietary patterns and not consumption of specific foods. While DDS it is a good measure of food access within the context of food security, it does not provide an indication of nutrient adequacy at the individual level (FAO, 2018) because it does not consider the nutritional quality of food groups consumed. This is particularly important considering that micronutrient deficiencies such as calcium, zinc, folate, and iron are prevalent among women in rural areas. To examine adequacy of the diet at an individual level, the WDDS-10 was used because it considers the quality of the diet by assessing the type of food groups consumed. The WDDS-10 is an easy-to-use proxy indicator for nutrient adequacy to determine diet quality when resources and time are limited (Arimond et al., 2010; FAO, 2018). The women from both farming systems had a mean DDS of 10 and consumed six food groups (WDDS-10 = 6) of the 10 required to achieve diet adequacy. Soybean was included in the FFQ as a food item under oil crops. While groundnuts are generally consumed in various forms, sunflower and soybean are mostly eaten as edible oil, represented in a different food category (i.e., oils and fats).

The study was a single time point study during the harvest months, which could change in the leaner months. Seasonality can influence dietary patterns and, consequently, the supply of dietary nutrients and nutrient adequacy (Caswell et al., 2018; Ambikapathi et al., 2019). For example, Caswell et al. (2018) shows that DDS for both women and children varied greatly across seasons in their study which involved 24h dietary recalls repeated 7 times over a period of a year. Food supply especially in rural setting could be influenced by seasonality and the geographical characteristics if the area e.g., proximity to food markets (Ambikapathi et al., 2019). Thus, future studies could design dietary assessment tools (e.g., a quantitative 24-h recall) that specifically ask questions about the consumption of different soybean foods alongside other foods and repeat this over time and across seasons.

6. Conclusion

This study has demonstrated that wealth status and income utilization are determinants of the dietary diversity of women from farming households in Zambia rather than agricultural diversification. Our study shows that diversifying small-scale agriculture through soybean farming does not appear to directly benefit diet diversity of women. Policymakers and promoters of agricultural diversification need to consider sociodemographic factors such as wealth status and market access as important drivers of dietary improvement. Policies that improve income need to be complemented with additional interventions to improve income utilization and increase soybean utilization in the household. This study provides a basis to inform nutrition-sensitive agriculture policies, including the implications of agricultural expansions to soybean on small-scale farmer livelihoods and nutrition outcomes. By better understanding the drivers and barriers, policymakers can develop appropriate strategies for improving nutritional outcomes among small-scale farming households affected by agricultural expansions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by University of Leeds (Ref No. MEEC 18-009) and in Zambia by ERES (Ref No. 2019-Apr-008). Verbal consent was given by participants in the presence of a witness, normally a local leader, or a government official. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

NK, CO, HS, JM, CN, and CC conceptualized the research. NK and HS developed the methodology. NK collected and curated the data and wrote the first draft of the manuscript. NK and MH analyzed the data. NK, CO, SM, HS, JM, CN, and CC critically evaluated the results and contributed to the writing and editing of the manuscript. CO, HS, and SM supervised the research. All authors contributed to the article and approved the submitted version.

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Conflict of interest

CC was employed by Agricultural Consultative Forum.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1115801/full#supplementary-material

SUPPLEMENTARY FIGURE 1

Percentage of women achieving different women's dietary diversity scores (WDDS-10) and prevalence of the minimum dietary diversity for women of reproductive age (MDD-W) among soybean farmers. MDD-W = 1 if the women consumed at least five or more different food groups during the past seven days and 0 otherwise. The dotted line denotes a cut-off point for MDD-W. $N = 66$.

SUPPLEMENTARY FIGURE 2

Percentage of women from soybean households in Chibombo and Mkushi who reported consuming a food group in the past 7 days.

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Practitioners' perspectives on improving ready-to-eat food vending in urban Nigeria: a practice-based visioning and back-casting approach

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In many parts of the world, food consumption is shifting from mostly home-based to out-of-home due to transforming of everyday lives as a result of urban development and changing infrastructure. This trend has spurred the expansion of informal ready-to-eat food vending, particularly among the urban poor. However, informal ready-to-eat food vending practices have faced challenges in provisioning menu settings with high energy and calories foods. Moreover, there are concerns about the safety, health, and diversity of food purchased through ready-to-eat food vending. This paper explores practice-oriented strategies, suggestions, and mechanisms through key actors' experiences and perspectives to understand how the provisioning of healthy and diverse food in informal ready-to-eat food vending can be improved in urban Nigeria as a future transformative initiative. A social practice-oriented approach, combined with participatory future visioning and back-casting, was employed in a multi-phase process of interlinked focus group discussions and workshops involving key food sector stakeholders. The findings reveal that achieving an increase in diverse foods and integration of fruits and vegetables requires changing food norms and promoting sensitization to the importance of diverse diets through training initiatives involving primary actors. Additionally, key skills/competences in the provisioning of healthy and diverse foods need to be learned and relearned, while adequate food materials, finance and effective and efficient integration of the different food vending practice elements are required for the realization of these initiatives. Furthermore, understanding the relationships between food vending and other food-related provisioning practices within the food vending environment is essential in transitioning to healthier and more diverse food provisioning in the informal food vending sector. Our findings provide insights for policymakers to provide strategic pathways for practical interventions to improve food vending practices that meet the food security and nutritional needs of the urban poor.

KEYWORDS

street food vending, nutrient intake, social practice, future initiatives, urban poor, Nigeria

1. Introduction

Urbanization, complex urban infrastructural change, and rural–urban migration are transforming food consumption practices in cities in the Global South (Karamba et al., 2011; Adeosun et al., 2022a). One key change in food consumption brought about by these dynamics is the shift from home-based to out-of-home food consumption, particularly among the urban poor (Piaseu and Mitchell, 2004; Tsuchiya et al., 2017). In many developing countries like Nigeria, ready-to-eat food vending has expanded tremendously (Adeosun et al., 2022b). This has raised concerns about poor urban dwellers who disproportionally depend on out-of-home food outlets, for whom food insecurity intersects with multiple other challenges in daily life, such as inadequate housing and long working hours in informal jobs (Adeosun et al., 2022a). These developments suggest that out-of-home food consumption will continue to grow and this trend has a range of consequences. Recent research reveals that changes in daily practices such as mobility, work, and family life associated with socio-economic transformations in urban settings have contributed to increasing out-of-home food consumption (Thornton et al., 2013; Adeosun et al., 2022a). In response, out-of-home food provisioning is expected to align more along these situational dynamics to ensure the food security of the concerned groups consumers.

Despite their increasing reliance on out-of-home food, low-income consumers do not have absolute control over the kinds of foods and the composition of meals provisioned by food vendors, so their out-of-home food intake is limited to what these vendors provide. However, the kinds of food provisioned intersect with different dynamic activities happening within the food vending environment. This includes location specific activities such as of the employment context of consumers, the period of the day that food is being provisioned and the mobility dynamics of food vendors (Adeosun et al., 2022a,b). More so, research shows that even though food vendors are aware of nutrition imbalances in current food provisioned, profit-making takes priority in selecting the food they offer (Githiri et al., 2016; McKay et al., 2016; Adeosun et al., 2022b). Furthermore, the tendency for most out-of-home food consumers to stick to a particular food vendor they trust in terms of factors such as hygiene, food safety and sometimes the perceived satiety and energy the food provides, rather than the food's nutritional benefits (Adeosun et al., 2022a), increases the likelihood of them consuming mostly monotonous diets. Even though some food vendors offer different food groups, some are provided and consumed in small quantities only (Adeosun et al., 2022b). Despite multiple benefits attributable to the intake of fruit and vegetables in daily diets, poor consumers still eat below the usual recommendation by (WHO, 2003). In most poor households in developing countries, Nigeria included, the consumption of fruits and vegetables is far below the minimum recommended level of 400 g *per capita* per day (WHO, 2003; Ruel et al., 2004; Lee, 2016).

Given these trends, it is therefore critical to consider how out-of-home food can be improved to enable consumers to access healthy and adequate diets. This study conceptualizes healthy food in a way that departs from a focus on individual choice alone to direct attention to the contexts of provisioning and consumption that shape whether and how consumers can access a diverse diet that includes a variety of food items and fruits and vegetables (WHO, 2015). In directing attention to the contexts of food provisioning and consumption, the paper investigates practice-oriented strategies and mechanisms that can aid improving the health and balance of ready-to-eat food.

Most studies on ready-to-eat food provisioning have until now focused on food handling practices, food hygiene, provision of high-calorie foods, and monotonous menu settings (Mwangi et al., 2002; Story et al., 2008; Muyanja et al., 2011; Lucan et al., 2014; Kolady et al., 2020; Adeosun et al., 2022b). However, it remains unclear how these interconnections and intersections of practices can aid the improvement of food vending practices in terms of the health and diversity of the ready-to-eat foods provisioned. In this research the study conceptualizes health and diversity of ready-to-eat food as two distinct aspects of obtaining an adequate diet through: (1) the integration of fruits and vegetables into menu settings and meals and (2) increasing the diversity of food groups provisioned.

In addressing this aim, the study builds on previous research on informal food vending in the Global South and in particular in Nigeria (Chukuezi, 2010; Leshi and Leshi, 2017; Dai et al., 2019; Kazembe et al., 2019; Resnick et al., 2019; Swai, 2019; Tawodzera, 2019; Wegerif, 2020; Zhong and Scott, 2020; Adeosun et al., 2022a,b). In doing so, this study adopts a social practice-oriented approach using participatory back-casting methods (Davies and Doyle, 2015; Oomen et al., 2022; Van der Gaast et al., 2022) to unpack practices, strategies and mechanisms suitable for improving food diversity in ready-to-eat food vending practices among the urban poor. A study by Davies and Doyle (2015) confirmed that only few studies in the domain of food vending apply back-casting using everyday social practices as their unit of analysis. Welch et al. (2020) studied the connections between social practices and regimes of engagement to understand future practices. Some studies applied visioning and back-casting in studying food futures in the Global North (Quist et al., 2011; Mangnus et al., 2019). For instance, Van der Gaast et al. (2022) employ social practice and future engagements in food entrepreneurship to understand possible transformations toward a sustainable food system. However, while the use of futuring and visioning methods has somewhat increased in food consumption research in the Global North, there is a lack of applying such methods in food studies in the Global South. This paper intends to fill this gap.

The remainder of the paper is structured as follows: section two outlines the conceptual-methodological framing underpinning of study. In section three, we present the study context and the methods used to collect and analyze the data. Section four reports the findings from the study, which are discussed in section five to arrive at a conclusion on the implications of the insights generated for urban food system research and out-of-home food policy.

2. Conceptual-methodological framework

2.1. Visioning and practice-oriented back-casting methodology

A practice-oriented participatory back-casting method was applied to collect empirical information on visioning on ways to improve the health and diversity of ready-to-eat food provisioning during focus group discussions and as well as a stakeholders' workshop. This combined approach was chosen because a social practice approach is inadequate for developing a normative direction to guide future transformational strategies. Thus combining a practice perspective with a normatively focused back-casting methodology can help to overcome this limitation to explore visions for alternative practice arrangements as well as pathways to their realization.

According to Davies and Doyle (2015), back-casting implies an overarching, multi-phased methodology. It starts first with generating future ambitions or possibilities and is followed by a process of back-casting which involves developing strategies, mechanisms and frameworks from the present to the future that can enable the realization of these future ambitions. Building on this, the approach employed in this study stimulates face-to-face interactions between diverse stakeholders who have some knowledge of food vending practices. It started with first generating future ambitions and was followed by a process of back-casting, which involved developing strategies, mechanisms and frameworks from the present to the future that would enable the realization of these future ambitions. According to Ahlqvist and Rhisiart (2015) and Kanatamaturapoj et al. (2022) present actions are crucial for directing how we think about the future in the present. The approach therefore allows for the co-creation of strategies for improving food vending practices in the present. The study therefore take every day social practices as the starting point for discussing present arrangements to enable future changes (Mandich, 2019; Welch et al., 2020; Oomen et al., 2022).

According to Shove et al. (2012), social practices might be transformed in different ways, for instance, by reconfiguring, substituting or changing how practices interlock (see also Spurling and McMeekin, 2015). Reconfiguring practices means rearranging one or more of the practice-elements (meanings, competences, materials) comprising them (Shove et al., 2012, 2015). Practices can also be transformed by substituting one practice for another to achieve the expected outcome. For example, consumers might shift from eating their lunch at home to eating it out-of-home. As practices interlock with other practices in practice-arrangement bundles, these connections may also change (Schatzki, 2002). For instance, the rise of out-of-home food consumption is interconnected to other related practices, including in food systems, the economy and the government. Consequently, attention should be paid to how transformations in routinised practices connect with dynamics in the wider socio-technical and socio-material contexts that both shape and are part of the practice. On a more situated level, daily food practices are linked with other practices in daily life, such as work and mobility. Thus identifying the linkages between these other practices allows for identifying options to re-arranging them and achieving the desired changes (Castelo et al., 2021). In this study, possibilities for more healthy and diverse food vending provisioning practices are explored through a lens that focuses on food vending practices and their arrangements with other related practices within the food environment.

The conceptual framework of this study envisages the changing interactions between food vending practices and governing practices and re-integrating the elements of these practices and how the practices themselves interlink to enable an improvement in the provision of healthy and diverse ready-to-eat foods.

The process of envisioning future ambitions and practice arrangements was informed by existing literature and insights from focus group discussions concerning the delivery of healthy and diverse foods (Steyn et al., 2014; Githiri et al., 2016; McKay et al., 2016; Adeosun et al., 2022a). Using insights from the literature combined with insights from the focus group discussions, a picture of what the future food vending landscape should look like (the "what") was generated. This was followed by back-casting to understand "how" this aimed-for future can be achieved and "who" should be responsible for particular actions and the probable prospects and challenges it may face. The process of visioning and back-casting used in this study followed two stage of visioning and back-casting.

The focus group discussions involved stakeholder-specific discussions. During these discussions, back-casting of key challenges, opportunities and mechanisms and strategies for the envisioned future initiatives (i.e., improving health and diverse ready-to-eat foods) provisioned were co-generated. The practice-based approach helped to embed this discussion in the changes, re-arrangements, and transformations of food vending and governance practices.

The results from the focus group discussions and the stakeholder workshop were further deployed to see whether they are practicable, implementable and will be widely adopted by the majority of the primary actors, i.e., the food vendors. A semi-structured questionnaire seeking to gain a wider view on food vendors views on the proposed visions and strategies was designed and administered to randomly selected food vendors from the study area. See Figure 1 for an overview of the methodological process.

3. Research context and methods

3.1. Study location

The study is carried out in Ibadan, Nigeria. Ibadan is one of the largest cities in Nigeria with about 4 million inhabitants (Adelekan, 2016). As an ancient city, it accommodates different ethnic groups and people from different religious backgrounds. It has about 11 local government areas (LGAs) with five in the city metropolis and six in the peri-urban area where the majority of the low-income people reside. Most people in these communities live below the standard urban poverty line of $1.90 per day (UNDP, 2004). The study selected these poor urban communities because relative to other social groups in the city, they rely most prominently on ready-to-eat food provisioning.

3.2. Food vending mapping

The study took a census of food vending outlets in the selected communities using Geographical Information System (GIS) to provide a spatial overview (see Figure 2). This method was applied to represent and analyze the food vending environment in the study area based on three identified food vending categories, that is: (1) traditional cooked meals local foods such as cooked rice, yam, soups, pounded yam, cassava mash "*eba*" *and* cassava flour *"amala*"; (2) processed foods (fried foods, roasted foods, smoked, snacks and beverages); and (3) unprocessed foods (fruits and vegetables). Six hundred eighty-six food vending outlets were mapped by taking the coordinates of all the food vending outlets in the selected communities, including 319 traditional food vending outlets, 268 processed food vending outlets and 98 unprocessed food vending outlets. From this larger sample, The study selected a diverse sample of food vending

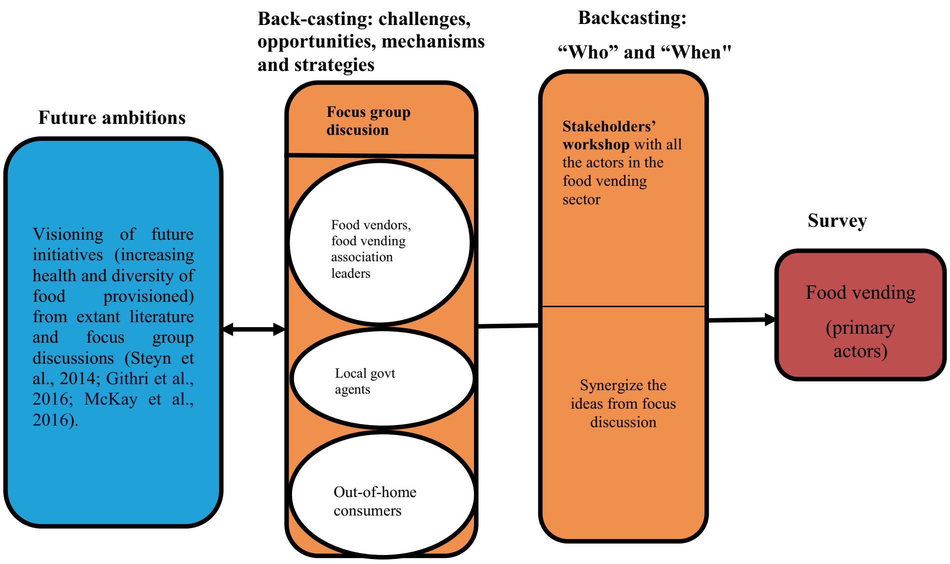

FIGURE 1
Participatory practice-oriented visioning and back-casting methodological process (adapted from Davies and Doyle, 2015).

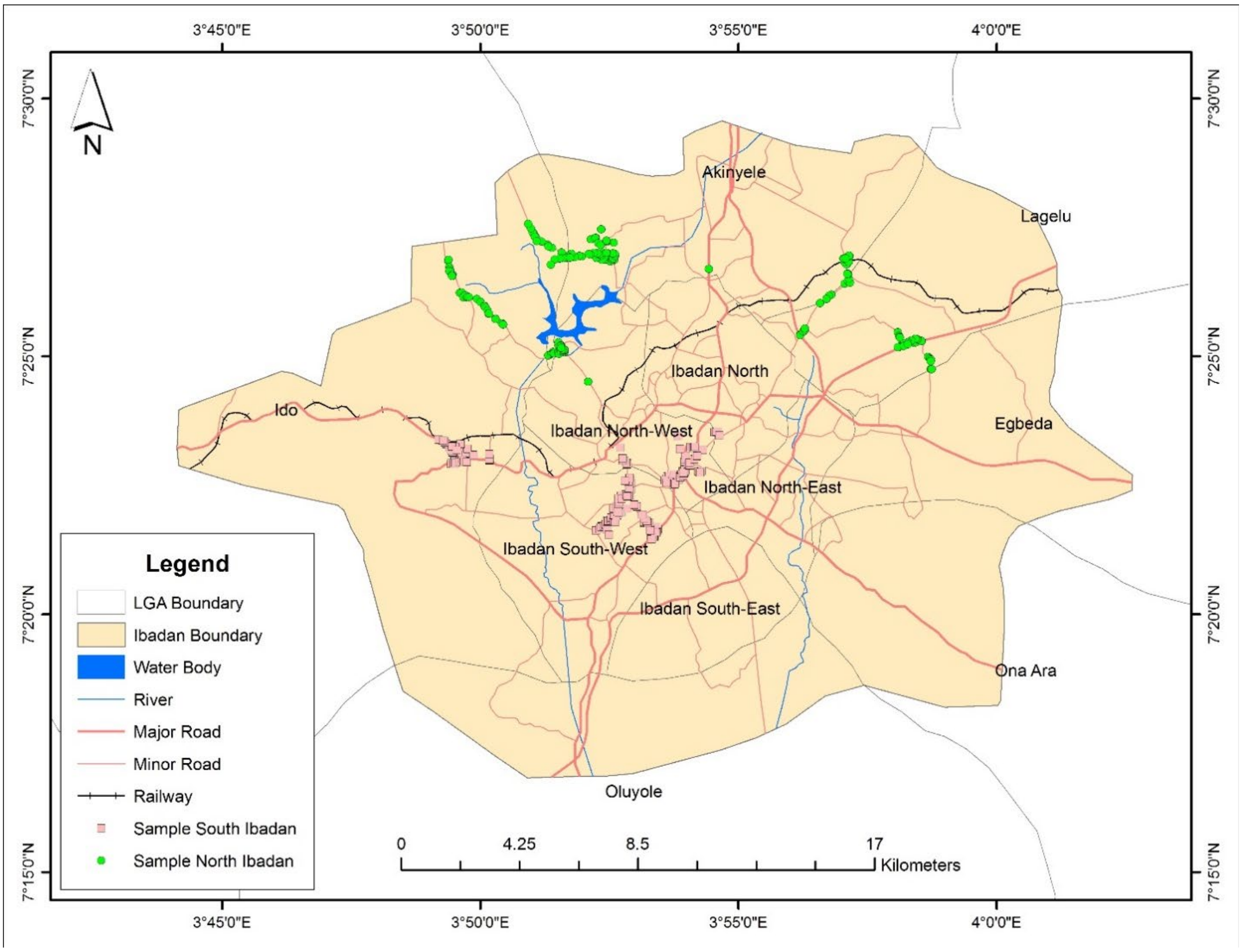

FIGURE 2
Location of mapped food vending outlet's in Ibadan.

outlets for participating in the focus group discussions, stakeholders' workshop and survey.

3.3. Sampling procedures

An exploratory sequential mixed-method design was applied in the sampling and data collection. This approach was applied to generate a broad range of empirical data. The sample for this study was selected on the basis of information from the state ministry allowing us to categorize the Local Government Areas (LGAs) in Ibadan. Based on this information, The study selected the lowest income LGAs, as areas where a majority of low-income residents live, for further investigation. To ensure a good representation of the study area, the study purposively (based on their revenue size) selected two LGAs from the Northern part of Ibadan where seven LGAs are located, one LGA from the Southern part of Ibadan where three LGAs are located and one LGA from Central Ibadan, located at the boundary between the Northern and Southern parts of the city. Thus, in total, four LGAs were selected as the sample area for the study and within each LGA, two communities were randomly selected as sites for the study.

The study developed a multi-modal approach that started with focus group discussions involving different food vending stakeholders. This was followed by a stakeholders workshop that brought them all together and a larger quantitative survey among the food vendors. Based on the particular research method, concurrent sampling techniques were applied. First, the study selected different groups of stakeholders for a series of four stakeholder-specific focus group discussions, i.e., (1) two groups of seven food vendors including food vending association leaders (elected leaders that supervise and manage the affairs of the food vending association); (2) one group of three local government agents who supervise the activities of food vendors and a nutritionist from the University of Ibadan, and (3) one group of seven out-of-home food consumers. These amount to a total four focus group discussion meetings conducted. For the stakeholders' workshop, the study included 13 stakeholders: (1) five food vendors including food vending association leaders, (2) five out-of-home food consumers, (3) two government agents and a nutritionist. These stakeholders were selected from the participants in the focus group discussions to participate in the stakeholder workshop. The overview of methodology applied and food vending's stakeholders selected are presented in Table 1.

Quantitative data were obtained from 300 food vendors who were systematically selected from the list of each food vending outlet's category mapped and a semi-structured questionnaire was administered to collect their opinions. Based on the mapping results, three lists of food vending categories were produced, and considering the size of each list, a systematic sampling was applied to select the respondents for the survey. Thus, 165 respondents were systematically selected from the list of traditional food vending, and 135 respondents were systematically selected from the list of processed food vending. Only traditional and processed food vending was considered in this study because they provide low food group diversity (Adeosun et al., 2022b). The consent letter was read to the respondents in their local language to seek their consent and the study only interviewed the respondents that gave their consent verbally, while, those that did not give consent were not interviewed.

The respondents were selected from across the four selected local government areas, based on their readiness to participate in the discussion as well as on specific conditions. These conditions differ per category: food vendors should be at least 5 years in service, association leaders should be active in service and have spent at least 1 year in that position, government agents should be from an office linked to food vending activities, consumers should regularly use out-of-home food (at least one meal out-of-home every day) outlet and rely on different categories of food vending. These criteria were applied to receive first-hand information from practitioners and stakeholders who have a wide range of experiences in food vending. Field work was organized by the first author between July to September 2022, with the support of four research assistants.

Data from the focus group discussions and stakeholders' workshop was recorded, transcribed, and coded inductively using (Atlas. ti). The open codes that were identified were then analyzed, compared and grouped into categories. An iteration between inductive and deductive analysis was used for particular themes and patterns and then this data was reviewed and further categorized in accordance with the social practice approach.

4. Results

This paper aimed to understand future strategies and mechanisms that can contribute to improved food vending practices in the contexts of health and diversity of food provisioned. Taking a nuanced approach the study analyzed different interconnections and interactions of practices, (sub) practices, elements of practices, and elements of governance that can support the future improvement of food vending practices. The study presents the findings under the following headings: first, the study analyzes the views of food practitioners (vending and consumption) on the benefits of increased health and diversity of food provisioned. This is followed by the expected future strategies. Different suggestions were made on practice-oriented mechanisms, including learning practice meanings, norms, competences and materials, as well as reshaping links and synergies among different food markets within the food vending

TABLE 1 Showing different methodology applied and the numbers of food vending stakeholders selected.

Methods applied	Food vendors/food vending association leaders	Consumers	Government agents	Nutritionist
Focus group discussions	7/7	7	3	1
Stakeholders' workshop	5	5	2	1
Survey	300	–	–	–

environment and establishing more effective and efficient regulatory frameworks guiding food vending practices. The last section of the results is based on the envisioned challenges and implementation process.

4.1. A paradigm shift in food vending practices

While there is variation among the different food vending categories (Adeosun et al., 2022b), changes in the ready-to-eat food vending practices are indispensable for ensuring healthy and adequate diets. The study explored potential arrangements and interconnections between different practices, that can support these needed improvements.

4.1.1. Future benefits of increasing the health and diversity of ready-to-eat food provisioned

Table 2 presents the vendors perceptions of the benefits of increasing the health and diversity of food provisioned and the possible processes of achieving this in the future.

The results showed that vendors agree that the food currently provided is not sufficiently diverse and that there is inadequate integration of fruits and vegetables in the meals provisioned. This was also a viewpoint shared with the wider stakeholder groups. During the stakeholder focus group discussions, it was reported that an increase in the diversity of the foods provided offers an opportunity for consumers to access more healthy diets.

> … Increasing food groups provision and inclusion of a good proportion of fruits and vegetables will avail us the privilege of improving the health of our customers and invariably increasing our income as vendors, (FGD, food vendor).
>
> … It is quite necessary for the food vendors to increase their menu settings because of the nutritional level we obtain from different varieties of food, each food supplies different nutrients to the body, more so as the adage goes that health is wealth, (FGD, nutritionist).

The majority of the food vendors also confirmed that increasing the number of food groups and an integration of sufficient fruits and vegetables is a welcome future initiative. The stakeholders agree that fruits and vegetables should be integrated in meals rather than provisioned as a separate dish as some consumers may not be interested to purchase it this way. This is important as the WHO (2015) recommends that 400 g of vegetables are consumed by individuals per day. Consumers in particular reported a need for food vendors to lead by integrating more fruits and vegetables into meals at affordable prices:

> … I would rather prefer fruits and vegetables integrated into my meals when I go to the food vending outlet and to not eat them necessarily as a sole meal, (FDG, consumer).

However, despite this general agreement, most stakeholders agreed that current food norms and practices as well as limited availability of diverse and healthy foods impeded this:

TABLE 2 Perceived future opportunities in food vending practices by primary actors (food vendors).

N/S	Opportunity/ prospects	Mean	SD	Decision
1.	Nutritional balance of food provisioned is not sufficient enough in terms of number of food groups provisioned by food vendors.	2.947*	0.014	Agree
2.	There is inadequate fruits and vegetables inclusion in the meal provisioned.	2.950*	0.013	Agree
3.	It is important to increase food group provisioned and integration of fruits and vegetable in a complete meal	2.950*	0.013	Agree
4.	Increasing food groups provision and integration of sufficient proportion of fruits and vegetables will avail us the privilege of improving the health of our customers and invariably increasing the income of food vendors.	2.921*	0.018	Agree
5.	Government empowerment programs through financial support scheme to food vendors as well as provision of enabling environment will be a welcome development and it will aid the implementation of the initiatives	2.937*	0.016	Agree

The measurements are on a scale of 1 to 3, with a weighted average = 2.0, where, 1 = disagree, 2 = neutral and 3 = agree. *Indicates significant with respected to the statement.

> … Most of the foods we eat outside of our homes are starchy foods with inadequate vegetables. We are just managing them since we have little or no option once we are out of our homes, (FGD, consumer).

For out-of-home food consumers, increasing the degree of food group diversity provisioned was understood as providing access to more variety of food items, thus enabling more diverse nutrient intakes, and enjoying good health through consuming an adequate diet. Food vendors were also seen as benefiting from a greater diversity of food groups as they generally also consume the meals they provision (Adeosun et al., 2022b).

> … Our customers will have easy access to a adequate diet at their door steps and we the food vendors make more profit providing nutritious food for them, (FDG, food vendor).

The food vendors asserted that having additional varieties of foods to provision without reducing the number of existing food items provisioned will likely increase patronage as well as their business' profit. This implies a win-win situation for both parties (vendors and consumers).

> … The benefit we will enjoy is that we will be able to make better choices of the right combination of different classes of foods, (FDG, consumer).

4.2. Expected future changing strategies

4.2.1. Changing food norms and sensitization

For both initiatives (increasing food group diversity and integration of fruits and vegetables in meals) to be fully accepted, there is a need for proper and intensive understanding of changing food norms and sensitization among both food vendors and consumers. The stakeholders reported that first the consumers and food vendors should be educated about the need to increase fruits and vegetables in daily diets. The government and food vending associations should have a mutual agreement in bringing food vendors together to educate them on the reasons why they need to change their menu settings and how they can go about it and benefit in terms of profit making.

This would involve challenging a belief, especially among the urban poor, that stresses the quantity rather than the quality of the food consumed. The government can play a critical role in this sensitization through public awareness campaigns using different media (i.e., TV stations, radio stations, newspapers, and social media). In particular using sell-designed jingles into these campaigns will drive home the importance of consuming fruits and vegetables and more food groups.

> … I think there is a need for the creation of awareness not only among the food vendors but also among the consumers because if the food vendors increase their menu and the consumers are not ready to buy, the seller will be at a loss, (Stakeholders' joint assertion).

The food vendors reported that they may change their provisioning strategy and provide different types of food at different periods of the day. For instance, they can have a timetable for provisioning different classes of foods so their customers know when a particular type of food is available. Likewise, their presentation might change because each type of food has a unique presentation style.

The different stakeholders are of the opinion that the campaign for increasing the provision of fruits, vegetables, and diversity of food groups should be linked to health benefits to enable both vendors and consumers to understand and absorb these initiatives. This is because the ideas cannot be forced upon food vendors or consumers. Rather, they should find ways to educate them on why these initiatives are important. Probably, the government can aid this via the food vending association leaders by organizing training, seminars, and workshops.

> … The government can also help in the area of publicity by creating awareness among the public about the benefits of eating vegetables and fruits in sufficient quantity, (FDG, government agent).

Non-governmental organizations and food vendors can also take the role of enlightening consumers about the essentials of the initiatives. This should also include efforts to improve engagement through embodied knowhow. For example, stakeholders discussed how awareness can also be increased through demonstrations by food vendors in public places by offering tastings of new dishes and speak with consumers about the nutritional importance of the menu settings provisioned.

4.2.2. Training needed for future changing food vending practices

This section presents the food vendors' perspectives on the possibilities, prospects and strategies embedded in the envisioned transformative initiative in food vending regarding the increasing food groups and integration of fruits and vegetables.

The food vendors reported that for these initiatives to be materialized, they need to procure new cooking utensils, improve existing skills and learn new skills. Changing food vending practices was recognized as a process that requires support and training to enable vendors to acquire the necessary skills and competences. Healthy and diverse food provisioning requires vendors to go beyond what they presently do. For example, as the number of food items increases, they need to develop skills to manage different food types, increase their menu settings, and discover ways to increase their income. Thus, the importance of training on increasing the variety of food groups provisioned and the integration of fruits and vegetables in meals was strongly emphasized. A food vendor will only prepare what he/she is skilled at, but once he/she has knowledge about different methods of preparation, different food items can be added to the menu. Food vendors in the survey also supported this, with about 84% asserting that they like to undergo training to improve health and diversity of ready-to-eat food provisioned. Regarding the organization of the training, about 46.3% of the food vendors suggest that collaboration between government agents and food vending association leaders is the most effective option (Table 3).

> … Some of our fellow food vendors who are not exposed to these different food preparation methods before would have to go and learn it. For instance, a vendor amongst us who hasn't prepared salad before will have to go learn it for the sake of its necessity and inclusion (FDG, food vendor).

The stakeholders also reported that such training is needed and should be organized by the government in consultation with food vending association leaders. Trained food vending association leaders can then train their members at their various clusters in developing new competences and skills. Trainings should be accessible and motivate the food vendors to adopt the content.

TABLE 3 Food vendors' perspectives on increasing food group provision and integration of fruits and vegetables provisioned.

Initiatives	Freq	%
The initiatives is something possible for me to imbibe	260	86.7
I will like to start with the two initiatives at the same time	193	64.3
I will like to start with one of the initiatives first		
Increasing food group provision	52	17.3
Integration of fruits and vegetables	15	5.0
Not interested in the initiatives	40	13.4
The food raw material sellers that are most important for the initiatives		
Open market	202	67.3
Raw food retailers	52	17.3
Grocery shops	6	2.0
These initiatives can start within this period		
I am not interested	40	13.3
Immediately	192	64
Next year	64	21.3
Next 2 years	3	1
I do not know	1	0.3
Receiving training for these initiatives is important	252	84.0
Organization of training for these initiatives		
Government agency only	50	13.3
Food vending association only	52	17.3
Non-government agency only	19	6.3
Government/food vending association	139	46.3
Monitoring of the implementation of the initiatives		
Government agency	51	17.0
Food vending association	72	24.0
Non-government agency	5	1.6
Government/food vending association	132	44.0
Total	300	100

> … I can tell you that the language of people those food vendors listen to and comply with is their association leaders (FDG, government agent).

In the past, the government has organized a series of trainings with food vendors centered on food safety and hygiene practices, which generally had positive impacts on vendors. A training specifically focused on health and diversity of ready-to-eat food provisioned and the skills and competences needed for increasing the variety of food groups and the integration of fruits and vegetables could be usefully integrated here.

> … Although our training has been on sanitation, food hygiene, personal hygiene, and how to prepare their meal in a neat environment, the government can also include the food nutrition balance benefit in the training (FDG, government agent).

Access to material resources in the context of executing the initiatives is important as the food vendors would need to add additional materials and the government could acquire more resources for training, sensitization and coordination. Trainings should also integrate information on prices, free training opportunities, loans and grant opportunities. There is a need to form synergies between nutrition experts, government, and food vending associations in organizing trainings. The food vendors further suggested that trainings would be more accessible if they were organized on a zonal basis.

4.3. Practice-oriented mechanisms

4.3.1. Materials and financing

The focus group and workshop discussions revealed practices and practice arrangements that can contribute to the execution of the proposed healthy and diverse food initiatives.

Important practices that would need to change to support more healthy food include food preparation and preservation techniques, food procurement processes, storage and stocking, menu-setting and vendor-consumer relations. These require hiring more staff to work in the food vending outlets, buying new kitchen tools, such as pots, more plates, bowls, different sizes of cutlery, equipment such as a freezer for the preservation of foods, and a generator for constant power supply and many more. They might also need to re-position their staff due to the expansion of activities in the food vending outlets.

> … I will surely need more hands in food preparation since I will be preparing many food items (FDG, food vendor).

The visioning and back-casting discussions identified different mechanisms that may need to be adopted in sourcing additional food materials. For example, procuring more food will impact the current way of sourcing food. As they require larger quantities, vendors need to transport raw food materials via reliable ways from their providers in the open market using logistic staff. This would require a shift from cash to online payment. It is also likely to impact the temporality of procurement practices: procurement of food currently occurs every day or every 3 days but may be adjusted to a weekly or bi-weekly basis. As it is envisioned, vendors would have less time to go to the market due to the increased labor demand at the vending outlets associated with the preparation of healthier and more diverse meals. This means they may buy larger quantities in fewer shopping trips or employ logistic personnel. To accommodate the changed procurement practices, storage practices would also need to change in the future. Storage space, infrastructure and materials will need to be improved, bought, or replaced. Since more food items need to be provisioned, current practices of selling all food items in 1 day are likely to be replaced by practices that allow for food to be preserved for several days. This means an increased demand for storage facilities for stocking and restocking prepared food items and raw food materials to preserve perishable foods and prevent it from being attacked by animals.

> … I can get people to help me construct a safe cabinet for stocking food raw materials to save me the stress of going to the market every day (FDG, food vendor).

The stakeholders agreed that food vendors would need financial support to be able to effectively engage in the new initiatives. Previous studies revealed that most people in food vending practices are of low-income status (Panicker and Priya, 2020). Therefore they will need more finance to be able to add to their menu settings. Stakeholders believe this support can come from either the government, food vending associations, or non-government organizations. The government can empower vendors through financial support schemes as well as by creating an enabling environment.

> … The support that we need is that of finances, for instance most of us use soft loans and thrift to support our food provisioning business (FDG, food vendor).

There is a need to support training programs for food vendors, equip farmers, and reduce the levy for food vendors. The food vendors believe that more support for farmers would positively impact the price of food raw materials who may sell their raw food materials at a lower price. The government can aid the implementation of these initiatives through an economic-friendly policy formulation and the creation of wider public awareness. Food vending associations in connection with the government can roll out proposals to banks and other financial bodies to finance training programs for its members and seek soft grants or loan schemes for their members to provide them with the means to effectively take up the initiatives.

4.3.2. Regulations

The focus group discussion included back-casting of different governing practices and arrangements that can support the envisioned future. Different governing practices and how they interconnect in shaping the future improvement of ready-to-food vending practices were identified. The stakeholders discussed and brainstormed governing practices that can increase the rate at which the initiatives are implemented in themes related to coordination and monitoring, to controlling and supervision, and to implementation. The results are presented below.

Coordination of transformations in the food vending sector can be carried out by both the government and association leaders. Food vendors trust and listen to their association leaders more than to any other stakeholder. Hence, whenever the government seeks to influence food vendors, they seek to mediate this through the food vending association leaders.

> … This new initiative can be successful when the coordination is done by the leaders of the food vendors association with the support of government agents. They are the closest to the food handlers (FDG, government agent).

The focus group discussions suggested that the association leaders should play a major role in the coordination and monitoring of the activities supporting future initiatives. Therefore, there must be a good understanding between the government and food vending leaders about the aim and the importance of the future initiatives, as that would make coordination easy. The food vending association leaders should champion the coordination with the support of the government agents. The leaders can take advice from the government agents on how to ensure voluntary compliance by the food vendors. Constant inspection at the point of operation of food vendors by government agents and association leaders will make the implementation of the future initiatives more effective. The government can carry out monitoring by improving the policies and guiding the actions and operations of food vendors in the communities. This can be achieved through roundtable meetings between the government agents and the food vending association leaders. About 44% of the food vendors in the survey believe that monitoring the implementation of initiatives will be effective if it is inclusively executed (Table 3).

To avoid price disparity for similar food items among food vendors, price control and standardization must be considered. The government can also support the initiatives by setting up a quality control agency that involves the leaders of the food vending associations and nutrition experts.

> … Key leaders among the food vendors must be contacted first, sensitized about the new initiatives after which, they can be released to disseminate and step down the idea to their colleagues at the grassroot level (FDG, government agent).

4.4. Synergies within food vending environment

4.4.1. Raw food markets

The food vendors reported that for the initiatives to be successful they need the support of other actors. Actors, such as unprocessed food (fruits and vegetables) sellers, raw food retailers, open wet markets, and small grocery shops, are important for ensuring accessible and stable raw food material supplies. About 67.3% of the food vendors perceive that open markets will be important in supplying raw food materials, while about 17.3% indicate that raw food retailers will be important (Table 3). Raw food suppliers could play an essential role in reducing the burden of procurement. In this case, food vendors could more easily call on them to supply the needed ingredients through delivery.

> … I would not need to stress myself going to the market as people who are selling fruits and vegetables here can help me buy in bulk from the market (FDG, food vendor).

4.5. Envisioned challenges and implementation process

Starting new initiative the initiatives to provision more food groups and the integration of fruits and vegetables come with their own future challenges and depend on ongoing dynamics. Some of the challenges that could hinder the rapid implementation of this scheme include a lack of sufficient staff at food vending outlets, inadequate start-up capital, and lack of storage facilities. Other constraining factors discussed include the instability in governmental policies, the persistent rise in the price of food commodities, the erratic power supply, and the vendors' and consumers' resistance to change.

Adding more food groups may also reduce the patronage of existing food items. For instance, if a food vendor is selling four food items before and she decides to add two food items, this addition is likely to reduce the sale of the existing ones. The food vendors also reported that the increase in food group diversity will largely depend on the prices of the food raw materials they get from the market.

> ... Another issue is the uncertainties that may come with consumers' acceptance of the initiatives. This can be handled by starting with a small quantity at first and then improving on that later as demand increases (FDG, food vendor).

The integration of fruits and vegetables into meals may likely lead to an increase in price per meal and vendors do not know if the consumers will be ready to pay for this.

It was, however, recognized that these initiatives will not only have positive but also negative effects for food vendors. For instance, positive effects may include access to diverse diets and an increase in profit in the long run, if the consumers patronage increased. Negative effects might encompass an initial loss of profit due to consumers lagging to adopt the new food groups.

Food vendors are of the opinion that a process of incremental change is the most feasible option. For instance, they may start with two or three food groups and see how consumers respond. According to the survey (Table 3), about 64% of the food vendors believe that the implementation of initiatives in an incremental fashion can commence immediately, while, 21.3% indicate that this process should start next year. Similarly, about 86.7% of the food vendors surveyed agree that the initiatives are possible and they can imbibe them in the future. Also about 64.3% of the food vendors indicate that they can undertake both initiatives (increase diversity in food group provision and integrate fruits and vegetables into a meal) at the same time, while, 17.3% prefer to start first with increasing food group diversity and 5% to start with the integration of fruits and vegetables (Table 3).

5. Discussion and conclusion

The study presents deeper insight into how informal food vending practices can be improved to deliver healthy and diverse foods to the urban poor. The study presents its findings to corroborate with existing literature on identifying practice-oriented processes that can enable/engineer solutions to multiple challenges and shortcomings of ready-to-eat food vending practices in the Global South (Mattioni et al., 2020; Adeosun et al., 2022b; Bezares et al., 2023). Being the most commonly used food provisioning outlet among the urban poor (Mwangi et al., 2002; Steyn et al., 2014), ready-to-eat food vending is an important food supply channel through which to focus attention in efforts to achieve healthy and diverse food systems. This study takes a practice-centered participatory back-casting methodological approach to explore mechanisms, strategies, and empirical information that can aid the improvement of urban food vending practices.

Our methodology and practice-oriented approach enabled us to analyze the "future in the present," and provided an analytical framework to understand the improvement of food vending practices. In doing so, we have responded to the call by Van der Gaast et al. (2022) for more research on the interactions between near and distant futures in different contexts and circumstances. Our approach deviated somewhat from the usual application of visioning and back-casting by implementing both into a process that involved two stages of visioning combined with one stage of back-casting. Previous studies have employed back-casting and visioning approach to other situational dynamics (Bibri and Krogstie, 2019; González-González et al., 2019; Sisto et al., 2020; Soria-Lara et al., 2021; Villman, 2021) but none has been applied in the study of informal ready-to-eat food vending. The application of our method of two-staged visioning and back-casting may also be applied to analyze challenges and solutions for other components of the food system in the Global South.

The results from mapping the food vending environment indicate that out-of-home food provisioning has expanded and continues to expand in the food landscape. These observations underline the importance of food vending for the food security of the urban poor. This agrees with the findings of Swai (2019) and Tawodzera (2019) that street food vending is expanding and serving most people food needs in the city of Dar Es Salaam, Tanzania and Cape town, respectively. Most out-of-home consumers depend on street foods for at least one to two of their daily meals and they patronize food vendors for their daily meals regularly (Ogundari et al., 2015). This implies that any transformation toward improving food vending will directly benefit the urban poor consumers.

First, we analyzed the perspective different stakeholders have on the prospects of food vending and we found that there is wide agreement that transformations in the food vending sector are overdue and necessary to adequately meet the nutritional needs of consumers. According to Mwangi et al. (2002), a high proportion of food vendors do not sell food that is sufficiently diverse for a healthy diet. If consumers have access to and consume an adequate diet, this will be reflected in their health. According to Branca et al. (2019), transforming the food system can contribute to reducing non-communicable diseases. This study found that this transformation should entail two initiatives: (i) the increased consumption of fruits and vegetables and (ii) access to more diverse diets that include a broader range of the different food groups. The stakeholders reported that it is important that fruits and vegetables are integrated into meals sold in the food outlets rather than servicing them as separate meals. This is also important as WHO (2015) recommended that 400 g of fruits and vegetable should be consumed per day. This way, low-income consumers can have access to a portable meal with fruits and vegetables as well as an adequate diet at affordable prices. However, the stakeholders suggest that more is needed for these initiatives to be successful. Both food vendors and consumers should be made more aware and sensitized on the competencies that are needed for the success of these initiatives. According to Panicker and Priya (2020) street vending can supply healthy and nutritious food to consumers if it is well organized.

Extant literature further indicates that some out-of-home food consumers prefer to eat food that has high satiety value, can fill their stomachs quickly and enable them to withstand their often physically intense daily jobs with a consequence that they ignore healthy foods

(Adeosun et al., 2022a). However, consumers should be encouraged to seek food that can suits their physical demands as well as provide enough nutrients, i.e., an adequate diet. Even though consumers follow their normal food routines, changes in a practice they are connected to can change the actual food they consume. Since, food consumption practices are interconnected with food vending practices (Adeosun et al., 2022a), transforming food vending practices can lead to changing food consumption practices.

Second, the starting point in transforming food vending practices should be a focus on changing food norms and practices through training-related activities supported by the government and food vending association leaders. NGOs aiming for increasing the consumption of healthy foods should also be carried along in implementing the initiatives. Training of food vendors centered on the know-how of the necessary skills and competencies and material resources usage required to execute the initiatives is indispensable. The stakeholders suggested that such training should be organized by the government with the collaboration of the food vending association leaders. This suggestion is in line with insights from research that highlight mutual understanding between the government and food vending association leaders on organizing training for food vendors (Zhong et al., 2019).

Third, the study analyzed different elements that are integrated to form the social practice of ready-to-eat food vending. Seeking to transform these, existing practice-elements and activities may need to be adjusted, changed, or supplemented. From our findings, adjusting practice-elements and processes that include skills, material resources, and capital are considered essential for the implementation of the initiatives. Buying additional food raw materials, kitchen utensils, other food preparatory materials and effective storage facilities will be needed to accommodate more food materials to be stored and ensure they are prevented from being spoiled and eaten by rodents. In addition, the initiatives will require more capital as they have to buy additional food and other materials. The study suggested that such capital can come via soft loans from the government as a special package for these initiatives. NGOs can also provide financial support to food vendors. From our findings, confirming Herrero et al. (2020), it can be inferred that transforming food vending components of the food system involves the re-integration of key practice-elements such as procurement of raw food materials, storage facilities, food preparation and presentation, stocking, and re-stocking.

Fourth, the study analyzed how interconnections between food vending and governing practices can support the implementation of the initiatives. We found that governing practices can drive changes in food vending practices. The government should play this role in conjunction with food vending association leaders. This is because food vendors trust and listen to their leaders more than to government staff. This implies that for formal actions to be effective in informal settings, the stakeholders of the informal settings need to be included from the start of the discussions. According to Vermeulen et al. (2020) bottom-up and top-down approaches to dietary and food system transformations should be complementary. The study also suggested that past intervention strategies in food vending in the area of food safety and hygiene practices can be built on for the implementation of the initiatives.

In conclusion, transforming food vending practices to increase the diversity of food groups provisioned and the integrations of fruits and vegetables in meals, involves the integration of practice-elements, interconnection of practices, and interconnections with governing practices. The study identified several key food vending practice-elements and elements of governance that need transforming. Specifically, adjustments in the procurement of raw food materials, food preparation and presentation, storage, and stocking strategies will enable the realization of the initiatives. Furthermore, key governance elements, including monitoring, supervision, coordination, and steering in collaboration with food vending association leaders will facilitate the implementation of the initiatives. Our findings also provide some insights for policymakers to support the improvement of food vending practices. The study recommends further research on understanding consumers' receptiveness toward an increase in the diversity of foods provisioned by informal food vending.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

KA, MG, and PO conceived and designed the paper and wrote the paper. KA collected and analyzed the data. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Policies for optimal nutrition-sensitive options: a study of food and nutrition security policies, strategies and programs in Ghana, Kenya and South Africa

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Sub-Saharan Africa is experiencing the coexistence of overnutrition, undernutrition and micronutrient deficiencies. Comprehensive programs and coherent public policies are required to address this problem. A study of food and nutrition security policies, strategies and programs in Ghana, Kenya and South Africa was conducted between February and July 2022 through desk reviews and key informant interviews. The aim was to generate evidence on the extent to which the policies, strategies and programs were nutrition-sensitive and add value to the scaling up of nutrition and food security. The assessment of the documents was based on the four dimensions of food security, and the Food and the Food and Agriculture Organization of the United Nations guidelines on nutrition-sensitive agriculture. A total of 48 policies, strategies and programs were reviewed. To ensure food availability, most reviewed documents tend to focus on food production and income generation, with limited attention on production and supply of diverse and nutrient-dense foods. Access to inputs, credit and land is targeted at smallholder farmers, without little sensitivity to women and youth engagement. Food access is promoted through improved market access by upgrading infrastructure and promoting social safety nets for vulnerable populations. However, information systems for agricultural marketing as well as labor- and time-saving technologies are lacking. Although nutrition education is widely promoted, especially for mothers and children, there is a gap in addressing the nutrition needs of adolescent girls. Regarding food stability, inadequate funding, poor leadership and governance and inadequate monitoring and evaluation systems are the main barriers to successful implementation of policies, strategies and programs. While efforts have been made to promote nutrition-sensitive options in the agriculture and food system value chains, the study identified several gaps that need to be addressed to ensure adequate food and nutrition security.

KEYWORDS

nutrition, nutrition-sensitive, policies and programs, sustainable food systems, women and youth empowerment

Introduction

Food security refers to secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life (FAO, 2022a). The four main dimensions of food security are availability, accessibility, utilization, and stability [Committee on World Food Security (CFS), 2014]. Other dimensions of food security include agency, sustainability [High Level Panel of Experts on Food Security and Nutrition (HLPE), 2020] and governance (Chen et al., 2021).

According to the State of Food Security and Nutrition (SOFI) 2022 Report, 2.37 billion people experienced food insecurity (moderate or severe) in 2021, with Africa experiencing the highest increase compared to other regions (FAO, IFAD, UNICEF, WFP, and WHO, 2022). The report indicates that the rates of food insecurity have been consistently increasing at the global level since 2014 and confirms that the world is not on track to achieve the Sustainable Development Goal (SDG) 2.1, Zero Hunger target, by 2030 (FAO, IFAD, UNICEF, WFP, and WHO, 2022). It is noteworthy that women experience a higher burden of food insecurity. Globally, the prevalence of food insecurity among women was 10% higher than in men in 2020, compared to 6% in 2019 (FAO, IFAD, UNICEF, WFP, and WHO, 2021).

Recent analysis also indicates that the world is not on track to achieve the 2025 Global Nutrition Targets set by the World Health Assembly (WHO, 2018a,b). According to the 2020 Global Nutrition Report, no country is on track to achieve all 10 targets (Global Nutrition Report, 2020). Globally, stunting still affects one in five children, wasting one in fourteen children, and overweight about one in seventeen children under 5 years of age, well above the global nutrition targets. Similarly, the NCD targets are off-track, with adult obesity rates (13%) above the 2025 target, with no country on course to halting the prevalence rate. Notably, Africa was the region experiencing the highest levels of the triple burden of malnutrition (childhood stunting, anaemia in women of reproductive age, and adult overweight/obesity).

Nutrition-specific interventions on their own cannot address the burden of malnutrition (Bhutta et al., 2013). The Global Nutrition Report (2020) highlights the need to focus on maximum impact actions such as equitably mainstreaming nutrition into food and health systems to enable countries to reach their targets. Agriculture has a role to play due to its ability to influence the underlying determinants of nutrition outcomes (Black et al., 2013). Therefore, it is beneficial to get agriculture and health/nutrition to work together.

The COVID-19 pandemic has exacerbated food and nutrition insecurity and exposed the dysfunctionality of our food systems. According to a report by the Food and Agriculture Organization of the United Nations (FAO), the pandemic has disrupted global food systems and threatens people's access to food *via* various pathways, including disruptions to food supply chains; loss of income and livelihoods; widening social and gender inequality; increasing food prices in localized contexts; lack of access to fresh food markets; and disruption of social protection programs (FAO and WFP, 2020). These disruptions caused global food prices to rise almost 20% in 2020, affecting the most vulnerable the hardest (FAO and WFP, 2020). The ongoing pandemic has called for better integration of food and health systems to safeguard nutrition and health gains made to date (Committee on World Food Security, 2021).

Food systems encompass the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food and the outputs of these activities, including socio-economic and environmental outcomes (FAO, 2018a,b). These components, viewed through a human rights lens, encompass the food systems framework which is essential for optimal food and nutrition security policies (High Level Panel of Experts on Food Security and Nutrition (HLPE), 2020). Food systems in Sub-Sharan Africa (SSA) have evolved over the past decades to provide positive benefits such as off-farm employment opportunities and an increased array of food choices outside of local staples. However, non-desirable consequences, including the wide availability and consumption of ultra-processed nutrient-poor foods, and high levels of food loss and waste, have accompanied evolving food systems.

To ensure Africa's food systems provide healthy diets and positive nutrition outcomes for the population, food and nutrition security policies, strategies and programs need to be developed and implemented in a way that minimizes negative impacts and maximizes positive contributions, including prioritizing people's right to food, and bridging socio-economic inequities. Lately, the issue of governance of food systems, which is a critical enabling factor for food and nutrition security, has become topical. As part of governance of food systems, the UN Food Systems Summit [United Nations Food Systems Summit (UNFSS), 2021a,b,c] highlighted that food systems transformation requires bringing together actors from different sectors and institutions to work in a coordinated way that is place-based, with a long-term and multi-generational commitment. Addressing the triple burden of malnutrition requires a food systems approach, with coherent public policies, strategies and programs that address both the supply and demand side of food, as well as the food environment where consumers engage with a food system to make food-related decisions.

Food systems across the continent are very diverse, with unique historical, social, and economic contexts (FAO and WHO, 2019). To ensure that each country delivers on all the dimensions of food security and nutrition, while considering these unique contexts, the FAO and WHO emphasize the need for territorial diets. This territorial approach may provide an avenue for the continent's policy makers to assess the impact of policies on the different aspects of sustainability (health, environment, culture, economy, society), as well as to assess any trade-offs and ensure policy coherence (FAO and WHO, 2019).

The three countries are at different stages of achieving global nutrition targets. Whereas Kenya is on track to achieve four of the global nutrition targets (childhood stunting, childhood wasting, childhood overweight and exclusive breastfeeding), Ghana is on course to achieve one (childhood stunting), while South Africa is on track to achieve two targets (childhood overweight and childhood wasting) (Global Nutrition Report, 2022).

All the three countries are making efforts to ensure functional food systems that contribute to attainment of the global nutrition targets. In common with many other countries, the three countries provided pathways to transformed and sustainable food systems as part of their commitments to the United Nations Food Systems Summit [United Nations Food Systems Summit (UNFSS), 2021a,b,c]. The three countries also convened and made declarations on urban food systems by creating enabling policy and local governance systems within urban areas (FAO, 2020). The UNFSS has proposed five action tracks to achieve sustainable food systems: (i) ensure access to safe and nutritious food for all; (ii) shift to sustainable consumption patterns; (iii) boost nature-positive production; (iv) advance equitable livelihoods; and (v) build resilience to vulnerabilities, shocks and stress [United Nations Food Systems Summit (UNFSS), 2021a,b,c]. To be implemented, these commitments and pathways will need to be adopted as official policy in each country.

This paper describes a study on food and nutrition security policies, strategies and programs in Ghana, Kenya and South Africa. These countries were chosen as case studies in the three Sub-regions of Eastern, Southern and Western Africa. The purpose of the study was to assess the extent to which the policies, strategies and government programs are nutrition-sensitive, equitable, and add value to the scaling up of food security and nutrition in the three countries, and how this can provide lessons for other African countries. Examining these policies at the national level is in line with the recommendation that transformation of food systems should be in accordance with and dependent on national contexts and capacities (Committee on World Food Security, 2021).

Methodology

Study setting

The study was conducted in Ghana, Kenya and South Africa between February and July 2022.

Study objectives

The objectives of the study were to address the following key issues:

(i) The specific nature and range of policies and related strategies and programs to improve nutrition through food and agriculture, with a lens on women and youth;
(ii) Key knowledge gaps in the relationship between food and agricultural systems and nutrition;
(iii) Specific aspects of the agriculture and food system and its potential impact on nutrition, including the following study components:

(a) Identify and describe policies in agriculture that may have an impact on diet and nutrition, focusing on nutrients of concern, e.g., iron, zinc and vitamin A;
(b) Identify applied language and terminology regarding food and nutrition security with a women and youth lens; and
(c) Identify information and knowledge needs and gaps that should be addressed through further study and suggest potential processes for monitoring and evaluation.

Study approach

This study received ethical approval from the Faculty of Natural and Agricultural Sciences Research Ethics Committee, University of Pretoria (Reference No: NAS 101/2022).

A desk review was conducted first, starting in February to May 2022, followed by key informant interviews during the period June to July 2022. To identify current national policies, strategies and programs, searches were conducted on websites of government departments working in the food and nutrition sectors and the FAOLEX database (FAO, 2022b). The programs were limited to those at national level and led by government ministries or departments. Representatives from government departments were contacted to verify that the policies identified were in use and to provide guidance on additional policies that might have been missed from the online searches. A total of 48 documents, comprising 15 from Ghana, 20 from Kenya and 13 from South Africa, were reviewed (see Table 1 for list of documents).

The policies were analyzed using a checklist adapted from the FAO (2015) guiding principles for nutrition-sensitive agriculture, the four dimensions of food security [Committee on World Food Security (CFS), 2014], and additional criteria on agency/governance and sustainability. The checklist was used to assess the extent to which the policies, strategies and programs were nutrition-sensitive and can add value to key actions on the scaling up of nutrition and food security. Further, these documents were reviewed for the extent to which they create opportunities for women and youth. The checklist and key informant interview guides are attached as Supplementary information 1.

Key informant interviews were conducted with relevant stakeholders working in the food and nutrition sector, including representatives of relevant government departments and ministries, civil society organizations and development partners. The purpose of the key informant interviews was to triangulate the information gathered during the desk reviews and to get an in-depth understanding on the status of implementation of the policies, strategies and programs. The targeted stakeholders were purposively selected and included the following: (i) Government ministries and departments (e.g., Ministries of Health, Food and Agriculture, Women in Agriculture, Food and Drug Authorities, Social Development, and Planning, Monitoring and Evaluation); (ii) UN agencies (WFP, UNICEF); and (iii) other organizations (research institutions and farmer organizations). A total of five key informants in each country were interviewed Ghana and Kenya and eight in South Africa.

Relevant institutions were engaged *via* telephone, emails and virtual conference calls to explain the purpose of the study and request the participation of their representatives as key informants. Following the engagements, the heads of departments nominated their representatives to participate as key informants. The interviews were conducted in English through in-person interviews or remotely *via* internet-based platforms. An interview guide (see Supplementary information 2) containing open ended questions was used. The interview guide covered issues related to agriculture and nutrition policy formulation and implementation, organizational roles, collaboration, technical capacities, identified gaps, and factors that either enhance or hinder these issues. The duration of the interviews varied between 1 h 30 min and 3 h. The discussions were captured through writing notes as well as recording (based on consent from the participants).

Data analysis

The policies were analyzed based on the criteria in the checklist. Depending on the level of coverage of each criterion from the checklist

TABLE 1 List of reviewed policies, strategies and programs for Ghana, Kenya, and South Africa.

Ghana	Kenya	South Africa
11 policies 4 strategies/plans	4 policies 16 strategies/plans	5 policies/legislation 8 strategies/plans
Policies • National Medium-Term Development Policy Framework (MTNDPF) • Ghana Shared Growth and Development Agenda (GSGDA) II • Food and Agriculture Sector Development Policy (FASDEP) II • Ghana Livestock Development Policy and Strategy (GLDPS) • National Nutrition Policy (NNP) • National Food Safety Policy (FSP) • National Policy & Strategy for the Prevention and Control of Chronic NCDs in Ghana • Ghana School Feeding Policy (GSFP) • National Social Protection Policy (NSPP) • Ghana National Climate Change Policy (NCCP) • Ghana Trade Policy (TP) *Strategies* • Medium-Term Agriculture Sector Investment Plan (METASIP) II • Investing for Food and Jobs (IFJ): An Agenda for Transforming Ghana's Agriculture • Gender and Agricultural Development Strategy (GADS) II • Ghana Agriculture Investment Plan (GhAIP)	*Policies* • National Food and Nutrition Security Policy (NFNSP) • Kenya Health Policy (KHP) • Kenya School Healthy Policy (KSHP) • National Maternal, Infant and Young Child Nutrition Policy Guidelines (NMIYCNPG) *Strategies, plans and implementation framework* • Food and Nutrition Security Strategy (FNSS) • Agricultural Sector Transformation and Growth Strategy (ASTGS) • National School Meals and Nutrition Strategy (NSMNS) • Kenya National Strategy for the Prevention and Control of Non-Communicable Diseases (NSPC-NCD) • The Scaling up Nutrition Business Network Kenya Strategy (SUN-BNKS) • National Food and Nutrition Security Policy- Implementation Framework (NFNSP-IF) • The Kenya Nutrition Action Plan (KNAP) • The Kenya Nutrition Monitoring and Evaluation Framework (KNMEF) • National Guidelines for Healthy Diets and Physical Activity (NGHDPA) • Kenya Nutrition Capacity Development Framework (KNCDF) • The Big Four Agenda Program • The Kenya Vision 2030 • Livestock Strategic Plan (LSP) • National Agricultural Investment Plan (NAIP) • Nairobi City County Urban and Peri-Urban Agriculture, Livestock And Fisheries Policy (UPALF) • Agri-Nutrition Implementation Strategy (ANIS)	*Policies* • National Policy on Food and Nutrition Security (NPFNS) • Early Childhood Development Policy (ECD) • Integrated School Health Policy (ISHP) • Food Fortification Legislation • Regulations Relating to Labeling and Advertising of Foods *Strategies, plans and implementation framework* • National Strategic Plan for the Prevention and Control of Obesity • National Strategic Plan for the Prevention and Control of NCDs • Agro-processing Strategy for SMMES • The Zero Hunger Framework • National Food and Nutrition Security Communication Strategy for South Africa (NFNSCS) • Medium Term Strategic Framework Priority 2019–2024 (MTSF) • National Development Plan (NDP) • The National Food and Nutrition Security Plan (NFNSP)

FAO (2022b).

in each of the policies, strategies and programs, these were placed in one of three categories as being (i) covered; (ii) partly covered; or not covered. For the key informant interviews, key themes were extracted using a deductive analytical approach and incorporated into the report.

Results and discussion

The food and nutrition security situation in the three focal countries

Ghana is a lower middle-income country with an estimated population of 30.8 million and a gross domestic product (GDP) (purchasing power parity) of $164.8 billion (Ghana Statistical Service, 2021). Some key challenges facing Ghana's food systems include poor dietary choices, increasing urban food insecurity, non-mechanized agriculture, inadequate funding, high levels of environmental degradation, unpredictability of food supply and prices due to climate variability, and limited institutional and human resource capacity (Cooke et al., 2016). Ghana, in common with other African countries, is grappling with the triple burden of malnutrition. An estimated 17.5% of children under 5 years of age are affected by stunting, 6.8% are wasted, and 1.4% are overweight (Global Nutrition Report, 2020).

Kenya's food system combines traditional and modern dynamics. Traditional elements are associated with widespread extreme poverty and undernourishment, and this is more dominant than the modern dynamic (Kenya National Bureau of Statistics, 2022). In the drought-prone areas of the Arid and Semi-Arid Lands (ASALs), which make up 80% of the country's land area, there have been increased vulnerabilities, which have resulted in chronic emergency needs, driven by food insecurity and high rates of acute malnutrition. Additionally, urbanization and rapid population growth, a large and youthful workforce, and technological advances, are also changing the demands and opportunities for food systems. The outbreak of the COVID-19 pandemic has led to increased levels of food shortage. In 2020, about 26.2% of children under 5 years of age were stunted, while 4% were wasted and 4.1% overweight (Global Nutrition Report, 2020).

South Africa has a population of about 61 million people and is classified as a middle-income country. It is food secure at the national level, yet there are high levels of food insecurity at community and household levels. Approximately 3.4% of children under 5 years of age are wasted, while 21.4% are stunted [Southern African Development Community (SADC), 2021]. Concurrently, overweight and obesity are increasing rapidly, and South Africa is not on track to achieve SDG 2 targets (Global Nutrition Report, 2020). Approximately 18.2% of men and 42.9% of women are obese, while 16.3% of girls and 13.5% of boys aged 5–19 years are classified as obese (Global Nutrition Report, 2020). Due to an increase in population and urbanization, there are high levels of food insecurity in rural areas and urban informal settlements.

Food availability

Food availability is achieved when there is adequate physical existence of food at national and household levels. This is a function of food production, supply and distribution. The policies, strategies and programs were assessed against four priority areas and corresponding key elements and a cross-cutting priority area of women and youth (Table 2; Priority areas and key elements of the availability dimension).

Overall, 37–73% (18–35 out of 48) of the policies, strategies and programs in Ghana, Kenya and South Africa address the priority areas and key elements related to food availability, while 12–26% (6–13 out of 48 documents) partly cover the same issues (Table 2). Great efforts and emphasis are focused on the provision of factors of production in the form of land, credit, seeds and other inputs to rural smallholder farmers in general, with little or no special attention being paid to urban and peri-urban production and women, youth and other vulnerable groups, inspite of the recent urban food systems dialogues in the three countries (FAO, ICLEI, 2022). A recent policy on Urban and Peri-Urban Agriculture, Livestock and Fisheries Policy for Nairobi City County (2015) in Kenya is an exception. As a result of urbanization, food insecurity in urban and peri-urban areas is high.

Fresh fruits, vegetables and animal source foods are inaccessible to the rural, urban and peri-urban poor due to high food prices [High Level Panel of Experts on Food Security and Nutrition (HLPE), 2017]. It is, therefore, necessary to promote traditional foods such as legumes, local fruits and vegetables as well as forest foods to improve dietary diversity and improve nutrition [Cernansky, 2015; High Level Panel of Experts on Food Security and Nutrition (HLPE), 2017]. Nutrient-dense crops such as vegetables and fruits are promoted by almost all the reviewed documents across the three countries. However, there is little attention to use of biofortified seed and traditional or indigenous crops. These areas should be strengthened, possibly by providing incentives to producers. Production of protein-rich foods such as legumes and small livestock is not adequately promoted in policies, strategies and programs.

Only 35–54% (17–26 out of 48) of the policies, strategies and programs promote access to productive resources among women in Ghana, Kenya and South Africa (Table 2). The lack of targeted efforts to empower women in food production is a missed opportunity, considering that nearly half of the agricultural workforce globally are women (FAO, 2018a). In addition, women's control of productive resources has been associated with improved nutrition for household members (Quisumbing, 2003; FAO, 2015; Hodge et al., 2015).

Most of the Ghanaian policies and related documents (86.7%;13 out of 15) cover the priorities and key elements to maintain and improve the natural resources such as water, soil and climate change, compared to Kenya (15%; 3 out of 20) and South Africa (38.5%; 5 out of 13). Some of the practices promoted in the reviewed policies include climate resistant crops, organic farming and preservation of land meant for agriculture. However, more needs to be done by the three countries to be proactive to address climate change adaptation and mitigation. Globally, climate change is a problem which is characterized by shifting seasons and increased episodes of natural disasters such as floods and droughts.

Improved food processing, storage and preservation are covered by 40–87% (19–42 out of 48) of the policies, strategies and programs. Food processing, storage and preservation are important in preventing post-harvest losses, preserving nutrient content of food, adding value to crops and increasing income, preventing seasonal shortages of micronutrient-rich foods and improving food safety (FAO, 2015). Food safety is covered by 23–67% (11–32 out of 48) of the reviewed documents. These results are indicative of a major gap in food safety and actions to address aflatoxin poisoning are almost non-existent.

Aflatoxin poisoning leads to suppressed immunity, liver cancer in humans and stunting in children (WHO, 2018a,b). This calls for an urgent need for all country policies to improve on documentation of food safety measures. Further, issues on post-harvest losses and food waste (DEFF and CSIR, 2021) are not adequately addressed in most reviewed documents. These findings are consistent with a policy review study that was conducted in Senegal (Lachat et al., 2015).

Women- and youth-related issues were addressed in 35–54% (17–26 out of 48) of the framework documents, showing a major gap when it comes to women and youth empowerment. Where framework documents partly cover women and youth, the focus is mainly on women rather than youth in food production and availability value chains.

Food access

Food access is achieved when all households have enough resources and are physically able to obtain food in sufficient quantities, of good quality and diversity, for a nutritious diet. The policies and related strategies and programs were assessed against three priority areas and corresponding key elements, including women and youth (Table 3; Priority areas and key elements of the access dimension).

At least half (24 out of 48) of the reviewed documents promote the expansion of markets and consumer access to markets (Table 3). Market access in all the three countries focuses on developing infrastructure and creating markets, although this varies across the different documents. Improved access to markets has positive effects on food access, including increasing income for farmers, incentivizing food production by farmers and improving dietary diversity among consumers (FAO, 2013).

An analysis of data from Ethiopia, Indonesia, Kenya and Malawi showed that farmers' market access had a greater effect on dietary diversity compared to production of diversified foods (Sibhatu et al., 2015). Further, children in Ethiopia living closer to markets had more diverse diets and higher mean weight for height (WHZ) and weight for age (WAZ) z-scores (Abay and Hirvonen, 2016). Some of the efforts outlined in the reviewed documents to create markets for smallholders include linkages with school feeding programs and facilitating bulk government purchases from smallholders. However,

TABLE 2 Priority areas and key elements of the availability dimension.

Priority areas	Key elements of each priority area	Proportion of policies, strategies/plans and programs addressing priority areas (%)								
		Ghana (*n*=15)			Kenya (*n*=20)			South Africa (*n*=13)		
		Covered	Partly covered	Not covered	Covered	Partly covered	Not covered	Covered	Partly covered	Not covered
Facilitate increased and sustainable production of diversified nutrient-dense crops	• Promote increased access to diverse and improved seeds, including biofortified seeds • Increase production of horticultural crops (fruits and vegetables), legumes and animal source foods, including fish and livestock • Promote the production of underutilized foods such as indigenous and traditional crops • Promote "home grown" school feeding and home gardening • Promote urban and peri urban agriculture • Increase access to credit for inputs • Increase access to extension services and information • Promote innovative approaches to agricultural financing and insurance schemes for farmers	73.3% (11/15)	26.7% (4/15)	0% (0/15)	55.0% (11/20)	15.0% (3/20)	30.0% (n=6)	53.8% (7/13)	30.8% (4/13)	15.4% (2/13)
Maintain or improve the natural resources base	• Include measures to improve and manage water, soil, air, climate, biodiversity • Promote increase of area of land under irrigation • Facilitate capacity building on climate change adaptation and mitigation • Encourage treatment of recycled water in agriculture	86.7% (13/15)	0% (0/15)	13.3% (2/15)	15.0% (3/20)	15.0% (3/20)	70.0% (14/20)	38.5% (5/13)	15.4% (2/13)	46.2% (6/13)
Improve processing, storage and preservation of food	• Promote techniques that aim to retain nutritional value and increase shelf-life of food • Have strategies that reduce seasonality of food insecurity and post-harvest losses • Ensure the availability of healthy foods that are convenient to prepare • Promote low-cost technologies on food processing, handling, preservation and storage • Legislation on mandatory fortification of foods	86.7% (13/15)	6.7% (1/15)	6.7% (1/15)	40.0% (8/20)	15.0% (3/20)	45.0% (9/20)	46.2% (6/13)	30.8% (4/13)	23.1% (3/13)
Food safety	• Facilitate the development of evidence-based food safety policies, legislative and institutional frameworks, and mechanisms to strengthen the coordination of food safety management • Harmonize and monitor the enforcement of food safety standards, including updating and implementing national legislation and regulations to meet the international food safety standards such as the Codex Alimentarius • Regulate nutrition labelling and claims on food packaging	66.7% (10/15)	13.3% (2/15)	20.0% (3/15)	40.0% (8/20)	25.0% (5/20)	35.0% (7/20)	23.1% (3/13)	53.8% (7/13)	23.1% (3/13)
Empower women and engage youth	• Promote access to land, water and inputs for vulnerable persons, in particular, women, youth, persons with disabilities and other special categories of disadvantaged people • Improve land tenure rights for increased access to land for women and youth	53.3% (8/15)	13.3% (2/15)	33.3% (5/15)	35.0% (7/20)	35.0% (7/20)	30.0% (6/20)	53.8% (7/13)	0% (0/13)	46.2% (6/13)

10.3389/fsufs.2023.1088216

TABLE 3 Priority areas and key elements of the access dimension.

Priority areas	Key elements of each priority area	Proportion of policies, strategies/plans and programs addressing priority areas (%)								
		Ghana (*n*=15)			Kenya (*n*=20)			South Africa (*n*=13)		
		Covered	Partly covered	Not covered	Covered	Partly covered	Not covered	Covered	Partly covered	Not covered
Expand markets and market access for vulnerable groups	• Promote marketing of nutritious foods • Restrict marketing of unhealthy foods • Facilitate the development and/ or upgrading of marketing infrastructure • Facilitate the development of agricultural market information system, including use of information and communication technologies (ICT) • Domesticate regional trade policy instruments to support women, the youth, rural masses, and vulnerable groups • Ensure food produced by vulnerable groups has a comparative advantage. • Promote value addition • Improve access to price information and farmer associations • Facilitate the removal of non-tariff barriers, especially sanitary and phytosanitary measures • Increase tariffs on unhealthy foods and lower tariffs on healthy foods • Impose taxes on ultra-processed foods, e.g., sugar sweetened beverages	73.3% (11/15)	20.0% (3/15)	6.7% (1/15)	60.0% (12/20)	10.0% (2/20)	30.0% (6/20)	23.1% (3/13)	38.5% (5/13)	38.5% (5/13)
Empower and protect women and the poor	• Ensure access to productive resources • Promote labor saving technologies for food production, processing and food preservation • Promote the provision of social and recreational facilities for children, particularly in rural areas, to release women's time into productive activities • Encourage men to be involved in maternal and child nutrition • Support women's voices in household and farming decisions. • Facilitate safety nets (e.g., food parcels, vouchers, school feeding) • Improve market access for vulnerable producers • Address inequalities to support the marginalized poor, women, the youth, rural masses, and vulnerable groups • Facilitate the creation of decent, diversified productive employment opportunities including income generating programs and rural agro-processing businesses, • Is the language gender sensitive, does it incorporate gender terms?	66.7% (10/15)	20.0% (3/15)	13.3% (2/15)	25.0% (5/20)	15.0% (3/20)	60.0% (12/20)	0% (0/13)	69.2% (9/13)	30.8% (4/13)
Target vulnerable populations and improve equity	• Facilitate participation of vulnerable populations in agriculture and food systems • Promote access to resources by vulnerable groups • Create decent employment for vulnerable groups	80.0% (12/15)	13.3% (2/15)	6.7% (1/15)	50.0% (10/20)	15.0% (3/20)	35.0% (7/20)	61.5% (8/13)	7.7% (1/13)	30.8% (4/13)

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issues of trade and how it affects the smooth functioning of markets are not addressed comprehensively.

All three countries are battling overweight and obesity among their populations. Efforts have been made to impose tax on unhealthy foods such as sugar sweetened beverages. Nevertheless, there is a huge gap at policy level in advocating for tax on ultra-processed foods high in sugar, salt and fats, whilst lowering taxes on healthy foods such as vegetables and fruits. This is a barrier to promoting consumption of nutritious foods, considering that food prices affect consumers' food choices (Griffith et al., 2015).

The three countries are faced with a challenge of high consumption of ultra-processed foods and low consumption of nutritious foods. Highly processed energy-foods are more affordable compared to nutrient-dense foods (Drewnowski and Specter, 2004). In common with findings of a study in Senegal (Lachat et al., 2015), marketing of nutritious foods is quite low in all three countries. Women empowerment through income opportunities is partly addressed but there is limited priority regarding decision making roles, labor and time-saving technologies for women. A study in East Africa proposed focusing on export production to reduce the time burden on women (Hodge et al., 2015).

Regrettably, a huge gap still exists regarding youth as they continue to experience high unemployment rates. Various social safety nets for vulnerable groups are well documented in policy and related documents, including food and cash support. School feeding programs are well supported by policies in all three countries to increase access to food among vulnerable school children. In addition, school feeding programs create a market for smallholders to sell their produce and earn income [High Level Panel of Experts on Food Security and Nutrition (HLPE), 2017]. In general, the policies, strategies and programs in all three countries are limited in promoting the development of agricultural market information systems, including use of information and communication technologies (ICT).

Food utilization

Food utilization refers to digestion and assimilation of the nutrients from the food consumed, which in turn is influenced by health status, preparation of food, water and sanitation conditions, and the microbiological and chemical safety of the food. In addition, utilization is influenced by nutritional knowledge (Baute et al., 2018), food habits, child-feeding practices, and the social role of food in the family and in the community. The priority areas and the corresponding key elements are shown in Table 4 (Priority areas and key elements of the utilization dimension).

Most reviewed policies, strategies and programs promote knowledge-based nutrition interventions, including nutrition education and, sometimes, behavior change in communities, schools and health care settings. Between 40 and 73% (19 and 35 out of 48) of the reviewed documents adequately cover food utilization in Ghana, Kenya and South Africa (Table 4). Interventions on reducing all forms of malnutrition across different age groups and populations are prioritized. However, inclusion of adolescent nutrition and the roles of men in ensuring good nutrition for women and children are not well covered. Adolescents are mostly targeted through school nutrition in all three countries, leaving those that may not be enrolled in schools. An example of a good practice is the promotion of anemia screening for girls in schools in South Africa.

All three countries have policies that adequately promote exclusive breastfeeding and complementary feeding. Dietary diversity is also promoted but the link between a diverse diet and prevention of malnutrition, including micronutrient deficiencies, is not spelt out in some of the documents. Instead, when it comes to micronutrient deficiencies, supplementation with vitamins (such as Vitamin A, iron, zinc and folate), rather than consuming diets rich in those nutrients, is mostly emphasized. Although water, sanitation and hygiene (WASH) were mentioned in some of the policies, they were not included in the monitoring frameworks.

Food stability

Food stability is attained when the supply of and access to nutritious food at national and household levels remains constant during the year and in the long-term, even in the face of economic and climate shocks or cyclical events such as seasonal changes. Stability is felt through the availability and access dimensions. *Sustainability* refers to long-term viability of the ecological and social bases of food systems (FAO, 2018b; Clapp et al., 2022). Stability and sustainability are also determined by the governance of food systems.

Governance relates to the rules of the game, that is, how the rules, norms and actions are structured, sustained, regulated and implemented through the interaction of different actors, such as government institutions, civil society, the private sector and consumers (Chen et al., 2021). Agency, the capacity of individuals to exercise voice and make decisions about their food systems, is an important component of governance (Clapp et al., 2022). Good governance of food systems facilitates equitable, coherent, coordinated, and transparent design and review of mechanisms and processes such as policies, legislation, planning, finances, monitoring and coordinated implementation (GAIN, 2021). The priority areas and their corresponding key elements that were assessed are shown in Table 5 (Priority areas and the key elements of the stability dimension, sustainability and governance).

Ensuring food stability and sustainability is complex and often a challenge in many settings. On paper, all three countries have very good collaboration and coordination among sectors to ensure good governance of the food system (see Table 5). However, in practice, there is a preponderance of vertical programming as most sectors prioritize their own mandate rather than integrated food and nutrition systems and interventions. The study has highlighted the need for effective multi-sectoral collaboration and governance, instead of the vertical programming which is often seen in policies and programming.

Although multi-sectoral collaboration and participatory governance is often referred to in the policies, key informant interviews revealed the need to strengthen this, especially at the regional and district levels. It is evident that most sectors prioritize their main goals rather than nutrition goals. For example, the focus of agriculture and food policies is on food production; there is limited focus on production of diverse and nutrient-dense foods. In addition, evidence-based policy development appears to be limited. Some of the reasons found to hinder evidence-based policy development include

TABLE 4 Priority areas and key elements of the utilization dimension.

Priority area	Key elements	Proportion of policies, strategies/plans and programs addressing priority areas (%)								
		Ghana (*n*=15)			Kenya (*n*=20)			South Africa (*n*=13)		
		Covered	Partly covered	Not covered	Covered	Partly covered	Not covered	Covered	Partly covered	Not covered
Incorporate nutrition promotion and education	• Promote food and sustainable food systems that builds on existing local knowledge, attitudes and practices • Promote nutrition education and counseling to increase demand for and preparation of nutritious foods, optimal infant and young child feeding and weight management to prevent malnutrition in all populations • Promote the development of pre-school and school nutrition programs • Promote adolescent-friendly nutrition interventions – especially in girls to prevent the vicious cycle of generational stunting • Promote and advocate consumption of foods with adequate micronutrient content • Promote micronutrient supplementation such as Vitamin A and use of micronutrient powders • Promote and advocate for access to and use of safe potable water	73.3% (11/15)	13.3% (2/15)	13.3% (2/15)	40.0% (8/20)	20.0% (4/20)	40.0% (8/20)	53.8% (8/13)	30.8% (4/13)	7.7% (1/13)
Women and youth	• Involve women and youth in food utilization initiatives	46.7% (7/15)	26.7% (4/15)	26.7% (4/15)	25.0% (5/20)	15.0% (3/20)	60.0% (12/20)	15.4% (2/13)	38.5% (5/13)	46.2% (6/13)

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TABLE 5 Priority areas and the key elements of the stability dimension, sustainability and governance.

Priority areas	Key elements	Proportion of policies, strategies/plans and programs addressing priority areas (%)								
		Ghana (*n*=15)			Kenya (*n*=20)			South Africa (*n*=13)		
		Covered	Partly covered	Not covered	Covered	Partly covered	Not covered	Covered	Partly covered	Not covered
Governance – Collaborate and coordinate with other sectors and all relevant stakeholders to address concurrently the multiple underlying causes of malnutrition.	• Promote multisectoral collaboration and commitment for integrated nutrition response • Advocate for increased budgets for nutrition at both national and regional level • Involve private sector, producers' organizations, consumers' organizations, workers' representatives, civil society, municipalities and traditional rulers, development partners, Non-Governmental Organisations (NGOs), academia (food research institutes, universities), school boards and parents' associations, women's associations, media	100% (15/15)	0% (0/15)	0% (0/15)	75.0% (15/20)	15.0% (3/20)	10.0% (2/20)	69.2% (9/13)	15.4% (2/13)	15.4% (132)
Increase incentives for availability, access and consumption of diverse, nutritious and safe foods	• Incentivize credit for production of nutritious, diverse and local foods focusing on horticulture, legumes, and small-scale livestock and fish	53.3% (8/15)	20.0% (3/15)	26.7% (4/15)	10.0% (2/20)	5.0% (1/20)	85.0% (17/20)	15.4% (2/13)	7.7% (1/13)	76.9% (10/13)
Monitor dietary consumption and access to safe, diverse and nutritious foods	• Monitor food prices of diverse foods and dietary consumption indicators for vulnerable groups • Conduct real time monitoring of IYCF: • Harmonize and monitor the enforcement of food safety standards, including updating and implementing national legislation and regulations to meet the international food safety standards such as the Codex Alimentarius	73.3% (11/15)	13.3% (2/15)	13.3% (2/15)	55.0% (11/20)	15.0% (3/20)	30.0% (6/20)	15.4% (2/13)	15.4% (2/13)	69.2% (9/13)
Develop capacity, e.g., human resources and institutions	• Facilitate capacity strengthening of human resources and institutions to improve nutrition through the food and agriculture sector, supported with adequate financing. • Promote the inclusion of food and nutrition-sensitive curricula at all levels	100% (15/15)	0% (0/15)	0% (0/15)	35.0% (7/20)	10.0% (2/20)	55.0% (11/20)	23.1% (3/13)	30.8% (4/13)	46.2% (6/13)
Implement policies and strategies	• Presence of an implementation plan to accompany the policy • Specific actions on how the policy is to be implemented - SMART (Specific, Measurable, Attainable, Realistic and Time bound)	80.0% (12/15)	6.7% (1/15)	13.3% (2/15)	15.0% (3/20)	75.0% (15/20)	10.0% (2/20)	61.5% (8/13)	23.1% (3/13)	15.4% (2/13)
Include nutrition and food security objectives and indicators	• State goals specific to food and nutrition security in the policy • Include food and nutrition security indicators in the results framework and all framework documents	40.0% (6/15)	40.0% (6/15)	20.0% (3/15)	70.0% (14/20)	5.0% (1/20)	25.0% (5/20)	38.5% (5/13)	15.4% (2/13)	46.2% (6/13)
Women and youth	• Empower women and engage youth in sustainable food and nutrition security	60.0% (9/15)	6.7% (1/15)	33.3% (5/15)	10.0% (2/20)	5.0% (1/20)	85.0% (17/20)	0% (0/13)	61.5% (8/13)	38.5% (5/13)

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policy makers' own interests and attitudes, lack of accountability and lack of time to wait for and examine evidence (Gillespie et al., 2015).

Often, budgetary constraints hinder successful multisectoral approaches. In general, there is limited advocacy for increased nutrition budgets in all three countries. The government is the main funding source for food and nutrition security programming in all three countries. Private sector involvement is mentioned in policies, although their roles in policy processes are usually not fully spelt out. The COVID-19 pandemic has been a major barrier for implementation in all three countries, as highlighted by key informants. It took away resources (especially financial and human resources) from an already strained sector.

Regarding sustainable supply of nutritious food, the greater proportion of policies and related documents lack incentives to promote production of nutritious and diverse foods such as legumes and small livestock. Except for Ghana, less than 50% (7 out of 15) of the policies incentivize the availability, access and consumption of diverse, nutritious and safe foods.

Strong leadership and participatory governance are critical to ensure the successful implementation of interventions and sustainable food and nutrition security. The reviewed policies and related documents demonstrate the need for very well-organized systems of governance and accountability. However, some gaps are evident, for example, policies are fully embraced at national level but not at provincial and district levels. Nutrition indicators (mainly impact level) are partly included in at least half of the documents reviewed per country. However, most indicators do not capture women and youth issues. The lack of an integrated monitoring system for food and nutrition security also hinders collaboration and accountability among various sectors and actors. Additionally, the lack of women empowerment and youth indicators in most policy action plans and M&E frameworks, poses a significant challenge for monitoring progress of inclusivity objectives [International Fund for Agricultural Development (IFAD), 2012].

As part of the United Nations Food Systems Summit (UNFSS) (2021a,b,c), youth committed to action, advocacy, and empowerment to transform food systems. This would be achieved by raising awareness for healthy, nutritious, and sustainable diets; supporting, advocating and acting on climate and biodiversity actions for a liveable resilient future; and advocating for fair and decent wages and social protection for people working in food systems. These commitments will need to be incorporated into national food systems policies and strategies.

Vulnerable populations, for example, the elderly and disabled, are also inadequately targeted in food and nutrition security policies, strategies and programming. Implementation of policy action plans and strategies suffers from non-robust monitoring and evaluation (M&E) mechanisms. Lack of resources – staff, technical capacity, funding, and equipment – are cited by key informants as issues impeding effective implementation and monitoring of food and nutrition security action plans.

Technical capacity building, which this study has helped to surface, is needed to ensure policy and program objectives are achieved. These observations are similar to those from a policy review in Senegal where some gaps in agricultural programs included lack of nutrition goals in program implementation as well as inadequate monitoring of nutrition indicators (Lachat et al., 2015). In general, there is insufficient involvement and the voice of consumers in the governance of the food systems, while participation by smallholder farmers is largely limited to compliance with regulations, either from government or marketing channels.

Lessons for Sub-Saharan African countries

A number of lessons that would be of value to other African countries were identified from the three country case studies. These are listed as follows:

(i) Protection of land for agricultural use through levying taxes on land changed from agricultural to other uses, while using the taxes to fund agricultural development programs;
(ii) Acceptance and formalization of urban and peri-urban agriculture and providing the necessary support as a way of addressing food and nutrition insecurity in urban areas;
(iii) The need to promote traditional and orphan/neglected crops, some of which are known to be highly nutritious and have the ability to withstand adverse conditions brought about by climate change;
(iv) Expansion of food storage facilities and strategic grain reserves to strategic food reserves, covering traditional cereal and/or staple foods, to include other nutritious foods such as pulses, fruits and vegetables;
(v) Facilitate access of women to traditionally male-dominated commodity chains by providing financial and capacity development;
(vi) Support increased participation of women and youth in agriculture and food system value chains as employees and agripreneurs, especially by creating dedicated funding mechanisms and capacity development;
(vii) Sensitize and develop the capacity of agricultural extension services in nutrition-sensitive agriculture;
(viii) Nutrition education and behavior change communication programs to improve food and nutrition security to include men as they influence most food and dietary choices at household level;
(ix) To achieve effective multi-sectoral coordination of national food and nutrition security programs, it is necessary to set up one national leadership and coordination structure at the highest level, for example the office of the presidency or prime minister's office; and
(x) Countries need to promote private sector investment in smallholder agriculture and food system value chains by making smart public sector investments through innovative fiscal and economic incentives.

Conclusion

The study assessed the nutrition-sensitivity of food and nutrition security policies, strategies and programs in Ghana, Kenya and South Africa. The intended objectives of assessing key gaps in policy and programming relating to the four pillars of food security (availability of safe and nutritious food, access, utilization, and stability, including sustainability and governance) have been adequately analyzed in this report. The report has highlighted the need for effective multi-sectoral collaboration and governance, instead of the vertical programming which is often seen in policies and programming. Although multi-sectoral collaboration and participatory governance is often referred to in the policies, there is still a need to strengthen this, especially at the regional and district levels.

Implementation of policy action plans and strategies suffers from non-robust M and E mechanisms. Lack of resources – staff, technical capacity, funding, and equipment – are all cited as issues impeding effective implementation and monitoring of food and nutrition security action plans. Technical capacity building, which this report has helped to surface, is needed to ensure policy and program objectives are achieved. Some focus areas of women empowerment which have not achieved adequate progress include access to credit and decision-making roles for women in agriculture.

Focus on women and youth issues is mentioned in most policies but has not been adequately achieved. The lack of women and youth indicators in most policy action plans, and M and E frameworks poses a significant challenge for monitoring progress of inclusivity objectives. Vulnerable populations, for example, the elderly and disabled, are also inadequately targeted for food and nutrition security policies and programming.

Whilst efforts have been made to make policies nutrition-sensitive, the following gaps have been noted:

(i) Food production and income generation are the main priorities of food policies, with limited attention on production and supply of diverse and nutrient-dense foods.
(ii) Allocation of farming resources are not women- or youth-sensitive.
(iii) Information systems for agricultural marketing as well as labor- and time-saving technologies are lacking.
(iv) There is lack of male involvement in ensuring adequate nutrition for mothers and children. In addition, nutrition-specific interventions do not address adolescent girl's needs.
(v) Inadequate funding, poor leadership and governance and inadequate monitoring and evaluation systems hinder successful implementation of policies, strategies and programs, even when they are nutrition-sensitive.

The findings were used for capacity building of mid-level policy makers during planned virtual national and regional roundtables. The meetings highlighted the gaps that exist and provided awareness to policy makers to discuss actions aimed at developing measures to improve future food and nutrition policies and their implementation.

There is a need to conduct research on sustainable funding mechanisms and identify successful cases of how governments and their partners should sustainably fund nutrition programs. It is critical that all three countries research and implement evidence-based interventions, whilst identifying a basic set of indicators which measure the impact of agriculture on nutrition and ensure efficient use of resources. Efforts should be made to investigate the most effective incentives to improve nutrition outcomes and how to create functional public-private partnership arrangements. It is also necessary to conduct research on how to empower women and youth for more meaningful participation in food and agriculture value chains.

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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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1088216/full#supplementary-material

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Consumer willingness to pay a premium for orange-fleshed sweet potato puree products: a gender-responsive evidence from Becker–DeGroot–Marschak experimental auction among low- and middle-income consumers in selected regions of Nairobi, Kenya

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Vitamin A deficiency (VAD) is a major public health problem affecting people of all ages, particularly women of reproductive age and young children in the Global South. Nutrient-enriched (biofortified) orange-fleshed sweet potato (OFSP) has promising potential as a sustainable food vehicle to combat VAD. Part of ongoing efforts to combat VAD, particularly among the urban poor populations, include the introduction of innovative OFSP puree, which is utilized as a functional and substitute ingredient in widely consumed baked and fried products. In Kenya, the OFSP puree is used to make commercial products that are affordable by low- and middle-income households. However, there is limited knowledge of consumer awareness, willingness to pay (WTP), and/or how gender plays a role in the uptake of these products. Following a multistage sampling technique, this study employs the Becker–DeGroot–Marschak (BDM) experimental auction method to assess if men and women consumers—from selected, highly populated low- and middle-income areas of Nairobi County in Kenya—are aware and if they would be willing to pay for OFSP puree products. Integrating gender considerations, we use three of the most widely consumed OFSP puree products, bread, buns, and chapati, and three treatment categories, naive, nutritional information, and OFSP puree substitute products' references prices to deduce the WTP for OFSP puree products among men and women. Results showed limited awareness of OFSP and OFSP puree products among men and women. However, both men and women were willing to pay a premium for the OFSP puree products. The intergender comparison showed that women were more willing to pay a premium for the OFSP puree products than men. Gender, age, education, knowledge of OFSP puree products, income category, availability of nutritional information, and reference pricing stand out as significant determinants of WTP.

KEYWORDS

OFSP puree, vitamin A deficiency, gender, willingness to pay, Becker–DeGroot–Marschack auction, consumers, nutrition, urban-poor

1. Introduction

Biofortified orange-fleshed sweet potato (OFSP) is a highly nutritious crop with a relatively higher concentration of beta-carotene (BC) compared to many vegetables, and is also a good source of potassium, fiber, and vitamin B6 (Burri, 2011; Laurie et al., 2015, 2018; Owade et al., 2018; Neela and Fanta, 2019). The root has favorable sensory traits such as color and aroma (Adebisi et al., 2020). OFSP can be used for various industrial applications, having both functional and nutritional properties, in the form of flour or puree. The puree has been used to develop innovative nutrient-dense products (Owade et al., 2018), capable of fighting vitamin A deficiency (VAD) among the most vulnerable groups, mainly women of reproductive health and children below 5 years of age (Hagenimana et al., 2001) whose daily vitamin A (VA) needs are higher than those of other groups. In the bakery sector, OFSP puree can replace up to 40% of wheat, reduces the need for added sugars and sweeteners in products, and enriches the overall nutritional characteristics of a formulation without adversely affecting the flavor (Bocher et al., 2017; Muzhingi et al., 2018; Owade et al., 2018; Wanjuu et al., 2018). Commercial and homemade OFSP puree is presently retailing in the formal commercial market in Kenya, but a substantial volume finds its way into the informal market where products are sold unpackaged and unbranded. Some OFSP puree products developed in Kenya to date include bread, buns, chapatis, "kangumu," "mandazi," and "bhajias," among others.

However, over the years, the acceptability and the availability of the OFSP have been at the household level of production and consumption (Bouis and Saltzman, 2017). While considerable experience has been gained in East Africa on the manufacturing and marketing of highly acceptable bakery products in which 20–45% of wheat flour has been replaced by OFSP puree, knowledge of consumer awareness of the availability of OFSP puree baked and fried products and their WTP for these products is still limited. Commercialization efforts of the OFSP puree products in Kenya by the International Potato Center (CIP) and partners have seen a significant uptake by a section of health-conscious consumers—mostly high-end consumers—who source for the products from selected retailers in the upmarket (Low et al., 2007a,b, 2017; Muzhingi et al., 2016, 2018; Bocher et al., 2017, 2019). However, information on the extent to which economically vulnerable consumers in low- to mid-income urban and peri-urban areas in Kenya are aware of OFSP puree products and their nutritional benefits is limited. Besides, several studies have only focused on consumer preferences and acceptance of OFSP puree products based on sensory and functional attributes of the OFSP puree (Muzhingi et al., 2018; Bocher et al., 2019; Wanjuu et al., 2019). While these studies indicate the readiness of consumers to accept and possibly increase consumption, the information available is small on consumer WTP for such products, especially gender differences and implications for marketing strategies. WTP models, such as the BDM that adopt an experimental auction design using different treatments, have been used in several studies to determine consumer WTP for products and/or services. A significant element for WTP by consumers is the information available to them, mostly on the value proposition of the product or service. Consumers need to know how they will benefit from the product they are buying to inform their buying and price decisions. Numerous efforts to reduce malnutrition have been made, and studies have been conducted on consumer acceptability of fortified foods across developing countries.

Chege et al. (2019), in a study among low-income consumers in Kenya and Uganda, found that providing nutrition information influenced WTP for improved and nutritious porridge flour. De Groote et al. (2018), in an experimental auction, showed that after providing additional information on the products, consumers were willing to pay a modest premium for instant flour, and a big premium for added natural extracts such as carrot but were not willing to pay for macronutrients from natural sources; the study area depicts the Kenyan population with a matching national poverty rate. Candace Jackson et al. (2013) showed that consumers in Botswana were more willing to buy multicomposite porridge flour, a low-cost quality product if they perceived that the ingredients would improve their overall nutritional status and health. Bocher et al. (2019) detail that the frequency of use of a substitute product, sensory attributes, and knowledge of the nutritional benefits of OFSP are significant in determining consumer WTP. This current study explores the influence of nutritional information and reference prices to build on this knowledge gap.

Researchers have studied consumer knowledge, preference, attitudes, and their WTP for foods with the improved nutritional quality, especially in developing economies (Mabaya et al., 2010; Jackson et al., 2013; Birol et al., 2015; De Groote et al., 2018, 2020; My et al., 2018; Bocher et al., 2019; Chege et al., 2019). However, many of these studies broadly focus on foods with enhanced nutritional quality through biofortification as a strategy (Meenakshi et al., 2012; De Groote et al., 2014; Birol et al., 2015) and not on specific foods with altered and improved recipes such as puree-based products (Mabaya et al., 2010; De Groote et al., 2018, p. 201; Bocher et al., 2019; Chege et al., 2019). For instance, in bakery, OFPS puree is estimated to replace up to 40% of wheat flour (Low and van Jaarsveld, 2008; Muzhingi et al., 2018; Owade et al., 2018; Wanjuu et al., 2019) cutting on the production costs while enhancing the nutritional contents of the high-calorie wheat products such as bread, buns, "mandazi," and "chapatis." Wanjuu et al. (2019) reported that consumers agreed that the OFSP bread, made from a combination of wheat and OFSP puree could be a good source of energy, especially vitamin A (94%). The authors, however, did not differentiate the knowledge of the products among both men and women. Few studies that attempted to understand the WTP for OFSP puree-based products (Nkokelo, 2016; Bocher et al., 2019; Wanjuu et al., 2019) have used contingent valuation using double or single-bound modeling. While the method is widely used in assessing consumer WTP, it does not create a real market scenario where a potential buyer and consumer visualize, feel, and with information that makes a more informed decision about their WTP.

While the aforementioned studies provide interesting insights into consumer attitudes toward nutritious and biofortified foods, gender gaps and differences in the knowledge, attitude, and practices in the use of OFSP puree products remain unexplored. Besides, while there are several studies on WTP of OFSP puree bread, none has given a focus on WTP across gender. Further, the studies compare the WTP of a single OFSP puree product while consumer preferences could be different. Besides, the studies do not reflect the consumption and purchasing behavior of poor and middle-income consumers who are more vulnerable to micronutrient deficiencies such as VAD, and do not highlight the gender and age differences. To contribute to this knowledge gap, we conducted a gender-responsive study to assess consumers' level of awareness of OFSP puree products and consumer WTP for the products. We concluded the role of gender and generation in the uptake of OFSP puree products. We further analyzed the effect of nutritional information and reference prices on WTP for the VA-rich OFSP puree products while controlling for other socioeconomic and institutional characteristics. The findings of this survey are intended to be used for refinement of the delivery approach through a gendered lens, to reach more households with the nutrient-dense OFSP puree products, as well as inform policy development along the OFSP value chain.

2. Materials and methods

Consumers are ideally rational, and they tend to buy a bundle of goods that they would derive maximum utility from. As such, gauging a consumer's WTP for a service or product is crucial, which not only assists in mapping out competitive strategies but also in developing new products, as well as carrying out value audits (Jayson, 2007; Miller et al., 2011). In relation to healthy and nutritious food products, consumers will integrate information into their utility maximization as they are concerned about the quality and safety of the food they consume (Goktolga et al., 2006). Therefore, a product that gives better benefits is preferred. Besides the context of health consciousness such as vulnerability to VAD, especially among the women of reproductive age and caregivers of children below the age of 5 years, the willingness to pay for nutritionally enhanced products, such as OFSP puree products varies across consumer segments, for example, gender, income, and generation, compared to other products (Miškolci, 2011). In the context of OFSP puree products, consumers will be willing to pay a premium price if the utility accrued is higher than using conventional wheat products. Assuming that n_s is the nutritional aspect of OFSP puree product, consumers would be willing to pay a premium (p_s) subject to other consumer knowledge and demographic factors if the nutritional component of the conventional wheat products n_w is deemed significantly lower than that of OFSP puree products. To elicit this willingness to pay for OFSP puree products, we employ the full-bidding method, Becker–DeGroot–Marschak (BDM).

2.1. Overview of experimental auction

Extensive literature has been generated from estimating WTP, especially for food products. Typically, four methods have been used to estimate WTP, namely, contingent valuation, hedonic prices, conjoint analysis (choice experiments), and experimental auctions (EAs). The EAs method values goods' attributes in terms of consumers' revealed preferences while the former three methods are widely based on stated preferences for new and existing products (Morawetz et al., 2011; Akaichi et al., 2012). Unless it is feasible to combine stated preferences with revealed preferences, the hypothetical nature of contingent valuation and choice experiments is a drawback (Morawetz et al., 2011). As a result, EAs are becoming an important substitute especially to contingent valuation methods as they overcome the hypothetical nature by mimicking the market and the choice process in that they involve a real product and real money exchange (Poole et al., 2007).

Therefore, over the years, EAs have gained recognition among economists, marketers, psychologists, and others (Akaichi et al., 2012; Canavari et al., 2019). They are used to determine the monetary value people put on non-market goods. In EAs, actual products are put up for sale, and the participants are endowed with some money to make the purchase (De Groote et al., 2018, 2020; Maredia and Bartle, 2023). On the WTP, EAs bring out more accurate estimates compared to other methods as they are based on genuine behavior, and not on individual intent, involving real money and products, bringing out consumer preferences *ex ante* while dispensing real incentives. The classic open-ascending price auction, the second-price sealed-bid auction, and the Becker–DeGroot–Marschak (BDM) approaches are popularly applied. The classic open-ascending price auction (English auction) involves price increment until no participant is willing to bid higher. The highest bidder then gets to buy the product at a price equating to his or her bid. In second-price sealed-bid auctions (Vickrey auction), bidders simultaneously submit their sealed bids (corresponding to their WTP) for good, from which the highest bidder wins. This winner then purchases the good at the price stated by the second-highest bidder in the same auction (De Groote et al., 2011; Chege et al., 2019). This approach is used to elicit a participant's actual WTP. The BDM approach is methodologically equivalent to a second-price sealed-bid auction (Morawetz et al., 2011). However, individual participants are not compared to each other but to a randomly generated number. This approach is not an actual auction but rather a simulated auction used to seek individuals' WTP (Shogren, 2005). The Vickrey auction and the BDM approach are incentive compatible in which participants are provided with an incentive to set their bids (Skuza et al., 2015). This gives them room for truthfully undertaking the bidding process and revealing their actual WTP (Lusk et al., 2004; Shogren, 2005).

In BDM, the bid submitted by the participant is compared to a selling price that is randomly drawn from a distribution of reasonable prices usually defined by the marketer or researcher. This random number represents the market price of the good or product in question. The participant whose bid exceeds or is equal to the randomly drawn price wins the auction and gets to purchase the product at the random price he or she drew. In the case that the participant's bid is lower than the randomly drawn price, he or she does not get a chance to buy the product (loses the auction). The BDM mechanism discourages participants from overbidding. This is because an overbid (bidding higher than their WTP) puts them at risk of paying an increased value than what the product is worth to them. On the other hand, participants are at risk of losing a valued product if they put up a bid lower than their WTP. The BDM approach thus allows participants to reveal their actual WTP for the product so as not to fall on either of the above-mentioned extremes (Becker et al., 1964). As Skuza et al. (2015) detail, BDM is superior to other EAs in that, it is relatively easy to implement in a point-of-purchase setting without creating an artificial choice environment while allowing one or several participants in the experiment at a time preventing participants' bids from becoming affiliated since participants do not bid against each other, instead, the bidding outcome and binding price are determined by drawing from a random distribution. This is a particularly attractive feature in the field where researchers have limited ability to control the flow of traffic in the experiment area, for instance, in our case, controlling the traffic of respondents in urban poor who are all willing to participate.

BDM limitations include it being expensive to conduct bringing about regional and geographical restrictions when selecting subjects. Concurrently, it has been conveyed that the amount of cash issued to participants as their participatory fee in the auction may give rise to biased bids from their side. Lastly, a common occurrence that has been evident is the observation of null bids. This is generally due to the lack of interest by the participants in the goods being auctioned (Lusk and Hudson, 2004). Nonetheless, these limitations can be overcome through a rigorous process of selecting a sample, auction design and recruiting, and implementation aspects (Canavari et al., 2019), which were taken into account in this study.

2.2. Study design

Three OFSP puree products (bread, chapati, and bun) and their conventional wheat products were used to elicit WTP. Using the BDM experimental auction approach, three treatments (naive, information, and reference prices) were applied alternatingly to individuals. The experimental auction model mimicked a real market context where a consumer has a variety of products to choose from and has money to spend on the product. Individual respondents were presented with the three OFSP products alongside their conventional equivalents and asked how much they were willing to pay for each of the products. To reduce bias and contamination within the treatment categories, a respondent would only bid under either of the three treatments, that is, in the three rounds of alternation of the three products, a respondent only quoted prices from either a naive perspective (based on their prior knowledge or the lack of knowledge) and the visual attributes, or he or she was furnished with nutritional information about the OFSP puree products using a stack of photos of OFSP puree products with the nutritional information of OFSP and benefits, or he or she was given reference prices of the counterpart products. In all the treatments, a show-up fee of Kenyan Shillings (KES) 200 (approximately US$2) was given to enable the respondents to take part in the auction considering that most of the respondents were of resource scarce and the likelihood of participating in the experiment without financial facilitation would have been low, and the actual market scenario would not have been created.

2.2.1. BDM experimental auction process

The BDM experiment started with a test round to ensure the respondents understood the process well as described in the following sections.

2.2.1.1. Test auction round

The test round was done using unrelated products (biscuits from three brands). At first, a respondent was given KES 50 (100 KES was approximately US$1 during the study period) to enable them to participate and purchase in the experimental test and encouraged to use it to pay for the products offered in the test. First, an explanation of the auction procedure for respondents to understand by using the delayed steps below while controlling for overstating or understating WTP:

I. I will show you three different types of biscuits (Ginger: 1; Milk: 2; and Digestive: 3), one at a time, and ask you to think of how much you are willing to pay for each.
II. I will ask you to bid for each type of biscuit, one at a time, and I will write down your three bids.
III. I will then ask you to pick a random number (from 1 to 3) to determine which of the three types of biscuits is bidding, i.e., will proceed to auction.
IV. Next, I will ask you to pick another random number to determine the "random price," for that binding product. This is the price you will pay if you win the auction.
V. If the bid you had offered for that product is higher than or equal to the random price, you win the auction, and you have to buy the product at the value of the random price.
VI. If the bid you set is lower than the random price, you lose the auction, so you keep the money, and you do not receive the product.

To limit respondents from exaggerating their WTP, they were informed of running a risk of having to pay a price above what they valued the product at.

2.2.1.2. Actual auction round

Treatment clusters; Naive, nutritional information, and reference prices were used to assess consumers' WTP for OFSP puree products. The first treatment was the naive scenario, where the respondent was presented with all three OFSP puree products together with their corresponding conventional wheat products, one at a time with no details. On the nutritional information, the respondent was presented with the three products in the same way and shown a poster with OFSP puree products with accompanying dietary benefits. Under the reference prices treatment category, the price of conventional products (100% wheat) was given while similarly presenting the products. The procedure followed on the test round was repeated but revised to bread, buns, and chapati under three treatment categories.

2.3. Study area: sampling and design

Following a multistage sampling technique, Nairobi County was purposely selected since it is the capital city of Kenya with the biggest urban population which has a consequential effect on food systems. The cluster sampling design was then used

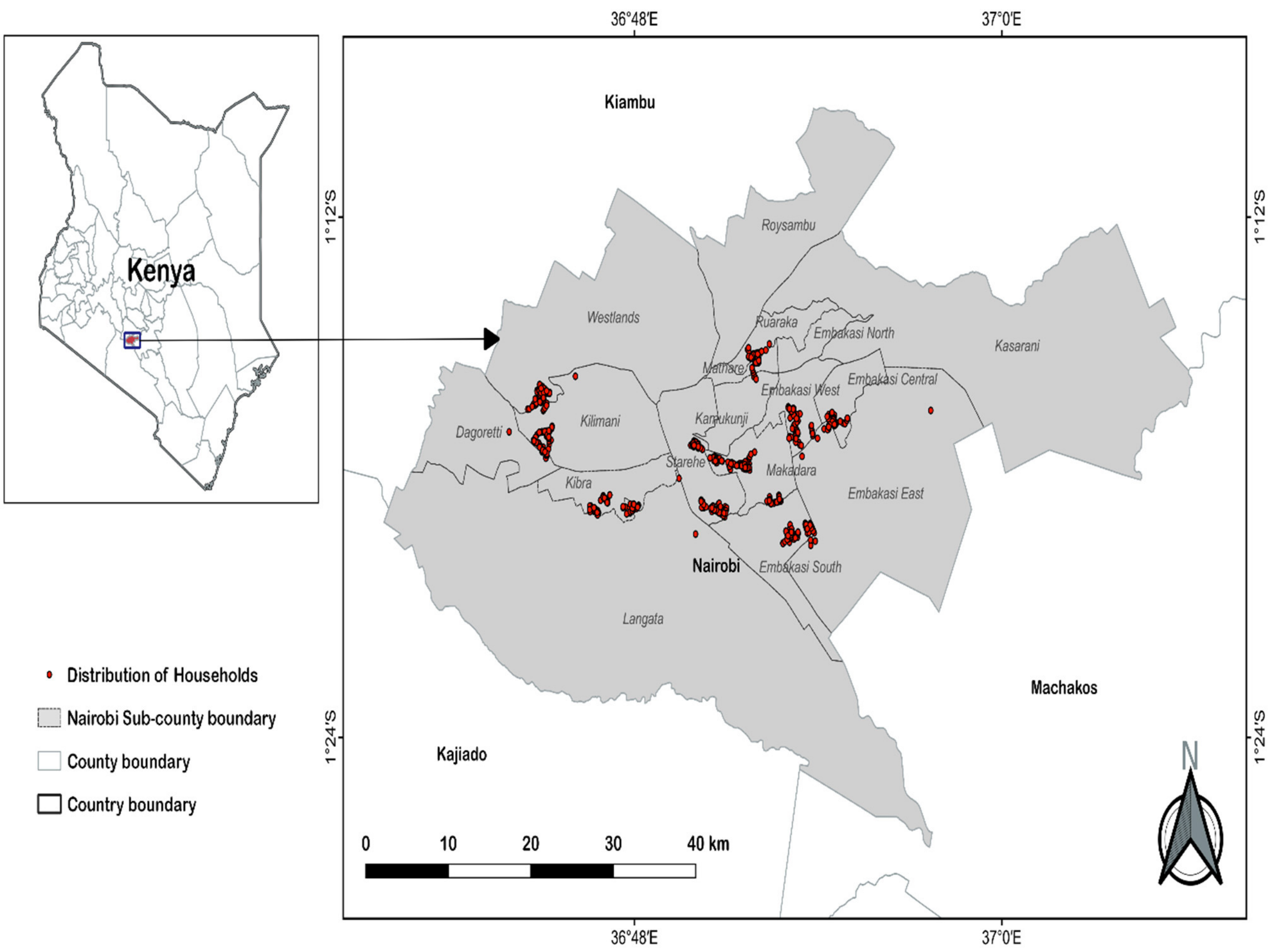

FIGURE 1
Map showing the distribution of respondents in the study area.

to randomly select the study estates; Huruma, Mathare, Kibera, Soweto, Kangemi, Kawangware, Mukuru kwa Njenga, Muthurwa and Marikiti markets, Mukuru kwa Reuben, Imara Daima, Githurai, Umoja area, city stadium area, Donholm, Dagoretti as shown in Figure 1. The clustered estates were then grouped into two strata: low- and mid-income groups providing a deeper analysis of the consumers. Lastly, simple random sampling was used to select 948 respondents spread across the three treatment categories while maintaining a 95% confidence level (417 men and 531 women). Gender-responsive qualitative and quantitative data were collected to understand gender and age differences in the knowledge of, and in the consumption of, OFSP and OFSP puree-based baked and fried products, the level of decision-making power in food purchase and choices, and the type of shops they frequently visit to purchase sweet potato and bread. A detailed desk review of the project documents; the results framework, project proposal, and both peer-reviewed and gray literature was conducted to understand the status of commercialization of the OFSP puree and availability of baked and fried OFSP puree products in Kenya to guide on questionnaire development. To study consumers' knowledge and attitude to OFSP puree products, structured and semi-structured questionnaires, programmed in Computer Assisted Personal Interviews (CAPI) using CSPRO were administered at the market level to men and women consumers who confirmed to have consumed any sweet potato in the past 6 months. Complementary pictorial references were used to guide respondents.

2.4. Empirical framework

In this study, each participant put forward one bid for each type of product that was presented to them for only one treatment category; more than one observation per participant was then recorded. This in turn implies that the individual-specific error needs to be included in the error term of the regression model. For experimental designs, such as this, the estimated coefficients for random effects, ordinary least squares, and random fixed effects regression models are the same. However, the random-effects model is preferred as it allows the estimation of coefficients for variables that do not switch in the middle of rounds (Morawetz et al., 2011). In EAs, the lowest bid is zero. Nonetheless, some participants may go for a negative value. For this BDM, participants were not allowed to give negative amounts and thus the bids were censored at zero; the WTP data are said to be censored from the left (left-censored) (Morawetz et al., 2011; Chege et al., 2019).

Our model choice accounted for this characteristic to avoid biased estimates (Amemiya, 1973; Chege et al., 2019). Tobin's Tobit model can be used when left-censored data are involved (Tobin, 1958).

Unlike the OLS, it takes precise account of the limited nature of the response variable giving rise to unbiased parameter estimates. Further, the Tobit model explains the relationship between the non-negative response variable and one or more predictor variables and can be combined with the random effects model (Morawetz et al., 2011; Chege et al., 2019). When the Tobit model is compared to the Truncated Regression model, the latter appears to be less efficient but still a consistent estimator for model parameters with non-zero observations. If the predictor variables have different impacts when determining the probability of encouraging non-zero values and establishing the WTP amount, then the Truncated Regression model would be a better fit for capturing the predictor variables' effects on the WTP amount. However, the Tobit model is preferred as it makes use of information from the total sample while the Truncated Regression model highlights the impacts of the variables, especially compensation, on mean WTP (Skuza et al., 2015). We adopt the Tobit model (Morawetz et al., 2011; Skuza et al., 2015; Chege et al., 2019)

$$Y_i^* = X_i\beta + n_i, \text{and} Y_i = Y_i^* \text{ if} Y_i^* > 0$$

where Y_i is the value of ith observation on the bids made for OFSP puree products, regress, and variable (WTP) and Y^* is the corresponding latent value, explained by a set of regressors X_i; socioeconomic characteristics, knowledge, and perception of consumers on OFSP roots and puree products, institutional and other context-specific variables (Table 1). β is the unknown parameter and n_i is the error term.

Determining factors of WTP are related to behavioral, attitudinal, cognitive, and socioeconomic aspects (My et al., 2018). Information is a powerful influencer of consumer WTP. However, similarly, demographic characteristics of consumers play a significant role in the uptake and WTP for a product as discussed in the studies by Bett et al. (2013), Chege et al. (2019), Chowdhury et al. (2011), De Groote et al. (2018, p. 201), and Wang and Huo (2016). Knowledge and perception of a product and awareness of the nutritional benefits of a product by consumers too can have both positive or negative effects on consumer WTP for an enriched biofortified product (Akaichi et al., 2012; Bocher et al., 2016, 2019; De Groote et al., 2018; My et al., 2018; Rani et al., 2018; Chege et al., 2019). A few studies also show that information on reference prices of the conventional product relative to the improved product has an influence on consumer WTP (Depositario et al., 2009). Gender and generational differences in the uptake of OFSP puree products have not been investigated, to our knowledge. Men and women have different roles, interests, and priorities in the uptake of food innovations, technologies, or products during their life stages. Factors such as gender roles within a household, cultural attachments to food, and the level of education and employment status of household decision-makers, among other gender aspects, govern household food choices and consumption patterns (Wardle et al., 2004). Gender roles such as who allocates money for household food or buys and prepares food, among others, also influence food choices (Chikweche et al., 2012).

TABLE 1 Description of variables used in the regression analysis.

Explanatory variables	Variable definition	Expected Sign for *Willingness to Pay*
Socioeconomic variables		
Gender of the respondent	*1=male 0=Female*	+
Household size	Household size in count	-
Education level	Number of schooling years-respondent	+
Age	Age of the household head	-
Income category	Income classification of the respondent *1=low 0=mid*	+
Generation of the respondent	Generation classification *1=youth 0=Elderly*	
Product specific		
Used for weaning	Respondents use of sweet potatoes for weaning *1=Yes; 0= No*	+
Knowledge OFSP roots	Knowledge of OFSP roots *1=Yes 0=No*	+
Knowledge puree products	Knowledge of puree products *1=Yes 0=No*	
BDM treatment variables		
Nutritional Information	Respondent provided with nutritional information during BDM auction *1=Yes 0=No*	+
Reference prices	Respondent provided with pricing information of the conventional during BDM auction *1=Yes 0=No*	±

In the African context, women are primarily involved in decisions of food purchase, but the degree of men's financial contribution determines the quality of food the family can purchase (Ochieng et al., 2017). While gender aspects are important in traditional food choices and consumption patterns, the youth play an integral role in influencing the uptake of new foods. Presently, the youth are seen as key influencers, agents, and voices for change toward healthier eating. Youths we describe in our study are the men and women aged 18–40 years, who have access to various platforms, including social media, that provide information on the nutritional benefits of various foods, are flexible to trends, and are creative and innovative (Yavisha and Krishna, 2013).

3. Results and discussions

3.1. Characterization of the survey participants

Demographic characteristics of the sampled respondents play a significant role in understanding their knowledge and awareness

TABLE 2 Demographic characteristics of the sampled respondents per treatment category.

Variables	Sample	Treatment groups (%)			Pooled (948)	*F*-test
	N	Naïve ($n = 333$)	Nutrition ($n = 322$)	R* Prices ($n = 293$)		
Gender respondents (%)						
Male	417	45.65	41.30	45.05	43.99	0.72
Female	531	54.35	58.70	54.95	56.01	
Gender Household head (%)						
Male	705	74.17	73.60	75.43	74.37	0.14
Female	243	25.83	26.40	24.57	25.63	
Age respondent (years)	948	34.01 (9.56)	35.23 (9.84)	36.40 (10.72)	35.16 (10.06)	4.40**
Education respondent (years of schooling)	948	11.74 (2.81)	11.96 (2.56)	11.64 (3.04)	11.78 (2.80)	1.02
Household size (count)	948	3.52 (1.83)	3.43 (1.49)	3.53 (1.66)	3.49 (1.66)	0.37
Marital status (%)	948					
Single		32.13	23.91	24.23	26.90	2.98**
Married		57.06	62.73	63.82	61.08	
Separated/divorced		10.81	13.35	11.95	12.02	
Employment status (%)	948					
Self		67.27	62.42	65.87	65.19	1.38
Salaried		20.12	20.19	18.77	19.73	
Unemployed		12.61	17.39	15.36	15.03	

**$p < 0.05$; R, reference; Standard deviation in parenthesis.

of OFSP roots and puree products. While our study aimed to understand the *ex ante* demand for OFSP puree products, we characterize the survey respondents to further use the variables in understanding the determinants of WTP (Table 2). A one-way ANOVA test was done to test for significant differences in the means of the socioeconomic variables across the three treatment categories used in the BDM experimental auction: naive, nutritional information, and reference prices. There was a statistically significant difference ($p < 0.05$) among the age and marital status of the respondents across the naive, nutritional information, and reference prices clusters. While women respondents were more than men among those interviewed, the household heads were dominated by men, 74% on average. On average the respondents had attained 12 years of education while the average age was 35 years.

3.2. Gender dynamics in household OFSP purchasing decisions, consumption, and knowledge

To understand gender roles and respondents' familiarity with OFSP, respondents were asked about their involvement in food purchase decisions, knowledge, and consumption of sweet potatoes and specifically the OFSP. The results showed that more women were fully involved in food purchasing decisions compared to their men counterparts at 71 and 34%, respectively (Table 3). On whether sweet potato was used in weaning children, only 33% of women respondents and 22% of men respondents used the roots for weaning. Much of the reference when making sweet potato purchasing decisions in a household is given to all household members (54.32%), and household heads (33.9%), while children below 5 years rarely influence the consumption of sweet potatoes (1.9%). A photo catalog of different colored varieties was presented to the respondents to identify them accurately. When shown the pictorial reference codes for the sweet potato varieties and whether they had seen, heard, or consumed the OFSP, only 29.2% of the women and 27.1% of the men had knowledge of the root but lacked information about its nutritional benefits. Respondents aware of OFSP identified them as sweet (38.1%), healthy/nutritious while some said the OFSP roots were suitable for children. Further, the respondents who were aware of OFSP noted that sweet potatoes are used for weaning since they are nutritious (38.5%), and infants like them (37.4%). In this study, the yellow variety is the most common in weaning babies. The preference of yellow variety relative to other common ones such as the white variety could be a potential for the orange-fleshed ones if available as consumers relate the color with nutrition. Both men and women had mainly consumed OFSP as boiled; however, more women had eaten OFSP in baked or fried form (7.27%) than men (2.25%).

3.3. Knowledge and information pathways on OFSP roots and puree products

Street vendors (32.36%) are the primary source of sweet potato distribution to urban dwellers. Other sources include mobile and open-air sellers, hotels, or street vending kiosks (Figure 2). For

TABLE 3 Consumers' involvement in food purchasing decisions, knowledge, and consumption on OFSP and its products.

Variable	*N*	Women (%)	Men (%)	Pooled (%)	*T*-test/χ^2
Involved food decisions	518	70.62	34.29	54.64	124***
Fully partly	385	26.74	58.27	40.61	
Not involved	45	2.64	7.43	4.75	
Use sweet potato for weaning					
Yes	302	38.98	22.78	31.86	28.24***
No	646	61.02	77.32	68.14	
Knowledge on OFSP					
Heard of OFSP (general)					
Yes	268	29.19	27.1	28.27	0.5
No	680	70.81	72.9	71.73	
Know what about OFSP	**Freq**				
Healthy/nutritious	162	36.47	34.95	35.84	
Sweet	172	36.84	39.79	38.05	
Good for children	44	9.77	9.68	9.74	
Rich in vitamin A	32	7.14	6.99	7.08	
Used in baking	8	2.26	1.08	1.77	
Have eaten OFSP					

***$p < 0.01$.

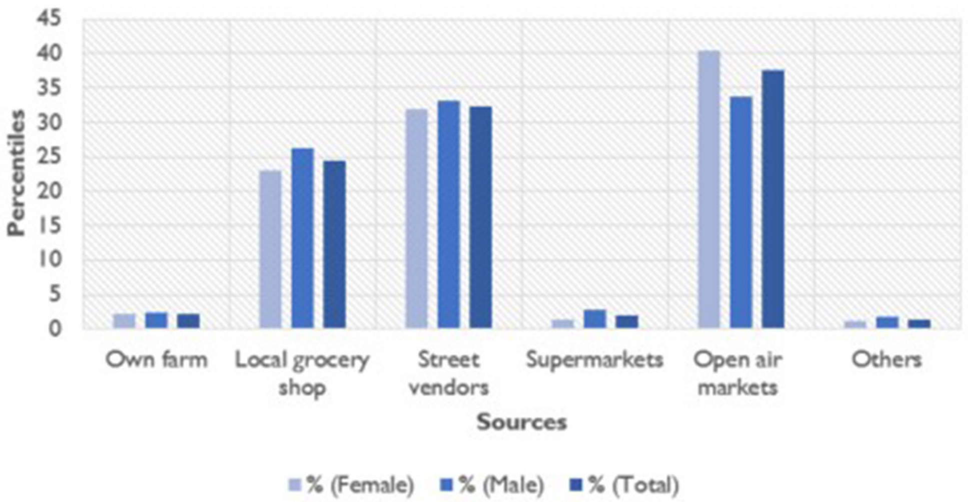

FIGURE 2
Sources of sweet potatoes among sampled respondents.

massive promotion of awareness of the nutritional benefits of OFSP, these sources could act as pathways and agents of change at the point of sale. Knowledge of OFSP puree products among women and men was low; only 17.7% of women and 15.1% of men have heard about them, and there was only an average of 16.6% of the sampled respondents had knowledge of OFSP puree products (Table 4). Family and friends were the major information pathways for OFSP according to the sampled respondents. Street vendors and local kiosks also disseminated knowledge on OFSP as 20.9% of the respondents learned about OFSP from them. To increase consumer knowledge of OFSP, more innovative pathways need to be explored, for instance, the use of digital spaces such as social media. Our recommendation conforms to a study by Oteh et al. (2020) that to scale up demand for biofortified products, awareness creation is key to improving communication networks. As such studies have shown that both mainstream and digital media spaces can enhance consumers' knowledge and decision making (Yavisha and Krishna, 2013; Pambo et al., 2014; Mwaisaka, 2017),

TABLE 4 Consumer information pathways of OFSP.

Variable	Frequency (Female)	% (Female)	Frequency (Male)	%(Male)	Frequency (Total)	%(Total)
Family/friends	75	48.39	61	53.98	136	50.75
Street vendors/kiosks	31	20.00	25	22.12	56	20.90
Mainstream media	16	10.32	7	6.19	23	8.58
Social media	3	1.94	2	1.77	5	1.87
Institutions	3	1.94	0	0.00	3	1.12
Workshops	2	1.29	1	0.88	3	1.12
Supermarkets	1	0.65	2	1.77	3	1.12
Others	24	15.48	15	13.27	39	14.55
Total	155	100.00	113	100.00	268	100.00

TABLE 5 OFSP puree products purchase decision in male- and female-headed households.

Buyer	% Female-headed HHs	% Male-headed HHs	% (Total)
Household head	19.35	45.16	64.52
Spouse	0.00	29.03	29.03
Female children	3.23	3.23	6.45
Total	22.58	77.42	100.00

coupled with banners and awareness programs within nutritional departments in state and non-state institutions, could lead to far fetching effects on consumer awareness of OFSP puree products and associated benefits.

While street vendors were the major source of OFSP roots, those who had eaten OFSP puree products bought them ready mainly from supermarkets (60%), indicating that puree products are not available in major informal markets targeted for urban poor consumers. A few also prepared the OFSP puree products at home by boiling and mashing the roots into a puree (20%). While consumers could have preferred making the puree products by themselves, the OFSP puree was not available on the shelves, it's therefore hard to deduce consumer preference between buying or preparing OFSP puree products. The unavailability of puree on the shelves limits consumer acceptability and use of nutritious food. Other respondents had eaten the OFSP puree products as gifts (15%) or as samples in promotions (5%) representing women alone which can be an indicative gap on potential pathways in increasing awareness and acceptability of the OFSP puree products.

The household head was the leading buyer of the OFSP puree products in both female (19.35%) and male (45.16%) headed households (Table 5). Most households were headed by men (74.2%). While literature shows that women are more involved in household food purchase decisions (Blitstein and Evans, 2006), our study finds that men play a significant role in the acceptability and purchase of OFSP puree products in that they are the actual buyers or financial providers. This finding resonates with a study from Tanzania (Ochieng et al., 2017) that men are influential in purchasing nutrition-rich food. Although women are influential in making food purchase decisions, with dominance in resource access and management, men can enhance their household consumption of nutritious foods if well targeted in consumer profiling. Women were however more involved in preparing the OFSP puree products at 91.7%. Hence their incentive, knowledge, and workload should be considered to promote OFSP puree.

To understand the consumption pattern of OFSP puree products, consumers were asked about the frequency of use. A majority of the respondents consumed several times a week presenting a market potential for OFSP puree products if availability and knowledge are enhanced. Results show that OFSP puree products were consumed since they were sweet and healthy as shown in Table 6. Limited knowledge and limited understanding of the nutritional components of OFSP is exhibited especially among women as only consumed them due to the rich content of VA and only about 10% said that it was suitable for children. Sensitizing and enhancing awareness of the importance of VA for children can be a great incentive for women consumers.

3.4. Consumer willingness to accept and WTP for OFSP puree products

OFSP puree products are highly accepted by both women and men at 91.7% and 90.3%, respectively, with no significant statistical difference between gender (Table 7). On inquiry on the level of WTP for the three products used in the experimental auction, more women (60%) were very willing to pay for OFSP puree products than their men counterparts (50%). Further analysis of WTP is presented from the results of the BDM auction.

3.4.1. Consumer WTP, estimation from the BDM experimental auction

Three treatment categories—naive, nutritional information, and reference prices—were used to assess the WTP for the OFSP puree products (a six-piece packet of buns, a whole piece of chapati, and 400 g loaf of bread) as presented in Figure 3. Across all the OFSP puree products and treatment categories, WTP was a premium. In the naïve scenario, the respondents were willing to pay more for the six-piece packet of OFSP puree buns at KES 61.20

compared to KES 53.50 for the same quantity of non-OFSP buns. Similarly, the consumers were willing to pay a premium for a piece of OFSP chapati and the 400-g loaf of bread. On the nutritional information treatment scenario, consumers were willing to pay a premium for OFSP puree-based buns, chapati, and bread at KES 62.30, 21.40, and 58.10 compared to KES 52.90, 13.70, and 50 for conventional wheat products respectively. The difference in WTP bids was statistically significant. Similarly, under the reference price treatment category, consumers were willing to pay a premium for OFSP puree-based buns, chapati, and bread at KES 60.80, 21.70, and 58.60 compared to conventional wheat at KES 54.60, 17, and 54.10, respectively. However, the price difference due to reference price was less than that due to nutritional information treatment.

We conducted one-way analysis of variance (ANOVA) to test if there was any statistically significant difference in the means of the OFSP WTP bid price of the same product across the three treatment categories as shown in Table 8. Across the three treatment categories, there was a statistically significant difference in bid price for chapati and bread ($p < 0.01$). This could be explained due to the popularity of the two products in the Kenyan consumer market, especially among the urban poor. Buns on the other hand may not be a popular product, especially for the low consumer segment which was the target respondents for this study. To test whether there were any differences in WTP between men and women, a t-test statistics test was done, and the results are presented in Table 9. On OFSP puree products, there was a statistically significant difference in the WTP prices for bread between men and women with women willing to pay more ($p < 0.01$). This result confirms that women value OFSP products and marketing strategies should consider women's preferences and needs. Bread is a typical food for breakfast in most households especially in urban and peri-urban areas, explaining the willingness to pay a premium price by women.

TABLE 6 Gendered consumption practices of OFSP puree products.

Variable	Women (%)	Men (%)	Pooled (%)
Reason eat OFSP puree			
They are sweet	32.22	32.76	32.43
They are healthy	25.56	22.41	24.32
Good for children	13.33	4.44	10.81
Rich in vitamin A	6.67	15.52	10.14
Liked by children	6.67	3.45	5.51
They are affordable/cheaper	6.67	12.07	8.78
Easy to use	3.33	1.72	2.03
Reduce baking costs	1.11	0	0.007
How often eat OFSP puree			
Rarely	51.43	48	50
Several times a week	22.86	28	25
Once a week	11.43	12	11.67
Every 2 weeks	8.57	8	5
Once a month	2.86	4	5
Every 3 months	2.86	0	3.33
Reason not eat OFSP puree			
Don't know where to buy	67.80	67.57	67.71
Not available in the market	8.47	8.11	8.33
Never heard	6.78	2.70	5.21
They are expensive	5.08	5.41	5.21

3.4.2. Determinants of WTP premium bids for OFSP puree products

We conducted a Tobit regression to understand factors attributed to consumer WTP for premium prices on VA-rich OFSP puree buns, chapati, and bread and make a generalizable conclusion. Data were censored to the left since the BDM auction didn't allow for hostile prices. Socioeconomic characteristics, knowledge of OFSP, income category, nutritional information, and reference prices were regressed against the bids made for OFSP puree products as shown in Table 10. The age of the respondent significantly but negatively influenced the WTP for buns at a 95% confidence level. The inverse relationship between age and WTP depicts that older generations are not willing to pay for unfamiliar products. The results conform to many studies on the

TABLE 7 Gendered consumers' willingness to use and pay for OFSP puree products.

Variable	N	Women (%)	Men (%)	Pooled (%)	Chi^2
Willingness to accept					
Yes	803	90.34	91.71	90.94	0.13
No	43	5.43	4.15	4.87	
Not sure	37	4.23	4.15	4.19	
Willingness to pay for OFSP puree					
Very willing	445	59.91	49.72	55.42	5.69**
Willing	331	36.97	46.61	41.22	
Not willing	2	0.22	0.28	0.25	
Not sure	25	2.90	3.39	3.11	

**$p < 0.05$.

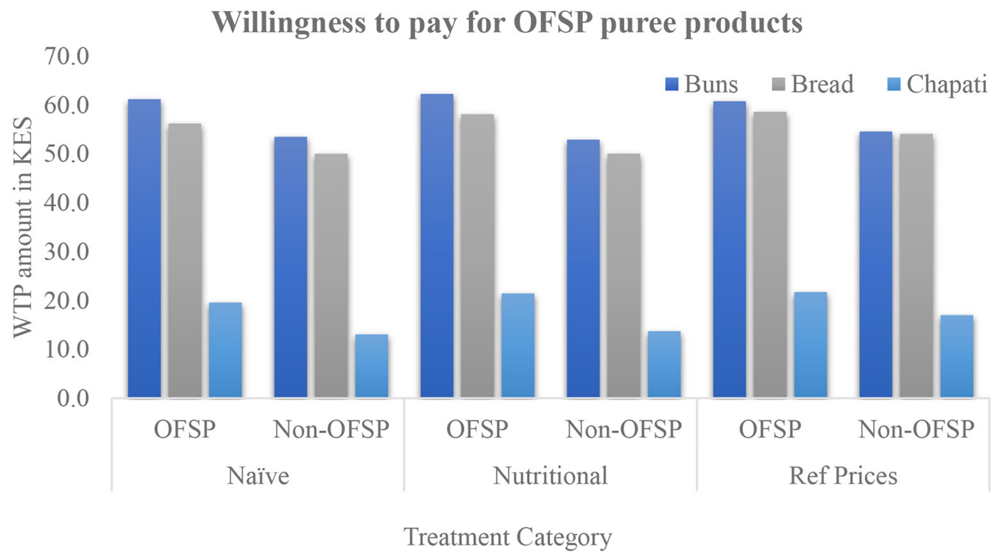

FIGURE 3
WTP for OFSP puree and non-OFSP products- BDM experimental auction of buns, chapati, and bread.

TABLE 8 A comparison of the WTP prices for OFSP puree and non-OFSP buns, chapatis, and bread in Kenyan Shillings.

OFPS puree products	Buns (F-test= 2.02)			Chapati (F-test= 4.32***)			Bread (F-test= 8.02***)		
Treatment	Naive	Nutr.	Ref.P	Naive	Nutr.	Ref.P	Naive	Nutr.	Ref. P
OFSP	61.10	62.30	60.80	19.60	21.40	21.70	56.20	58.10	58.60
Non-OFSP	53.30	53.00	54.60	13.10	13.70	17	50	50	54.10

***$p < 0.01$.

TABLE 9 Gender differences in the WTP prices among men and women on OFSP puree and non-OFSP buns, chapati, and bread.

OFPS puree products	Buns			Chapati			Bread		
Gender	Men ($n = 417$)	Women ($n = 531$)	T-test	Men	Women	T-test	Men	Women	T-test
OFSP	61.67	61.85	−1.42	21.22	20.43	1.55	57.17	58.11	3.2*
Non-OFSP	53.34	53.97	−1.53	13.98	14.90	1.97**	51.30	51.25	−0.25

**$p < 0.05$; *$p < 0.1$.

use of new products and innovations where a relatively older population is unlikely to try out new inventions Bocher et al. (2019) necessitating innovative product profiling and awareness programs. Education of the respondent on the other hand positively and significantly affects consumer WTP for both buns and chapati. Education level improves comprehension, interpretation, and access to information and therefore consumers who have better education could easily access and interpret the nutritional benefits of OFSP. Educated consumers are assumed to be aware of the nutritional attributes of OFSP puree products, and hence the willingness to pay more (Bett et al., 2013). However, most of our target consumers have limited educational attainment. Specific interventions for promoting OFSP are required to influence the decisions of this population.

The gender of the respondent negatively but significantly affects WTP for chapati. Being a male lowered the WTP for OFSP puree products. This could be explained by the nature of the food product which is mainly prepared by women. The inverse relationship further reveals gender norms and practices on household food decisions. To isolate the effect of gender on WTP, a regression analysis across the three treatments was done, and the results reveal that gender had a positive influence on WTP for OFSP puree chapati and buns only under the naïve scenario (Table 11). This could mean that other factors such as awareness of substitute product prices, and nutritional information about OFSP puree products overshadowed the effect of gender on WTP premium prices.

We grouped consumers into two categories, low- and mid-income consumers depending on their residence area. Consumers from the mid-income category were willing to pay for premium for OFSP chapatis; this presents a market potential for OFSP puree products while offering nutritional security to the vulnerable

TABLE 10 Factors affecting WTP for OFSP puree products.

Variables	OFSP Buns (n = 897)		OFSP (n = 897)	Chapati	OFSP (n = 897)	Bread
Coefficient		Std errors	Coefficient	Std errors	Coefficient	Std errors
Gender (1 = male 0 = female)	0.2951	0.6596	−1.5667**	0.7823	0.8833	0.5551
Age (years)	−0.1191**	0.0564	−0.0746	0.0669	−0.0732	0.0475
Income category (0= mid 1=low)	−0.3308	0.6526	1.8074**	0.7738	0.2030	0.5492
Generation (1= youth 0= Elderly)	0.6476	1.1597	0.2486	1.3762	0.2217	0.9760
Education (years)	0.2828**	0.121	0.3705***	0.1436	−0.0041	0.1018
Household size	−0.0282	0.2077	−0.1774	0.2462	−0.1528	0.1747
Used for weaning (1 = Yes 0 = No)	0.2237	0.7259	0.5365	0.8600	0.6322	0.6109
Knowledge OFSP roots*(1=Yes 0= No)*	0.4572	0.7732	−0.6650	0.9168	0.5531	0.6507
Knowledge puree products (1 = Yes 0 = No)	−0.1412	0.9169	−3.4877***	1.0960	1.0196***	0.7716
Reference prices (dummy)	−0.4305	0.8000	2.8353***	0.9480	2.3251***	0.6738
Nutritional info (dummy)	1.2926*	0.7663	1.9651**	0.9072	2.1102***	0.6449
Constant	61.1119	2.2058	17.4952***	2.6088	58.0158	1.8564
Sigma	9.5057	0.2247	11.1612	0.2944	8.0000	0.1890

***, **, and * represent significance levels at 1, 5, and 10%, respectively.

TABLE 11 Gender regressed effect on WTP for OFSP puree products across three treatment categories.

Parameters	Buns		Chapati		Bread	
Observations treatment	Coef	Std.err	Coef	Std.err	Coef	Std.err
Naïve (333)						
Gender constant	2.1245** 60.2044	1.072 0.7243	−0.9816 20.0276***	1.0819 0.731	1.9109** 55.326***	0.9325 0.63
Nutritional info (322)						
Gender	0.3732	1.1612	−1.6653	1.1063	0.6558	0.8352
Constant	62.1005***	0.7463	22.1164***	0.711	57.8254	0.5368***
Ref. prices(293)						
Gender	−0.1581	1.0026	0.5169	1.2310	0.2793	0.9506
Constant	60.8323***	0.6729	21.4907***	0.8263	58.4783***	0.6381

***$p < 0.01$; **$p < 0.05$.

poor in the society to whom food availability is supreme to nutritional security. The findings supplement the study by Bocher et al. (2019) on OFSP juices in Rwanda where mid-income consumers are explained to be more conscious of the nutritional contents of food products. Reducing processing costs and increasing demand are required to reduce the prices of OFSP products as low-income consumers cannot afford premiums, but they and their children are more likely to have nutritional problems.

Knowledge of OFSP puree products has a negative but significant influence on WTP for OFSP chapati but a positive effect on bread. While both chapati and bread can be eaten for breakfast, chapatis are ideally eaten for main meals, and their preparation method differs from bread. The negative correlation could be attributed to misconception and attitude on the taste and texture, which is debunked in our study through the nutritional information regression analysis. In all three OFSP puree products, nutritional information positively and significantly influenced the WTP. This further shows that knowledge alone is not enough to derive consumer WTP for relatively new products rather quality information is a key driver. The availability of reference prices leads to premiums on the WTP for both bread and chapatis, similarly to Akaichi et al. (2012) who found that providing reference prices of substitute products positively affects WTP for high-quality white beans. Nutritional information plays a significant role in determining the WTP of VA-rich OFSP buns, chapatis, and bread as shown in this study. Correspondingly, providing nutrition information had a positive and significant effect on WTP for the improved flour among the base of pyramid (poor) consumers in Uganda (Chege et al., 2019). Similarly, Bocher et al. (2019) found out that WTP increased when consumers were provided with the nutritional information that OFSP juices have the highest pro-vitamin A contents.

4. Conclusion and policy recommendation

The prevalence of VA deficiency in many sub-Saharan African countries persists decades after massive innovations and campaigns against it. OFSP has been proven as an effective solution to VAD. Incorporating OFSP puree in baked and fried products may benefit the poor and urban population since affordability of nutritionally adequate diets is a big challenge majorly for the urban-poor and peri-urban dwelling households. This study sought to understand the urban poor and mid income consumers' knowledge and practices on OFSP and OFSP puree-based baked and fried products and their WTP for the products. We mimicked a real market scenario by adopting BDM experimental auction to deduce bid prices for three OFSP based products; buns, chapati and bread.

Results depict great potential for OFSP and OFSP puree products, if the value chain is strengthened to ensure sustainability. However, knowledge of both OFSP roots is low among urban consumers; in this study, with only 29% and 27% of women and men respondents, respectively, are aware of OFSP and OFSP puree products. OFSP puree products were still not very popular with 18% women and 15% men having heard about them. The poor knowledge levels are explained by the unavailability of both roots and puree products in local markets. Most respondents that are aware of OFSP puree products learned from friends and neighbors revealing weak information pathways. The urban poor and mid consumers spend significant time working and may not have strong social capitals to act as information sharing networks therefore innovative communication channels to create awareness on OFSP nutritional benefits need to be explored.

Interestingly, though the low knowledge levels on OFSP puree products, 90% of women and 92% of men respondents were willing to use OFSP puree products once they have source information. Results from BDM bidding prices show that in all three treatment categories, namely, naive, nutritional information, and reference prices, consumers were willing to buy OFSP products at a premium. Under the nutritional information scenario, consumers were willing to pay 18, 56, and 16% more for OFSP buns, chapatis, and bread, respectively, relative to the 100% wheat product. The reference pricing scenario also triggered the intention to pay 11, 28, and 8% more for buns, chapatis, and bread respectively relative to the conventional wheat products. Women were willing to pay more for OFSP compared to men. Owing to the high acceptance and WTP level, the results depict great potential for OFSP puree products if the OFSP value chain is strengthened to ensure consistent availability and supply of puree to the local processors. The OFSP value chain is a sure path to Vitamin. Deficiency management and prevention among children below the age of 5 years while ensuring food and nutritional security to the most vulnerable population.

Regression analysis on drivers of WTP showed that women play a significant role in determining WTP. While the nutritional components of the OFSP are important to mothers, OFSP's nutritional value can be an excellent incentive for mothers if they have knowledge of the importance of VA for children. Since women play significant roles in preparing food, especially for children, enhancing women's knowledge and skills in OFSP puree food preparation is also important. Selling ready-made OFSP puree can also help women to save time. Men and women have different incentives, so we need to promote additional messages—women buy for their children—the message is that VA is important for children and OFSP is rich in VA, women also prepare food; thus, women's voices need to be reflected to develop new readymade OFSP puree and OFSP products. Age is a negative but a significant influencer of WTP although the generation variables (youths and elderly) were insignificant; older consumers are less likely to accept and pay a premium to comparable new products. Education was seen as a significant variable in determining WTP. Awareness campaigns could use more educated community members as agents of change to trickle down the knowledge to their fellows. The mid-income consumers were also willing to pay a premium compared to the low-income consumers, this stresses the need to profile products according to the market segments and to increase sensitization that nutritious products are not necessarily expensive. As presented in our study, offering reference prices and nutritional information is a sure way to enhance *ex ante* demand.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CW, AN, RS, MM, TM, and NK were involved in the contextualizing and designing of the study. CW and AN were involved in data collection, cleaning, analysis, and drafted the first manuscript. All authors critically reviewed and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Opportunities for higher education institutions to develop sustainable food systems in Africa

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An African Vice-Chancellors' Regional Food Systems Dialogue was hosted with the aim to provide a multi-stakeholder platform for stakeholders to explore various existing and emerging approaches that have the potential to deliver sustainable solutions at scale and encourage collaborative actions to directly transform Africa's agriculture and food systems. Various food system experts and leaders from policy research institutions, universities, and other stakeholders participated. A lack of coherent linkages among stakeholders, youth restlessness, and silos within and between higher education institutions were some of the challenges identified to hindering the much needed transformation. Poor links with ministries and political red tape, inadequate programme funding and capital for coping with rising input costs, as well as unsustainable resource mobilization were also reported as having a negative effect. To address these, stakeholders must embrace collaboration and transdisciplinary practices, mobilize resources, and harness partnerships for greater leverage. In addition, a systems-thinking approach to dealing with complex issues should be adopted, while partners co-design and co-create research initiatives. Information and Communications Technology (ICT) and Big Data were identified as key enablers that can ensure relevant research with appropriate translation into practice while maintaining quality and excellence. This research—together with society-relevant curriculums with emphasis on agricultural sciences and practical on-farm skills—must inform policies and practice. Higher education institutions must be committed to driving the sustainable food system transformation agenda in partnership with other stakeholders. Institutions must be at the forefront of reimagining the sector's role when it comes to transdisciplinary knowledge co-creation aimed at strengthening the continent's agro-food systems.

KEYWORDS

sustainable food systems, higher education, transdisciplinary research, agriculture, partnerships and collaborations

1. Introduction

In order to ensure sustainable food security for all, the food system must be linked to nutrition and health outcomes. Agriculture provides for the primary sources of energy and essential nutrients, while simultaneously creating sustainable livelihoods. Yet agricultural activities often face many challenges due to population growth, urbanization and climate change, which threaten the availability of water, land and other natural resources (FAO, 2017). On the other hand, current farming practices has significant impact due to agro-chemical pollution, desertification, deforestation, eutrophication, biodiversity loss, and land degradation. Many of these are linked to intensive crop monocultures and industrial-scale feedlot production. Agriculture, forestry and other land uses are responsible for at least one-third of all global anthropogenic greenhouse gas emissions, and may be the world's greatest contributors to climate change (IPES-Food, 2016).

In 2021, nearly 2.3 billion people in the world were moderately or severely food insecure, with Africa the most vulnerable. Recent data suggest that around one in five people in Africa (20.2 percent of the population) was facing hunger in 2021 with a rising trajectory. The lingering Covid-19 pandemic and the war in Ukraine will have negative implications on food security and nutrition for many countries on the continent (FAO et al., 2022).

Transforming Africa's agriculture and food systems is an opportunity for higher education institutions to contribute to improved health and livelihoods. Sustainable and resilient food systems provide sufficient, safe, nutritious, culturally appropriate, and consumer-driven food for modern-day Africa while empowering graduates and researchers to demonstrate research excellence.

2. African Vice-Chancellors' Regional Food Systems Dialogue

An African Vice-Chancellors' Regional Food Systems Dialogue was hosted on 9–10 March 2021 by the African Universities Research Alliance (ARUA) Center of Excellence for Sustainable Food Systems (ARUA-SFS[1]) GCRF/UKRI[2] CaBFoodS-Africa[3] project under the auspices of the University of Pretoria in collaboration with the University of Nairobi and the University of Ghana, Legon. It was registered as an independent dialogue under the UN Food Systems Dialogues. The dialogue provided a platform for multiple stakeholders to explore various existing and emerging approaches that have the potential to deliver sustainable solutions at scale and encourage collaborative action to directly inform the United Nations Food Systems Summit process.

The Food Systems Dialogue program featured a plenary session and four parallel African geographical regions (Eastern, Northern, Southern and Western Africa) break-away sessions. The dialogue provided time and space for informal discussion groups, enabling participants to engage fully. Social media, including Facebook, Twitter, and YouTube, formed part of the communications strategy to promote the dialogue as well as disseminate proceedings and outcomes.

The Vice-Chancellors were joined by selected representatives of the scientific committee, food systems academics, policy experts, and the participants from the regional food systems dialogue to construct the message and shape pathways to sustainable food systems that will inform African universities' contributions to the 2021 UN Food Systems Summit.

The curators and convenors emphasized the importance of respect throughout all processes and chose prominent leaders to be the facilitators at each regional dialogue. This high-level colloquium, with 15–20 participants per region respectively, formed part of a process to synthesize the key messages from African universities to be delivered at the 2021 UN Food Systems Summit by the nominated special envoy. Official Dialogue Feedback were given to the United Nations 2021 Food Systems Summit (https://summitdialogues.org/dialogue/4137/). Various food system experts and leaders from policy research institutions, universities, farmer organizations, agri-business, agricultural financiers, civil society, policymakers, and oversight bodies representing 247 different institutions from 62 countries participated.

The dialogue focused on key constraints, key opportunities, much needed partnerships, required skills and capabilities and governance issues of higher education institutions to play a role in the transformation of Africa's agriculture and food system.

2.1. Key constraints identified that affect transformation toward a more sustainable system

A lack of coherent linkages among stakeholders, youth restlessness, and silos within and between higher education institutions affect multi-stakeholder engagement, while poor links with ministries and political red tape regarding the redirection of food waste affect political support. Capacity building is made difficult due to the limited time or opportunities for university staff to do research, student training that is not focused on interdisciplinary skills production, and limited funding for the high-tech facilities required for skills development causing a student skills gap. Poor identification of data gaps, uncoordinated resource mobilization and poor flow of information produce an information gap, while inadequate program funding, inadequate capital for coping with rising input costs, and unsustainable resource mobilization affect resource management.

2.2. Key opportunities for transformed, sustainable food systems

Adoption of a systems thinking approach to dealing with complex issues is necessary, while co-designing and co-creating research initiatives, and embracing diversity and inclusivity. Information and Communications Technology (ICT) and Big Data must be harnessed as critical enablers, which will ensure ongoing relevance of research with appropriate translation into practice, while maintaining a continuous pursuit of quality and excellence. Guiding principles should be tested frequently against evolving issues. Invest in diversification of agricultural production and consumption to curb the double burden of malnutrition. Research must be effectively translated into informed policies and practices, society relevant curriculums with emphasis on agricultural sciences, while embracing practical on-farm skills. Cross-disciplinary training focusing on the whole food supply chain, from production to consumption, so that agricultural

1 ARUA-SFS: African Universities Research Alliance Center of Excellence for Sustainable Food Systems.

2 GCRF/UKRI: Global Challenge Research Fund/UK Research and Innovation.

3 CaBFoodS-Africa-project: Capacity Building in Food Security project.

extension and marketing, processing and digital innovation can be brought together.

2.3. Partnerships are needed to unlock these food system transformations

Partnerships are needed in the areas of research and innovations, with a multidisciplinary and training focus, to increase agricultural productivity, mechanization and technology-driven value chains. Partnerships should seek opportunities for research and collaboration, including local, regional and international collaboration, investing in diversification of agricultural production and consumption, and emerging structure to break silo's between institutions but also within an institution. Opportunities for funding will benefit resource mobilization, while research opportunities and capacity building will be benefitted through transdisciplinary research teams, university sharing, global nutrition summits, opportunities for business, research and collaboration, the availability of skilled and unskilled labor, linking universities, agricultural colleges, and attempting new forms of cross-disciplinary training focused on food supply chains and production systems together. Partnerships should be mutually beneficial and have equal engagement, in order to aid in unlocking the food system transformation. South-South-North partnerships and public-private partnerships with the support of governments would also be beneficial. An approach to dealing with complex issues should be adopted, while partners co-design and co-create research initiatives.

Stakeholder engagement through universities connecting with communities to address food system challenges, and with farmers in rural areas to ensure relevant research would benefit such partnerships, as well as leveraging technology to enable connection, and linking universities, extensions and end users. Implementation of food gardens at home and within communities, as well as the use of university food tunnels to feed students of the university during Covid-19 and onwards are examples of how research and infrastructure can create opportunities within communities.

2.4. Skills and capabilities that universities need to provide to its researchers and students to navigate, trigger and steward complex food system transitions

Development of networking capabilities through collaboration skills, critical thinking, problem solving and communication skills, open-mindedness and adaptability to inform change is necessary for researchers and students alike. T-shaped skills which involve knowledge, skills and collaborative workmanship, is valuable within different stakeholder groups. Entrepreneurial skills, in particular, for youth, young women and mothers, as well as co-creating innovation or solutions to respond to community needs are a more examples of skills and capabilities that the university can provide to people and communities to aid in the transition toward sustainable food systems. It is essential to build skills on how to integrate teaching, research and service to community with a focus on applied research rather than basic research, in view of the transition we want to achieve. Digital innovation and application of technology can also be used to tackle the complex problems, helping to scale-up agricultural productivity and accelerate food security.

2.5. Challenges of traditional university governance systems to respond to the transformation of the food system

Various challenges to traditional university governance systems to respond to the transformation of the food system exists. Universities are known to be slow to respond to challenges and do not provide community solutions. Most universities are public institutions; therefore, their policies are aligned toward the political agenda of the current government, and have no absolute academic freedom. A lack of academic freedom and silos of disciplines within universities affect inclusivity. Limited funding for the high-tech facilities required for skills development, minimum effort to move toward sustainability science, limited time or opportunities for university staff research, and student training that is not focused on interdisciplinary skills production form part of the capacity building challenges.

3. Discussion

The dialogue clearly highlighted the opportunity for higher education institutions in transforming African agriculture and food systems for improved health and livelihoods with shared prosperity, and providing sufficient, safe, nutritious, culturally appropriate and consumer-driven food for 21st century Africa, while empowering graduates and researchers to demonstrate research excellence.

As universities strengthen critical thinking, teaching, and produce multidisciplinary research on sustainable agricultural practices, students, government decision-makers, and farmers will be able to make informed decisions based on reliable scientific evidence (Ferrand and Nelles, 2021). Curriculum re-design is necessary taking into account the needs of the society, but also the needs of the students and future adults. Universities have a crucial role to play in sensitizing students to think about the food systems they want to support as part of their daily food choices. Therefore, students need contextual knowledge and specific skills, such as critical and creative thinking, skills to handle complexity and change (Migliorini et al., 2020).

A long-standing problem of accurate data collection in developing countries is often cited as a challenge in achieving development goals aimed at poverty and hunger reduction. The sharing of information and data on agriculture and nutrition is supported and encouraged by the Sustainable Development Goals (SDGs), but recent research indicates knowledge gaps between agriculture and food systems, and how to translate this data into insights and action. Higher education institutions needs to invest in information, communication and technology (ICT). Harnessing big data and ICT can unleash the potential of Africa's crops, improve African herds and provide Africa with safe, sufficient, nutritious, consumer-driven food (Sharma et al., 2020). Also, recent challenges in the monitoring of the SDGs with evidence-based solutions increased the demand to harness big data and exposed the need for new and innovative datasets to support sustainable development. The use of machine learning and computer models can facilitate the collection of poverty statistics that previously would have taken too much time and money (Burke and Lobell, 2017).

Higher education institutions must be committed to drive the sustainable food system transformation agenda in partnership with all stakeholders, as well as reimagining the role of universities for transdisciplinary knowledge co-creation. Emphasis must be placed on transformational approaches and solutions for a broader societal interest, embracing collaboration and transdisciplinary practices, protecting biodiversity and indigenous knowledge systems, mobilizing resources, and harnessing partnerships for greater leverage. There is a need to reorient the institutional capacities to better align with the change in research focus toward sustainable practices.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below:https://summitdialogues.org/dialogue/4137.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Food safety in the horticultural sector in Ghana: challenges, risk factors and interventions

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The fruit and vegetable industry remains one of Ghana's most promising agricultural sectors mainly because of heightened awareness of the health benefits associated with their consumption. However, food safety is of ultimate concern due to the association of foodborne hazards resulting in escalation of foodborne illness. This report is a review of key foodborne hazards in Ghana's horticultural value chain. The study identified the risk factors and hazards that contaminate fruits and vegetables in addition to existing methods for mitigating health risks and reducing pathogen levels in the produce. The study revealed that enteric pathogens such as *Escherichia coli* and *Salmonella* spp. mainly contaminate produce through fresh manure and contaminated irrigation water used during the production of vegetables. Chemical hazards identified included pesticides (organochlorine pesticides) and heavy metals such as cadmium, arsenic, chromium, and lead. Physical hazards identified included twigs, roots, sand, and stones. Washing fruits and vegetables thoroughly with potable water and sanitizing with vinegar and Chlorine solutions were among the common practices stakeholders adopted to reduce microbial levels. Soil remediation was also reported as a common approach for reducing chemical contaminants in agricultural fields. The study, therefore, recommends establishing a traceability system as well as appropriate measures and standards for hygienic practices for fresh fruits and vegetables produced and sold on the local market in Ghana. Value chain actors should be sensitized regularly on measures and interventions that can be employed to significantly reduce the levels of foodborne hazards and associated risks.

KEYWORDS

food hazards, food safety & quality, fruits and vegetables, foodborne illness, health risk, horticultural value chain

Introduction

The fruit and vegetable industry remains one of Ghana's most promising agricultural sectors, mainly owing to the heightened knowledge of the health benefits linked to their consumption. The sector is also supported by a vibrant export industry—a motivation for increased production due to the financial rewards. It also creates jobs for the youth as well as the vulnerable and marginalized members of society. There is a steady increase in consumption and utilization of fresh cut and packaged fruits and vegetables in Ghana and globally due to ease of accessibility and an awareness of the immense health and nutritional benefits (Nwachukwu and Osuocha, 2014; Balali et al., 2020). High consumption rates of sliced fruits, particularly, pawpaw, pineapple, watermelon, apple, and mango have been observed and this increase in consumption has boosted cultivating and trading of fruits and vegetables in many countries including Ghana.

Although the consumption of fruits and vegetables has many benefits, food safety is still of great concern owing to poor pre and postharvest handling. Such poor practices result in the contamination of produce with foodborne hazards, which when consumed result in an escalation of foodborne illness (Olu-Taiwo et al., 2021). According to an FAO/WHO report, out of the 1,400 microbial species responsible for contaminating food, 58% were identified as zoonotic which included *Listeria monocytogenes*, *Salmonella*, and *Escherichia coli* O157:H7. These three pathogens have been isolated from a wide variety of fresh produce and have thus been classified as among the most important pathogens of concern when it comes to the safety of fresh produce (FAO and WHO, 2008). In recent decades, several foodborne outbreaks associated with the consumption of fresh produce contaminated one of these pathogens have been reported in several countries around the world. In 2021, the United States alone reported outbreaks of *L. monocytogenes*, *S. typhimurium*, and *E. coli* O157:H7 associated with the consumption of pre-packaged salads (CDC, 2023; accessed 05/09/2023).

Chemical and physical hazards are also of concern when it comes to fresh produce safety in Ghana. It has been noted that chemical contaminants are introduced in fruits and vegetables *via* various routes such as from chemicals that are used during production, postharvest handling, sewage water, cattle manure, inorganic fertilizers, limes, pesticides, natural geological anomalies, mining activities, and industrial wastes (Norton et al., 2015). Chemicals such as pesticides, antibiotics, heavy metals, food additives, grease etc. have been found to be unsafe at high levels resulting in acute toxic responses and chronic illnesses. Physical hazards include glass and sharp objects, packaging, wood, metal, personal effects, residual soil and stones, foreign matter collected during harvesting, etc.

Over the years, studies, including epidemiological investigations, have been conducted in Ghana to understand the microbial pathogen situation as well as the physical and chemical contaminants associated with the fruit and vegetable value chain. To fully understand the magnitude and nature of the problem, a desk review was conducted to harmonize all the information gathered over the years. The aim was to provide an overview of the food safety situation in the country. The following objectives were adopted for the review: (i) identify key microbial pathogens, chemical and physical contaminants associated with horticultural produce in Ghana, (ii) determine the risk factors that influence microbial pathogens, chemical and physical contaminations of horticultural produce, (iii) identify available interventions used by actors to mitigate the risk factors and also reduce the levels of contaminants on horticultural produce, and (iv) to identify gaps, if any, in information obtained from the review.

Microbiological hazards

Pathogens that contaminate horticultural produce originate from various sources such as irrigation water, organic manure, poor postharvest handling, etc. In Ghana, it is observed that both contaminated irrigation water and organic manure that are not properly treated are applied on crops especially vegetables right before harvest. Studies conducted in Accra and Kumasi in Ghana (Cornish et al., 1999; Drechsel et al., 2000; Mensah et al., 2001; Keraita et al., 2002) have confirmed that most horticultural produce are contaminated using fresh poultry manure and also with contaminated irrigation water with fecal coliforms that exceed the WHO recommended level of 1×103, $100\,\text{mL}^{-1}$ for unrestricted irrigation. Handling, especially during harvesting, slicing and transportation where good sanitary standards (such as washing with potable water) are lacking also results in the contamination of produce (Olu-Taiwo et al., 2021).

In a 2008 report by FAO/WHO, *Salmonella* spp., *Shigella* spp., *E. coli*, *Campylobacter* spp., *Enterobacter sakazakii*, *E. cloacae*, *Entamoeba coli*, *Cryptosporidium* spp. were microbes that had been isolated from leafy green vegetables and green onions in Ghana. Enteric pathogens such as *E. coli* and *Salmonella* are of great concern in food safety and food-related outbreaks because several illnesses have been linked to the consumption of vegetables grown in soil fertilized with contaminated manure or sewage (Beuchat, 1998; Buck et al., 2003). Contaminated water used for irrigation and poor worker hygiene (handling of fruits and vegetables by infected fieldworkers) have also been identified as probable causes of contamination.

A study carried out in the Tamale in the Northern region of Ghana indicated contamination of 96.7% of lettuce samples with *E. coli* and *Bacillus cereus* was found in 93.3% of ready-to-eat vegetable salads (Abakari et al., 2018). *Salmonella* spp. and *Shigella* spp. were also present in 73.3% and 76.7% of salads, respectively.

In another study conducted in the Kumasi Metropolis in the Ashanti region, fresh-cut mixed vegetable samples collected from 270 sources were found to be contaminated with total coliforms and *E. coli* (Abubakari et al., 2015). Out of the samples tested, *E. coli* O157:H7 was detected in three (3) of the samples meaning there was a prevalence of 1.1%. Although, the prevalence is low, it still indicate that *E. coli* O157:H7 is still a major public health concern especially for ready-to-eat mixed vegetables.

Cabbage, carrots and scallions sold on the Abura and Kotokuraba markets in the Cape Coast Municipality (Central Region) analyzed for foodborne microorganisms tested positive for *E. coli*, *Enterobacter* spp., *Klebsiella* spp., *Salmonella* spp., *Serratia marcescens*, and *Staphylococcus*, as well as fungi of the genera *Aspergillus*, *Candida*, *Fusarium*, *Penicillium*, and *Rhodotorula* (Yafetto et al., 2019).

Abass et al. (2016) conducted a study with urban and peri-urban vegetable farmers in the Kumasi Metropolis and documented that all eighteen (18) vegetables samples were highly contaminated with *E. coli* and total and fecal coliforms.

Table 1 shows the key microbial pathogens that have been associated with horticultural produce in Ghana.

Among the key pathogens isolated from fruits and vegetables, the most recurring pathogens were *E. coli* and *Salmonella* spp.

Risk factors that influence the contamination of horticultural produce with the microbial pathogens

Contamination of horticultural produce with microorganisms can occur at any stage along the supply chain. The two broad

TABLE 1 Key microbial pathogens isolated from fruits and vegetables in Ghana.

Type of pathogen	Pathogen	Produce
Bacteria[a]	*Citrobacter koseri* *Citrobacter* sp. *Enterobacter* sp. *Klebsiella pneumoniae* *Klebsiella* sp. *Proteus vulgaris* *Pseudomonas* sp. *Staphylococcus aureus* *Staphylococcus epidermidis* *Listeria monocytogenes* *Salmonella enterica*	Cut watermelon, Cut pawpaw
	Salmonella sp. *Listeria monocytogenes* *Escherichia coli* O157:H7 *Erwinia carotovora*	Cut lettuce, cabbage Green Onions
	Pseudomonas fluorescens *Pseudomonas aeruginosa*	Cut watermelon, cut pawpaw

[a]Olu-Taiwo et al. (2021).

categories noted for contaminating fresh produce are from pre-harvest and postharvest sources (Gil et al., 2015). Some preharvest activities that result in the contamination of fresh produce relate to the soil in which fruits and vegetables are grown, water used for irrigation, water used to apply pesticides, feces, dust, and human contact with the produce at various points during the production process. Postharvest sources of contamination include human and animal feces, equipment used in harvesting and processing produce, poor postharvest handling of produce, insects, wild and domestic animals, por transportation methods, dust and water used in washing produce (Gil et al., 2015).

Organic fertilizers

Organic fertilizers, such as manures and slurries from animal sources (Beuchat, 1996; Natvig et al., 2002), wastes obtained from abattoirs (Avery et al., 2005) and sewage sludge (Al-Ghazali and Al-Azawi, 1990) which are applied directly to crops on the field contaminate the produce and the run-off may contaminate irrigation water which is later used to irrigate the produce. Organic manure which sometimes contain fecal matter harbor pathogens and crops that are very close to the ground, like lettuce and cabbage, easily get contaminated when it is applied to them. During watering, organic manure can splash unto vegetables close to the ground, contaminating them.

Irrigation water

Water sources used for irrigating fresh produce are usually contaminated with enteropathogens found in fecal matter, soil and run off from production fields as well as sewage overflow. Wastewater is used in many countries both developed and developing; however, the difference is that in developed countries they are treated before being applied to crops. In the United Kingdom, according to Tyrrel et al. (2006), surface waters that receive treated sewage effluent provide 71% of irrigation water. In developing countries such as Ghana, when wastewater is used to irrigate crops, the risk of pollution *via* irrigation water is higher since the water is usually untreated. Wachtel et al. (2002), reported that *E. coli* was isolated from cabbage roots irrigated with sewage-contaminated stream water but it was noteworthy that the edible parts of the cabbage were not contaminated. According to Islam et al. (2004), carrots and radishes at harvest tested positive for *S. typhimurium* when a single application of inoculated water was used to irrigate the produce. *Salmonella* was isolated from the soil 203 days after the inoculated water was applied to the produce and into the soil. In a similar study, lettuce plants irrigated with water inoculated with *E. coli* O157:H7 tested positive for *E. coli* O157:H7 during harvest which was 30 days after inoculation. Solomon et al. (2002) demonstrated that irrigation water polluted with *E. coli* O157:H7 is likely to penetrate and move to the edible sections of the plant through the vascular system.

Soil

Pathogens such as *Listeria* spp. can naturally be found in soil or can be introduced into the soil through the use of organic fertilizers (Nicholson et al., 2005). When heavy rain or water gun irrigation causes splashing on leaves, pathogens in the soil can directly contaminate crops. Bhunia (2018) confirmed that lettuce can become contaminated with *E. coli* O157: H7 through exposure to contaminated soil and irrigation water. He indicated that the pathogen can remain on the plant throughout the life cycle of the plant and can be transmitted to humans who consume the crop after harvest.

Handling practices

Several studies have found that washing, handling and storage of fresh fruits and vegetables are major sources of microbial contamination with microbial hazards, however, it a real connection between contamination of fresh fruits from handling practices and outbreak of foodborne illnesses has not be fully established (Amoah, 2014; Acheampong, 2015; Amoah et al., 2018; Ankar-Brewoo, 2018). During processing, packaging and distribution, fruit handlers often use their bare hands in handling fruits such as mangoes. As a result, many mangoes in the country have been reported to be infected before marketing which can result in food-borne illnesses if not properly washed before being consumed (Boateng, 2016).

Methods used by value chain actors to mitigate risk factors and reduce levels of pathogens

Washing with water

A common conventional method for reducing microbial contamination of fruits and vegetables is by washing them with pipe borne/tap water. Although water is useful in reducing the contamination of fruits and vegetables, it can also transfer pathogenic microorganisms through cross-contamination of other clean produce when the same water is used in washing both clean and contaminated produce (Banach et al., 2015). In Ghana, washing of vegetables is mostly done using readily available water bodies such as streams and ponds near the production or retailing locations (Acheampong, 2015). Washing fresh produce using running water is usually not a common practice amongst farmers and retailers. Produce is usually washed in containers filled with water by farmers and fresh produce vendors. The obvious concern is that the water is reused for several cycles thereby fresh produce is contaminated because of the dirty water used (Acheampong, 2015).

Washing with sanitizers

Washing with disinfectants such as benzalkonium chloride, peracetic acid, hydrogen peroxide and calcium hypochlorite produces favorable outcomes in microbial risk reduction because it maintains water quality, especially when removing soil and debris during the processing of fresh-cut produce (Samadi et al., 2009). Compared to washing fresh produce with water, sanitizing solutions are very effective in reducing microbial levels in the produce after washing, however, when produce is stored, epiphytic microorganisms have been observed to grow rapidly and can reach similar levels in produce washed with plain water. In this regard, studies in some European countries have advocated for the use of potable water for washing fresh cut vegetables instead of using water containing chemical disinfectants (Gil et al., 2009). According to Ölmez and Kretzschmar (2009), the use of sodium hypochlorite in washing fresh produce is believed to adversely affect the environment and has been suggested to be associated with occupational and operational hazards and may have cumulative adverse effects on humans. Novel technologies which would be more effective and safer is therefore very necessary to explore microbial risk reduction.

Washing with organic acids

Organic acids such as citric, acetic, and sorbic acids are known to reduce microbial levels depending on concentration of the acid used and the exposure time. Karapinar and Gonul (1992) and Beuchat (1998) reported significant reductions in microbial populations on fruits and vegetables when varying concentrations of acetic, citric and sorbic acids in water was used to wash the fresh produce. It has been observed that a 2% increase (0.5%–2.5%) in the concentration of acetic acid solution used in washing fruits and vegetables resulted in a reduction in microbial load from 15% to 82%. Previous studies by Beuchat (1998) also revealed that parsley leaves dipped in varying concentrations of acetic acid resulted in a 3 to 6 log10 reduction in the number of aerobic bacteria.

Chemical hazards

The review determined the key chemical contaminants of fresh agricultural produce to be pesticide residue/pesticide poisoning and heavy metal accumulation.

Pesticides

Pesticides are used in controlling insect pests and diseases in fruits and vegetables and human exposure to these pesticides above acceptable limits has been linked to the incidence of diseases such as immune dysfunctions, respiratory and neurobehavioral disorders (Bempah et al., 2011a). Fruits and vegetables grown and sold in Ghana are often exposed to chemical hazards, especially organochlorine pesticides (OCPs). It has been established that they can pose risks to consumers' health.

According to Dinham (2003), a high percentage of farmers in Ghana (87%) use pesticides during production to combat pests and diseases on horticultural produce. The types of pesticides used widely by farmers on their vegetables farms were as follows: herbicides (44%), fungicides (23%), and insecticides (33%) (Ntow, 2005).

A study by Asiedu (2013) detected pesticide residue at 52%, 40%, 45%, and 48% on lettuce, garden eggs, pineapples and mangoes, respectively. Less than half the number (39.2%) of fruits and vegetables sampled had no trace of the pesticides of interest; 51% showed trace levels of the pesticides and these were below the maximum residue level (MRL) and 9.8% of the samples had levels that were above the MRL.

The difference in the concentration of pesticide residue observed in the study could be attributed to the types of fruits or vegetables as well as the different agronomic practices carried out by farmers. The average residue concentrations for organophosphates, synthetic pyrethroids and organochlorine ranged from 0.01 to 0.45 mg/kg, 0.01 to 0.30 mg/kg and 0.01 to 1.27 mg/kg, respectively (Bempah et al., 2012; Asiedu, 2013). These residue levels exceeded the MRLs recommended by FAO/WHO. Analysis of four different produce for heptachlor showed that the level of this pesticide far exceeded the reference doses. This therefore indicates that heptachlor may be of public concern with great potential for systemic toxicity to consumers in Ghana. The most common and frequently used pesticides (organochlorine, organophosphate and synthetic pyrethroid) were Lindane, chlorpyrifos and cypermethrin, respectively (Bempah et al., 2012; Asiedu, 2013).

Pesticide poisoning has been reported in Ghana as a result of human ingestion of pesticide-contaminated food commodities. In a report by Gerken et al. (2001), three children died after consuming fruits containing high residues of carbamates in Ghana. Darko and Akoto (2008) detected pesticide residue in pepper, tomato and eggplants when samples were analyzed from farms in Kumasi. Bempah et al. (2011a,b) also detected similar pesticide residue in pawpaw, tomato, apple and other fruits and vegetables samples from the Accra and Kumasi Metropolis. The pesticide residues detected in both cases included Chlorpyrifosmethyl, Chlorpyrifos, Dichlorvos, Dimethhoate, Malathion, Monocrotophos, Omethioate, Parathion-methyl, Parathion, γ-HCH, δ-HCH, Heptachlor, α-endosulfan, β-endosulfan, p,p'-DDE, Endrin, o,p'-DDT, Endrin aldehyde, p,p'-DDT, and Endrin ketone.

Heavy metals

Soil contamination by heavy metals is often restricted to the surface of the soil and it also depends on the soil texture and the level of anthropogenic activities or land use. The key heavy metals encountered in the horticultural industry in Ghana include arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), manganese (Mn), nickel (Ni) and lead (Pb) (Lente et al., 2014; Fordjour, 2015). According to Bempah et al. (2011b), the most common heavy metals detected in fruits and vegetables in Ghana are lead (Pb), cadmium (Cd), and chromium (Cr). The highest levels of Pb and Cd were detected in lettuce, although these levels were below the permissible limits set by (WHO/FAO). However, it is important to take note of the adverse health risks that their cumulative effects are likely to cause. Soil amendments can be made to contaminated soils to reduce the toxicity of heavy metals in the soil before using them for farming.

Addae (2015) sampled 479 vegetables in the farm and market sites within the Accra Metropolis. From the study, it was observed that all the vegetables sampled were contaminated with at least two (2) or more heavy metals. He reported that with reference to the European Union guideline values, a higher percentage had heavy metal values above the limits while only 18.99% of the samples had metal detections below the limits. Vegetables sampled from Mallam Attah Market and the Ghana Broadcasting Corporation (GBC) sites (both sites in Accra) recorded the highest levels of heavy metals (100). Higher levels of heavy metals were also detected in vegetables at the point of sale compared to the production sites farms except for As, Cd, Co, and Fe. The highest concentrations of nickel and chromium (1.236 and 2.459 mg/kg respectively) were detected in lettuce sampled from the markets whilst at the farm sites the metals were undetected.

In a similar study, Lente et al. (2014) discovered that concentration levels of heavy metals (mg/kg) in vegetables analyzed were not elevated except for Pb in cabbage (10.51), lettuce (10.19), green pepper (9.44), hot pepper (7.61) and ayoyo (9.05). These levels far exceeded the FAO/WHO maximum recommended limit of 0.30 mg/kg for Pb. Odai et al. (2008) in a study on vegetables grown on waste dumping sites in Kumasi detected high levels of cadmium from 0.68 to 1.78 $mg\,kg^{-1}$; values which is above the allowable limits.

Risk factors that influence chemical contamination of horticultural produce

According to various studies, it has been established that plants naturally pick up both the important metals for growth as well as some toxic ones (Hg, Cd, Ni, and Pb) (Singh et al., 2004; Anim-Gyampo et al., 2012; Chen et al., 2013). Heavy metals can be accumulated in vegetables *via* different routes. Some routes through which metals are deposited into the soil are (i) Human waste deposits, (ii) agricultural inputs such as untreated manure and lastly, and (iii) the effect of industrial and urban pollution (Wilson and Pyatt, 2007). It has been reported that activities that are conducted by farmers also contribute significantly to the accumulation of heavy metals in the soils and uptake by vegetables. The main routes that heavy metals are known to have access into vegetables and fruits are through the soil, irrigation water and atmospheric depositions. These routes of entry constitute the main risk factors of chemical contamination so far as heavy metal accumulation is concerned.

Soil factors

It is reported that heavy metal ions which are immobilized by soil are released into the soil through natural weathering and/or mining methods. Transport of these metals is determined by their physicochemical properties such as density, conductivity, and reactivity. The physicochemical properties of the soil such as pH, organic matter content, clay fraction content, and mineralogical composition also play a vital role in determining a soil's binding capacity (Dube et al., 2001).

Chemicals and metal ions can adsorb, exchange, oxidize, reduce, catalyze, and precipitate in soils (Weber, 1991). Due to their solubility and exchangeable forms, metals become readily mobile, or may be bound within a crystalline lattice framework of clay minerals. Metals are mobile at low pH but are immobilized at higher pH levels (Wright et al., 2006). Due to the high surface area of clay minerals and the poor pH dependency of cation exchange power, heavy metal levels typically decrease from clay to coarse silt and to rich organic matter soils (Schulten and Leinweber, 2000).

Furthermore, agricultural lands have been exposed to directly or indirectly by different types of residues from the atmosphere and industries, especially mining companies. Levels of heavy metals and other contaminants have increased in the soils because of depositions from the atmosphere and industries. Additionally, as these heavy metals accumulate in agricultural organic soils, it allows for easy transfer of the metals from soils to vegetables. To reduce the uptake of these metals from the soil to the plants, greenhouse vegetable production rooms and soilless greenhouse vegetable production systems have been used to grow safer and higher-quality vegetables devoid of the high levels of heavy metals.

Water factor

In Ghana, there is continuous water shortage for domestic use and to a larger extent for commercial purposes such as irrigation of agricultural produce. In this regard, many urban and peri-urban vegetable growers rely on wastewater for irrigation. The wastewater which is channeled uncontrolled into stagnant drains, is a mixture of hospital and other industrial effluent which contain chemicals and pathogens.

In a study conducted by Arora et al. (2008), it was discovered that heavy metals accumulated significantly in vegetables irrigated with wastewater. His findings revealed that both adults and children who eat vegetables grown in wastewater-irrigated soils consume large amounts of these metals, even though the levels of the metal values below tolerable levels. Although, the levels were low, he recommended that heavy metal levels in effluents and sewage, as well as in vegetables and other food materials, be monitored on a regular basis to avoid excessive build-up of the metals in food.

Atmospheric depositions

Urbanization has resulted in an increase in manufacturing activities, raising concerns about air pollution. Many toxic metals, such as mercury, arsenic, and selenium, are released into the atmosphere as unwanted gases by factories. Demirezen and Aksoy (2006) found higher Pb, Cd, and Cu concentrations in okra collected from urban areas in Turkey compared to those collected from rural areas. Several farms are located near highways and are, therefore, regularly exposed to metal-aerosol depositions in the atmosphere.

Accra experiences heavy vehicular traffic on a regular basis, which has increased the rate of toxic gas emissions into the atmosphere and, agricultural produce. In urban India, Sharma et al. (2008) reported high levels of Cd, and Pb in a variety of vegetables caused by atmospheric deposition with Cd and Pb presenting a significant health risk to the local population when consumed. Finally, they concluded that during the sale, atmospheric depositions increased the levels of heavy metals in vegetables. According to Agrawal (2003), air pollution can pose a threat to post-harvest vegetables during transportation and marketing, due to higher levels of heavy metals in the vegetables.

Available interventions used by actors to mitigate the risk factors posed by chemical contaminants

Soil remediation is a popular approach for reducing pollutants in the environment. One easy approach is to eliminate polluted topsoil from agricultural fields, which usually contain higher levels of pollutants than subsoil (Lai et al., 2010). Alternatively, soil turnover and *in-situ* mixing may be necessary to reduce contaminant concentrations, such as heavy metals, to an appropriate level.

Phytoremediation may be used to eliminate pollution from soils or reduce contamination in plants in a variety of ways. Reduced absorption is advantageous if the plants are intended for human consumption. The selection of plants to explicitly extract pollutants from agricultural land is an example of phytoremediation, such as the use of black nightshade (*Solanum nigrum* L.) to remove thallium from soil (Wu et al., 2015). Yu et al. (2014) found that two oilseed rape cultivars accumulate cadmium differently in cadmium-contaminated agricultural land. In a recent study, Opoku et al. (2020) showed that four indigenous plant species; *Chromolaena ordorata*, *Paspalum viginatum*, *Chrysopogon zizanioides* and *Cynodon dactylon* can be used to reduce Cadmium levels in the soils that have a history of illegal mining.

The latest studies have also used microalgae in irrigation waters to extract free metal ions from the water as a solution to heavy metal contamination because of their high affinity to sequester (biosorbents) heavy metals (Kumar et al., 2015). Some farmers are aware of the dangers of using wastewater for crop production and the use of this microalgae technology, which is cost-effective, may help to encourage safer vegetable production.

Physical hazards

Physical hazards that can be found in produce include oils that may leak from farm tools and equipment, glass fragments, metal chippings that break off from farm equipment, nails, plastic, roots, sticks, insects, sand and stones. These contaminants can be introduced from farm equipment, while workers may drop rubbish into the harvested produce. In most instances, weeds also contaminate the produce, especially leafy vegetables. Such contamination may arise because of cultivation near bushes, landfill sites and poor attention to farm hygiene. Sometimes, parts of the packaging materials such as boxes, baskets and wooden boxes may also chip off into the produce.

Gaps identified between existing interventions in Ghana and documented technologies

Although regulators have outlined standards that are used to monitor horticultural produce, these standards are not harmonized and thoroughly documented. It, therefore, makes it difficult to strictly enforce regulations for produce designated for local consumption in Ghana. There are no clear locally adopted standards for reducing pathogen levels in the various horticultural produce and therefore consumers have the perception that there is no "safe source" of fruits and vegetables, and they bear the risk if they do not take any action to reduce the levels of contamination. Although some of the traders are aware of the indicators to look out for, they are unable to insist on what they want because there is a limited supply of the produce.

In literature, physical hazard consists of foreign materials such as stones, hairs, sand, metallic objects, broken glasses, insects, etc. However, no literature was cited in the Ghanaian context with regards to the present study. All the literature reviewed focused on already prepared meals and not on horticultural produce.

Conclusion and recommendations

Food-borne pathogens

From the information gathered, the major microbial pathogens in fresh fruits and vegetables in Ghana are *Staphylococcus aureus*, *Listeria*, *Salmonella*, *Bacillus*, *Escherichia coli*, *Enterobacter* spp., *Citrobacter* spp., and *Klebsiella* spp. Among these, *E. coli* and *Salmonella* are the most common foodborne pathogens in the country. The risk factors for microbial contamination include water used for irrigation, organic manure, soil, and handling practices. The use of contaminated water, especially wastewater from gutters has gained notoriety as the chief culprit for spreading food-borne pathogens in fruits and vegetables. It was also discovered that vegetables or fruits that are closest to the ground are highly susceptible to food-borne pathogens as compared to their other counterparts which are high above the ground.

Heavy metals and pesticide residue

The key heavy metals in the Ghanaian horticultural space include arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), cupper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn). Among these, As, Cr, Cd, and Pb are the most common heavy metals encountered in the Ghanaian horticultural industry. The risk factors for contamination are dependent on the soil, water used for irrigation and atmospheric deposition. Per this review, heavy metal accumulation in fruits and vegetables in Ghana still remains a problem. Although the only solution has been to avoid cultivation in affected soils, recent research has shown that soil remediation and phytoremediation can be used to reduce the accumulation of heavy metals in fruits and vegetables.

Fruits and vegetables grown and sold in Ghana are often exposed to chemical hazards, especially organophospates, synthetic pyrethroids and organochlorine pesticides (OCPs) that pose potential risks to consumers' health because residual levels exceed the maximum residue limits (MRLs) adopted by the FAO/WHO Codex Alimentarius Commission. Residues of pesticides such as Chlorpyrifosmethyl, Chlorpyrifos, Dichlorvos, Dimethhoate, Malathion, Monocrotophos, Omethioate, Parathion-methyl, Parathion, γ-HCH, δ-HCH, Heptachlor, α-endosulfan, β-endosulfan, p,p'-DDE, Endrin, o,p'-DDT, Endrin aldehyde, p,p'-DDT, and Endrin ketone have been reported in different concentrations.

Recommendations to improve the safety of fruits and vegetables

1. A food safety monitoring program for fresh fruit and vegetables should be designed and implemented.
2. A Traceability System for fresh fruits and vegetables should be developed in consultation with the regulators to facilitate the identification of sources of contamination along the value chain during food safety incidences.
3. Periodic soil testing should be done by regulatory institutions to ascertain heavy metal concentrations in areas where fruits and vegetables (especially lettuce and carrots) are produced. The introduction of appropriate soil amendments to help remove heavy metals from highly concentrated soils.
4. Extension officers assigned to urban vegetable producers to be trained in food safety issues and well-equipped with the appropriate logistics.
5. Farmers are to be trained on rainwater harvesting techniques and be resourced with irrigation equipment to have access to potable water for production.
6. Buyers, marketers and transporters who buy produce at the farm gate must be sensitized to demand and insist on quality and safe produce from producers.
7. Sensitization and training of farmers on the safe use of pesticides as well as strict adherence to Pre-Harvest Intervals.
8. Market women and other intermediaries should be trained on basic postharvest handling practices and consumer health.
9. Further research should be done to find out more practical ways of reducing heavy metals in soils used for fruit and vegetable cultivation.

Author contributions

GE, GA, WH, MO, and FA contributed to the conception and design, critically reviewed the first draft, and approved the final version of the manuscript. RB and SL wrote the first draft. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Underutilised food crops for improving food security and nutrition health in Nigeria and Uganda—a review

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Food and nutrition insecurity are pressing global issues, pertinent to the United Nations' Sustainable Development Goal 2 (zero hunger). About 1 in 10 people globally are food insecure, with both the COVID-19 pandemic and the Ukraine-Russia crisis exacerbating the problem, partly due to unprecedented shortages in major food commodities, such as wheat, rice, and sunflower oil. Food and nutrition security have been negatively impacted in sub-Saharan African countries like Nigeria and Uganda where, prior to both crises, 25% of the population were already food insecure and children under five and women of reproductive age faced severe undernutrition, micronutrient deficiencies, and their associated health challenges. The recent crises have highlighted the need for a paradigm shift from relying on a few crops to a diversified, sustainable food system that harnesses the potential of neglected and underutilized species (NUS) for food and nutrition insecurity solution, especially in low and middle-income countries. Despite their abundance (>100 edible species) and high nutritional value, various political, socio-cultural, and infrastructural factors have deterred commercialization and utilization of NUS in sub-Saharan Africa. Moreover, there are limited sophisticated studies on many of NUS local to the region. This review aimed to discuss selected NUS, peculiar to Nigeria, namely, African walnut (*Tetracarpidium conophorium*), African breadfruit (*Treculia africana*), and Uganda, namely, sesame (*Sesamus indicum L.*) and pigeon pea (*Cajanus cajan L.*), and their potential to sustainably contribute towards improved food and nutrition security. The crops are briefly described, and their indigenous uses, nutritional value and medicinal properties highlighted. Issues relating to their production, processing, consumption, and exportation are reviewed considering their contribution towards sustainable food systems.

KEYWORDS

underutilized species, African walnut, African breadfruit, wild sesame, pigeon pea, food security, nutrition health

1. Introduction

The global population is expected to reach approximately 10 billion by 2050, with much of this growth anticipated in sub-Saharan African countries, such as Nigeria, the Democratic Republic of Congo, Ethiopia, Tanzania, and Uganda (United Nations Department of Economic and Social Affairs, Population Division, 2022). Although some progress has been made in recent decades, a significant proportion of people living in sub-Saharan Africa are still hungry, food insecure, and face micronutrient deficiencies, commonly iron deficiency anemia and vitamin A and zinc deficiencies, presenting a huge global challenge (Baldermann et al., 2016; Li et al., 2020; Li and Siddique, 2020; FAO, IFAD, UNICEF, WFP and WHO, 2022). In these countries, malnutrition, and its negative implications on health, and quality of life, are even more pertinent among children under five, women of reproductive age, and pregnant and lactating mothers. Of the United Nations' 17 Sustainable Development Goals (SDGs), SDG2 (zero hunger) aims to directly address these challenges by 2030, with SDG3 (good health and wellbeing), SDG12 (responsible production and consumption) and SDG15 (life on land), contributing to an enabling environment (Baldermann et al., 2016; Li et al., 2020; Li and Siddique, 2020). Various factors have contributed to global food and nutrition insecurity and malnutrition, including income inequalities, poor soil health, and more recently, climate change and conflict/war (FAO, IFAD, UNICEF, WFP and WHO, 2022). Moreover, the continued reliance globally, on a few (150–200) plant species has negatively impacted nutrition and health outcomes, by contributing to low individual and household dietary diversity, resulting in poor diet quality and inadequate macro and micronutrient intakes. In many sub-Saharan African countries, including some nations where the populations are expected to grow exponentially over the next 30 years, political unrest, the COVID-19 pandemic, and Russia-Ukraine war, negatively impacted global food supply chains and food production, consequently undermining food access, availability, and affordability.

Sustainable agriculture and food system transformation, which capitalize on "neglected and underutilized" species (NUS), are one way of tackling some of these challenges. This is being achieved by broadening the possibilities of what can be eaten as food, outside of the four key commercialized plant species (rice, wheat, maize, and potato) that supply 60% of human calorie and protein intakes (Biodiversity International, 2017; AARINENA, 2021). NUS, sometimes called "orphan crops", "forgotten foods", "minor crops" or "under-researched" foods (Gruere et al., 2006) are "wild, domesticated, or semi-domesticated plants, that have been cultivated previously for human and animal food, oil, and medicinal properties, but whose potential to improve livelihoods, food security, justice and sovereignty, has not been maximized by researchers, policy makers and local and global markets, due to their limited competitiveness with c crops commonly traded in mainstream agriculture" (Ulian et al., 2020, p. 422). NUS, although "unconventional", contribute to incomes and livelihoods of farmers that cultivate them and often are an integral part of the cultural fabric and ethnic identities of people in the places from which they originate (AARINENA, 2021). NUS encompasses a diversity of food groups, including fruit and vegetables, oil seeds, pulses, cereals, roots, and tubers, and although underutilized, are often high in both macro and micronutrients and dietary fibre (Baldermann et al., 2016; AARINENA, 2021; Talabi et al., 2022). For example, moringa (*Moringa olifera*), quinoa (*Chenopodium quinoa*), and teff (*Eragrostis tef*), three NUS, can supply all eight essential amino acids, in addition to energy, minerals, vitamins and bioactives like polyphenols. Moreover, teff has been used in the production of alcoholic beverages and gluten-free baked goods, providing an alternative for people living with coeliac disease (Gebremariam et al., 2014). NUS also have medicinal properties, and the plant parts can yield other products, e.g., fodder, gums, resins, and building materials, which are of high economic value to various industries, e.g., animal industry, construction, pharmaceuticals (Ulian et al., 2020). It is no wonder that NUS have been called "crops of the future" (Baldermann et al., 2016). Moreover, many NUS are not resource-intensive, can grow on marginal lands, are tolerant to environmental stresses like drought, high salinity and can be easily intercropped or rotated with staples and trees (Li and Siddique, 2018, p. 3; AARINENA, 2021). Thus, NUS could contribute to sustainable food systems by enhancing biodiversity and strengthening ecosystem resilience (Padulosi et al., 2013; Shelef et al., 2017; FAO, 2019; Raneri et al., 2019; Ulian et al., 2020). Despite their myriad advantages, NUS are currently only marginally used by rural, smallholder farmers and indigenous communities. NUS have been largely excluded from agricultural and nutrition research, agricultural extension service delivery, and nutrition policy (Li and Siddique, 2018). A few NUS are currently traded in niche markets globally, e.g., quinoa, teff, amaranth, some pulses, partly due to government interventions, investments in research and innovation, and increased technology transfer between national and international partners. In sub-Saharan Africa, NUS utilization are limited due various reasons, including: (1) lack of organized value chains; (2) their perceived low competitiveness and economic potential; (3) limited value-addition know-how stemming from low prioritization in agricultural and food processing and innovation research; (4) ecosystems destruction for development leading to extinction of some species; and (5) the stigma attached to such crops as "food for the poor", decreasing their popularity, particularly in a context where many sub-Saharan African countries are experiencing a nutrition transition (Akinnifesi et al., 2008; Naluwairo, 2011; Li et al., 2020). Notwithstanding, due to growing interest in healthy and sustainable food systems, NUS have recently gained traction as one of the parts of a multi-pronged approach towards addressing food and nutrition insecurity in emerging economies in Asia and sub-Saharan Africa. In 2018, the Food and Agricultural Organization of the United Nations (FAO) published a document titled "Future Smart Food". Here, the authors, from an Asian perspective, highlighted examples of NUS as "future-smart foods" that warranted further exploration (FAO, 2019; Li et al., 2020; Li and Siddique, 2020, p. 4). In sub-Saharan Africa, on the other hand, a wider range of NUS remain underexplored (Gebremariam et al., 2014). To push the NUS agenda, the African Orphan Crops Consortium (AOCC), through a participatory exercise with farmers, scientists, development practitioners and producers, recently identified a list of 101 priority African plant species, important for alleviating malnutrition, supporting consumer diets and farmers' incomes and livelihoods, such as okra, spider plant, Baobab, Mangosteen, finger millet, Locust bean, etc. (Hendre et al., 2019; Talabi et al., 2022). The crops were selected based on three primary criteria: (1) being rich in micro- and macro-nutrient contents; (2) being relevant to Africa; and (3) having a need for developing breeding resources (Hendre et al., 2019). To this end, this review aimed to evaluate the potential of selected NUS species in two sub-Saharan African countries, Nigeria, and Uganda, for improved food and nutrition security and livelihoods improvement, within a sustainability food system. Building on the work by AOCC, we identified four neglected and underutilized species in Nigeria, that is, African walnut (*Tetracarpidium conophorium*) and African breadfruit (*Treculia Africana*), and Uganda, that is sesame (*Sesamus indicum* L.) and pigeon pea (*Cajanus cajan* L.). The four species fall under three food categories, that is, roots and pulses (pigeon pea), nuts and seeds (sesame, African walnut), and fruit and vegetables (African breadfruit) and were chosen based on five criteria: (1) relevant to Africa; (2)

resilient to environmental stress and ability to withstand effects of climate change, e.g., high salinity, drought, heat; (3) high nutritional value (macro and micro-nutrients); (4) potential for increased local and global utilization; and (5) locally available to allow for enhancement of local livelihoods.

2. Methodology

The search period for this review was from August 01, 2022, to November 30, 2022. The review focused primarily on the origins of the plants, the uses of the plant, nutritional composition, and potential for sustainable food systems. As such, search terms encompassing those concepts were combined with the common and/or botanical names of the crops, that is, pigeon pea, African breadfruit, African walnut, and sesame to yield simple search syntax, which were then inputted in two databases (Google Scholar, Scopus) for example: (i) for pigeon peas: ((“pigeon pea*” OR “Cajanas cajan”) AND (origin OR utilisation OR nutrition OR “nutri* value” OR “nutri* composition” OR “nutri* content” OR nutrition OR sustainability)); (ii) for sesame, syntax was: ((sesame) AND (origin OR utilisation OR nutrition OR “nutri* value” OR “nutri* composition” OR “nutri* content” OR nutrition OR sustainability)); (iii) for African walnut: ((“African walnut*” OR “Tetracarpidium conophorium”) AND (origin OR utilisation OR nutrition OR “nutri* value” OR “nutri* composition” OR “nutri* content” OR nutrition OR sustainability)); and (iv) for African breadfruit: ((“African breadfruit*” OR “*Treculia africana*”) AND (origin OR utilisation OR nutrition OR “nutri* value” OR “nutri* composition” OR “nutri* content” OR nutrition OR sustainability)). There was no restriction on publication year for articles included in this review.

3. Results and discussion

3.1. African walnut (*Tetracarpidium conophorium* Mull. Arg.)—Nigeria

3.1.1. Origin and utilization

African walnut plant (*Tetracarpidium conophorium* Mull. Arg.), synonymous with *Pleukenetia conophora* (Figures 1A–F) was originally classified by Hutchinson and Dalziel (1928a). It is not clear in literature about the specific country where the plant originated from, however, it is widely noted that the plant is indigenous to West Africa, in particular, Nigeria and Benin Republic, as well as Central Africa, mainly, Cameroon, Equatorial Guinea, and Democratic Republic of Congo (Hutchinson and Dalziel, 1928b; Burkill, 1985). Although they are found in Sierra Leone, it is believed that the nuts were transferred from Nigeria through migration during the slave trade era as there are no evidence of the plants in the neighboring countries around Sierra Leone, (Burkill, 1985). The fruit pods at early maturity are light greenish in colour while at late maturity, the colour turns to brownish black (Fasina and Ajibola, 1989; Nkwonta et al., 2016). Agro geography of the nut shows that it is grown in the coastal and lowland humid regions of Nigeria between 4° 15′ and 8° N of the equator (Asaolu, 2009; Nkwonta et al., 2021). The nuts are primarily consumed as snacks after processing by boiling or roasting (Nkwonta et al., 2013). However, the use in ethno botanical medicine such as management of chronic diseases (cancers, diabetes, cardiovascular conditions, hypertension etc.), and other health conditions including sexual dysfunctions, malaria, constipation, and dysentery etc., have been reported in different studies (Malu et al., 2009; Amanze et al., 2011; Onwuli et al., 2014; Akomolafe et al., 2015). Nevertheless, these pharmaceutical and medicinal assertions require more experimental testing and evaluation using sophisticated instruments as well as trial/intervention studies to substantiate the claims.

3.1.2. Nutritional composition and potential to improve nutrition and food security

African walnut kernels (Figures 1A–F) contains key nutritional characteristics (Table 1) considered essential in terms of tackling protein energy malnutrition, micronutrient deficiencies, maintaining omega-3/omega-6 fatty acid ratio and effecting antioxidation activities in biological systems. The nutritional composition (macro- and micro-nutrients) of the nuts has been reported in different studies. In particular, the protein content of both raw and processed nut samples ranges between 21.7% and 35.2%. It contains key vitamins (B1, B2, B3, B12, C, and E) with ascorbic acid—4.2 mg/100 g and tocopherol—0.123 mg/100 g being the most abundant (Ayoola et al., 2011). The oil content of raw, boiled, and processed samples (38%–49%) contain both linoleic and α-linolenic acids with the latter as the most abundant fatty acid in the oil (Nkwonta et al., 2015). Assessment of the protein content with respect to supporting growth and tissue maintenance highlights its potential use as alternative protein source in infant formulations. The fortification of wheat flour with African walnut flour for baking of various pastries (biscuits) indicated improved essential amino acid composition and lower microbial load of the final product when compared with the control (wheat flour biscuit only), even after storage of up to 8 weeks (Dauda et al., 2020). This is because African walnut flour is one of the oilseeds that contain all the essential amino acids necessary for various biochemical activities in man, particularly in protein synthesis (Tchiegang et al., 2001; Asaolu, 2009). The high concentrations of Vitamins C and E (Ayoola et al., 2011) as well as the presence of phytochemicals, including polyphenols belonging mainly to the classes of flavonoids and phenolic acids (Nkwonta et al., 2021) in the nut, effects antimicrobial and antioxidation on the products and in consumers.

Its potential for food security are embedded in the physicochemical characteristics of the plant and the nuts. African walnut plant is a perennial climber, which currently grows in the wild and utilizes other trees such as the cocoa and kola nut trees as support (Baiyeri and Olajide, 2022). As the plant is perennial, the fruits are produced annually between the months of June and September, thus ensuring the availability of the nuts on a yearly basis. The fruit pods contain two to five nuts with hard-brown shells encasing the edible kernels weighing about 4.50 g/kernel. Although the common method of consumption of the nut is as snacks, the primary food products generated from the kernels are the African walnut oil and the African walnut flour. These are valuable fundamental food forms that can be combined in various proportions with other condiments to produce nutrient-rich cooked or baked products such as pastries—biscuits, cookies, bread, etc. (Ndie et al., 2010; Awofadeju, 2020; Dauda et al., 2020; Awofadeju et al., 2021). Studies have reported favorably on the physicochemical characteristics of the African walnut flour, which has been applied in combination with wheat flour for baking of cookies, buns, and bread (Dauda et al., 2020). Additionally,

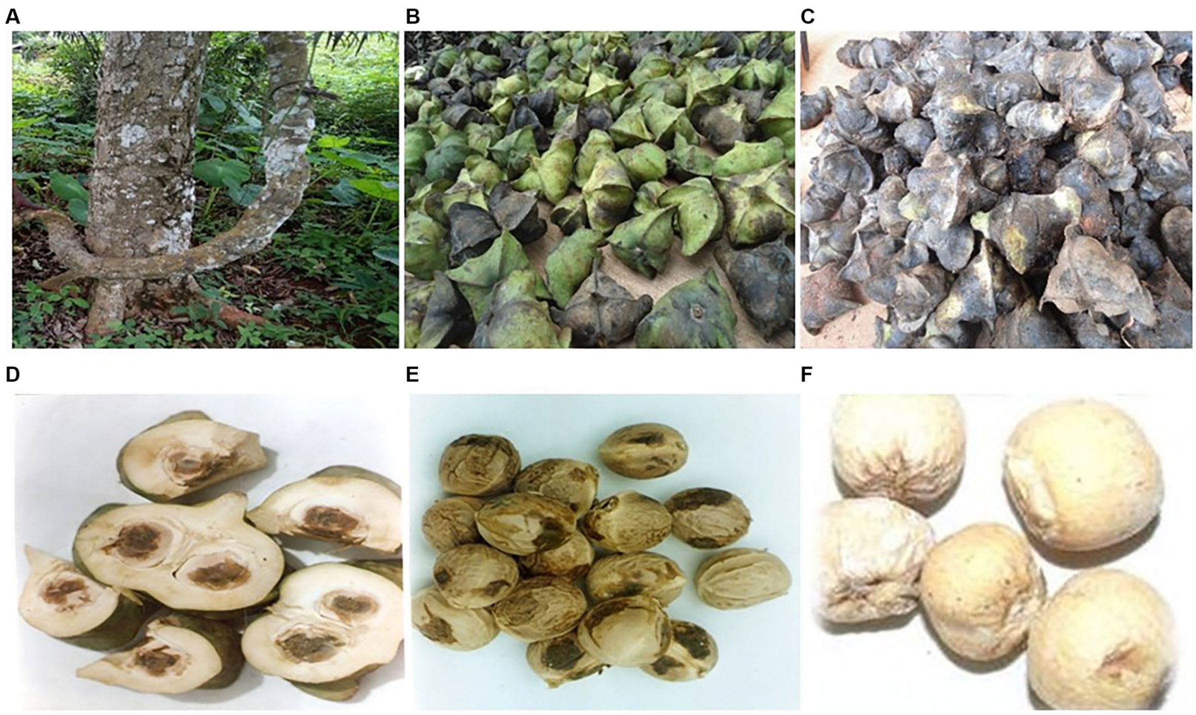

FIGURE 1
African walnut fruit and kernel. **(A)** African walnut climber curling around a host tree. **(B)** Fruit pods at early maturity (green colour). **(C)** Fruit pods at late maturity (brownish-black). **(D)** Fruit pods dissection exposing the nuts. **(E)** Nuts with shell. **(F)** Exposed edible kernel. Author **(A–C)** and Nkwonta et al. (2021) **(D–F)**.

the flour is used as a thickener in cooking various soups recipes. The large size of the nuts entails that a small harvest will potentially yield large amounts of oil and flour upon processing. This is of huge advantage in terms of ensuring sustainable abundance of the products if local farmers are only able to embark on subsistent farming because of limited availability of farmland. Conversely, the potential high yield of oil and flour from a small amount of the nuts underpins the need to domesticate the various accessions of the nut through germplasm garden and nursery development, study and select variants with higher potentials for high yield and disease resistance, and cultivate them using modern commercial precision farming system and technologies. Additionally, postharvest studies to improve storage time and conditions and ensure availability of the nut all year round are necessary.

3.2. African breadfruit (*Treculia Africana*)—Nigeria

3.2.1. Origin and utilization

African breadfruit (Figures 2A–C) belongs to the family *Moraceae*. The leaves are evergreen, and the tree can grow up to heights of 30 m. The tree bears a very large round greenish-yellow spongy-textured seeded fruit (Breadfruit), which can weigh 8.5–10 kg. The origin of the plant is also not clear in the available literature. Although the plant could be found throughout African regions, it is distributed mainly in the West and Central African regions in countries such as Nigeria, Benin Republic, Côte d'Ivoire, Cameroon, Central African Republic, Zambia, Senegal, Gabon, Tanzania, Angola, and Uganda (Ojimelukwe and Ugwuona, 2021; Hassler, 2022). The seeds are the main aspect of the fruit consumed in Nigeria. It is usually made into a porridge and consumed as a meal. Additionally, the seeds are roasted and eaten as snack with coconut or palm kernel seed. This snack is popularly known as "*Aki n'Ukwa*" in the Igbo-speaking states in Nigeria. Currently, there are four main varieties within the species, i.e., *T. Africana* Var. Africana, *T. Africana* Var. inversa, *T. Africana* Var molis and T Africana var. illcifolia. The differences are based on the size of the fruit head, hairiness of the branchlets and the leaves. The main varieties found in Nigeria are the *T. Africana* Var. inversa and *T. Africana* Var molis (Okafor, 1981; Ojimelukwe and Ugwuona, 2021; Hassler, 2022).

3.2.2. Nutrition composition and potential to improve nutrition and food security

Nutrient analysis of African breadfruit processed using variable methods have shown that the raw and processed seeds are rich in both macro- and micro-nutrients (Table 1). The crude protein content of raw, boiled, and roasted seeds range between 13.00% and 18.32%. Blending of African breadfruit with corn-starch normally utilized as a weanling food for children in Nigeria and other sub-Saharan African countries will help to improve the nutritive value of the food in terms of protein content. The African breadfruit seeds are rich in mineral contents, e.g., sodium, calcium, magnesium, zinc, phosphorus, copper, selenium, potassium (Table 1). It contains about 587 mg per 100 g dry matter serving of potassium (Osabor et al., 2009; Ojimelukwe and Ugwuona, 2021). This is far above the potassium content of bananas,

TABLE 1 Nutritional composition of African walnut and African breadfruit.

Nutrient component	African walnut kernel	African breadfruit seed
Proximate composition		
Total moisture (%)	2.20–4.28	11.25
Ash (%)	2.03–5.27	1.27–3.21
Total Crude protein (%)	21.65–35.22	10.62–18.32
Total carbohydrate (%)	12.58–53.20	77.44–82.41
Crude fibre	3.34–7.34	1.13–19.11
Total fat and oil	37.79–48.90	0.84–1.34
Micronutrients (mg/100 g)		
Minerals		
Calcium	100–431	3.34–7.35
Iron	3–100	1.10–8.00
Magnesium	20–170	1.40–3.80
Phosphorous	–	452–590
Potassium	625	511–589
Manganese	2	2.94–3.49
Sodium	483	365–390
Zinc	4–100	8.40–8.68
Copper	–	2.41–2.49
Vitamins (μg/100 g)		
Thiamine (B1)	0.06	2.99–12.73
Riboflavin (B2)	0.02	0.1–0.24
Niacin (B3)	0.05	15.03–18.36
Cyanocobalamin (B12)	0.12	–
Vitamin C	4,150	1.77–2.48
Vitamin E	122.6	–
Vitamin A	–	14.84–20.74
Amino acids (mg/g)		
Isoleucine	40.00	7.00
Leucine	70.00	8.70
Lysine	42.2–55.00	7.90
Methionine	1.00–8.00	1.60
Cysteine	35.00	1.20
Phenylalanine	23.70	7.20
Tyrosine	21.60–60.00	6.20
Threonine	40.00–52.70	7.10
Tryptophan	10.00	1.90
Valine	50.00–60.00	8.50
Alanine	61.30	5.80
Arginine	63.00	6.00
Aspartic acid	144.00	12.50
Glutamic acid	122.30	15.70
Glycine	138.30	9.20
Histidine	14.40	3.90
Proline	64.30	5.20
Serine	62.00	8.50

Values are ranges for both unprocessed and processed samples from different author. Where there are no ranges, values represent those of unprocessed samples. Tchiegang et al. (2001); Asaolu (2009); Ayoola et al. (2011); Enujiugha (2003); Edem et al. (2009); Nkwonta et al. (2010); Oladiji et al. (2010).

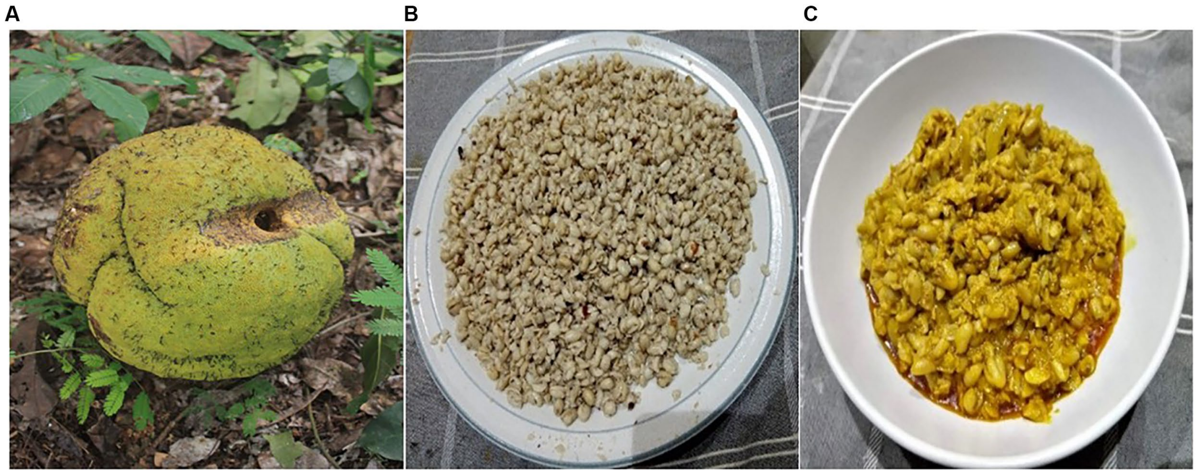

FIGURE 2
African Breadfruit: **(A)** Mature fruit. **(B)** Plane boiled seeds. **(C)** Porridge. IITA Forest Centre (https://www.flickr.com/photos/iita-media-library/8272252122/in/photostream/) used under CC by-NC license **(A)** and Author **(B,C)**.

which is about 330.6 mg per 100 g serving (Wall, 2006). Potassium is essential in maintaining blood pressure thus, consumption of African breadfruit meals contributes to towards reduction of the risk of cardiovascular disease. In ethnobotanical medicine, the consumption of the seed and root water extracts are normally recommended for the reduction blood glucose levels. The extracts have also been shown to improve liver functions as they decrease levels of liver function enzymes in test animals (Oyelola et al., 2007; Ojimelukwe and Ugwuona, 2021). The vitamin contents include mainly those in Vitamin B category (B_1, B_2, B_3), Vitamin A and C (Table 1). Studies indicated that milk blend containing Soybeans milk and African breadfruit milk had an improved concentration of Vitamin A with increase in the African breadfruit (Okwunodulu et al., 2021). These vitamins and minerals are necessary for bone and teeth development/maintenance (calcium, potassium, and Vitamin A), tissue repair and antioxidant activities (Vitamin C, selenium). Additionally, the seeds contain certain phytochemicals such as polyphenols, tannins, saponins, and phytates. Some of these phytochemicals serve as antinutrients, which reduce the bioavailability of the micronutrients. However, different studies have reported the reduction of these antinutrients using different processing methods such as fermentation, roasting, cooking/boiling, dehulling, drying, soaking, and sprouting (Ijeh et al., 2010; Olapade and Umeonuorah, 2013; Okwunodulu et al., 2021). Further research is needed to understand the individual polyphenol profile of the seeds, develop adequate postharvest storage treatments to enhance the shelf life of the fruit/seeds while maintaining the nutritional qualities.

Like African walnut, the African Breadfruit is a perennial tree, which takes about 4 years to mature before yielding fruits. However, the productivity lifespan for each tree is above 50 years making it a viable economic tree for continuous long-term food supply. The fruits are produced annually guaranteeing availability of the seed for consumption or conversion to other products. Each fruit, depending on the size, could yield 5–7 kg of seed after processing. Apart from the porridge and roast seeds, other forms of food products can be formulated from the seeds. The seeds are ground into powder and used as flour for baking of different pastries (Giami, 2004). The milk is usually extracted after boiling and blending and can be consumed as plant-based milk or utilized in yoghurt formulation (Ifediba et al., 2018; Okwunodulu et al., 2021) while the oil can be obtained by pressing and are suitable for consumption as well as in soap and shampoo production (Ajiwe et al., 1995). The pulp though not often eaten, is utilized in the formulation of a non-alcoholic beverage (Ejiofor et al., 2012). Despite the diverse food forms obtainable from the seed limited research has been made to upscale the fruit farming, seed production and processing. The production and utilization of the seed is still at subsistence level in Nigeria. There is no food manufacturing company dedicated to exploitation of the potentials of African breadfruit. Currently, the tree is sparsely distributed across the countries where they grow in Africa, particularly in the southern parts of Nigeria. It is among the list of endangered species in southern Nigeria as it is threatened with extinction (Ohajianya and Osuafor, 2017).

3.3. Sustainability issues relating to production and utilization of African walnut and African breadfruit in Nigeria

African walnut plant has broad adaptability potentials. It thrives very well in tropical fertile moist and well-drained loamy soil. It adapts very well in woodlands, fallow fields, and forest areas (Baiyeri and Olajide, 2022). However, studies are yet to be conducted on it potential for growth and survival in temperate climate. Its ability to twine around host trees for support enables it to adapt among competing plants as it reaches the apex of trees to receive sunlight. The twining of the plant helps to join different treetop thereby enhancing forest canopy (Amusa et al., 2014). Additionally, the young plant can be staked until the roots and trunk are strong enough to bear the weight. Subsistence farmers in Nigeria, who use their back gardens or allotments to cultivate the plant, mainly apply this technique. In terms of fertilizer requirements, studies have shown that soil amendments such as poultry manure are sufficient to promote optimum growth and fruit production of African walnut. Application of 10 t ha^{-1} of poultry manure is sufficient to complement soil nutrients and enable proper development of morphological traits of the African walnut plant at early stages (Baiyeri and Olajide, 2022). This fertilization requirement supports green and sustainable cultivation of the African walnut plant and reduces the risk of inorganic chemical contamination of the soil and disruption of the soil ecosystem. Apart from the nuts kernel, the root, bark, and vegetative parts of the plant are also utilized in ethnobotanical medicine to treat various health conditions. Some of these conditions include malaria, eczema, indigestion, constipation, and diarrhea as well as manage chronic diseases such as diabetes, high blood pressure and cancers (Payal et al., 2015; Suara et al., 2016; Nkwonta et al., 2021). The utilization of the various parts of the African walnut underpins its potential as a high value and economic crop.

The African breadfruit plant grows well in swampy areas in forests, near streams and riverine areas. It also thrives well in medium loamy as well as heavy clay soils with pH being ranging from mildly acidic to neutral and mildly basic (pH 5.0–8.5). The plant is well adapted to tropical and sub-tropical climate however, research is needed to determine its growth and performance in temperate climate (Amujiri et al., 2018). In Nigeria, the tree could be planted in privately owned fields for subsistence, although not close to houses, as the fall of the mature fruit can cause damage to the roof of buildings (Ojimelukwe and Ugwuona, 2021). Apart from consumption of the seed, the plant is utilized in different forms. For example, in agroforestry, the trees serves as a conservation plant because the fall of the leaves serve as compost for the soil around it enabling a thriving ecosystem. Given the huge size of the tree, it serves as a windbreaker against storms and can also be used in flood control (Nuga and Ofodile, 2010; Ojimelukwe and Ugwuona, 2021). The tree's wood is very suitable for pulp and papermaking as well as timber for other wood-based products. Given that, the lifespan of each tree exceeds 50 years and has a wide range of use in addition to producing fruits all year round which serves as food source, it usefulness as an economic resource for individual of family owners cannot be over-emphasized. Its management is substantially sustainable, as very little care is required to keep the tree productive (Nuga and Ofodile, 2010).

3.4. Factors affecting wider production and utilization of African walnut and African breadfruit in Nigeria

Within the communities where African walnut and African breadfruit are produced in Nigeria, they are well consumed in the most common forms as food when processed by boiling or roasting. They are consumed either as a meal such as the porridge or as snacks. The demands are also very high within these communities. For example, a study on the economics of household demand within an agricultural zone prominent in production of African breadfruit in Nigeria reported the demand rate as very high (63%) with 35% consuming it at least twice a week (Ohajianya and Osuafor, 2017). For example, a study on the economics of household demand within an agricultural zone prominent in production of African breadfruit in Nigeria reported the demand rate (63%) as very high with 35% of the residents consuming it at least twice a week (Ohajianya and Osuafor, 2017). Apart from the nuts kernel, the root, bark, and vegetative parts of African walnut are also utilized in ethnobotanical medicine to treat various health conditions. Some of these conditions include malaria, eczema, indigestion, constipation, and diarrhea as well as manage chronic diseases such as diabetes, high blood pressure and cancers (Payal et al., 2015; Suara et al., 2016; Nkwonta et al., 2021). For African breadfruit, the leaves and the bark are mixed in decoctions to treat various diseases including high blood pressure, diabetes, cough, oral thrush, helminthic infection, and gastro-intestinal complications, e.g., constipation (Oyelola et al., 2007; Kuete et al., 2008; Eleazu et al., 2017, 2018). The utilization of the various parts of the African walnut underpins its potential as a high value and economic crop. Nevertheless, beyond these producing regions, there is minimal demand, availability, and utilization. Several factor such as poor awareness of the general populace on the nutrition and health benefits, lack of government support to indigenous farmers, poor industry interest in exploiting the crops, urbanization, socio-economic transformations leading to shifts in dietary habits, and lack of financial investment/support for sophisticated scientific research all limit the wider production and utilization of these crops. With growth in population, gradual industrialization and need for housing to accommodate influx of employees in urban areas, farmlands are sold or hired out for construction of residential houses. Consequently, deforestation of the areas where these crops are already fully-grown leads to decline in production. Farmers in the rural areas, who cultivate these crops at subsistence level, often retire once they complete the training of their children whom they encourage to move to the urban cities to find jobs that are more lucrative. The continuous decline of existing elderly farmers with no replacement by younger ones inadvertently affects the rate of production of these crops. In terms of dietary shifts resulting from socio-economic and political dynamics, government policies encouraging importation of myriad of highly processed foreign food into the country has enabled acceleration of change in dietary habits of people living in both urban and rural areas in Nigeria. Several families switch to these foreign packaged diets (cereals, noodles, soups, etc.), as they are easy to stock/preserve, save time in preparation and very palatable particularly for the children. Furthermore, consumption of the foreign diets is often associated with upper and middle class families, as such; even the low-income earners strive to belong to the upper class through the switch in their dietary choices. Cumulatively, this preference of imported food over the local diets lowers the demand for production and utilization of local food such as the African breadfruit and African walnut. Finally, in Nigeria and in several other African countries, research findings are not considered as key drivers of development unlike what is obtainable in the western countries and other technologically advanced nations. Hence, the government invests minimally on scientific research activities particularly in the food and agricultural sector. Similarly, food industries invest less in research and development of the underutilized indigenous food crops. Even when independent researchers develop innovative/novel food products, there is lack of motivation and financial support from the government and industry stakeholders to scale-up production the new product through spinout companies. In other words, there is a lack of marketing systems for promoting NUS into large-scaled production. For instance, different scientific publications reporting on development of pastries such as cookies, bread, flour, cooking oil, etc., from African walnut and African breadfruit abound, however, these publications barely go beyond the papers due to lack of finances to move the product from the laboratories to the marketplace. A key challenge is the lack of modern fit-for-purpose infrastructure for industrial scale processing of these crops after harvest. Appropriate husking and nut-cracking machines are needed to facilitate quick large scale processing. Automated machines/systems are often lacking in the areas where these crops are produced as most of the farmers still apply traditional manual processes, thus reducing general production efficiency.

3.5. Recommendations on potential research, stakeholders and policy engagement to increase utilisation of African walnut and African breadfruit in Nigeria, African and globally

To minimize postharvest losses and improve shelf life and general utilization of the African walnut and African breadfruit seeds, comprehensive cold and retail storage experiments with the processed and unprocessed nuts sample with and without shells/bran are necessary. This will inform on best conditions for long and short-term storage necessary for local and export market. Studies on packaging of the nuts as snacks is also necessary given that this is the most popular mode of consumption. As the crops grow on a wide range of soil types, genetic studies following germplasm collections to select accessions that will be more tolerant to challenging climatic conditions will ensure optimum value is obtained from the crops. Reports have shown that these crops are threatened with extinction because of deforestation, socio-cultural shifts in dietary habits and urban migration (Baiyeri and Olajide, 2022). The government and industry stakeholders can therefore develop and promote agricultural land use policies that will favour preservation of farmlands as well as reward farmers efforts in terms of regulating competing imported crops and food products. Food scientists and researchers with viable ideas and intellectual properties for product development using these food sources as raw materials, should be incentivised to roll out spinout companies (micro and small businesses) and exploit further the reasonable utilization of the crops. Only a few studies have reported on the development of flour blends (Ndie et al., 2010; Awofadeju, 2020), bread and cookies (Dauda et al., 2020; Awofadeju et al., 2021) incorporating African walnut flour. More studies are needed to explore utilization of these blends in the culinary and baking industry as well as assess consumer views and acceptability through market analysis. Finally, promotion of African walnut and breadfruit as potential cash crops necessary to ensure food security in the face of challenging poverty and hunger, exacerbated by climate change factors such as flooding and drought, is essential at local, national and international levels. This can be done through funding of research focused on more sophisticated studies on the crop. The publication of the research findings will increase the information database and serve as authentic scientific evident backdrop to educate people.

3.6. Pigeon pea (*Cajanus cajan* L.)—Uganda

3.6.1. Origin and utilization

Cajanus cajan L. commonly known as pigeon pea, red gram, yellow dhal, no-eyed pea, Angola pea, Cajan pea, Congo pea, gungo pea, and tropical green pea (Raschke and Cheema, 2008; Fuller et al., 2019; Singh et al., 2020; Abebe, 2022), is a legume of the Fabaceae family and the Phaseoleae tribe, which contains many edible bean species, such as, soybean (*Glycine max* L.), common bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata* L.) and Bambara nut (*Vigna subterranea* L.) (Dakora, 2000). Pigeon pea (Figures 3A,B), a perennial diploid shrub, typically grows 1–4 m high and yields a harvest between 6 and 11 months, although some recent varieties can mature in 3–4 months (Odeny, 2007; Kingwell-Banham and Fuller, 2014; Fuller et al., 2019; Namuyiga et al., 2022). Pigeon pea seeds come in various colors (Figure 3B), such as, black, orange, cream, and are bitter or sweet, depending on variety (Upadhyaya et al., 2005). Although growing in popularity recently, pigeon peas remain one of the most underutilized pulses globally, with production in 2021 estimated at nearly 6 million tons, accounting for an estimated 5% of the total global legume production (Hillocks et al., 2000; FAOSTAT, 2022). While India and Myanmar are the largest global producers of pigeon

FIGURE 3
Pigeon pea **(A)** plant showing pods containing immature seeds, **(B)** mature dry seeds of varying colours. Harish N at www.pixahive.com **(A)** and Kundan Kumar at www.pixahive.com. Images used under CCO License (Free to use, Attribution optional).

peas to-date, the crop is cultivated by smallholders in a few other countries in the Global South including, Nepal, Kenya, Malawi, and Uganda (Simtowe et al., 2010; FAO, 2019; Abebe, 2022; Namuyiga et al., 2022; Rizvi et al., 2022). The origin of the pigeon pea has been widely debated. Some evidence suggests that *Cajanus cajanifolius*, the wild progenitor of the domesticated plant, first appeared in parts of Peninsula India (Fuller et al., 2019), from where it was introduced to Africa from India about 4,000 years ago (Simtowe et al., 2010; FAO, 2019). Other scholars have argued the crop to be of African origin, being traced to 2,200–2,400 BC Egypt, from where it was transported to India (Morton et al., 1982). Regardless of origin, what is clear is the versatility of pigeon peas, being eaten as human food and used as medicine, animal fodder, fuel, building and craft-making material, in addition to playing a role in soil enrichment through mulching, nitrogen fixation and soil binding (Upadhyaya et al., 2010; Yang et al., 2020; Abebe, 2022; Namuyiga et al., 2022), highlighting the crop's immense value for the resource-poor.

3.6.2. Nutrition composition and potential to contribute to nutrition and food security

In Uganda, pigeon pea is an important crop which is widely consumed in the diet among smallholders and resource-constrained households, particularly in the Northern and North-Eastern parts of the country, two semi-arid regions that experience only one rainy season annually and show some of the highest rates for food insecurity (Obuo et al., 2004; Manyasa et al., 2009; Namuyiga et al., 2022). Here, pigeon pea seeds are locally known as "*lapena*" and are eaten when they are fresh or dry and mature, in the form of whole seed sauce or split pea sauce locally called "*dek ngor*" or "*agira*". The green and tender immature seeds and pods, typically harvested 24–30 days after flowering, are sometimes eaten as vegetables, especially during the lean season (Simtowe et al., 2010; Upadhyaya et al., 2010; Kingwell-Banham and Fuller, 2014; FAO, 2019). Pigeon pea is an important food security crop in these areas owing to the that fact that it is not consumed fresh and minimally processed, but can also be dried, stored for long periods, and consumed in the lean season when many other less hardy crops cannot be cultivated. Pigeon pea seeds supply both macro and micronutrients (Table 2) highlighting their relevance for household food and nutrition security, particularly important among low-resource households that might not be able to afford more expensive sources of nutrition, e.g., animal-source foods. Both the immature and mature seeds are low in fat, with palmitic and linoleic acids being the predominant saturated and polyunsaturated fatty acid, respectively (Ade-Omowaye et al., 2015; Abebe, 2022). Pigeon pea seeds also contain moderately high amounts of carbohydrate (Table 2), a significant proportion of which is starch and soluble and insoluble dietary fiber, both of which have been found to play a major role in reducing risk for cardiovascular disease, type 2 diabetes, and some cancers, in addition to reducing body weight, blood pressure, LDL cholesterol and inflammation (Brown et al., 1999; Evans, 2020; Reynolds et al., 2020). Some of this could be due to the carbohydrate in pigeon peas showing a low glycemic index (7.0 ± 1.0 to 54.5 ± 0.6), which attenuates the glycemic response (Singh et al., 2021), or the fact that dietary fibre is a source of microbiologically accessible carbohydrates, which can be fermented by colonic bacteria producing short-chain fatty acids, that confer many health benefits.

Pigeon peas also contains high levels of protein (up to 24%) (Table 2), which are in the form of sulphur and non-sulphur amino acids, that is, lysine, leucine, isoleucine, threonine, histidine, and tryptophan (Fuller et al., 2019; Anitha et al., 2019a), which are limiting amino acids in other legumes, cereals and grains commonly consumed in Uganda, such as, maize, highlighting the role that pigeon pea could play in the complementarity of plant-based diets that are largely consumed in rural Uganda, where the plant is grown (Auma et al., 2019, 2021). Akporhonor et al. (2006) argue that combining pigeon peas with cereals can provide a diet with an essential amino acid profile comparable other crops of high protein value, such as, soybean. In fact, a recent study in Myanmar in which pigeon pea and millet were added to the diets of children 6–23 months, found improved intake of all nine essential amino acids, vitamin C, carotenoids, iron, and magnesium, resulting in significant reductions in proportions of wasted, stunted and underweight children (Anitha et al., 2019b). Moreover, Tapal et al. (2019) demonstrated the high digestibility of protein isolate from pigeon pea milling waste, owing to the high yield of essential amino acids and bioactive peptides, highlighting its potential as an ingredient in the manufacture of functional foods, that can be used to improve health. It's no wonder that pigeon pea has been called the "poor man's meat", owing to the high protein content (Fuller et al., 2019), although amounts will vary depending on seed maturity and variety.

Pigeon pea seeds generally contain good amounts of some B vitamins (Table 2), which are usually deficient in many cereals and grains, characteristic of the Ugandan food basket. The mature seeds are high in minerals that play various roles in the body, including, bone health (calcium, magnesium), blood pressure control (potassium, magnesium) and blood glucose control (magnesium) (Table 2). In their paper, Susmitha et al. (2022) highlighted the potential for pigeon pea seed coat as a material for the manufacture of pharmaceuticals, such as supplements due to high calcium and magnesium content. In addition to macro and micronutrients, pigeon pea also contains many phenolic compounds, such as, flavonoids and stilbenes, that are protective to human health, *via* their antioxidant and anti-carcinogenic properties and modulating of the gut microbiota (Nix et al., 2015; Talari and Shakappa, 2018; Abebe, 2022). Pigeon peas contain on average about 27 flavonoids, e.g., apigenin, orientin and vitexin (leaves), isoquercitin (pods), and genistein and cajanol (stem and root) (Nix et al., 2015). Pigeon pea leaves show the highest polyphenolic content, compared with pods, stems and roots (Nix et al., 2015), and the white-seeded varieties reportedly contain about a third of the amount in red-seeded varieties (Abebe, 2022). The high phenolic content, in addition to the unique nutritional profile of pigeon pea, could explain why pigeon pea leaf, stem root extracts, as well as seeds, have been found to have cholesterol-lowering and has traditionally been used to manage various conditions, such, diabetes and hepatitis (Kumar et al., 2021; Wei et al., 2022). While pigeon peas are nutrient-dense, the presence of anti-nutritional factors, i.e., phytic acid, tannins, and trypsin inhibitors, can limit protein bioavailability by inhibiting trypsin enzyme, and bioavailability of iron, calcium, zinc, by binding to minerals (Rizvi et al., 2022). Anti-nutritional factors can be reduced or eliminated through mechanisms like soaking, pressure cooking, and germination (Embaby, 2010; Kajihausa et al., 2014), all of which are effective to varying levels. For example, Rizvi et al. (2022) demonstrated that flour from pigeon peas germinated for 72 h, showed an increase in protein content, antioxidant activity, metal chelating activity, and an overall increase in protein digestibility and iron and zinc bioavailability. The authors attributed these improvements to tannins and phytate content decreasing by 60%, and a reduction in the amount of trypsin inhibitor (Rizvi et al., 2022).

TABLE 2 Nutritional composition of pigeon pea and sesame plant parts.

	Pigeon pea		Sesame	
	Seed (fresh, immature)	Seed (dry, mature, ripe)	Seed (dry, mature)	Butter (from mature seed)
Total moisture (%)	–	–	4.70–7.00	–
Dry matter (%)	–	86.60–88.00	93.00	–
Macronutrients (g/100 g)				
Total carbohydrate	23.88	62.78	9.85	14.20
Total sugars	–	3–6	3.00	–
Dietary fibre	–	9.8–15	10.80–14.90	8.40
Total fat	1.64	1.2–1.49	49.70–51.90	62.40
Total saturated fatty acids	–	0.33	6.70–7.60	8.97
Total mono-unsaturated fatty acids	–	0.01	18.90	22.60
Total polyunsaturated fatty acids	–	0.81	21.90	26.40
Total protein	7.20	21.70	17.00–23.00	19.70
Total protein (%)	–	19.00–24.00	3.20–28.00	–
Micronutrients (mg/100 g)*				
Minerals				
Calcium	42.00	130.00–167.00	714.00–1200.00	116.00
Iron	1.60	2.50–5.23	9.60	7.00
Magnesium	68.00	183.00	370.00	357.00
Phosphorous	127.00	367.00	540.00	719.00
Potassium	552.00	1,392.00–1,941.00	400.00	408.00
Selenium (μg/100 g)	–		2.2.00–51.90	46.50
Sodium	5.00	11.30–17.00	2.00	64.00
Zinc	1.04	2.76–8.20	–	6.04
Vitamins (mg/100 g)*				
Thiamine (B1)	0.40	0.64	0.95	0.99
Riboflavin (B2)	0.17	0.19	0.25	–
Niacin (B3)	2.20	2.96	5.1	5.81
Pantothenic acid (B5)	–	1.27	–	0.60
(B6)	–	0.28	–	–
Folate (μg/100 g)	–	456.00	97.00	108.00
Vitamin A (IU)	–	28.00	0.00	–
Carotene (μg/100 g)	–	–	17.00	–
Vitamin C	39.00	0.00	0.00	–
Vitamin E	0.39	–	0.03	<0.001
Vitamin K (phylloquinone) (μg/100 g)	–	–	–	1.7

Values are approximate to 2 d.p., based on results obtained from different pigeon pea varieties; for items with—data are not available; *values for vitamins are mg/100 g except for those where different SI units are usually reported. Amarteifio et al. (2002); Gbenga-Fabusiwa et al. (2018); Namiki (2007); Bhat et al. (2014); Saxena et al. (2002); Sekhon et al. (2017); U.S. Department of Agriculture, 2022; Wei et al. (2022).

3.7. Sesame (*Sesamum indicum* L.)—Uganda

3.7.1. Origins and utilization

Sesamum indicum L., commonly known as sesame, is an oilseed legume belonging to the order Tubiflorae and the family Pedaliaceae (Bedigian, 1985; Bhat et al., 2014; Wei et al., 2022). Sesame, an herbaceous annual, largely cultivated for its mildly aromatic edible oil that adds a distinct flavor to food, is most likely the first crop cultivated purposely for its oil, having been grown over 6,000 years ago (Namiki, 2007; Bhat et al., 2014; Pathak et al., 2020; Wei et al., 2022). Although "sesame" is the commonly used name, other names used are gingelly, til, benne seed and in Uganda, "*simsim*". Sesame (Figures 4A–D) grows on average 60–150 cm tall, with hairy, rectangular, or ovate-shaped leaves that are about 3–10 cm long and 2.5–4 cm wide (Wei et al., 2022). As sesame loves warm climates with little rain, it is mostly produced in tropical and sub-tropical Asia and African countries, including India. In sub-Saharan Africa, Sierra Leone, Sudan, Nigeria, and Uganda have been previously recognized as the leading producers (Namiki, 1995; Idowu et al., 2021), although recent data suggests that Tanzania has now replaced India as the leading global producer (Namiki, 2007; Wei et al., 2022). As of 2020, sesame production stood at approximately 6.8 million tonnes globally, with 146,000 tonnes being produced in Uganda, where in addition to the domesticated, cultivated variety, two wild species exist: *Sesamum angolense* and *Sesamum angustifolium* (Wacal et al., 2021; FAOSTAT, 2022). Although sesame seed oil is more economically valuable, production still trails other oil seeds, e.g., soybean, peanuts, rapeseed (Namiki, 2007). Like pigeon peas, sesame seeds come in various sizes and colors, such as, white, black, and brown, however, it is the black and white species are more commonly grown, because the black variety is hardier, being resistant to lodging and water stress and is believed to have higher medicinal value (Namiki, 2007; Wei et al., 2022). The exact origin of sesame is highly debated as the birthplace of *Sesamum indicure* L., the wild progenitor, has not been established with certainty (Bedigian, 1985). Some authors propose that sesame originated in India, a sub-continent that still has a diverse germplasm for the plant (Bhat et al., 2014; Pathak et al., 2020). However, other authors purport the origin of sesame to be in central Africa, from which it spread to Egypt, the Middle East, China, and beyond (Namiki, 2007). In countries where it is cultivated and consumed, sesame has various applications, including human food, animal feed, cosmetics, and pharmaceuticals.

3.7.2. Nutritional composition and potential to contribute to nutrition and food security

In Uganda, sesame is an important food and cash crop, widely used among smallholders and resource-constrained households, particularly in the Northern and Eastern parts of the country (Wacal et al., 2021). Here, sesame seeds are eaten as a snack in the form of roasted seeds, with or without salt added, or "*simsim*" balls (roasted sesame seeds bound with molten sugar and formed into a rounded shape). Sesame seeds can also be prepared into a butter that is added to various dishes, like fish, chicken, beans, pigeon peas, beef (Figure 4D), sometimes in combination with peanut butter. In some instances, sesame leaves may be eaten as a vegetable (Namiki, 2007). Like pigeon pea, sesame seeds can be dried and stored for long periods of time, making it an important food security crop among these resource-poor households. Sesame seed, sesame cake, and sesame butter are all high in macronutrients and micronutrients. Sesame is a rich source of protein (3%–28%), with considerable amounts of essential amino acids, in addition to carbohydrate and fat (Table 2). The high oil content of sesame seed (Table 2), which constitutes the main source of calories, has earned sesame the name "queen of oil seeds" (Namiki, 2007; Bhat et al., 2014). Sesame seed oil is rich in n-6 and n-3 polyunsaturated fatty acids (PUFA), mainly oleic (≈39.1%) and linoleic (≈40.0%) acids and linolenic (trace amounts), while the saturated fatty acids are found in smaller amounts, that is, palmitic (≈9.4%) and stearic (≈4.76%) (Namiki, 2007). Sesame has an average protein content of 20%, although some varieties can have as high as 23 g/100 g (Table 2). The larger portion of the amino acid content of the protein in sesame is attributed to methionine (36 mg/100 g), cystine (25 mg/100 g), arginine (140 mg/100 g), and leucine (75 mg/100 g), with small amounts of lysine (31 mg/100 g), highlighting the potential for complementarity with other plant protein foods that are higher in lysine, like pigeon pea (see Section 3.6). In addition to the essential amino acids, Namiki (1995) found unroasted sesame seed to contain high amounts of glutamic acid, arginine, aspartic acid, and alanine, the amounts of which reduce with roasting. The carbohydrate content of sesame seed is largely dietary fibre (Table 2), with small amounts of glucose, fructose and some planteose oligosaccharide fractions (Namiki, 2007). The vitamin content of sesame mostly comprises B-vitamins such as, thiamine, niacin (Table 2), which is largely contained in the seed coat, necessitating the use of the whole seed, even as cake or butter to realize the full benefits of these B-vitamins. Although sesame contains no vitamin A, and only small amounts of carotenoids (Table 2), there are considerable amounts of vitamin E, mainly in the form of

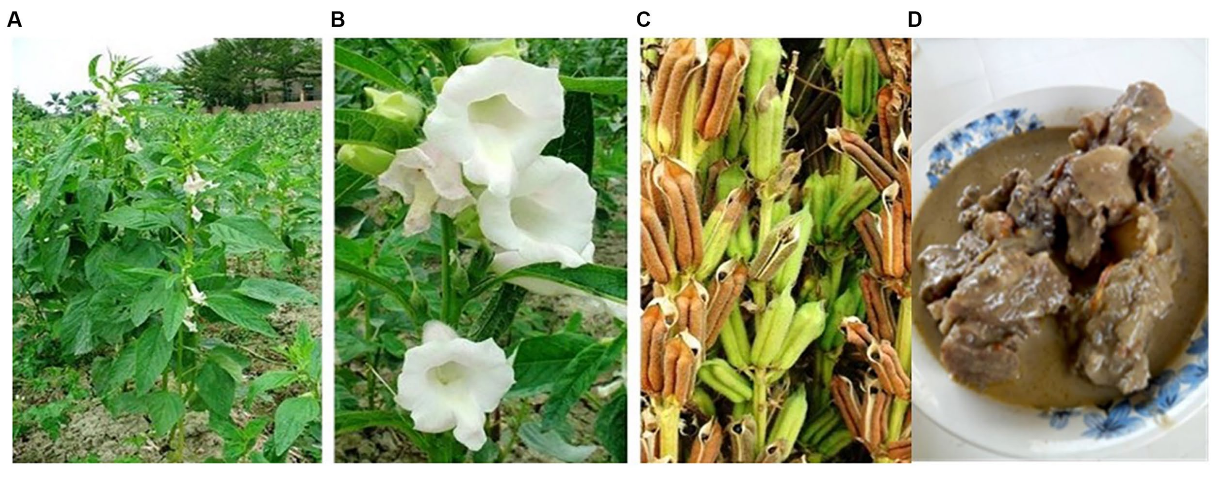

FIGURE 4
Photo series showing sesame showing: **(A)** sesame plant at various stages of growth **(B)** sesame plant flowers in bloom, **(C)** sesame seeds contained within calyx, and **(D)** local Ugandan dish prepared from sesame butter and smoked beef. **(A–C)** Hsu et al. (2011) and author's own for image **(D)**.

10.3389/fsufs.2023.1126020

γ-tocopherols, and only minute amounts of α-tocopherol (Namiki, 2007). The content of many minerals is noteworthy, including potassium, iron, magnesium calcium and selenium (Table 2). Like the B-vitamins, many minerals are contained in the seed coat, and some are bound to anti-nutritional factors, such as, calcium oxalate (Namiki, 2007), presenting some challenges for micronutrient bioavailability.

Sesame has also been found to contain bioactives in the form of isoflavones (daidzein, genistein and glycitein) and campesterols and lignans (sesamin, sesamolin, sesamol and sesaminol glucosides), some of which are not found in other edible oils (Bedigian, 1985; Namiki, 2007; Bhat et al., 2014; Yaseen et al., 2021; U.S. Department of Agriculture, 2022; Wei et al., 2022). Lignans are a special type of dietary fibre that, together with campesterols and isoflavones, have been found to have several health benefits to humans, including lowering amounts of LDL cholesterol and improving the overall blood lipid profile, preventing high blood pressure, as well as having anti-carcinogenic, antimitotic, antivirus, anti-proliferation, pro-apoptosis, anti-inflammatory, anti-metastatic, and antiangiogenic effects (Namiki, 2007; Bhat et al., 2014; Singh et al., 2017; Yaseen et al., 2021; Wei et al., 2022). The anti-inflammatory effects of sesame oil have been attributed to various mechanisms including decrease in lipid oxidation, C-reactive protein, and interleukin-6 (Barbosa et al., 2017). Moreover, the lignans in sesame, as well as γ-tocopherols are strong antioxidants, which enhance the stability and shelf life of sesame oil by delaying or preventing rancidity of the polyunsaturated fatty acid (PUFA) fractions (Fukuda et al., 1985; Bhat et al., 2014). This would be particularly useful for resource-constrained households that might not have adequate storage facilities to maintain the integrity and quality of similar oils with high PUFA content. The nutritional and functional profile of sesame has increased its use in the food industry as health food, as well as seen its applications in the pharmaceutical, cosmetic and other industries as antiseptics, bactericides, disinfectants, antifungal, antibacterial, emollient and laxative, carrier for drugs, solvent for intramuscular injections and healing salve for minor burns, base for creams and lipsticks, natural sunscreen (Bedigian, 1985; Prasad et al., 2012; Bhat et al., 2014), although this is limited in Uganda. However, sesame, like pigeon peas, also has significant amounts of anti-nutritional factors, that is, phytic and oxalic acids, which impact on the bioavailability and digestibility of sesame protein and some micronutrients like calcium. This must be taken into consideration in promoting sesame consumption for food and nutrition security.

3.8. Sustainability issues relating to production and utilization of pigeon pea and sesame in Uganda

Pigeon pea is drought-tolerant and grows well in soils of low fertility. It can thrive in areas with average temperatures of 20–40°C and less than 625 mm of annual rainfall, where other crops like maize would fail (Subbarao et al., 2000; Gichohi-Wainaina et al., 2022). Pigeon pea has high potential because its deep taproots, means the plant can draw water and other nutrients from deeper layers in the soil, allowing it to thrive during dry seasons (Abebe, 2022; Gichohi-Wainaina et al., 2022). Although the pigeon pea can thrive in soils of various pH the crop is sensitive to frost, high salinity, and flooding. Some of these conditions describe what Uganda is already facing due to climate change, with erratic rain patterns and longer-than-usual dry seasons, both without and within the greater North, East, and West Nile regions (Wacal et al., 2021), where pigeon pea is cultivated. While there is scant data on environmental impact of pigeon peas, like other legumes, such as, beans and peas (Clune et al., 2017; Poore and Nemecek, 2018), it can be assumed that pigeon pea cultivation, particularly among smallholders where it is only subject to minimal processing, has a lower water footprint and greenhouse gas emission (GHGE). In studies where pigeon peas have been intercropped with cereals, e.g., maize and millet, the water use efficiency and crop yield of the cereals is greatly enhanced (Musokwa and Mafongoya, 2020; Singh et al., 2020). Moreover, pigeon pea also contributes to maintaining overall soil health, by enhancing fertility and binding soil particles, partly, due to its ability to fix nitrogen in the soil (Musokwa and Mafongoya, 2020; Namuyiga et al., 2022). Some authors like Wei et al. (2022) have suggested that sesame is an easy-to-cultivate, drought-tolerant crop that is suited to intercropping with other cereals and pulses, such as, pigeon pea, making it a suitable crop for areas like Uganda, which is already facing the effects of climate change, particularly in the main sesame-producing areas of the North and East (Demissie et al., 2019; Wacal et al., 2021). Notwithstanding, other authors purport that sesame is sensitive to drought especially during the vegetative stage of growth, which has resulted, in part, to decreased sesame production in Uganda as rains have become less reliable (Wacal et al., 2021). Other factors that have negatively impacted sesame production in Uganda are insect pests and diseases, poor soil fertility as a result of continued poor agronomic practices, poor agronomic practices, e.g., spacing, weeding, etc., low yielding varieties, and limited access to credit by smallholder farmers, who largely engage in the trade (Wacal et al., 2021). While environmental impact at the primary production level may be low for both pigeon pea and sesame, because there is limited research on value-added chains and only small amounts are exported, it is difficult to ascertain the cumulative impact of pigeon pea seeds and processed products from the farm-gate and beyond.

3.9. Factors affecting wider production and utilization of pigeon pea and sesame in Uganda

Anecdotal evidence suggests that pigeon pea was formerly a wild food eaten by wild animals, however, during a period of intense hunger in the 16th and 17th centuries, people in the greater Northern region (Acholi, Lango, and West-Nile) turned to the plant for food (Daily Monitor, 2020). Further evidence indicates that the pigeon pea was part of the pre-colonial and colonial-era diets, constituting an integral part of indigenous food systems of some ethnic groups in Uganda, like the Lango (Obuo et al., 2004; Raschke et al., 2007; Raschke and Cheema, 2008). At the time, and even in present times, pigeon peas, especially in the form of the split-pea sauce "d*ek-ngor*", had strong cultural connotations, being served at naming ceremonies, and at traditional marriages to the in-laws, during which time it is mixed with shea butter, locally called "*moya*" (Daily Monitor, 2020). Like pigeon pea, sesame oil was part of traditional diet in Uganda during pre-colonial and colonial times (Raschke and Cheema, 2008). During colonial times, the growth of the cash-crops economy heralded the beginning of a shift from traditional food crop cultivation, which resulted in reduced household and regional availability of traditional, nutrient-dense crops, such as, pigeon peas, sesame, pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine corocana*), cowpeas (*Vigna unguiculata*), Bambara groundnut (*Vigna subterranea*), all of which can withstand varying levels of water and heat stress (Gura, 1986; Abegaz and Demissew, 1998). Still during colonial times, "modern" foods', such as, refined sugar, wheat, maize flour, were greatly pushed with little consideration for the nutritional, socio-cultural and economic benefits of the indigenous African foods (Allen, 1955; Latham, 1964; Price, 2000).

Pigeon peas and sesame are generally accepted in Uganda, albeit to a larger degree in the Eastern and Northern regions. However, considering that peanuts and peanut butter are commonly used throughout the country both as a food and spread, and sesame and peanut butter are often used similarly, there is potential for even greater acceptance of sesame throughout the country. On the other hand, pigeon peas could complement other dried beans and peas, which are already used widely (Auma et al., 2021). More recently, Uganda, along with many sub-Saharan African countries, is experiencing a dietary transition—furthering the shift from traditional diets, characterized by legumes, nuts and seeds, fresh roots and tubers, and minimally processed foods, to more Westernized diets, characterized by high intake of refined sugar, refined carbohydrates, animal protein, saturated and trans fats and low dietary fiber (Auma et al., 2019, 2021; Revoredo-Giha et al., 2022). The dietary transition has been driven by globalization and economic growth, which has increased individual and household purchasing power, and marketing and advertising (Popkin, 2001; Popkin et al., 2012). These factors, in addition to wider macro food environment factors, such as, poor markets, little research on improved varieties and value addition, have possibly undermined the importance of pigeon pea and sesame as sustainable, nutritional powerhouses. In this regard, for example, sesame is currently seen more as a cash crop than a food crop, being exported to European and Asian countries, e.g., China, Japan, Turkey, and Vietnam (Wacal et al., 2021), where it is used in many industries. On the other hand, the production and consumption of sunflower oil has increased in Northern Uganda—the same areas in which sesame has traditionally been cultivated, with the resultant effect that more households now use it in place of sesame oil. Nevertheless, given changes in dietary consumption trends, there is scope for processing of both crops into products like noodles, gluten-free baked products, which can appeal to the emerging consumer. For acceptability in urban areas, it is suggested to explore further food processing, such as., pigeon-pea tofu, high-protein nutraceuticals, milks, meat replacers, high-protein, or high-fibre baked goods, which can be consumed by discerning or health-conscious consumers (Astuti et al., 2000; Silky and Tiwari, 2014; Tapal et al., 2019), and used to make baked goods, noodles, among others. The use of pigeon pea flour could act as a preplacement for wheat flour (and gluten-free). Recommendations on potential research, stakeholder, and policy engagement to increase utilization of pigeon pea and sesame in Uganda, Africa, and globally.

In addition to products liked gluten-free baked goods, wing to the nutritional profile and potential for complementarity with cereals and other legumes, food processors can formulate flour blends, comprising germinated or fermented pigeon pea flour as weaning foods to alleviate malnutrition, among children under five and as women of reproductive age. Furthermore, there is potential for the use of both pigeon pea and sesame in the production of local ready-to-use foods (RTUFs), which can be used in the treatment and management of malnutrition in other regions within the country. Here, soybean and peanut butter can be replaced by or used in combination with pigeon pea and sesame, respectively. Furthermore, some authors have identified the potential of pigeon pea and sesame protein isolates and hydrolysates for the manufacture of functional foods (Tapal et al., 2019; Aondona et al., 2021). However, for this to happen, it is critical to protect the germplasm and diversity in existing varieties and conduct research, through National Agricultural Research Laboratories, with support and involvement from national and international research organizations, as well as food and agricultural industry players, policy makers and the public, on improved varieties that are still nutrient-dense but tolerant to environmental stressors, particularly salinity and flooding. Moreover, another starting point is to establish consumers' knowledge of pigeon pea nutritional and other benefits, as well as understand determinants of pigeon pea consumption or lack thereof. Similarly, there is a need to produce improved sesame varieties that are still high in nutrients, low in anti-nutritional factors, and yet resistant to the effects of climate change, particularly water stress. Farmers need to be educated on good agronomic practices, such as, pest and disease control and soil fertility management, with reliable microcredit facilities extended to them especially at critical times in the crop production cycle, such as, land preparation and harvesting, to prevent post-harvest losses and infestation with microorganisms like *Aspergillus*. On the other hand, like pigeon pea, consumers need to be educated on the nutritional benefits of sesame oil over alternatives, like sunflower oil and hydrogenated vegetable fat. Also, an exploration of the determinants of sesame seed consumption, or lack thereof, must be established for an understanding of what factors are pertinent to increasing uptake, and consequently, creating local demand. Stakeholders could also explore possible synergies between the two crops by formulating nutrient-enriched products, which harness the strengths of either crop, while at the same time, infrastructure to support the manufacture of these products needs to be put in place among both small and medium-size enterprises and well as large manufacturers. This should not only include adequate transportation to markets and the requisite food processing machinery, but should also consider sources of power, including renewable/sustainable/green energies. Stakeholders might consider taking advantage of the fact that the areas in which both crops are cultivated experience a longer dry season, which could facilitate the implementation of solar energy, for example. Lastly, an exploration of the potential for use of both pigeon pea and sesame in adjunct industries such as an ingredient in pharmaceuticals, and a base in cosmetics, should be explored by reviewing use in case-study countries that make use of them. This might increase among farmers across the country, and ramp up production. However, with any manufacturing processes, environmental impacts in terms of energy, GHGE and water footprint need to be determined, with respect to how that balances out with other aspects of sustainability, that is, economic (smallholder livelihoods enhancement) and sociocultural aspects. In summary, to increase pigeon pea and sesame production and consumption for improved food and nutrition security, a multidisciplinary approach is required between various stakeholders, including academics (plant breeders, nutritionists, and food scientists), local and international third sector organizations and policy makers.

3.10. Summary

Uganda is one of the most ecologically biodiverse countries (>18,000 flora and fauna species) globally (Kimani et al., 2020) and produces more than it consumes. However, a high proportion of children under five are still stunted (28.9%) and anaemic (53%), while high proportions of women of reproductive age suffer from iron deficiency anaemic. Moreover, severe household food insecurity in the country is still high, standing at 23.2% at the national level (FAO, IFAD, UNICEF, WFP and WHO, 2022.) and higher still, on average, in the Greater Northern region (Revoredo-Giha et al., 2022). Similarly, Nigeria, though rich in a variety of crops, with most of them falling within the category of NUS, is facing the same challenge such as severe food and nutrition insecurity, poorly managed land use and westernized diet transition. This is a timely call for more NUS plants to be promoted to be used for food, improve the diet diversity, and therefore, the quality of many household diets and wellbeing.

Raising awareness of the myriad benefits of the sesame, pigeon pea, African breadfruit and African walnut, alongside other NUS, while concurrently establishing value chains, including appropriate processing technologies for novel products, could help increase production and make these crops more desirable to consumers in Uganda, Nigeria, and sub-Saharan Africa generally. Moreover, value-added products could also be economically valuable for export markets. Greater utilization of NUS presents an opportunity to build healthier, more sustainable global, and indigenous food systems. However, this can only be realized by employing evidence-based information on the food and nutrition security potential of NUS and appropriate economically, socially, and environmentally viable processing methods and build a healthy marketing system, to enhance food production and dietary diversity, while contributing to resilience and improved livelihoods of smallholder and rural population.

Author contributions

CN, CA, and YG: conception of idea and revision and proofreading of manuscript. CN and CA: manuscript drafting, contributed equally, and hence, share the first authorship. YG: general supervision. All authors contributed to the article and approved the submitted version.

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Recalibration of benchmarks is necessary: even the most basic meal was not affordable for Malawi's poor between 2017 and 2021

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Dietary quality has significant implications for health, nutrition and life quality. Yet, most people in developing countries, such as Malawi, consume inadequate diets due to the high cost of healthy and nutritious food. The international community has called for a radical transformation of food systems to ensure access to healthier food options at affordable prices. While the costs and affordability of healthy and nutritious diets have recently been established, little attention has been paid to the economic accessibility of basic nourishment. The most available price data (2017 to 2021) from the National Statistics Office of Malawi (NSO) were used to calculate the cost of the World Food Program's "basic plate." Food items were substituted to determine if local substitutes could improve the nutritional value of the plate. The plate cost was compared to the international poverty line and average food expenditure in Malawi. Slight variations in the purchase parity cost and affordability of basic meals were found between 2017 and 2021. However, the basic meal and alternative plates were not affordable to those living at or below the international poverty line over this period. A revision of the poverty line is necessary to ensure that basic nutritional needs can be met. Both revisions of the poverty line and cash-based food assistance should consider that meals using animal-sourced proteins were more expensive than plant-based protein sources, but animal-sourced proteins provide more nutrition than plant-based protein meals.

KEYWORDS

food security, nutrition, cost and affordability, basic meals, diet quality

1. Introduction

Recent global price inflation raises fears of increasing hunger and malnutrition. Since 2020, there has been a sharp increase in global consumer food prices that have increased the average cost of a healthy diet (FAO et al., 2022). Only recently has attention turned to determining the cost and affordability of a basic diet (Darmon and Drewnowski, 2015; Masters et al., 2018; Hirvonen et al., 2019; Bai et al., 2020; FAO et al., 2020; Herforth et al., 2020; HLPE, 2020; Suresh and Ma, 2020; Hendriks et al., 2021; Schneider, 2022).

Over three billion people globally cannot afford a healthy diet that meets dietary recommendations based on national food-based dietary guidelines (FAO et al., 2022). Another 1.5 billion people cannot afford a nutritious diet—one that provides adequate calories and enough of all essential nutrients (FAO et al., 2020; Herforth et al., 2020). The negative repercussions of consuming poor diets are well established [Galler et al., 2012, 2021; Waber et al., 2013; Global Panel on Agriculture and Food Systems for Nutrition (GloPAN), 2016]. We know that the poor are disproportionately affected by malnutrition. We also know that the poor are very sensitive to food and energy inflation because they spend a large proportion of their constrained income on food and the energy to prepare it.

The Food and Agriculture Organization of the United Nations and its partners (FAO et al., 2022) have reported that the average cost of a healthy diet globally in 2020 was USD 3.54 per person per day. This cost way exceeds the per person-per day international poverty line of US$1.9 based on 2015 prices. This raises alarm as the international poverty line is used as a base for determining the eligibility of countries and individuals to development aid and support. It is also commonly used as the base for determining social grants and cash-based food assistance.

With this concern in mind, in 2016 the World Food Program (WFP) investigated the cost and affordability of a basic meal in 33 developing countries compared to the cost of the same plate in the developed world [World Food Programme (WFP), 2017]. The results revealed that the cost of a basic plate of food or meal (not representing an adult's total required daily intake) exceeded the daily income for countries like South Sudan, Northeast Nigeria and some parts of Syria. Masters et al. (2021) expanded the WFP study to include nationally representative food price data from 168 countries obtained from the 2017 round of the World Bank's International Comparison Program (IPC; World Bank, 2019). Masters et al. (2021) found that the raw ingredients for a basic plate were unaffordable for the poorest, and the added cost of time and fuel can make such meals prohibitively expensive. Such insights play an important role in determining the underlying reasons for malnourishment, estimating the magnitude of the problem and setting baselines for a range of economic and social indicators and criteria for access to support. Therefore, this study used price data from Malawi to investigate the cost and affordability of a basic meal for the poorest citizens to inform benchmarks and policy change.

While globally much policy attention has focused on improving diets and dietary diversity through nutrition-specific and nutrition-sensitive initiatives, little attention has been paid to considerations of affordability and the role affordability plays in access to sound nutrition. For example, the consumer price index includes a basket of goods for an average household, but do these baskets include the elements necessary for sound nutrition? The poverty line (be it national or international) is used for grant access criteria. The cost of a basic plate is used to determine food aid cash values. Yet, the implications of the unaffordability of basic nourishment on the setting of core baselines at the national level have not been investigated.

More than a third of Malawi's children are stunted (35.5%—which is higher than the 30.7% average for the Africa region). Wasting is found in 2.6% of Malawian children (Development Initiatives Poverty Research Ltd, 2022). The World Bank (2023) has reported that poverty levels in Malawi are one of the highest globally. The Malawi Vulnerability Assessment Committee (MVAC) has projected that 3.8 million people (about 20% country's population) will face hunger between November 2022 and March 2023 (Integrated Phase Classificaiton (IPC), 2023). Could the affordability of food be an underlying cause of this suffering? This study seeks to address this question.

2. Methods and procedures

This study adopted World Food Programme (WFP)'s (2017) basic plate analysis approach and used the most recent secondary national data available at the start of the analysis. While it is acknowledged that the content of one meal does not constitute all that an individual requires for an adequate diet, the basic plate is a useful comparison of costs against the international poverty line.

The data used included food price data, food expenditure data and the international poverty line. Food price data was obtained from the National Statistics Office of Malawi (NSO) and was required to determine the cost of the various meals. NSO collects average monthly food price data for purposes of computing the Consumer Price Index (CPI; Schneider, 2022). This data was preferred for its consistency over time but also because it covered a wide range of food items across many markets countrywide (Schneider, 2022). The food price data comprised 20 food items collected across 13 markets from January 2017 to December 2021. The markets from which data was collected included both urban areas (Blantyre, Lilongwe, Mzuzu and Zomba) as well as rural areas (Karonga, Rumphi, Mzimba, Kasungu, Salima, Dedza, Mangochi, Chitakale and Nchalo). All prices were originally in Malawi Kwacha but following Herforth et al. (2020), the prices were converted to US$ Purchasing Power Parity (PPP) exchange rates to enable comparison with the international poverty line. Further, the original prices were per kilogram weight of each food item. During the course of the analysis, prices per kilogram were converted into the respective weights (grams) of plate ingredients.

The data required to evaluate the affordability of basic meals was sourced from the World Bank's International Comparison Program (ICP). ICP is a statistical initiative used to compare standards of living at the global level (Headey and Alderman, 2019). ICP collects global-level comparative price data and GDP expenditure for the purpose of computing Purchasing Power Parity (PPPs; World Bank, 2019). The latest food expenditure data was available in 2017 PPP hence the costs of ingredients from 2018 to 2021 were converted into 2017 PPP following Herforth et al. (2020).

The international poverty line was another type of data required to compute the affordability of the basic meals. The international poverty line was sourced from the World Bank's PovcalNet. Povcalnet is an online tool by the World Bank used to calculate and monitor the extent of poverty and inequality in the world (Zhao, 2019).

2.1. Data analysis techniques

Two main data analysis techniques were employed during the analysis of this study including the "basic plate" approach and the Friedman rank sum test.

First, the 'basic plate' least-cost approach as set out by Masters et al. (2021) and adapted from the original World Food Programme (WFP) (2017) approach was used. A basic plate only meets one-third of an adult individual's daily energy needs and thus it is neither nutritious nor healthy.

Abbreviations: AFEM, verage Food Expenditures for Malawi; FSIPL, Food Share of International Poverty Line.

It is typically compiled with least-cost ingredients and includes a starchy staple (75 g), protein source (57.25 g), tomatoes (55 g), onion (16.25 g), and vegetable oil (28.13 g; Masters et al., 2021). In this study, the basic plate ingredients were maize flour, brown beans, tomatoes, onion and vegetable oil. Maize flour would be used to make a paste locally called *nsima* while brown beans would make stew. Noteworthy, maize flour and brown beans were not the least-cost ingredients based on available data. However, they represent a typical meal that would be consumed in all parts of Malawi. In contrast, if the study had relied on the available data, cassava and pigeon peas would be the least-cost ingredients, but they are not representative of a typical Malawian meal, as their consumption is mainly limited to specific areas of the country (Kambewa, 2010; Orr et al., 2014; Köcke, 2019; Davies, 2022). The basic plate must be representative of the country's consumption realities (World Food Programme (WFP), 2017), hence the use of maize flour and brown beans. In addition, the choice of *nsima* and beans corresponds with the basic meal that was compiled by World Food Programme (WFP) (2017).

To assess the cost premiums of improving the nutrient content of the meal by switching from plant-source protein to animal-source protein, several variations of the basic plate were evaluated. These plates maintained the other ingredients of the basic plate but replaced brown beans with animal protein sources. The variations of the basic plate are referred to as 'alternative plates'. Seven alternative plates were created, which substituted brown beans with four meat types and three different fish. Table 1 provides a summary of the composition of each plate.

The meat protein sources included beef, chicken, goat and pork while the fish category comprised cichlid (*utaka*), fresh *chambo (tilapia)*, small herring (*usipa*; Table 1). Since the consumption of animal protein sources is low in Malawi (Gilbert et al., 2019), an understanding of the costs of consuming different animal protein could provide insights into whether costs could be a hindrance to animal protein intake in Malawi. Animal protein considerations are especially important because animal protein has high nutritional quality, essential for the nutrition status and health of individuals, especially children (Day et al., 2022).

Second, to assess whether there were statistically significant differences in the cost of food items over a five-year period, the study employed the Friedman rank sum test (Friedman, 1937). The Friedman rank sum test was deemed appropriate because of its ability to test for differences in three or more groups when data has equal variance but fails to fulfill the normality assumption (Nahm, 2016). Importantly, the test was chosen because among the many applications of the Friedman rank sum test, is the use of the test to ascertain statistical difference across the same subjects over three or more time periods (Ali and Bhaskar, 2016, Liu and Xu, 2022, p.3)—in this case the years. The test statistic for the Friedman test was performed such that;

$$Q = \frac{12}{nk(k+1)} \sum_{j=1}^{k} R_j^2 - 3n(k+1)$$

Where Q is the Friedman test statistic.
n is the number of subjects (food items/costs of food items).
k is the number of repetitions (number of years).
$\sum k_{j=1} R^2_j$ is the sum of the squares of the sum of ranks.

The null hypothesis was, therefore, be rejected if Q was greater than the critical chi-square value (Pereira et al., 2014; Eisinga et al., 2017). Alternatively, the null hypothesis was rejected if the value of p accompanying Q was less than or equal to the α level of significance. When the null hypothesis is rejected, *post hoc* comparison tests are conducted (Pereira et al., 2014).

Last, the study determined the affordability of each plate over time, which was carried out (after Herforth et al., 2020) in two ways. Firstly, with respect to daily average food expenditure (AFEM) for Malawi. To determine affordability using AFEM, the cost of each plate was compared to daily average food expenditure. From the ICP 2017 food expenditures data, Malawi had an average food expenditure of US$ 298 *per annum* which translated to US$ 0.82 per day. Affordability with respect to AFEM was, therefore, defined as the proportion of the cost of each meal to AFEM (US$ 0.82).

Secondly, affordability was evaluated with respect to the food share of the international poverty line that can reliably be kept for food expenditures. For low-income countries like Malawi, 52% of the international poverty line is the estimated mean expenditure on food by poor households. In this study, the international poverty line of US$ 1.90 per day was used. Taking 52% as the amount spent on food, the food share of the international poverty line US$ 0.99 (Herforth et al., 2020). In this study, the food share of the international poverty line was abbreviated FSIPL. To this end, affordability was defined as the proportion of the cost of the basic plate and alternative plates to FSIPL (US$ 0.99).

3. Results

Table 2 presents the cost of various food items over 5 years. These food items were the ingredients used to compile the basic plate and alternative plates following WFP's "basic plate" approach [World Food

TABLE 1 Summary of the composition of each plate between 2017 and 2021.

Food group	Basic plate	Meat	Fish
Staples	Maize flour (75 g)	Maize flour (75 g)	Maize flour (75 g)
Vegetables	Tomato (55 g)	Tomato (55 g)	Tomato (55 g)
	Onion (16.25 g)	Onion (16.25 g)	Onion (16.25 g)
Fruit	-	-	-
Legumes and nuts	Brown beans (57.25 g)	-	-
Animal foods	-	Beef, Goat, Chicken, and Pork (57.25 g)	Fresh *chambo (tilapia)*, Small herring (*usipa*), and Cichlid (*utaka*) (57.25 g)
Fats	Vegetable oil (28.13 g)	Vegetable oil (28.13 g)	Vegetable oil (28.13 g)

Author's own compilation. Food groups based on Malawi's nutrition guidelines (Ministry of Health et al., 2007). Weight of ingredients based on Masters et al. (2021).

TABLE 2 The cost of food items.

	Food item	Cost (US$)				
		2017	2018	2019	2020	2021
Starchy staples	Maize flour-gramil	0.09	0.15	0.17	0.17	0.15
Protein sources	Fish-fresh *Tilapia (chambo)*	0.72	0.71	0.65	0.55	0.57
	Fish-cichlid (*utaka*)	0.37	0.29	0.27	0.28	0.24
	Fish-small herring (*usipa*)	0.39	0.31	0.32	0.28	0.25
	Brown beans	0.19	0.23	0.18	0.17	0.21
	Beef	0.45	0.49	0.50	0.51	0.47
	Pork	0.40	0.48	0.50	0.52	0.47
	Goat	0.41	0.48	0.49	0.46	0.46
	Chicken	0.54	0.50	0.49	0.47	0.50
Others	Cooking oil	0.09	0.08	0.09	0.08	0.11
	Tomato	0.10	0.10	0.11	0.09	0.10
	Onion	0.04	0.06	0.04	0.04	0.03

NSO food price data (2017–2021). The color blue indicates increases in ingredient costs across the years while the color orange indicates cost decreases.

TABLE 3 The cost of substituting beans with animal protein sources.

Plate protein source		2017	2018	2019	2020	2021
Basic	Brown beans	0.51	0.62	0.58	0.56	0.60
Fish						
Ingredients: Maize flour (gramil), fish, onion, tomato, cooking oil.	*Utaka*	0.69	0.68	0.67	0.66	0.63
	Usipa	0.71	0.69	0.72	0.66	0.65
	Fresh *chambo*	1.04	1.10	1.05	0.93	0.96
Meat						
Ingredients: Maize flour (gramil), meat, onion, tomato, cooking oil.	Beef	0.77	0.87	0.90	0.90	0.86
	Pork	0.72	0.87	0.90	0.90	0.86
	Goat	0.73	0.86	0.89	0.84	0.85
	Chicken	0.86	0.89	0.89	0.85	0.90

NSO food price data (2017–2021). The color blue indicates increases in plate costs across the years while the color orange indicates cost decreases.

Programme (WFP), 2017] and the adaptation by Masters et al. (2021). A total of 12 food items were included at different stages of the analysis (Table 2). The foods consisted of a starchy staple, a pulse, animal protein source, vegetables and vegetable oil. There were slight variations in the cost of ingredients across the years. Overall, the cost of maize flour ranged between US$0.09–US$0.17 over time while the cost of brown beans, the different fish and meat types fell in the range of US$0.24–US$0.72.

On average, the cost of most basic plate ingredients was lowest in 2020 and 2021. When the cost of the protein sources was compared per weight, *chambo* was the most expensive protein source followed by chicken, beef, pork and goat. Brown beans were the cheapest protein source per weight. In general, while the costs of the other protein sources fluctuated over the years, the cost of *chambo* was highest in 2017 and lowest in 2020 (Table 2).

Table 3 presents the cost of the basic plate across 5 years. The cost of the basic plate varied over time, albeit slightly, ranging from US$0.51–US$0.62 between 2017 and 2021 (Table 4). Overall, the basic plate was relatively costlier in 2018 and lowest in 2017. Notably, the cost of the basic plate was also fairly low in 2020 relative to what could be expected in a period when the Covid-19 pandemic jump-started a

TABLE 4 Testing for statistical significance of food costs over time.

Friedman rank sum test	
Statistic	Value
Chi-squared	6.06
Degrees of freedom	4
p-value	0.19

NSO food price data (2017–2021).

rise in global food prices. The Friedman rank sum test was conducted to determine if the observed variation in ingredient prices across the years was statistically significant. Given a Chi-squared statistic of 6.06 with a corresponding value of p of 0.19 (Table 4), the Friedman rank sum test revealed a lack of sufficient evidence to support the existence of statistically significant differences in the cost of the ingredients over time.

Generally, switching from beans to animal protein sources raised the cost of the plate in all 5 years (Table 4). However, the cost increments varied across individual protein sources and years of analysis. Within the

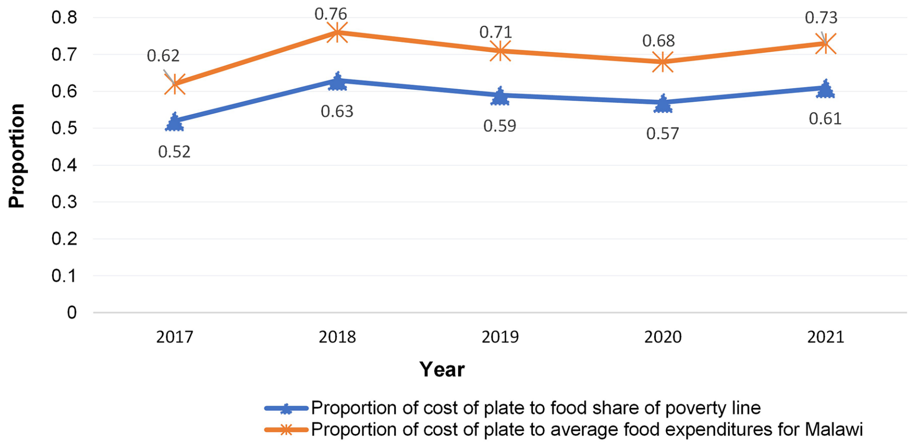

FIGURE 1
Affordability of the basic plate with respect to daily average food expenditures for Malawi (AFEM) and food share of the poverty line (FSIPL). NSO food price data (2017–2021).

fish category, substituting brown beans with *chambo* raised the cost of the basic plate considerably higher by a factor ranging between 1.7 and 2 across the years. At the same time, switching to *usipa* and *utaka* raised the cost of the basic plate only slightly.

Similar differences could be observed in the meat category. Substituting brown beans with chicken significantly raised the cost of the plate with a factor of 1.44–1.7. Switching from brown beans to goat was relatively cheaper and the cost of the plate increased by a factor in the range 1.39–1.5. Ultimately, the incremental cost on the basic plate upon switching to animal protein sources was highly dependent on the type of animal protein source. In general, *chambo* was the most expensive protein source per weight followed by chicken (Table 4). Smaller fish like *usipa* and *utaka* were the cheapest animal protein sources per weight.

Generally, there were slight changes in the affordability of the basic plate between 2017 and 2021 (Figure 1). With respect to the international poverty line, the cheapest basic plate over the 5 years was approximately half of the FSIPL while the most expensive plate was more than 63% of the FSIPL. Further, with respect to food expenditures, the cheapest basic plate between 2017 and 2021 was 62% of AFEM while the most expensive plate was 76% of the AFEM.

Apart from evaluating the affordability of the basic plate, the study also determined the affordability of alternative plates. The affordability of the alternative plates was determined by the proportion of the cost of the various alternative plates to the FSIPL and AFEM. These results are presented in Figure 2. While the affordability of alternative plates varied from plate to plate and year to year, findings reveal that affordability was better for the *utaka* plate than the other alternative plates. *Utaka* plate took the smallest portion of both the FSIPL and AFEM, followed by *usipa*. In contrast, the least affordable plate with respect to both measures of affordability was *chambo* in all 5 years. *Chambo* was followed by chicken as the least affordable plates. This finding is also in line with the high cost of *chambo* as demonstrated in Tables 2, 4 which made the plates less affordable to the poor.

The results further reveal that the affordability of alternative plates with meat (beef, pork, goat, chicken) was only worse when compared to AFEM between 2018 and 2021 (Figure 2). Notably, the affordability of some meat plates, particularly beef, goat and pork were better in the year 2017 as evidenced by low plates costs in comparison with both measures of affordability. Overall, the alternative plates were less affordable than the basic plate.

4. Discussion

On average, the cost of most basic plate ingredients was lowest in 2020 and 2021. *Chambo* was the most expensive protein source followed by chicken, beef, pork and goat while brown beans were the cheapest protein source per weight. These findings concurred with Masters et al. (2021), who found that switching from beans to fish significantly raised the cost of the basic plate. Animal and plant proteins differ significantly in their bioavailability, digestibility, nutritional content and quality; making them unequal substitutes (Moughan, 2003, 2021; Lofgren, 2013; Day et al., 2022), especially for children who cannot consume large quantities of food at a time. However, differences in bioavailability between plant protein and animal protein were not factored into the calculations in this study. The same weight of raw ingredient was used but if bioavailability is considered, higher rations of plant-based protein in the plate may need to be included.

Cost increments varied across protein sources and years of analysis. The variation in ingredient costs could mainly be due to food price fluctuations, especially related to the country's main staple, maize. Maize availability tends to influence food prices in Malawi so much that one could expect a low cost of ingredients in years of bumper maize yields and a higher cost when national maize stocks are low (Ngoleka, 2013). The specific ingredient's price is determined by a number of factors.

The incremental cost on the basic plate upon switching to animal protein sources was highly dependent on the type of animal protein source. In general, *chambo* was the most expensive protein source per weight followed by chicken. Smaller fish like *usipa* and *utaka* were the cheapest animal protein sources per weight. *Usipa* and *utaka* are quite small, cheap and unimportant at the commercial level while *chambo* is a commercially significant fish and retails for high prices, especially when dried (Singini et al., 2013). Similar differences could be observed

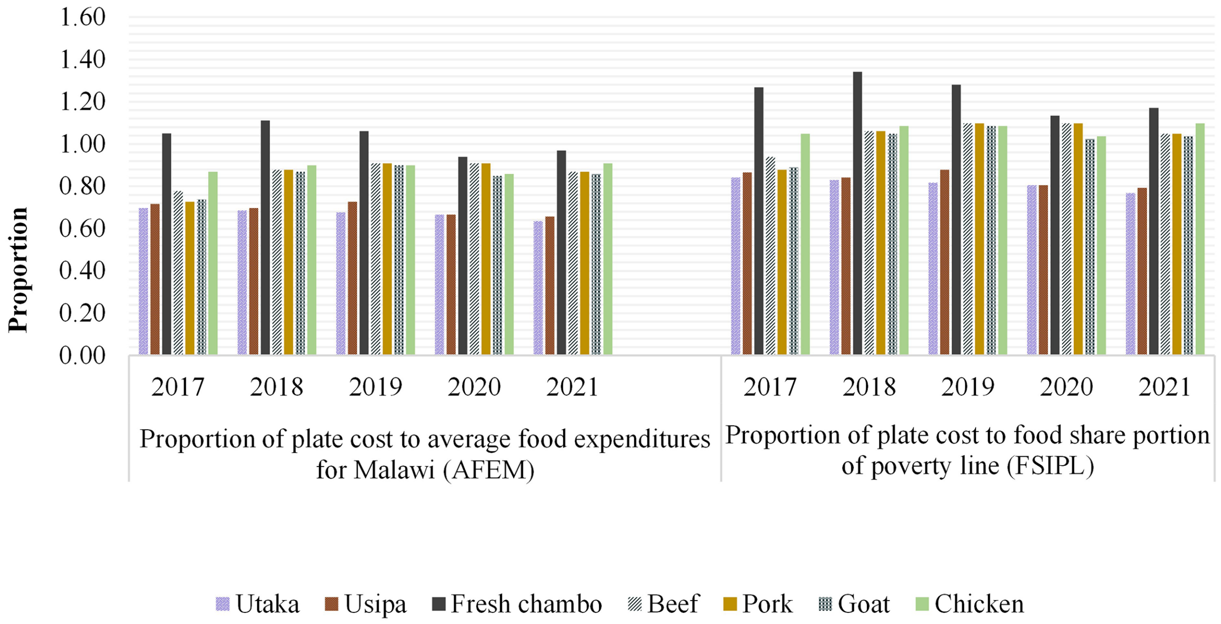

FIGURE 2
The affordability of alternative plates with respect to daily average food expenditures and food share of international poverty line. NSO food price data (2017–2021).

in the meat category. The desirability of the meat type influenced the price, affecting total plate cost (Desiere et al., 2018).

In developing countries like Malawi, where poverty rates are high and the consumption of animal-source foods is low (Allen and Dror, 2011), the high cost of animal protein sources could pose a huge obstacle to people's access to the same, possibly resulting in a substantial proportion of the population unable to consume high-quality protein of which animals and seafood are an excellent source (Day et al., 2022).

The cheapest basic plate between 2017 and 2021 was 62% of AFEM while the most expensive plate was 76% of the AFEM. These findings make the basic plate appear affordable at first glance. However, the basic plate is but a single meal. If the full day's energy and nutritional needs of adult person are considered, the basic plate quickly becomes unaffordable, especially when compared to the AFEM between 2018 and 2021. All alternative plates would become less affordable if the full day's energy and nutrient requirements of an adult person were considered.

5. Limitations of the study

The methodological approach employed in this study has several limitations. First, this study examined the cost of basic meals. However, basic nourishment is hardly adequate for an active and healthy life. A human being needs to consume diets that are diverse in macro and micronutrients. By only considering basic nourishment, the study does not cover the costs that could be incurred in accessing nutrient adequacy. Be that as it may, some studies have looked at the cost and affordability of nutritious and healthy diets, like Herforth et al. (2020), albeit at the global level, while Schneider (2022) evaluated the cost of nutrient adequacy in rural Malawi. Second, by analyzing the costs of plates, the study does not consider plates and diets available to households through non-purchase means. For example, the study did not consider the dependency on, among others, own production, food aid, gifts from family, friends, neighbors, or well-wishers. Last, this study is limited to Malawi and reflects the Malawian population's consumption patterns and food choices, which may not be generalized to other countries. However, countries that present similar characteristics as Malawi may find the findings of this study useful.

6. Conclusions and recommendations

The findings of this study raise alarm of the plight of the poor in Malawi and indicate the need for further investigation of the affordability of even the most basic nutrition more broadly. The analysis determined that the cost of even one basic meal was unaffordable to the poorest in Malawi. Substituting more bioavailable protein sources made the meals less affordable between 2017 and 2021. The cost of substituting cheaper ingredients did not make the meals affordable either. Slight variations in the purchase parity cost and affordability of basic meals were primarily linked to fluctuations in domestic food supply. While the findings of this study are not generalizable to other countries in the region, it is recommended that this study could be replicated in other countries to better inform policy decisions and the design of development programs to address undernutrition and poverty.

Without a significant change in the incomes of the poor, access to a nutritious diet is impossible in Malawi. A radical re-benchmarking exercise is necessary if the country intends making progress on reducing undernutrition and allowing people to escape poverty. Reformulation of the components included in the consumer price index and basic baskets of goods used to estimate national and international benchmarks of poverty are necessary and the recalibration of basic wages and cut-offs determining access to social protection and international development aid (including cash transfers for food) are necessary to ensure access to even the most basic nourishment—one meal a day.

A number of policy interventions could support improved access to affordable and nutritious meals. Apart from a radical recalibration of poverty benchmarks and improvement in the value of social protection payouts, interventions that improve incomes, increase the supply to reduce prices and the provision of social protection to the very poor to increase their purchasing power are essential. Projects to support the production of fish, poultry and other small animals could provide livelihoods, incomes and increase the supply of animal-sourced-protein for communities. Likewise, removing value-added tax (VAT) on foods that provide basic foods could reduce the cost of meals. A redirecting of input and production subsidies could incentive the production of more nutrient-rich foods.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: Food composition data are publicly available at https://dl.tufts.edu/concern/pdfs/d217r336d. Food price data are available upon request from the National Statistics Office of Malawi. Requests to access the food price dataset should be directed toward commissioner@statistics.gov.mw. Food expenditure data are publicly available on the World Bank's website at https://databank.worldbank.org/source/icp-2017. The international poverty line is also publicly available on the World Bank's website at https://pip.worldbank.org/poverty-calculator.

Author contributions

MB and SH conceptualized the study. MB conducted the review of literature, analyzed the data, and drafted the initial paper. SH supervised the research and reviewed the drafts. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Current practices, challenges and new advances in the collection and use of food composition data for Africa

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High-quality food composition data are indispensable for improved decision-making in food security, health policy formulation, food labeling, diet formulation, agricultural policymaking, nutrition research, and many other nutrition-related activities. The optimisation of dietary patterns is a powerful tool to reduce the impact of malnutrition on a population's health and well-being. Many countries in resource-poor settings lack a framework for developing and managing food composition data appropriate for these purposes. In the article, an overview of available food composition tables in Africa and the origin, use and limitations of theses tables are discussed. It is important that those working on any nutrition-related activity for resource-poor settings understand the limitations of current food composition data. Production of high-quality data requires the harmonization and adoption of international standards and guidelines across Africa. Moreover, continuity in the production, compilation and management of high-quality food composition data is challenged by suboptimal capacity building in terms of organizational, institutional and legal framework development. In this perspective article, the authors deliberate on challenges with a focus on Africa, while discussing new advances in food composition activities. Opportunities (such as the Internet of Things (IoT), wearable devices, natural language processing (NLP) and other machine learning techniques) to improve existing resources must be more actively explored and supported.

KEYWORDS

food composition data, food security, information and communication technology (ICT) tools, machine learning, capacity building

1. Introduction

Reliable, high-quality data on the composition of foods intended for human consumption is an important resource for different applications. These data are used in various ways throughout the food system, for example, but not limited to: (1) assessing the dietary intake of individuals or groups and carrying out epidemiological studies and clinical research, (2) formulating diets at the individual and/or population level, (3) educating consumers, (4) formulating agricultural and food policies in relation to public health, and (5) supporting industries for product labeling purposes and improved food processing methods.

There are currently over 150 food composition tables or nutrient databases, printed or electronic, in use worldwide (Schönfeldt and Pretorius, 2019). In general, the quantity, quality and availability of food composition data vary by country and region, but most developing countries still lack sufficient and reliable data (de la Revilla et al., 2023). Many tables are based on data from the United States Department of Agriculture's (USDA) National Nutrient Database (Schönfeldt and Pretorius, 2019; de la Revilla et al., 2023). In 1968 "Food Composition Table for Use in Africa" (Leung, 1968) was developed and published. In 1988, a collection of data on the regional food composition data of foods most commonly eaten in Eastern Africa evolved from a table compiled for use in a joint research program in Tanzania on vitamin A deficiency (West et al., 1988). Most of this data has been derived from other tables and literature. A regional food composition database, the Composition of Selected Foods from West Africa, was published by the FAO in 2010 and revised in 2012. Most of the collected data were for raw foods, representing average values of the collected compositional data from 9 countries (Benin, Burkina Faso, Gambia, Ghana, Guinea, Mali, Niger, Nigeria and Senegal) (FAO, 2012). This food composition table was superseded by the 2019 Food Composition Tables for Western Africa (FAO, 2020). Over the years, some African countries have also published their own country food composition tables. A comprehensive list of the food composition tables available can be obtained from the Food and Agriculture Organization of the United Nations (FAO) International Network of Food Data Systems (INFOODS) page.[1] Additional country-specific tables are also available either as limited addition printed documents or at a cost which restricts access to information.

The data, in especially the older tables but not limited to these tables, are based on a very limited number of samples, a limited number of foods and nutrients (missing values), and analytical methods that are outdated by today's standards. However, these tables are still being used as there are limited up-to-date tables with country-specific data readily available. Additionally, the reuse of data may propagate nutritional composition values based on outdated analytical methods and equipment, as well as nutritional, food, and recipe values with inadequate descriptions and documentation (de la Revilla et al., 2023). A variety of factors influence food nutrient content over time, including agricultural practices, food policies, and consumer pressure, which are rarely reflected in databases. For example, the nutrient composition of maize and maize meal, a starchy staple in Sub-Saharan Africa can vary geographically due to environmental factors (e.g., soil type and climate), farming and food processing practices (e.g., fertilizer use, milling, storage) and policy (e.g., country-specific fortification) and these variations can be nutritionally relevant leading to an over- or underestimation of nutrient intake.

Despite having a multitude of use cases of undisputable importance, the management of food composition data (FCD) faces several challenges in Africa. This is particularly the case from a data quality management perspective, where 'missing data' continues to be a serious challenge for most food composition databases (FCDBs). A lack of adequate documentation and incomplete referencing of these databases may also hide important issues. Challenges in managing FCD can be experienced across its entire data lifecycle, from how the data are created, stored and distributed or shared, through to the consumption or use, and archival or disposal of such data. This article summarizes the authors' specific viewpoint on current practices, challenges and new advances in the collection and use of food composition data for Africa.

2. Origin, uses and limitations of different types of food composition data

Diet is the most important determinant of disease globally, with large regional differences. Maternal and child malnutrition contributes for more than 25% to the loss of healthy life years in populations with a low socio-demographic index (Institute for Health Metrics and Evaluation (IHME), 2020). That includes many African countries. Relationships between diet and health have not only been shown at the level of the dietary pattern, food groups, and foods but especially also at the level of nutrients (Zinöcker and Lindseth, 2018). Hence, the World Health Organization recommends that the intake of saturated fat and sugar to be less than 10% of total energy intake and the intake of salt not to exceed 5 g per day (equivalent to sodium intake of less than 2 g per day) (WHO/FAO, 2003; FAO, 2010). Therefore, to establish relationships between diet and health, but also for monitoring and surveillance in public health nutrition, reliable information on the composition of foods is indisputable.

Food composition data are generally classified in their different types, based on the method used to collect or acquire the data. There are five recognized types, namely, analytical, copied or borrowed, calculated, imputed and presumed or assumed data. A combination of these methods is often used to create national or regional FCDBs (Kapsokefalou et al., 2019).

Analytical data are renowned for being the most accurate, as data are generated from foods that are commonly consumed in a particular region. Ideally, representative samples collected from selected foods are analyzed using standardized chemical methods. However, generating original analytical food composition data is very expensive in comparison to the other four types. This high cost has contributed to the fact that most FCDBs on the African continent only contain a relatively low amount of analytical data (De Bruyn et al., 2016).

Copied data are acquired from FCDBs, scientific articles, dissertations, laboratory reports and gray literature that were collected in other parts of the world. They are typically collected from foods that are grown and consumed in the country or region of origin, and not necessarily the country that is retrieving the data. It is less likely that copied data will accurately represent foods consumed in the region that is copying the data. This is mainly a result of several factors such as soil composition, climatic conditions, seasons, biodiversity, agricultural practices, industrial processing and food preparation. Thus foods grown and consumed in different geographical locations are unlikely to have the same composition (Ene-Obong et al., 2019). When copying data, guidelines for checking food composition data prior to publication must be established. FAO/INFOODS recommends adjusting proximates and water-soluble components when the moisture content between the foods differs by more than 10 percent, and adjusting fat-soluble components when the fat content differs by more than 10 percent (FAO, 2020).

1 https://www.fao.org/infoods/infoods/tables-and-databases/en/

Imputed data are estimates derived from analytical values obtained from similar food or for another form of the same food (Ispirova et al., 2020). Imputed data can also be a result of calculation from incomplete or partial analysis of food, e.g., chloride calculated from the value for sodium. Consequently, these values carry a lower degree of confidence as it may often be impossible to refer back to the original source and should be included only when original analytical data are not available or are known not to be of sufficient quality (Greenfield and Southgate, 2003).

Calculated data in the context of food composition refers to the values that are estimated or derived through calculations based on various methods rather than directly measured. The energy content of food is typically calculated using the Atwater system. Vitamin equivalents are used to express the total activity of a vitamin in a food or supplement, taking into account different forms of the vitamin that may have varying levels of biological activity. A third example is the procedure for estimating nutrient values for mixed dishes, recipes (including meal preferences and food habits), and processed foods, based on the composition of ingredients and corrected for preparation factors such as retention and yield factors (Greenfield and Southgate, 2003). Recipe calculation methodology is often used by industry for labeling of products or reformulation of existing products. However, there are many challenges associated with recipe analysis, including sourcing of the appropriate nutritional values, convert ingredient amounts from units and household measures to weights, availability of retention and yield factors and assign weight change factors (Church, 2015). Cooking conditions/preparation methods can vary considerably affecting yield and retention, therefore, results obtained by this calculation should almost always be observed as an approximation (Marconi et al., 2018).

The last type of food composition data referred to is presumed or assumed data. It is common for FCDBs to contain values that have been presumed or assumed as being at a certain level or as zero based on current knowledge of the food or current regulations. For example, cholesterol, retinol and vitamin D values are assumed to be zero in unfortified plant-origin foods (Kapsokefalou et al., 2019).

There is growing recognition that food consumption patterns guided through country-specific policies (such as food labeling, food based dietary guidelines (FBDG), food fortification, sodium reduction and taxation on high sugar foods) can reduce disability and premature deaths leading to improved health, well-being, and longevity (Delgado et al., 2021; Pretorius et al., 2021; Dembska et al., 2023). Dietary diversification, through the inclusion of food groups from different food cultures and habits, making it adaptable to different local contexts sustainable diets, can be pursued all over the world in a way that is healthy, accessible, affordable, safe, equitable and culturally acceptable (Dembska et al., 2023). Knowledge of the nutrient content of foods in local diets is necessary at the core of the development of these policies and regulations.

3. Management of food composition data

Relational databases are often used for the storage of FCD, although some countries still manually manage their data in spreadsheets. There are also countries that do not have their FCD in electronic format. Many countries and regional blocks have compiled their own FCDBs. While this localized FCD compilation is of huge importance (Delgado et al., 2021), there is also a need for sharing data between countries or regions, especially with the high cost associated with analytical data generation. To make this data sharing effective, and to unleash the benefits of comparing nutrients between countries or regional blocks, FCD must be standardized or harmonized through the use of standardized thesauri, and harmonized food descriptors and documentation. Food descriptor systems, such as the models created by the International Network of Food Data Systems (INFOODS) (Egan et al., 2007), the European Food Information Resource (EuroFIR) project (Pakkala et al., 2010) and the European Food Safety Authority (EFSA), have made a significant contribution to data harmonization between countries or regions. Even with these efforts, accessing and combining FCD from multiple sources remains a challenging task (Kapsokefalou et al., 2019).

As most FCD are managed in relational databases and/or spreadsheets, the ability to use this data for data analysis, reporting and decision-making, has significantly improved. However, there are still countries in Africa that either do not have the FCD in electronic form or have chosen not to publish them in electronic form. This later case makes access and usage of FCD a huge challenge, as it significantly reduces the ability to use the data for research, data analysis, reporting and decision-making by the ever-growing user community. Having FCD in electronic format also creates an opportunity for the data to be used in modern ways, with the use of mobile, wearable and other digital technologies (Traka et al., 2020). Figure 1 below depicts the wide coverage of modern FCD usage. The bidirectional nature of data flows in the image is an attempt to reflect the responsibility that FCD users have to collaborate and enrich the availability of data in FCDBs.

In most cases, access to national FCDBs is granted for free. Typically, data are made available online, in spreadsheets or CSV files that can be downloaded at no cost, or through a searchable web tool. However, there are still countries where access to the national FCDBs comes at a fee.

4. Challenges ahead of African food composition databases

Considering the many applications of FCD by different stakeholders, as depicted in Figure 1, high-quality food composition databases deserve a prominent role in all nutrition-related activities in all countries. Although nutrient databases are available in numerous African countries, verifying their accuracy can be challenging and have important limitations that impede relevant applications. These limitations include that only for a restricted number of (mostly raw) foods information is available with a limited coverage of nutrients for each food; the presence of many outdated and unreliable data; lack of nutrient information on underutilized nutrient-dense foods; incomplete food descriptions and poor component and value description; poor distinction between missing values and "zero" values, and poor documentation of data sources and assumptions, thereby complicating the assessment of the quality of the data. Data is sourced from diverse providers who may use different methods, often driven by availability rather than applicability. In addition, certain national laboratories primarily dedicated to food safety testing also perform food composition analysis. This situation can introduce challenges related to equipment reliability and the competence of laboratory personnel.

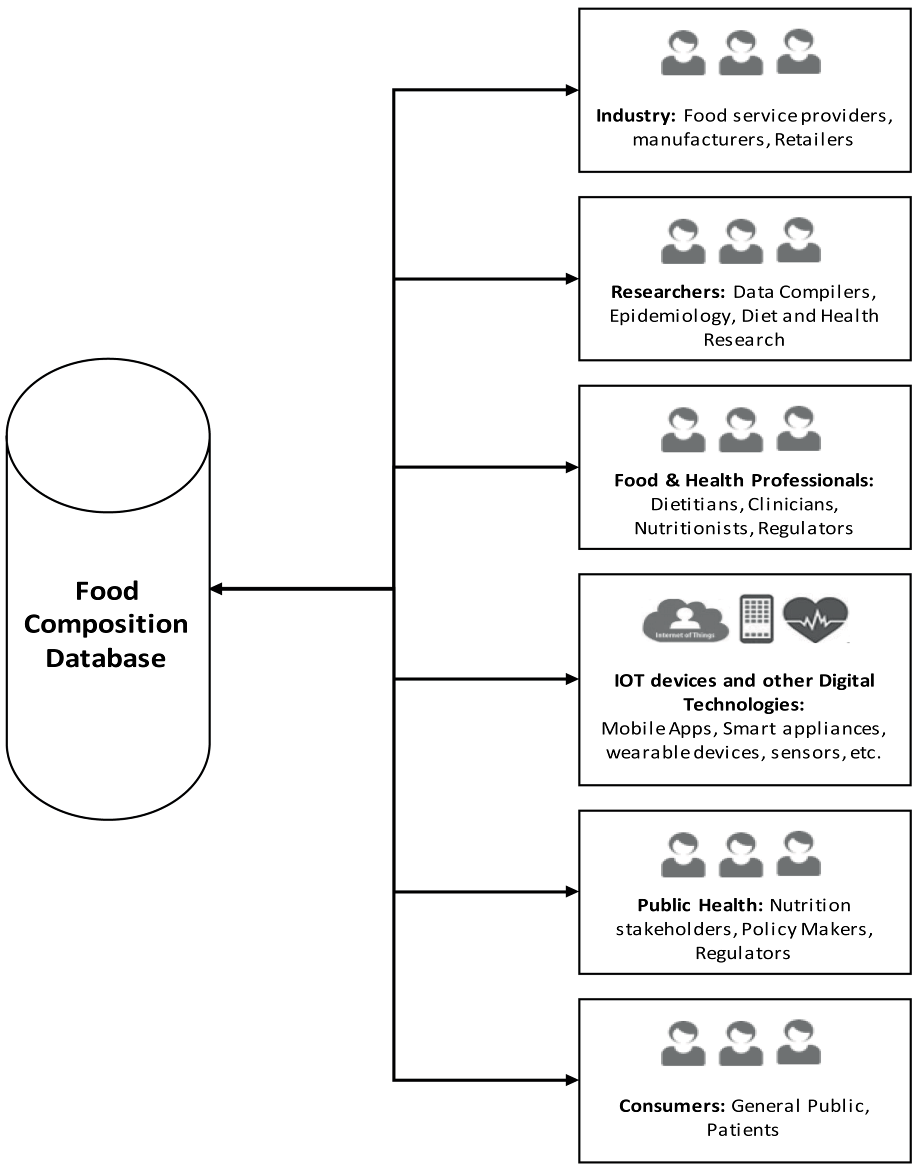

FIGURE 1
FCD users (adapted from Traka et al., 2020).

As laboratory facilities are sparse and nutrient analyzes expensive, most African FCT/FCDBs contain a limited amount of analytical values, and data are often copied from other databases from other parts of the world. For example, in the South African Food Data System, only 44% is from South African-referenced food items. The rest mainly contains copied values from FCDBs collected in other parts of the world, such as the United States and the United Kingdom (SAFOODS, 2017). The open data approach towards the management and use of FCD is an important factor that influences the high usage of the most popular FCDBs, such as the American FCDB (USDA) and British national FCDBs. However, as alluded before, data copied from databases elsewhere, are unlikely to be relevant within the country-specific context for which the database is compiled.

As a consequence of the confinements of food composition databases, errors can accumulate and propagate in the assessment of intake, leading to either an overestimation or underestimation of the proportion of the population that is below the RDA for a specific nutrient. In nutritional epidemiology, errors can lead to weakened associations. In individuals, overestimation or underestimation may lead to wrong advice in clinical practice or misleading consumer information, e.g., incorrect food labeling. Furthermore, data gaps and low-quality data affect areas beyond human nutrition, such as food systems sustainability and the pursuit of Sustainable Development Goals (Ferraz de Arruda et al., 2023). SDGs require food system sustainability, as well as consumers' dietary shifts influenced by environmental concerns.

5. Conclusions and recommendations

Gathering and curating more and better data; the ability to establish connections between databases; and the ability to search through multiple FCDBs and easily find available data, are essential to the mitigation of further nutritional problems and to solving those already experienced. The use of AI techniques presents opportunities for African FCDBs to evolve and overcome some of these limitations. Artificial Intelligence (AI) techniques such as machine learning can be used as a potentially more accurate and cost effective way to generate imputed food composition data and increase the completeness of FCD in African FCDBs. This imputed data will complement the limited analytical data available, thereby, addressing the huge 'missing data' problem and making availability of high-quality food composition data, a more achievable goal for Africa. However, without having reliable historical and current data it will be difficult to train AI models (Ferraz de Arruda et al., 2023). In addition, sources of Big Data such as social media platforms, mobile apps, sensors, Internet of Things (IoT) devices, and wearable devices can all be leveraged to increase the amount, the accuracy, and timeliness of data coverage in African FCDBs. This can be achieved through the use of AI techniques known as natural language processing (NLP), and deep learning (Zhang et al., 2023). These are both subfields of machine learning, which is a form of AI. Intelligent and personalized search capabilities are an added advantage of AI-enabled systems. A specific example is the use of NLP to find specific food items or nutrients, across multiple databases, even if they use different terminologies or synonyms.

To expand the available information on the continent, a combination of AI techniques, specifically natural language processing, and other Information and Communication Technology (ICT) tools, can be used to establish connections between different African databases. Linking these data have the potential to enhance research and decision making for improved nutrition and food security (Zeb et al., 2021). The food system is driven by many actors, from farm to fork. During every phase of the food value chain, significant amounts of data are generated for example: consumer demand and market value, use of fertilizers and pesticides, environmental footprint and nutrient content of raw and final products. Composition and origin data of raw materials are used by manufacturers for product development. Food composition data are also used by the food industry for marketing and promotion or labeling purposes. Examples are "low in salt," "reduced fat," "no added sugar," and "high in fiber." The nutrition fraternity use this information towards consumer education and to shape consumer choice. Such AI use cases on FCD have already been implemented elsewhere. An example is FoodEx2, a food classification and description system covering different food safety domains maintained by (EFSA) (European Food Safety Authority (EFSA), 2015; Durazzo et al., 2022). Connections between FCDBs can complement information about a certain food or about region-specific indigenous food sources for a certain nutrient (Delgado et al., 2021). However, it must also be highlighted that establishing these connections will be made much easier by making more efforts to standardize and harmonize data (including FCDBs) across countries and regions in Africa.

To ensure the continuous compilation of food composition databases in Africa, it is necessary to focus on capacity building. This involves developing the skills and knowledge required to drive innovation and adhere to international standards and guidelines for managing food composition data. Higher education institutions play a crucial role in this process by providing the necessary training and expertise in areas such as big data, information and communication technology (ICT), and transdisciplinary collaboration, involving among others experts in food composition data, nutrition scientists, and AI specialists. However, capacity building goes beyond human resources development through education and training. It also encompasses organizational development, including the establishment of physical and management infrastructure, processes, and procedures that align with international standards. Additionally, an institutional and legal framework must be developed to gain recognition, authority, and enhance capacities. Advocacy skills, leadership skills, and communication skills are vital in all these domains. Together they define a pre-requirement of ensuring good quality data in food composition databases to provide Africa with safe, sufficient, nutritious and consumer-driven foods.

Data availability statement

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

Author contributions

BP and JM wrote the article. PH and HS critically reviewed the article. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Examining the contribution of an underutilized food source, Bambara Groundnut, in improving protein intake in Sub-Saharan Africa

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Introduction: Bambara groundnut (BGN) is an underutilised, indigenous crop in sub-Saharan Africa. As an underutilised crop the nutritional contribution it can make is not well researched and documented. This study aims to better understand the nutritional profile and protein quality of BGN and the potential of this legume to combat food and nutritional security in rural and malnourished communities.

Methods: Nutritional analysis, including proximate analysis, minerals, total fat and amino acid profile of BGN from three different regions in the Mpumalanga (MP) province of South Africa (SA), were determined. The protein quality was evaluated with various methods including CSEAA, IEAA, PDCAAS and DIAAS and compared with other pulses and legumes in the diet.

Results: BGN consists of - 18,9% carbohydrates, 9,4% protein and 3% fat as consumed. The protein quality is lower than some other commonly consumed pulses but can still be valuable as a complementary protein in the current traditional diet of the region.

Discussion: There is the potential that BGN, together with other commonly consumed plant-based foods (e.g. maize) form a complete protein, that can contribute to protein intake and alleviate the burden of protein-energy malnutrition, specifically in developing countries.

KEYWORDS

Bambara Groundnut, legumes, underutilized foods, protein quality, dietary diversity, plant-based protein sources, drought resistant

Highlights

- Carbohydrates and protein are the most abundant nutrients in BGN.
- The protein quantity of BGN does not predict protein quality.
- DIAAS score for BGN is lower than other legumes such as soybeans but higher than chickpeas.

- BGN is a potential complementary food that contributes to improving the protein quality of typical SSA dishes.
- BGN can contribute to dietary diversity as a plant-based protein source.

1. Introduction

Food and nutrition security face several challenges, including climate change, the repercussions of the COVID-19 pandemic, the war in Ukraine, and the large-scale production of cash crops such as maize and wheat (Cloete and Idsardi, 2013; Mayes et al., 2019; Tan et al., 2020; FAO et al., 2022). In 2021, one in five people (20.2%) in Africa suffered from hunger and 29.3% of people globally faced moderate to severe food insecurity (FAO et al., 2022). Extreme droughts in Sub-Saharan Africa (SSA) in recent years have severely impacted the agricultural sector and further compromised food and nutrition security in the region. Climate change projections indicate a future of low and erratic rainfall with an increased frequency of drought occurrences in SSA (Mabhaudhi et al., 2018). Given the climate and sustainability challenges, Chivenge et al. (2015) emphasized the need for alternative approaches to ensure food and nutrition security. Researchers have suggested promoting indigenous, drought-resistant, and climate-smart crops as a solution (Massawe et al., 2015; Soumare et al., 2021).

Affording a healthy and balanced diet in the current economic climate has become increasingly difficult (FAO et al., 2022). Animal protein sources have seen a significant price increase, putting them out of reach of many consumers (Moore and Moseley, 2022). Poorer consumers, especially in low-and middle-income countries (LMICs) rely mainly on a cereal-based diet to fulfill their energy needs resulting in an inadequate intake of macro- and micronutrients. Cereal-based foods should be 15% of the diet and yet in many SSA, it comprises over 50% of the diet (Makumba et al., 2016; FAO et al., 2022). The consumption of energy-dense, nutrient-poor cereal-based diets has further contributed to the serious problem of protein-energy-malnutrition (PEM) in SSA along with the increasing rate of NCDs leading to a double-burden of disease (Labadarios et al., 2011; Makumba et al., 2016).

The most recent publication of "The State of Food Security and Nutrition in the World" by the FAO, IFAD, UNICEF, WFP and WHO (2022) calls for a transformed (agri) food system driven by policies that increase the availability of healthy and nutritious foods that are more affordable, sustainable and inclusive. The need for alternative, more affordable protein sources in the diet has become urgent as consumers transition to more climate-positive, plant-based dietary patterns that include plant-based protein sources (van den Berg et al., 2022). Policymakers, producers, and consumers must support this growing demand for good quality, affordable, plant-based protein foods to drive the necessary changes in the current food system (FAO et al., 2022).

Studies on plant-based protein sources from indigenous and traditional crops are necessary to promote climate-resilient indigenous foods that can contribute to dietary diversity, focusing on reintegrating indigenous and traditional foods into the diet (Cloete and Idsardi, 2013). Indigenous and traditional crops are specific to a region and subsequently form part of the endemic plant culture growing readily, despite harsh climate conditions, with minimal intervention as they are adapted to the environment (Modi and Mabhaudhi, 2016; Pieterse et al., 2022). For centuries, more than 7,000 indigenous plant species have been used globally for food, medicine and multiple other uses (Modi and Mabhaudhi, 2016; Akinola et al., 2020). Traditional crops can contribute significantly to social, economic and environmental outcomes. These crops provide subsistence farmers with livelihoods and contribute valuable macronutrients and other essential nutrients (Majola et al., 2021).

A significant proportion of the diverse indigenous and traditional foods available in our environment have been neglected over time despite the development of modern and improved agricultural practices, thereby decreasing dietary diversity and possibly narrowing global food security (Akinola et al., 2020). The lack of information and research on the production methods, post-harvest handling and the role of underutilized indigenous foods in the diet must be addressed to better understand how these foods can contribute to the alleviation of food insecurity in SSA (Cloete and Idsardi, 2013). Therefore, policy support and research on these neglected crops are essential for achieving improved nutrition outcomes, as with the Sustainable Development Goal (SDG) 2 (Zero Hunger) and the United Nations Decade of Action on Nutrition 2016–2025 (United Nations, 2015).

The promotion of underutilized indigenous crops, such as BGN, can furthermore contribute to achieving other SDGs:

- SDG 10—Reduce Inequalities: BGN, like many other indigenous crops, is mainly grown by female subsistence farmers in poor rural areas. The promotion of BGN production can contribute toward more equitable access to nutritious foods resulting in healthier diets and improved food and nutrition security.
- SDG 12—Responsible Consumption Patterns and SDG 13—Climate Action: the transition to plant-based diets becoming more popular in the developed world, climate-resilient foods with low impact on the environment (United Nations, 2015).

1.1. Bambara Groundnut

Bambara Groundnut (BGN; *vigna subterranean* (L.) Verdc) is an indigenous and traditional African crop mostly grown by rural female subsistence farmers in SSA (Omoikhoje, 2008). It is an underutilized crop, meaning it is not traded extensively globally, it is produced at low levels and under-researched (Omoikhoje, 2008; Halimi et al., 2019). BGN has gained popularity because of its ability to grow well, even under extreme conditions such as drought and poor soil conditions. Its ability to "fix" nitrogen in the soil makes it ideal for intercropping, especially for smallholder farmers (Mayes et al., 2019). BGN is classified as a drought-tolerant crop as it contains three important mechanisms as described by researchers—avoidance (reduced water loss due to various mechanisms including a prolific route system), escape (short lifecycle or growing period) and tolerance (ability to grow, flower and display economic yield under suboptimal water supply), respectively (Farooq et al., 2009; Mabhaudhi et al., 2018). BGN has confirmed drought avoidance and escape and low water use—giving it all three mechanisms (Chai et al., 2016).

 10.3389/fsufs.2023.1183890

In rural communities where BGN is grown, it is accepted and consumed as part of a regular diet. As BGN is mainly grown by subsistence farmers in SSA across rural and fragmented farmlands, it is very challenging to obtain adequate production and productivity data (Majola et al., 2021). Freshly harvested and dried seeds are purchased from local markets and usually cooked before consumption. However, urban and westernized communities in SSA are generally not familiar with the product and its preparation which pose a challenge to its uptake in the commercial market.

It is primarily grown as a plant-based protein alternative to meat in rural cuisines rather than an oil-producing seed, as commonly seen with other legumes, like soybeans. BGN is consumed in Southern, Eastern and Western Africa and is utilized by various cultures, as shown in Figure 1. Approximately 0.15 million tons of BGN are produced annually in SSA, with the majority being produced by West African countries (Majola et al., 2021). In Southern Africa, it is consumed roasted, boiled or dried with maize porridge or added to cowpea grain for improved flavor (Tan et al., 2020; Majola et al., 2021). Western African countries incorporate it into other foods such as grilled flatbreads, flour, snacks, and biscuits.

The nutritional contribution, specifically the amino acid and fatty acid composition of cooked BGN in SSA, is poorly researched and documented. Therefore, little is known about the potential role it can play in contributing to the nutritional quality of the diet in rural communities as a drought-resistant traditional crop.

This study aimed to determine the nutrient content of BGN and examines the protein quality of BGN as an underutilized, traditional and drought-resistant indigenous crop in Africa.

2. Materials and methods

2.1. Selection of samples

All the BGN samples were planted in December 2018 by rural subsistence farmers and harvested in May 2019. A total of 12 fresh samples of approximately 500 g each were collected from 12 farms in three regions (Gomoro, Langeloop and Mbombela) in the Ehlanzeni District Municipality in the Mpumalanga province of South Africa (SA; Table 1; Figure 2). Officials and extension officers from the Department of Agriculture, Rural Development, and Land and Environmental Affairs helped to identify the farms. Samples were harvested mid-morning in autumn directly from the soil. Farmers were compensated for a 500 g sample with the equivalent amount of maize meal. The BGN was placed in labeled brown paper bags and transported to the University of Pretoria in cooler boxes. Samples were placed in sealed plastic bags and in the freezer until cooking and sample preparation could take place.

2.2. Processing of samples

The samples from the three regions were processed separately. The samples from each region were, thawed, combined, soaked in water for 120 min, and then thoroughly washed with tap water (two or three times) to remove all soil debris. Samples from different regions were kept separate. Each batch was cooked in tap water for 60 min at 100°C. After cooking, the samples were drained and cooled. Once cooled, the hull of each BGN was removed manually. The hull was not

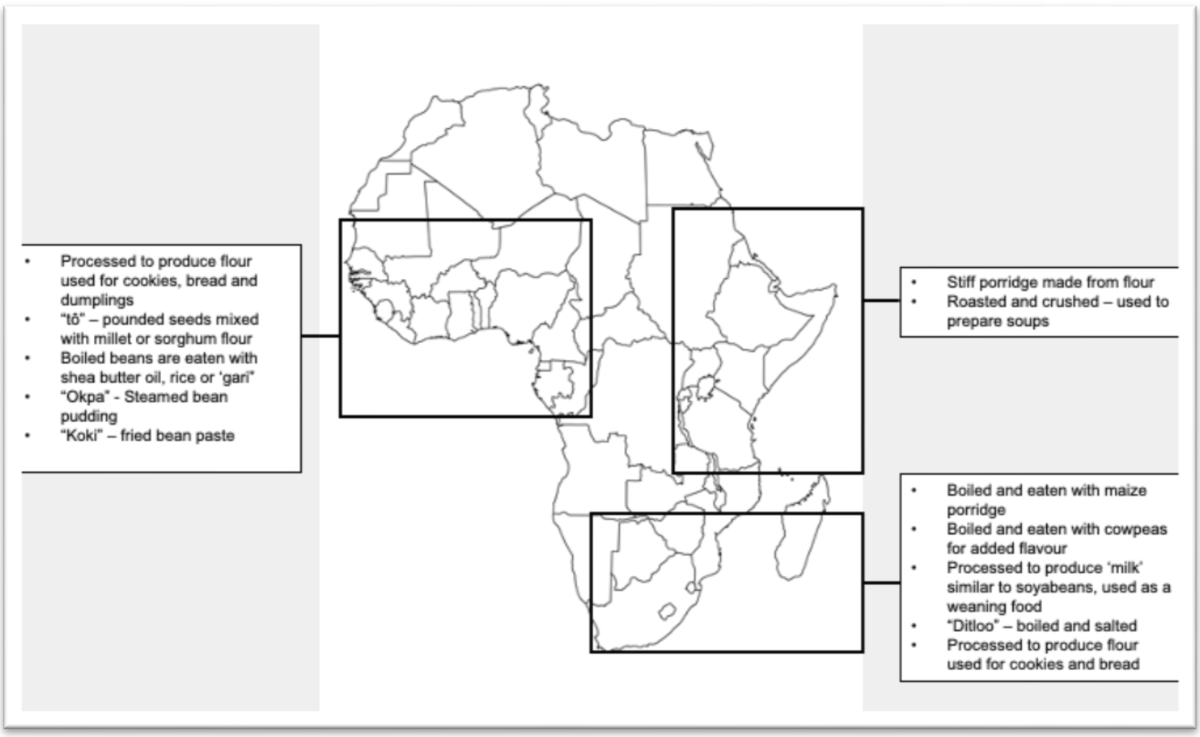

FIGURE 1
Different uses of BGN in SSA (Adapted from Tan et al., 2020 and Majola et al., 2021).

TABLE 1 List of regions and farms in Ehlanzeni District Municipality, Mpumalanga, from where BGN samples were collected.

Region	Farm name	Environment
Langeloop	Phezukomkhono	*Climate:* The Mbombela region experiences a humid subtropical climate, characterized by hot summers and mild winters. Rainfall is distributed throughout the year.
Gomoro	Sabo	
	Hlowe	
	Mahwya	*Rainfall:* The rainy season falls in the months: January, February and December with an average annual precipitation of 678 mm.
	Salaphi Masilela	
	Makamo	
	Moyane	*Vegetation:* The area exhibits a combination of bushveld and savanna vegetation.
	Masilela	
	Mknan	
Mbombela	Tingwenyana	*Farm size and structure:* Informal farms in the region tend to be small, typically covering only a few hundred square meters. These farms are managed by local community members who face limitations in terms of land and resources.
	Ka-khankela	
	Phalatrust Thushanang	
		Farming practices: Traditional and low-input farming methods are employed by farmers in the region. Soil preparation involves manual techniques such as tilling and hand digging. Due to the absence of formal irrigation systems, these farms rely on natural rainfall for water supply.
		Seed selection: Farmers commonly save seeds from their previous harvests for future planting.

consumed and, therefore, not included in the analysis. The dehulled BGN samples from each region (Langeloop, Gomoro and Mbombela) were sorted into three colors—cream, mauve and brown (Figure 3). Two 100 g samples of each color from each region were weighed (n = 6 per region), packed, and frozen at −8°C until analysis. A total of n = 18 samples were analyzed.

2.3. Chemical analyses of selected nutrients

2.3.1. Proximate analyses

Proximate analyses of the samples (n = 18) were carried out by Aspirata laboratory (AssureCloud, Cape Town, SA) to determine the total moisture (Official method of analysis, AOAC 930.15, 2000), ash (AOCS International, 2009) and nitrogen content (Official method of analysis 968.06, AOAC, 2000). The conversion factor of 5.71 (conversion factor for soybeans) was used to calculate the protein content [Food and Agriculture Organization (FAO), 2003]. The energy content for each macronutrient was calculated by multiplying the g/100 value with the respective conversion factors given in the list below (Greenfield and Southgate, 2003).

- Protein = 17
- Fat = 37
- Carbohydrates = 17
- Total dietary fiber = 8

2.3.2. Amino acid profile

The Agricultural Research Council's analytical laboratory determined the amino acid profile in Pretoria, SA. Three separate analyses used high-performance liquid chromatography (HPLC) with fluorescence detection for amino acid determination. All three analyses were completed by hydrolysis.

The first hydrolysis analyzed arginine, serine, aspartic acid, glutamic acid, glycine, threonine, alanine, tyrosine, proline, hydroxyproline, methionine, valine, phenylalanine, isoleucine, leucine, histidine, and lysine, excluding cysteine and tryptophan. The freeze-dried BGN sample was hydrolyzed with 6-N-hydrochloric acid at 110°C for 24 h in a vacuum. An internal standard was added to the hydrolysate and filtered. Nitrogen flow was then used to dry a portion of the hydrolysate. The derivatization of the hydrolysate was done with 9-fluorenylmethyl chloroformate (FMOC-Cl). The amino acid content was determined with HPLC with an eluent of a tertiary gradient of pH, methanol and acetonitrile (Einarsson et al., 1983). The second hydrolysis determined cysteine and was the same as the first except for the cysteine oxidation to cystic acid before hydrolysis using a peroxide formic acid solution (Gehrke et al., 1985). The third hydrolysis determined the tryptophan content and involved enzymatic hydrolysis using protease. The hydrolysis was filtered and tryptophan content was determined by HPLC equipped with an AMinoTAg column and fluorescence detection (DeVries et al., 1980).

2.3.3. Total fat and fatty acid profile

The total fat, saturated fat, polyunsaturated fat and monounsaturated fat content were determined for each sample (n = 18) at the Aspirata laboratory (AssureCloud, Cape Town, SA). Fat was determined by hydrolyzing the sample with concentrated hydrochloric acid in a boiling water bath for 3 h. Thereafter, the fat was extracted using petroleum ether and gravimetrically quantified. For the determination of the fatty acids, fat fractions were trans-methylated with methanol-potassium hydroxide. The fatty acid methyl esters were extracted with n-hexane and analyzed using gas chromatography with flame ionization detection (GC-FID) according to the official method of analysis AOAC 996.06 (2000).

2.3.4. Carbohydrates and total dietary fiber

Available carbohydrates were determined for each sample (n = 18) by Aspirata laboratory (AssureCloud, Cape Town, SA) using the Megazyme Available Carbohydrates and Dietary Fiber Assay Procedure from Kit K-ACHDF, 11/08 (Megazyme, 2018). The total dietary fiber reported was determined by the Aspirata laboratory (AssureCloud, Cape Town, SA) using an enzymatic-gravimetric method [AOAC 985.29 (2000)] method.

2.3.5. Minerals

Iron and zinc were analyzed for each sample (n = 18) by the Aspirata laboratory (AssureCloud) according to the AOAC Official Method AOAC 999.10 (2012). Samples were digested with 3 M nitric acid and 30% (w/w) hydrogen peroxide in a closed vessel heated by microwaves. Iron and zinc were quantified by inductively coupled plasma optical emission spectroscopy (ICP-OES) using an acidified calibration range.

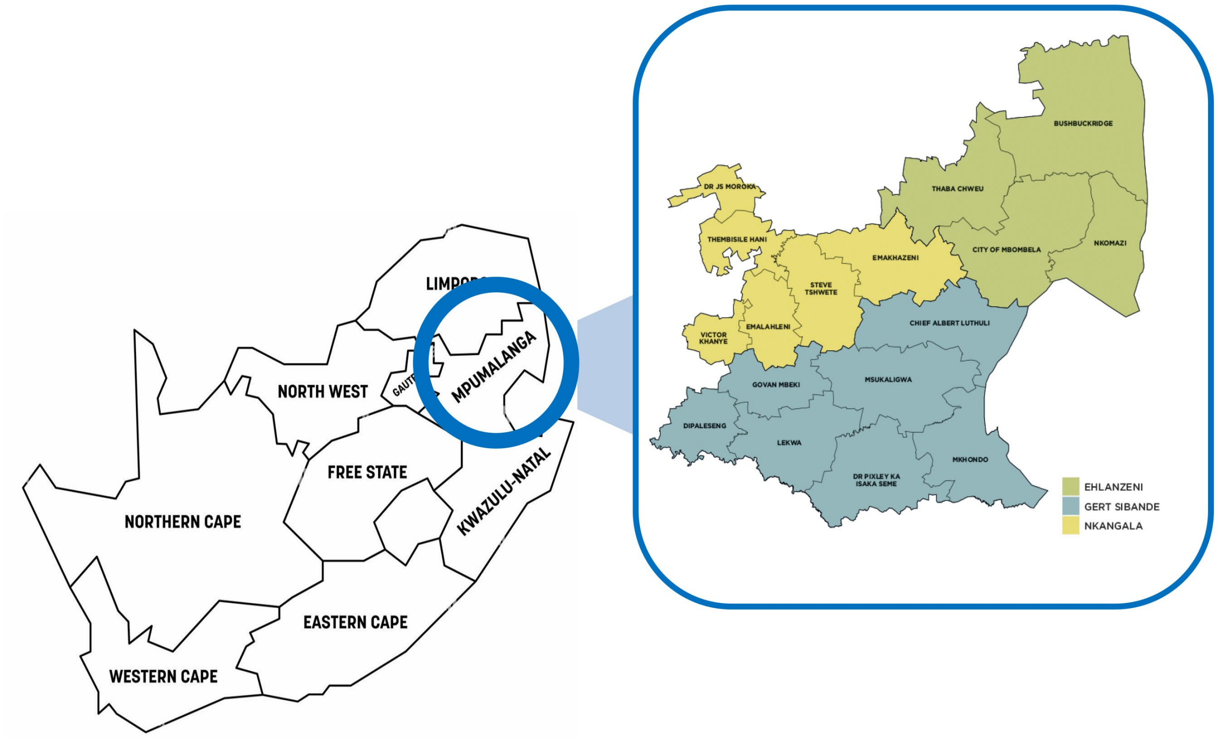

FIGURE 2
Map of South Africa and districts in the Mpumalanga province (Adapted from Municiplaities Mpumalanga, 2023).

FIGURE 3
Different colors of dehulled BGN (cream, mauve, and brown) with scale in centimeters for reference.

2.4. Evaluation of protein quality

The assessment of protein quality did not involve regional or color differentiation; instead, the mean amino acid values were employed by aggregating data from all regions for the calculations and multiple protein quality assessment methods were utilized. These methods included the Chemical Score of the Essential Amino Acids (CSEAA) or CS (Mitchell and Block, 1946; Eq. 1), the Essential

Amino Acid Index (IEAA; Oser, 1959; Rolinec et al., 2017; Huang et al., 2018; Abdualrahman et al., 2019; Eq. 2), Protein Digestibility-Corrected Amino Acid Score [PDCAAS; Food and Agriculture Organization (FAO), 2013; Eq. 3], and Digestible Indispensable Amino Acid Score [DIAAS; Food and Agriculture Organization (FAO), 2013, 2014; Eq 4].

The CSEAA/CS was calculated in relation to the amino acid pattern of the reference requirements outlined.

$$\mathbf{CSEAA} = \left[\frac{(\mathbf{gEAA\ in\ test\ protein})}{(\mathbf{gEAA\ in\ reference\ protein})}\right] \quad (1)$$

The Essential Amino Acid Index (EAAI) evaluates the presence of indispensable amino acids. In Equation 2 (Eq. 2), the variables a, b, c, …, j represent the content of histidine, isoleucine, leucine, lysine, methionine, phenylalanine, tyrosine, threonine, and valine in the sample. The variables ap, bp, cp, …, jp denote the content of histidine, isoleucine, leucine, lysine, methionine, phenylalanine, tyrosine, threonine, and valine in the reference protein according to the guidelines. The value of n corresponds to the total number of amino acids, accounting for pairs such as methionine and cysteine, which are treated as a single entity in the calculation.

$$\mathbf{IEAA} = 100 \times \sqrt[n]{\frac{a}{ap} \times \frac{b}{bp} \times \frac{c}{cp} \times \ldots \ldots \ldots \frac{j}{jp}} \quad (2)$$

The PDCAAS was calculated by dividing the amount of the limiting essential amino acid in the test protein by the amount of the same essential amino acid in a reference protein and then multiplying it by the digestibility coefficient (Eq. 3). The limiting essential amino acid is the amino acid present in the lowest quantity relative to the reference protein. PDCAAS values exceeding 1 were adjusted or truncated to 1 [Food and Agriculture Organization (FAO), 2013].

$$\mathbf{PDCAAS} = \left[\frac{(\mathbf{g\ of\ limiting\ amino\ acid\ in\ test\ protein})}{(\mathbf{g\ of\ same\ amino\ acid\ in\ reference\ protein})}\right] \boldsymbol{x\ digestibility} \quad (3)$$

DIAAS evaluates protein quality based on the digestibility (bioavailability) of individual dietary indispensable amino acids. The measurement of amino acid digestibility is preferably conducted in humans, but if not feasible, it can be done in pigs or rats [Food and Agriculture Organization (FAO), 2013; Rutherfurd et al., 2015]. DIAAS was calculated by dividing the standardized ileal digestible amino acid content of the test protein by the standardized ileal digestible amino acid content of the reference protein, multiplied by 100 (Eq. 4). In the absence of a specific ileal digestibility value for BGN, the value reported for chickpeas, 84, reported by Han et al. (2020) was used instead. DIAAS values were not truncated.

$$\mathbf{DIAAS} = \left[\frac{\left(\begin{array}{c}\mathbf{mg\ of\ digestable\ dietary\ indispensable}\\ \mathbf{amino\ acid\ in\ 1\ g\ test\ protein}\end{array}\right)}{\left(\begin{array}{c}\mathbf{mg\ of\ the\ same\ dietary\ indispensable}\\ \mathbf{amino\ acid\ in\ 1\ g\ reference\ protein}\end{array}\right)}\right] \mathbf{x\ 100} \quad (4)$$

2.5. Statistical analysis

The nutrient values from each region were consolidated (n = 6 per region), and a mean value was calculated and reported. Additionally, an overall mean for all the regions combined (n = 18) was determined and included in the analysis. Statistical analysis was conducted using GenStat for Windows (2008) software (Payne et al., 2009). The significance of all variables measured for each sample was tested using a one-way analysis of variance (ANOVA). The locality effect was tested with a Fisher's protected t-test least significant difference at the 5% level of significance.

3. Results and discussion

3.1. Nutrient composition

The nutrient composition of Bambara groundnut (BGN) was analyzed and compared in this study. The moisture content of the cooked edible portion ranged from 55.6 to 56.7%, with an average of 56.1% (Table 2). These values were similar to those reported in the West African Food Composition Tables [54.7%; Food and Agriculture Organization (FAO), 2019]. Factors such as long storage, thawing, cooking, and refreezing may have influenced the moisture content in the current study, along with differences in soil and climate conditions compared to the West African region.

Carbohydrates and protein were found to be the most abundant macronutrients in BGN. The carbohydrate content ranged from 17.5 to 20.4 g per 100 g of edible portion (EP), which did not significantly differ between regions (Table 2). It was slightly lower than a study by Tan et al. (2020) (30 g/100 g EP) and similar to the values reported in the West African Food Composition Tables [16.0 g/100 g EP; Food and Agriculture Organization (FAO), 2019]. The dietary fiber content averaged at 11.4 g/100 g EP and did not differ significantly between regions (Table 2). However, it was lower than the values reported in the West African Food Composition Tables for BGN and higher than the values for soybeans (4.8 g/100 g EP) and chickpeas (6.6 g/100 g EP) in South Africa (SAFOODS, 2017). The dietary fiber content can be influenced by factors such as maturity stage and processing methods (Tan et al., 2020).

The mean fat content of BGN was 2.97 g/100 g EP, similar to the values reported in the West African Food Composition Tables [2.70 g/100 g EP; Table 2; Food and Agriculture Organization (FAO), 2019]. The fat primarily consisted of unsaturated fatty acids (2.08 g/100 g EP). However, the total fat content showed significant differences between regions (Hlanga et al., 2021). These differences may be attributed to genotypical differences among landraces. Compared to other legumes like soybeans, BGN has a relatively low fat content and is not suitable for oil extraction (Halimi et al., 2019).

Iron content did not significantly differ between regions, and the mean value (0.827 mg/100 g EP) in this study was notably lower than the value reported in the West African Food Composition Tables [1.90 mg/100 g EP; Table 2; Food and Agriculture Organization (FAO), 2019]. Variations in iron content among different BGN landraces, influenced by water regimes, locations, seasons, and harvesting methods, may explain the differences between regions and the West African Food Composition Tables (Gqaleni, 2014). Zinc was not detected in the BGN samples, which may be attributed to the soaking and cooking process (Tan et al., 2020). However, the West African

10.3389/fsufs.2023.1183890

TABLE 2 Summary of the nutrient composition of cooked Bambara Groundnut [per 100 g edible portion (EP)] from three different regions in South Africa.

Area	Moisture		Protein		Fat		Saturated fatty acids		Mono-unsaturated fatty acids		Poly-unsaturated fatty acids		Carbohydrate		Total dietary fiber		Energy calculated		Ash		Iron		Zinc	
	n	g/100 g	*n*	g/100 g	*n*	g/100 g	*n*	g/100 g	*n*	g/100 g	*n*	g/100 g	*n*	g/100 g	*n*	g/100 g	*n*	g/100 g	*n*	kJ/100 g	*n*	mg/100 g	*n*	mg/100 g
Langeloop	6	55.9 ±1.09	6	8.86^{ab} ±0.488	6	2.78^{b} ±0.197	6	0.855^{a} ±0.101	6	1.22 ±0.118	6	11.6 ±2.73	6	0.702^{b} ±0.0818	6	1.30 ±0.141	6	18.9 ±2.73	6	666^{ab} ±39.3	6	0.885 ±0.547	6	*
Mbombela	6	55.6 ±0.449	6	7.65^{b} ±0.316	6	3.38^{a} ±0.257	6	1.01^{b} ±0.121	6	1.408 ±0.180	6	11.5 ±2.65	6	0.96^{a} ±0.0978	6	1.28 ±0.214	6	20.4 ±2.07	6	684^{a} ±5.96	6	0.804 ±1.08	6	
Gomoro	6	56.7 ±0.618	6	9.10^{a} ±0.565	6	2.75^{b} ±0.163	6	0.813^{b} ±0.0692	6	1.24 ±0.112	6	10.9 ±1.34	6	0.698^{b} ±0.0264	6	1.26 ±0.151	6	17.5 ±0.516	6	636^{b} ±18.9	6	0.792 ±1.66	6	
Mean	18	56.1	18	8.54	18	2.97	18	0.893	18	1.29	18	11.3	18	0.787	18	1.28	18	18.9	18	662	18	0.827	18	
West African Food Composition Tables #	^	54.7	^	10.4	^	2.7	^	^	^	^	^	14.5	^	^	^	1.7	^	16.0	^	666	^	1.9	^	1.08
value of p	0.060		<0.001		<0.001		<0.009		<0.001		0.069		0.170		0.831		0.015		0.945				0.122	

*Not detected, and therefore no values were reported for statistical analysis. Limit of detection (LOD) for zinc = 0.257 mg/100 g and limit of quantitation (LOQ) for zinc = 0.792 mg/100 g.
#Values from Ghana as reported in the West African Food Composition Tables [Food and Agriculture Organization (FAO), 2019].
^Data not reported.
Values with different superscripts in a column differ significantly.
Values below the mean indicate Standard Deviation (±SD).

Food Composition Tables [1.08 mg/100 g EP; Food and Agriculture Organization (FAO), 2019] and other studies have reported BGN as a valuable source of zinc (Singh and Pratap, 2016; Halimi et al., 2019). It is important to note that these studies reported compositional values of raw BGN without considering the effects of storage, soaking, and cooking. Cooking processes can improve nutrient digestibility and bioavailability by breaking down antinutritional factors such as phytic acid and tannins (Oyeyinka et al., 2019).

The protein content of BGN was analyzed in the present study, yielding levels between 7.65 and 9.10 g per 100 g of EP (Table 2; Tan et al., 2020). Significant differences in protein content were observed among the three regions (Table 2). The mean protein value per 100 g of edible portion was determined to be 8.54 g (equivalent to 21.3 g per 100 g dry basis). A review by Nwadi et al. (2020) on available nutrient content data revealed a range of 9.6 to 40 g per 100 g dry basis for protein in BGN. Variations in protein content can be attributed to factors such as genetic background (landraces), growing conditions, and analytical techniques, including the specific nitrogen conversion factor employed (Friedman, 1996; Morris, 2006). It is worth noting that no formal classification of BGN species has been conducted in SA.

The essential amino acids (EAAs) necessary for human nutrition include phenylalanine, valine, tryptophan, threonine, isoleucine, methionine, histidine, leucine, and lysine, with arginine considered as a conditional EAA (Morris, 2006). In the present study, four amino acids (arginine, histidine, phenylalanine, threonine) among the nine EAAs displayed significant differences between the three regions (Table 3). Arginine, leucine, and lysine were found to be the most abundant EAAs, while sulfur-containing amino acids such as methionine and cysteine were present in relatively low concentrations. Methionine was identified as the limiting amino acid, consistent with the findings of Halimi et al. (2019). The United States Department of Agriculture [U.S Department of Agriculture, Agriculture Research Service (USDA), 2014] reported similar low concentrations of sulfur-containing amino acids in soybeans (0.224 g/100 g EP) and chickpeas (0.116 g/100 g EP) compared to BGN. Heat processing methods, such as boiling and roasting, can enhance the bioavailability of certain EAAs in BGN compared to their levels in raw seeds (Omoikhoje, 2008; Akande et al., 2009; Oyeyinka et al., 2019; van den Berg et al., 2022). However, prolonged boiling has been shown to reduce the availability of lysine in other legumes like soybeans, necessitating further investigation into heat processing methods for BGN (van den Berg et al., 2022).

3.2. Protein quality

Protein quality refers to the ability of a protein to fulfill metabolic functions by providing specific amino acid patterns, and it is equally important as protein content (Millward et al., 2008). Accurate measurement of protein quality and digestibility of food products relies on evaluating amino acid concentrations (Huang et al., 2018). Amino acid analysis can offer insights into a food's ability to meet an individual's amino acid requirements (Caire-Juvera et al., 2013; Huang et al., 2018; van den Berg et al., 2022).

Various methods exist to assess the protein quality of food products, including the Essential Amino Acid Index (EAAI), Protein Digestibility-Corrected Amino Acid Score (PDCAAS), and Digestible Indispensable Amino Acid Score (DIAAS). The protein quality measurements for this study are summarized in Table 4. EAAI evaluates protein quality based on the contribution of all essential amino acids, as described by Oser (1959) and Rao et al. (1959). The calculated EAAI index for the three regions is 1.49, slightly lower than that of canned chickpeas (1.66; Halimi et al., 2019). According to Oser's method, the protein quality of BGN can be considered good.

PDCAAS is the most commonly used method for protein quality assessment due to its cost-effectiveness and efficiency (Schaafsma, 2012). This method was developed by the FAO Expert Consultation group on protein quality and human requirements [Food and Agriculture Organization (FAO)/World Health Organization (WHO), 1991]. The has limitations, such as truncating scores to 1.0, which may inaccurately estimate the importance of proteins in mixed diets (Huang et al., 2018). PDCAAS values exceeding 100% are truncated to 1.0 since the body cannot utilize more than what has been absorbed (Schaafsma, 2012). In the present study, the reported PDCAAS value for cooked BGN is 52% (Table 4), which is not truncated to 1.0. This value is lower than PDCAAS values reported for other commonly consumed pulses like chickpeas and soybeans, which range from 80% to 100%. The PDCAAS value for raw BGN was reported as 32% (Halimi et al., 2019). The increase in PDCAAS value after soaking and cooking suggests that heat treatment enhances the protein digestibility of BGN.

DIAAS is the current standard for assessing protein quality and was introduced in 2013 as the recommended method [Food and Agriculture Organization (FAO), 2013, 2014; van den Berg et al., 2022]. In the present study, the DIAAS value calculated for BGN is 69 (Table 4), indicating that BGN can meet just under three-quarters of an adult's daily indispensable amino acid requirements. Similar to the PDCAAS value, the DIAAS value in the present study is lower than that reported for soybeans (DIAAS = 90/EP; Herreman et al., 2020) and (DIAAS = 86.4/EP; van den Berg et al., 2022) but higher than that of cooked chickpeas (DIAAS = 49/EP; Han et al., 2020). While the IEAA score suggests that BGN potentially contains high-quality protein, however, considering both the PDCAAS and DIAAS scores, the protein content of BGN can be considered lower quality compared to soybeans.

Table 4 presents the chemical score of essential amino acids, where the lowest score represents the first limiting amino acid. For BGN, methionine had a score below 1, indicating it as the first limiting amino acid. This finding is consistent with the results reported by Halimi et al. (2019) for BGN and similar to those reported for soybeans by van den Berg et al. (2022).

In SSA, the consumption of cereals forms the basis of local diets (Singh et al., 2007). The consumption of pulses in SSA is relatively low, at around 6% [Food and Agriculture Organization (FAO), 2008]. To improve dietary diversity and nutritional quality, an approach focusing on the inclusion of a variety of nutrient-rich foods is needed in SSA (Schönfeldt and Hall, 2012). As seen in Figure 1, BGN is primarily consumed with maize porridge in Southern Africa. Maize porridge, like many other grains consumed in large quantities in SSA, is rich in methionine but deficient in lysine (Boye et al., 2010; Makumba et al., 2016). The concept of combining different foods to enhance the amino acid profile is known as "complementation" (Tas et al., 2019). Due to its higher lysine concentration, BGN has the potential to complement maize porridge, resulting in a meal with

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TABLE 3 Amino acid content for Bambara Groundnut from three South African regions.

Bambara amino acid composition Mpumalanga: comparing areas						
		Langeloop	Mbombela	Gomoro	Mean	Value of *p*
Protein	g/100 g	8.86	7.65	9.10	8.54	<0.001
Essential amino acids		4.10	3.80	4.20	4.06	
Arginine	g/100 g	0.743^{a}	0.668^{a}	0.763^{b}	0.725	0.012
Histidine	g/100 g	0.253^{a}	0.148^{b}	0.277^{a}	0.266	0.005
Isoleucine	g/100 g	0.365	0.348	0.365	0.359	0.439
Leucine	g/100 g	0.668	0.627	0.680	0.658	0.054
Lysine	g/100 g	0.655	0.620	0.690	0.655	0.095
Methionine	g/100 g	0.105	0.097	0.105	0.102	0.383
Phenylalanine	g/100 g	0.492^{a}	0.457^{b}	0.505^{a}	0.484	0.025
Threonine	g/100 g	0.313^{a}	0.295^{b}	0.313^{a}	0.307	0.036
Tryptophan	g/100 g	0.090	0.107	0.097	0.098	0.093
Valine	g/100 g	0.413	0.390	0.407	0.403	0.177
Non-essential amino acids		5.43	5.38	6.13	5.97	
Alanine	g/100 g	0.390	0.372	0.390	0.384	0.129
Aspartic acid	g/100 g	0.858	0.945	0.970	0.924	0.271
Cysteine	g/100 g	0.157^{a}	0.170^{a}	0.120^{b}	0.149	0.009
Glutamic acid	g/100 g	1.402	1.397	1.512	1.437	0.139
Glycine	g/100 g	0.350	0.343	0.337	0.343	0.179
Proline	g/100 g	0.377^{a}	0.345^{b}	0.370^{a}	0.364	0.791
Serine	g/100 g	0.517^{a}	0.475^{b}	0.513^{a}	0.502	0.029
Tyrosine	g/100 g	0.235	0.233	0.242	0.233	0.878

Values with different superscripts in a row differ significantly.

TABLE 4 Protein quality measures for BGN.

Indicator	Score based on the grand mean
PDCAAS	52%
DIAAS	69
Essential amino acid index (IEAA)	1.49
Essential amino acid index %	149%

Essential amino acid		Essential amino acid	gEAA in the reference protein	CSEAA
Histidine	0.028	Histidine	0.015	1.90
Isoleucine	0.038	Isoleucine	0.03	1.28
Leucine	0.070	Leucine	0.059	1.19
Lysine	0.070	Lysine	0.045	1.56
Methionine	0.011	Methionine	0.016	0.68
Cysteine	0.016	Cysteine	0.006	2.65
Phenylalanine	0.093	Phenylalanine Tyrosine	0.038	2.44
Tyrosine				
Threonine	0.033	Threonine	0.023	1.43
Tryptophan	0.010	Tryptophan	0.006	1.74
Valine	0.0431	Valine	0.039	1.11

improved protein quality. The recommended ratio of legume to maize for addressing lysine deficiency in maize is 70% cereal to 30% legume (Ejigui et al., 2007). The amino acid profile of maize meal in SSA is typically low in lysine and contains trace amounts of essential amino acids such as methionine and tryptophan [Food and Agriculture (FAO)/Government of Kenya, 2018], contradicting reports that maize porridge is high in methionine. Calculating the DIAAS score of maize meal porridge using this data reveals a score of zero due to the trace amounts of essential amino acids. However, combining maize meal porridge and BGN in a 70/30 ratio increases the DIAAS score from zero to 20.7%, thereby enhancing the protein quality and nutritional contribution of this common dish in SSA. The inclusion of BGN in the local diet can improve dietary diversity and nutrient quality.

Considering the adverse impact of climate change on agriculture and the high cost of animal protein sources, incorporating indigenous products like BGN along with local products such as maize meal porridge can promote dietary diversity and contribute to achieving SDG 2—Zero Hunger—by 2030. BGN can be considered an affordable plant-based protein source that has a positive climate impact in SSA. It is important to carefully consider the preparation and cooking methods of BGN, as these can affect the nutrient density and bioavailability of nutrients, particularly protein quality, as observed with soybeans (van den Berg et al., 2022).

4. Conclusion

In conclusion, the cooked BGN has an average carbohydrate content of 18.9 g per 100 g edible portion, while the fat content was 3 g per 100 g edible portion, predominantly consisting of unsaturated fatty acids. The iron content was 0.827 mg per 100 g edible portion, and zinc was not detected. The protein content of cooked BGN, calculated using a nitrogen conversion factor of 5.71, was 9.35 g per 100 g. However, when considering protein quality using the PDCAAS method, the value was below 1. Comparatively, the DIAAS value for BGN was lower than that of soybeans but similar to chickpeas. BGN exhibited a high lysine content but a low methionine content, aligning with the characteristics of other pulses.

BGN represents a climate-positive crop that has the potential to contribute to a more nutrient-dense diet in the face of the ongoing climate and cost-of-living challenges. The utilization of BGN as a complementary protein source with low-protein staples such as maize holds great potential for enhancing the protein quality of the diet.

5. Recommendations

Research on the classification of BGN species in South Africa is fragmented. Therefore research on the formal classification of BGN species can lead to targeted breeding, potentially optimizing the amino acid composition, to optimize BGN as a potential complimentary food for lysine-poor cereals. More research on seeds' different species and origins is required for targeted breeding, which can improve the amino acid composition.

Data availability statement

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

Author contributions

ZV and BP substantially contributed to the conception or design of the work or the acquisition, analysis, or interpretation of data for the work, drafted the work or critically revised for important intellectual content. HS provided approval for publication of the content. ZV, BP, and HS agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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A basic healthy food basket approach to evaluate the affordability of healthy eating in South Africa and Kenya

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Introduction: Understanding the affordability of healthy eating has always been a critical question but has escalated in importance considering the global context of more recent soaring food prices and the worsening of food and nutrition security indicators since the COVID-19 pandemic. The objective of this study was to evaluate the cost and affordability of basic healthy eating in South Africa and Kenya, through the application of a Basic Healthy Food Basket (BHFB) modeling framework applied within the food intake and nutritional context of the target countries.

Methods: The construction of the BHFB models was based on a number of key considerations (i.e., 'building blocks'): household demographic (size and composition), socio-economically disaggregated household income levels, minimum wage data, typical food intake patterns, nationally monitored food retail prices and official country-specific nutrient intake and food consumption guidelines. For both countries BHFB's were compiled and interpreted at a national level, as well as for a 'more plant-based' BHFB. The nutritional adequacy of the national BHFB's was evaluated.

Results: Based on national demographical statistics in Kenya and South Africa, the reference family was defined as a four-member reference household consisting of 2 adults and 2 children. The detailed composition of the national BHFB's is presented, consisting of 31 food items in Kenya and 24 food items in South Africa – covering all the food groups according to nutritional guidelines. The nutritional adequacy of the various BHFB's is discussed and were generally deemed adequate for the majority of micro-nutrients – particularly the micro-nutrients of concern in the various countries. In January 2023 the cost of the national BHFB in Kenya and South Africa amounted to KSh33 800 (US$270) and R4 715 (US$ 262) respectively, – potentially excluding approximately 60% of the population from being able to afford a basic healthy food basket. A movement to 'more plant-based' BHFB's (i.e., proportionally less meat/fish/eggs and proportionally more legumes) reduced the cost of the BHFB's with 15% in Kenya and in South Africa. From a social support perspective, the analyses indicated that social support in the form of child support grants and children benefiting from school feeding programmes could result in the share of households able to afford basic healthy eating to increase by approximately 10 percentage points in the South African context.

Conclusions and recommendations: The study showed that the high (and rising) cost of basic healthy eating prevents large numbers of households in South Africa and Kenya from being able to afford basic healthy eating when considering current income distribution data. The research outcomes of the BHFB methodology applied in this study to monitor and evaluate the cost and affordability of basic healthy eating, should be monitored regularly and taken into consideration to inform food and nutrition policy decisions and actions. However, from a methodological perspective several critical challenges will have to be addressed to improve the measurement accuracy of the BHFB models, including the availability of official food retail price monitoring of a wider range of food items; household demographics, household income data, food intake data and household-level food expenditure data that are more frequently updated, as well as socio-economically and geographically disaggregated data on typical food intake behavior. From the perspective of plant versus animal protein sources, the study suggested that food intake patterns with an increased focus on legumes as a source of plant-based protein could help to improve the affordability of basic healthy eating. However, it is also important to consider consumer acceptability in this context from various perspectives, including sensory acceptability, cultural acceptability, and the available time for food preparation. The study identified the critical need to evaluate the cost of basic healthy eating on a geographically more refined level. This is based on the diversity of food intake behavior in different regions within the target countries as pointed out by in-country experts. However, future research to develop an improved understanding of food intake pattern in different regions/provinces/counties will be a critical enabler, along with geographically disaggregated food retail price data and demographical information.

KEYWORDS

food prices, affordability, food security, healthy diet, food basket, South Africa, Kenya, policy

1. Introduction

Food intake relates strongly to two of the Sustainable Development Goals (SDGs), targeting the window 2016–2030, specifically the second goal (to "end hunger, achieve food security, improved nutrition and promote sustainable agriculture") and the third goal (to "ensure healthy lives and promote well-being for all at all ages") (UNDP, 2018). Even though the third SDG is largely focused on disease eradication, food intake also plays a significant role in improving the health status of individuals by satisfying the nutritional requirements of individuals, to enhance general health and prevent chronic diseases (FAO, 2018).

Urbanization is a key driver of food system dynamics, affecting a wide range of factors such as consumer preferences, spatial food demand patterns and households' ability to produce their own food (Seto and Ramankutty, 2016; Tefft et al., 2017; De Bruin et al., 2021). In Sub-Sahara African countries (including South Africa and Kenya – the case study countries within this paper), increasing urbanization is a well-established socio-economic trend. According to the UN World Urbanization Prospects (United Nations, Department of Economic and Social Affairs, Population Division, 2018) the urban population in South Africa increased from 63% in 2012 to 68% in 2022 (projected to further increase to 80% in 2050) (United Nations, Department of Economic and Social Affairs, Population Division, 2018). Comparatively, urban residents in Kenya increased from 24% in 2012 to 29% in 2022 (projected to further increase to 46% in 2050).

With high and rising urbanization levels in South Africa, a strong reliance on purchased food is a dominant food procurement strategy for households. According to the Statistics South Africa (Stats SA) Community Survey 2016 (Statistics South Africa, 2017a) only 6% of all households obtained the majority of their food from their own agricultural activities in 2016. Several other sources confirm the increasing importance of purchased food from supermarkets as the dominant source of food for households (D'Haese and Van Huylenbroeck, 2005; Hendriks, 2005; Baipheti and Jacobs, 2009; Schönfeldt et al., 2010; Crush and Frayne, 2011; Pereira, 2013; Peyton et al., 2015).

With lower (but increasing) urbanization levels in Kenya, the 2015/2016 Kenya integrated Household Budget survey (KIHBS) (Kenya National Bureau of Statistics, 2018) indicated that at a national level purchased food account for 68% of total food consumed, with own food production only contributing 18%. As could be expected urbanites purchase a larger share of their food supply (86%) with only a 2% contribution from own food production. Rural households had a 28% contribution from own production while purchasing more than half (57%) of their food supply.

Food affordability can be defined as "the cost of the diet of a household relative to the household's income" (Lee et al., 2013), where the cost of the diet is strongly affected by food prices and the quantity of food purchased. Food prices and food affordability affect consumer food choices, with subsequent influences on dietary patterns, nutrition, health and food security status (James et al., 1997; Beydoun and Wang, 2008; Lee et al., 2013).

The intake of a healthy diet (in terms of dietary patterns and diversity) is an integral part of the concept of health, contributing to the prevention of malnutrition and non-communicable diseases (NCDs) (World Health Organization, 2015; World Health Organization, 2018). Unhealthy diets and inadequate physical activity are widely acknowledged as prominent global risks to health. Dissimilarities in the cost of healthy and less healthy food items and diets have been linked to public health issues such as obesity and NCDs (Drewnowski and Darmon, 2005). An increasing global policy focus on promoting the intake of healthier food options is fueling a need for data on the comparative prices and affordability of healthy foods versus less healthy alternatives (Lee et al., 2013).

In recent years various factors have increased the pressure on households' livelihoods, particularly factors such as food inflation, household income (or lack thereof), the prevalence of food insecurity and the nutrition transition which are explored in more detail below.

Global food prices (as measured by the FAO Food Price Index) soared to record high levels in 2021 and 2022 due to a complex combination of factors, particularly supply chain disruptions linked to the COVID-19 pandemic, the impact of the Russia-Ukraine war on grain and oil crop prices, high energy prices and weather disruptions (e.g., droughts in key global food production regions) (FAO, 2023). Despite some lagged response in upward inflation movements, food price inflation in developing African countries such as South Africa and Kenya also followed an upward trajectory for 2021 and 2022 (see Figure 1; Kenya National Bureau of Statistics, 2023; Statistics South Africa, 2023).

In addition to high and rising food prices, the COVID-19 pandemic and the state of the global economy in recent years has contributed to pressure on household income. As illustrated in Figure 2 year-on-year overall inflation was higher than income growth (as measured by Gross Domestic Product (GDP) *per capita*) from 2018/2019 to 2020/2021 (World Bank data on 'GDP per capita' and 'Inflation, consumer prices' for Kenya and South Africa as reported by The World Bank, 2023a,b,c,d) – with significant negative income growth observed in Kenya and South Africa for the period 2019/2020 which are strongly linked to the negative economic consequences of the pandemic. Thus, over the last few years there was a general deterioration in households' ability to purchase items and services to fulfill their needs in Kenya and South Africa.

The mounting pressure on the livelihoods of households in South Africa and Kenya is also evident when considering food security dynamics. According to the Global Food Security Index (The Economist Group, 2023), South Africa had a food security index of 61.7/100 in 2022 (being ranked 59th out of 113 countries), while Kenya had a comparably worse food security index of 53.0/100 in 2022 (being ranked 82nd out of 113 countries). According to the 2021 Stats SA General Household Survey (GHS) (Statistics South Africa, 2022a), the percentage of South African individuals that experienced hunger improved from 29% in 2002 to 11% in 2019, increasing to 12% in 2021. The percentage of individuals with limited food access improved from 29% in 2010 to 20% in 2019, worsening to 24% in 2021. In Kenya, FAO et al. (2022) estimates that for the period 2019–2021 severe and moderate food insecurity affects 27 and 70% of the population, respectively, (in the recent FAO publication 'The state of food security and nutrition in the world 2022'). The United Nations Children's Fund UNICEF (2022) reported that the population facing food insecurity in Kenya increased from 2.1 million in September 2021 to 4.5 million people in October 2022, strongly associated with the severe drought in Kenya in addition to other pressure factors as discussed in this section.

Food choices also have a critical impact on the livelihood and health of individuals. As mentioned earlier in this paper, changing food intake patterns often result from urbanization. From a broader perspective the nutrition transition refers to the shifts in dietary patterns toward more Western-orientated diets characterized by the intake of more animal protein, fat, salt, sugar and refined foods, while the intake of fresh produce and fiber-rich foods tend to decline (Bourne et al., 2002; Delgado, 2003; Popkin and Du, 2003; Du et al., 2004; Kruger et al., 2005; Steyn, 2006; Ghattas, 2014; Shisana et al., 2014). The nutrition transition is linked to adverse health outcomes such as overweight, obesity and resulting NCDs. Driving factors of the nutrition transition include rapid demographic, social and economic changes (due to economic growth and rising *per capita* income), increased urbanization and changes in food systems (including technological advances making low-cost, energy-dense and nutrient-poor foods more available) (Delgado et al., 1999; Pica-Ciamarra and Otte, 2009; Ghattas, 2014). Various studies have investigated and confirmed elements of the nutrition transition in Kenya (e.g., Peters et al., 2019; Mbogori et al., 2020; Rousham et al., 2020) and South Africa (e.g., Bourne et al., 2002; Steyn and Mchiza, 2014; Mbogori et al., 2020; Watson et al., 2021).

When considering the combined 'perfect storm' of the negative health outcomes associated with the nutrition transition, coupled with household income pressure, high food inflation and the prevalence of food insecurity, the necessity to measure the affordability of healthy eating is evident. An improved understanding of the cost of basic healthy eating in South Africa and Kenya can contribute to more comprehensive insights into the food and nutrition security landscape in these countries and can be a useful tool for policy analysis involving elements of consumer food choices and food affordability – ultimately helping the nation to achieve the goals of the UN sustainable development goals (SDGs) pertaining to food and nutrition security. In this study the main objective was to develop cost-effective and nationally representative models of basic healthy eating for Kenya and South Africa to measure the affordability of healthy eating. Furthermore, the study also focused on the formulation of policy recommendations to improve the measurement and application of the affordability of healthy eating in the target countries. The models of healthy eating presented in this paper flowed from an independent research initiative to explore the cost and affordability of healthy eating in the African context. These models could be adopted and applied by non-governmental organizations and/or government entities, and could also be applied to other African countries, to improve their ability to evaluate the cost and affordability of healthy eating in the continent.

2. Literature review

Before discussing the methodology applied to develop the models of basic healthy eating, this section presents an introduction to the concept of healthy food baskets, as well as examples of current

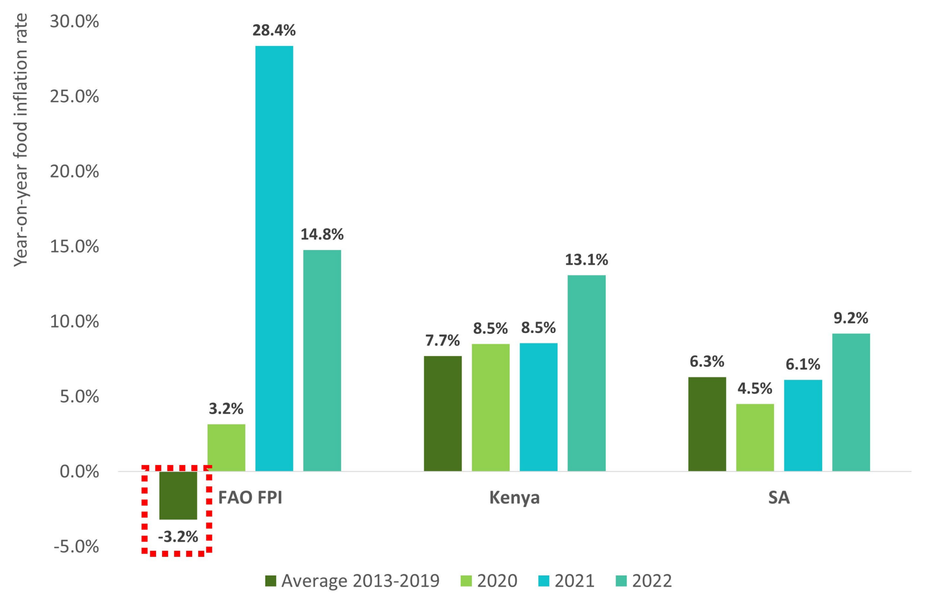

FIGURE 1
Global, South African and Kenyan year-on-year food price inflation for the period 2013–2022 (Sources: FAO, 2023; Kenya National Bureau of Statistics, 2023; Statistics South Africa, 2023).

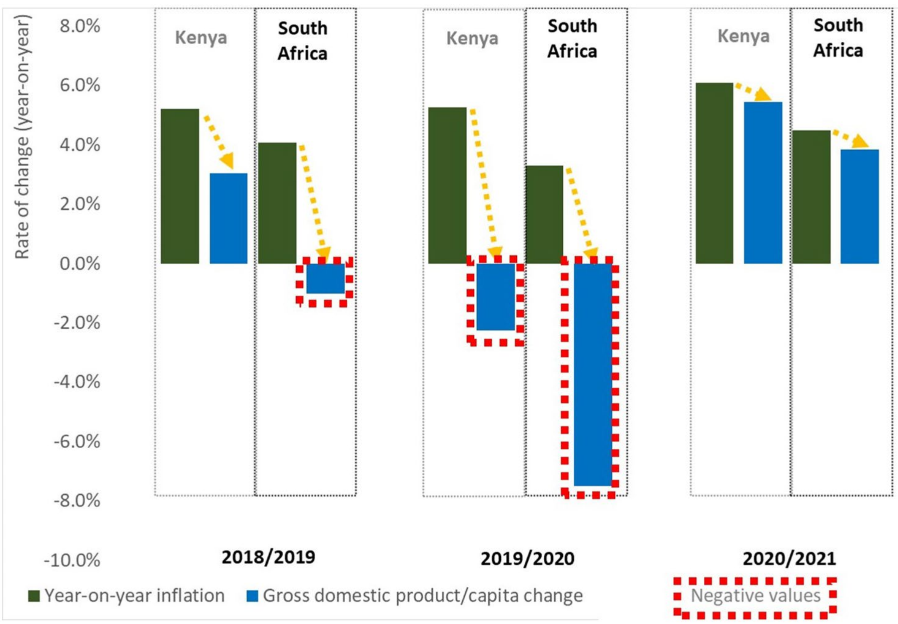

FIGURE 2
Is household income keeping up with inflation? Comparing annual year-on-year inflation with the annual change in GDP (Gross Domestic Product) *per capita* in Kenya and South Africa for the period 2018/2019 to 2020/2021 (Source: World Bank data on 'GDP per capita' and 'Inflation, consumer prices' for Kenya and South Africa The World Bank, 2023a,b,c,d).

applications in the target countries. A number of countries (e.g., United Kingdom, Canada, New Zealand, the United States of America (USA), Australia and Ireland) have been using baskets of 'healthy' food to monitor food cost and availability (Friel et al., 2004; Palermo and Wilson, 2007; Tsang et al., 2007; Carlson et al., 2007a,b; Health Canada, 2009; Williams, 2010; Department of Human Nutrition, University of Otago, 2018; Scott et al., 2018). The various reviewed healthy food baskets aimed to achieve a variety of objectives such as comparing the cost of healthy versus unhealthy foods, comparing the cost of healthy food in urban versus rural settings, examining the availability of healthy foods in various geographical settings, informing social grant policies, development of educational resources on healthy eating with a limited budget, investigating trends in food prices of healthy food items over time and comparing the affordability of healthy eating against particular household income scenarios (Williams, 2010; Lee et al., 2013). Methodologically these healthy food baskets vary in terms of numerous components (Williams, 2010; Lee et al., 2013), such as:

- The geographical level of monitoring (national, state, provincial or community level);
- The regularity of monitoring (e.g., monthly, *ad hoc* or once-off);
- The basis for defining 'healthy' food (e.g., focusing only on fruits and vegetables, based on national dietary guidelines, a selection of items which include 'more realistic' food items which are not generally considered as healthy or a selection of food items based on actual food choices made by consumers, measured with the help of nutritional surveys or household expenditure surveys);
- The socio-economic level of the target audience (e.g., healthy basket options varying from low-cost to moderate-cost to liberal-cost);
- The 'target audience' (e.g., hypothetical reference households or developed for specific age or gender groupings);
- The format of food items included [e.g., packaging sizes monitored, branded, generic or least expensive items monitored, level of processing considered (e.g., fresh, frozen, refrigerated, canned, juice options)];
- The methodology employed to obtain food price data (e.g., manual or electronic observations, in-store or online, the type of food stores surveyed, quantity of stores monitored and control for seasonality).

For South Africa limited existing food baskets could be found. The monthly monitored National Agricultural Marketing Council (NAMC) 28-item food basket (NAMC, 2022) is based on a selection of food items (and specific popular packaging sizes) commonly purchased by South African households and not on nutritional principles or a particular family size or composition. In a study investigating the "status of household food security targets in South Africa," Jacobs (2009) mainly applied the NAMC food basket. However, the basket was not nutritionally balanced or compiled for any specific household size or time period.

Rose and Charlton (2002) applied quantitative indicators from income and expenditure data surveys to investigate food insecurity in South Africa and calculated the cost of nine different individual types of food plans. The food plans (also referred to as food ration scales) were compiled in 1993 by the previous South African Department of National Health and Population Development. It was based on nutrient recommendations from the USA. The plans specified the minimum quantities of food items that would fulfill the nutritional needs of nine different age-gender groups. A tender process was followed by the South African National Department of Health (DoH) to update the Food Ration Scales.

The Pietermaritzburg Economic Justice and Dignity Group (PMBEJD) (2023) monitors a basic and nutritionally complete diet on a monthly basis, focusing on several geographical locations in South Africa (Johannesburg, Cape Town, Durban, Springbok and Pietermaritzburg) where a small selection of food prices is recorded monthly at 44 supermarkets and 30 butcheries targeting the low-income market.

Similar to South Africa, limited existing food baskets could be found in the context of Kenya. The African Population and Health Research Center (Mohamed et al., 2021) investigated the cost of healthy eating in Kenya. The study used data from the 2015/2016 KIHBS which was evaluated against nine WHO/FAO healthy eating guidelines to evaluate the healthiness of diets. Comparisons involved gender, rural versus urban and different counties in Kenya. The study showed that 84% of households only achieved four or less of the healthy eating guidelines and that healthier eating habits were associated with factors such as higher income levels, rural living locations, the presence of young children in households, female headed households and higher education levels among the household head.

Based on the 2015/2016 KIHBS, the 'Basic Report on Well-being in Kenya' (Kenya National Bureau of Statistics, 2018) describes a rural and an urban food basket (achieving an energy intake of 2250 Kcal based on typical food preferences) compiled to determine food poverty lines. Both baskets contain a selection of 44 food and beverage items typically purchased by rural and urban households, within nine food categories (starch-rich foods, dairy, meat/fish/eggs, fruit, vegetables, legumes, fats/oils, sugar, and non-alcoholic beverages). The compilation of these baskets was based on typical food expenditure patterns and did not focus on healthy eating guidelines.

To the best knowledge of the authors, no evidence could be found of existing examples of nationally representative, regularly updated healthy or nutritionally balanced food baskets in South Africa and Kenya.

3. Materials and methods

The paper is based on two case study countries – South Africa and Kenya. The selection of these two countries was based on three main considerations: food security status, the availability of national food price data and the availability of official food intake guidelines at a national level. Within Sub-Saharan Africa, South Africa is the country with the best Global Food Security Index score (overall score of 61.7/100, ranking 59th out of 113 global countries and a food affordability score of 63.4/100). Kenya on the other hand has a much lower Global Food Security Index score (overall score of 53.0/100, ranking 82nd out of 113 global countries and a worse food affordability score of 41.7/100 compared to South Africa). In both countries monthly national food price data for a selection of foods is published regularly by national statistical agencies and both countries have official food-based dietary guidelines.

As previously mentioned, the BHFB's aimed to provide an approach to enable the regular (monthly) monitoring of the cost and affordability of healthy eating in the target countries at a nationally representative level in a cost-effective manner. These healthy food baskets were based on the best publicly available data foundations as listed above. These BHFB's were also developed to be a versatile and adaptable tool to monitor the cost and affordability of healthy eating, by allowing for the characteristics of different households to be accounted for, e.g., in terms of the total household size, as well as the number of household members from different age and gender groupings. Furthermore, the models were developed to have the potential to be expanded to a geographically disaggregated level (e.g., provincial level or even more specific geographical regions) subject to the availability of data on food prices and food preferences pertaining to the particular geographical area.

A schematic view of the methodology applied to develop the basic healthy food baskets (BHFB's) in South Africa and Kenya is illustrated in Figure 3. By interpreting official dietary guidelines along with typical food preferences and household characteristics the food items and food quantities required to feed the reference family for a one-month period was determined. Official food composition data for the target countries was applied to evaluate the nutritional adequacy of the BHFB's. Food retail price data was subsequently applied to determine the BHFB's cost per month after which the BHFB costs were analyzed in the context of typical household income levels and food expenditure shares to evaluate the affordability of healthy eating. Specific model inputs for each country (i.e., in terms of official dietary guidelines, typical household size, typical household composition, defining single serving units, food retail price data, food composition data and household income data) are described in more detail below.

A number of assumptions were applied to develop the BHFB models, based on lessons learnt from literature (Lee et al., 2013): minimal food waste at household-level, the majority of purchased foods are consumed, all food consumed by the reference group is prepared at home, equitable consumption of food amongst individual household members according to their nutritional needs and the purchasing of all food required by the household (i.e., no production of food at household-level taken into consideration).

3.1. Defining healthy eating

Official national healthy eating guidelines formed the basis of the BHFB's, with specific reference to the South African Food-based Dietary Guidelines (Vorster et al., 2013), the Kenya National Guidelines for Healthy Diets and Physical Activity (2017) (Kenya Ministry of Health, 2017) and the WHO healthy diet guidelines (WHO, 2020). These guidelines were applied within the practical framework included in the South African DoH "Guidelines for Healthy eating" (National Department of Health, South Africa, 2013a), providing guidance on the number of servings from different food groups to be consumed by different age and gender groupings with average height and moderate activity levels with different energy needs. Single serving units (a single unit of a particular food within a particular food group providing a similar amount of nutrients as other units within the same group) were also defined based on the content of the "Guidelines for Healthy eating" and the respective country dietary guidelines (for example one slice of bread, half a cup of cooked starch-rich food, an 80 g edible serving of fresh produce, half a cup cooked beans, one teaspoon of plant oil and 85 g lean cooked meat).

3.2. Household characteristics

Table 1 presents the characteristics of a typical household in Kenya and South Africa (with relevant literature sources), consisting out of a 4-member household with two adults and two children in both countries. It should be noted that the flexible design of the BHFB models allows for the calculation of the cost of basic healthy eating for other household sizes and compositions as well if required.

3.3. Typical food preferences in South Africa and Kenya

Tables 2, 3 presents summaries of the literature information applied to select the food items to be included in the BHFB's for Kenya and South Africa, respectively. In addition to literature sources a survey among experts within the food and nutrition context in Kenya was conducted in 2022 to identify the dominant food items within the food groups. The combination of sources were applied to identify the dominant food items within the various food groups for inclusion in the BHFB's.

3.4. Food retail price data

3.4.1. Food retail price data in Kenya

The retail-level food prices available on the World Food Programme (2022) Price Database for Kenya, include foods from a variety of food groups: maize grain, maize meal, rice, sorghum, wheat flour, Irish potatoes, beef meat, camel meat, goat meat, fresh camel milk, fresh cow milk, UHT milk, cooking fat, vegetable oil,

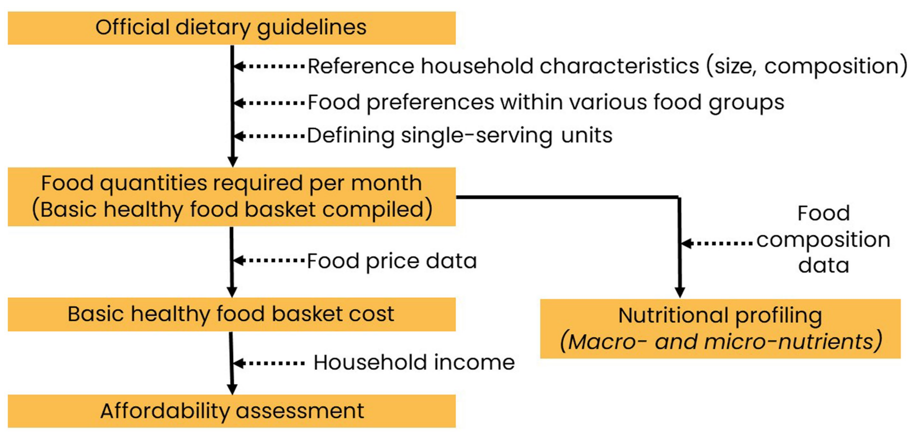

FIGURE 3
Overview of basic healthy food basket methodology (Source: Authors' depiction of the methodology).

TABLE 1 Household characteristics.

Country	Variable	Characteristic	Literature source
South Africa	Household size	The national average household size in South Africa is 3.4 members, rounded up to a 4-member household.	South African General Household Survey 2021 (Statistics South Africa, 2022a)
	Household composition	At least 60% of households in South Africa contains children within double-, triple-or skip-generation households. Thus, with a typical household size of 4 members, the reference household was constructed with 2 adults and 2 children.	South African General Household Survey 2021 (Statistics South Africa, 2022a)
Kenya	Household size	The national average household size in Kenya is 3.9 members, rounded up to a 4-member household.	Kenya Population and Housing Census 2019 (Kenya National Bureau of Statistics, 2019a,b)
	Household composition	In Kenya 58 of children in Kenya were living with both parents in 2015/2015, thus confirming a more typical household structure of 2 parents living with children. Thus, with a typical household size of 4 members, the reference household was constructed with 2 adults and 2 children.	Kenya Integrated Household Budget Survey 2015/2016 (Kenya National Bureau of Statistics, 2018)

bananas, dry beans, salt and sugar. The availability of recent food retail prices in Kenya within this source is problematic with the most recent data for March 2022 for selected items only, with some items only having observations captured until 2020 or even earlier dates. Furthermore, the current selection of food retail prices for Kenya in the WFP food price database contains a limited selection of fruit, legumes, vegetable oil products, meat and no non-starch-rich vegetables.

The complete food price database applied by the Kenya Bureau of Statistics to compile the CPI (consumer price index) is not available in the public domain and despite the best efforts of the authors could not obtained from the Kenya Bureau of Statistics. Only the average monthly retail prices of some varied food items are reported in the monthly publication 'Consumer Price Indices and Inflation Rates' (more detail on the food prices reported for 2022/2023 can be obtained from the authors on request). Based on an analysis of the 2022 and 2023 Consumer Price Indices and Inflation Rates' publications the following food items are monitored:

- Starch-rich foods (fortified maize flour, loose maize flour, sifted maize flour, loose maize grain, white wheat flour, white bread, Irish potatoes, aromatic and unbroken rice, non-aromatic and unbroken rice).
- Animal-source foods (Beef with bones, eggs, cow milk (fresh, packeted), cow milk (fresh, unpacketed), goat milk).
- Vegetables (avocado, capsicums, cabbages, carrots, kale, onions, spinach, tomatoes).
- Fruit (mangoes, oranges).
- Legumes (beans, cowpeas, green grams).
- Fats/oils (cooking fat, cooking oil).
- Sugar.

Comparing these food items against the food included in the Kenya BHFB revealed a number of foods with non-available national average retail prices: chicken meat, fish (Tilapia & Nile perch), goat meat, pork meat, broad beans (dried), pigeon peas (dried), garden peas, bananas, avocado's, pineapple, papaya, sunflower oil, margarine, palm oil and maize/corn oil.

Costing the Kenya BHFB for January 2023 was based on the available retail prices from the Kenya Bureau of Statistics, supplemented with retail prices obtained from prominent Kenyan retailer(s) (researched online) to enable costing based on all food items included the basket design.

3.4.2. Food retail price data in South Africa

In South Africa, Statistics South Africa engage in the monthly monitoring of a wide range of food items from all food groups (Statistics South Africa, 2023):

- Starch-rich foods (rice, white bread, brown bread, sweet biscuits, savory biscuits, bread rolls, rusks, spaghetti, macaroni, other pasta, instant noodles, cake wheat flour, bread wheat flour, maize meal, breakfast cereals, hot cereals (porridge) including instant porridge, ready-mix flour, samp (coarsely crushed maize grain), potatoes, frozen potato chips, sweet potatoes).
- Animal-source foods beef (rump steak, brisket, chuck, T-bone, mince, filet, sirloin, stewing meat, offal, corned beef), pork (chops, ribs, filet, ham, bacon), mutton/lamb (rib chops, loin chops, leg, neck, offal, stewing meat), chicken [whole bird, fresh portions, individually quick frozen (IQF) portions, giblets (neck, gizzards, hearts, etc)], other meat options (polony, dried meat, sausage, beef extract), fish (frozen hake, frozen fish fingers, canned tuna, canned pilchards), eggs, dairy (fresh and long life full cream and low-fat milk, powdered milk, condensed milk, yogurt, cheese, fresh cream, sour milk, prepared custard, maize based food drink with dairy, flavored milk).
- Vegetables (lettuce, spinach, cabbage, cauliflower, broccoli, tomatoes, pumpkin, sweet peppers, frozen vegetables, cucumber, onions, carrots, beetroot, mushrooms, prepared salads, canned mixed vegetables).
- Fruit (oranges, bananas, apples, pears, avocados, papaya, pineapple).
- Legumes (peanut butter, peanuts, dried beans, caned baked beans).
- Fats/oils [margarine, sunflower oil (including canola oil)]
- Sugar-rich foods (white sugar, brown sugar, jam, chocolates, sweets, chewing gum, ice cream).
- Other foods (potato crisps, corn chips, vinegar, chutney, tomato sauce, mayonnaise, salad dressing, whiteners, salt, spices, curry powder, baby food, instant yeast, baking powder, soup powder).

TABLE 2 Dominant food items consumed in Kenya.

Food group	Literature information		Kenya BHFB food items
	Most popular food items (*National level*)[1]	Literature sources	
Starch-rich foods	Maize > Wheat > Potatoes > Rice > Cassava > Sweet potato > Sorghum	FAOSTAT (2022)[2]	Maize meal Rice Potatoes Bread Cooking bananas (plantains)
	Maize flour > Rice > Wheat flour > Cassava > Cooking banana > Bread & Sorghum & Irish potatoes > Maize grain > Arrow roots > Yams.	Kenya National Bureau of Statistics (2018)[3]	
	Maize (mostly flour and some grain) > Rice > Potatoes > Cooking bananas > Wheat-based foods > Sorghum > Millet & Sweet potato	Stakeholder survey	
Meat, fish and eggs	Beef > Fish > Offal > Mutton, goat > Poultry > Eggs > Pork	FAOSTAT (2022)[2]	Beef Chicken Fish (fresh water) Eggs Goat Pork
	Fish > Beef > Chicken > Camel meat > Offal > Mutton, goat > Pork > Eggs	Kenya National Bureau of Statistics (2018)[3]	
	Beef > Chicken > Fish > Eggs > Mutton, goat > Pork	Stakeholder survey	
Dairy	Cow milk fresh > Camel milk > Goat milk > Sour milk > UHT-Long-life milk > Yoghurt > Condensed/powder milk > Ghee	Kenya National Bureau of Statistics (2018)[3]	Fresh cow milk
	Cow milk fresh > UHT / long-life milk > Fermented milk > Camel milk fresh > Yoghurt > Goat milk fresh & Cow milk pasteurized > Powdered milk	Stakeholder survey	
Legumes	Beans > Peas > Cowpea beans > Tinned beans > Dolicos beans (Njahi) > Green grams > Groundnuts > Tinned pulses > Peanut butter	Kenya National Bureau of Statistics (2018)[3]	Broad beans (dried) Pigeon peas (dried) Green grams Garden peas
	Common beans > Pigeon peas & (Garden) peas > Green grams > Cowpea beans > Groundnuts	Stakeholder survey	
Vegetables	Cabbage > Kale (Sukuma wiki) > Traditional vegetables > Spinach > Tomatoes > Tree tomatoes > Carrots> Onions	Kenya National Bureau of Statistics (2018)[3]	Kale Cabbage Spinach Tomatoes Onions Carrots
	Kale > Cabbage > Spinach > Tomatoes > Onions > Carrots	Stakeholder survey	
Fruit	Bananas > Pineapple > Oranges > Apples	FAOSTAT (2022)[2]	Bananas Mangoes Oranges Avocado's Pineapple Papaya
	Papaya > Guava > Avocado > Mango > Banana > Pineapple > Melon > Oranges	Kenya National Bureau of Statistics (2018)[3]	
	Banana > mango > orange > avocado > pineapple	Stakeholder survey	
Fats/oils	Sunflower oil & Margarine > Palm oil >Maize/corn oil > Soybean oil > Coconut oil	Stakeholder survey	Sunflower oil Margarine Palm oil Maize/corn oil

[1]Presented in order of importance.
[2]FAOSTAT 'food supply quantity' data for Kenya (2010–2019) (FAOSTAT, 2022).
[3]Author calculations based on the Kenya Integrated Household Budget Survey 2015/2016 (Kenya National Bureau of Statistics, 2018).

- Non-alcoholic beverages (coffee, tea, drinking chocolate, mineral water, fizzy drinks, fruit juices, dairy mixture drinks)

All the food prices needed to cost the South African BHFB are monitored and reported by Stats SA. Even though the food price monitoring activities of Stats SA are very comprehensive selected items could be added to improve the applicability of the database, including different types of plant oils (sunflower oil, canola oil, cooking oil (mixed content) and olive oil), as well as a more comprehensive selection of legumes, e.g., specific types of dried and canned beans (such as split peas, lentils, samp and beans mix, sugar beans, white beans, speckled beans, kidney beans and sugar beans), as well as a more comprehensive selection of soya-based foods, e.g., soya beans, soya 'mince' (budget meat alternative product). The

TABLE 3 Dominant food items consumed in South Africa.

Food group	Literature information		South African BHFB food items
	Most popular food items (*National level*)[1]	Literature sources	
Starch-rich foods	Maize porridge > White bread > Brown bread > Potatoes	Mchiza et al. (2015)	Maize meal Brown bread Rice Potatoes Wheat flour
	Maize meal > Brown bread > White bread > Rice > Potatoes > Wheat flour	Stats SA LCS 2014/2015[2]	
Meat, fish, eggs	Chicken > Eggs	Mchiza et al. (2015)	Chicken meat Beef Eggs Fish
	Chicken > Beef > Fish > Eggs > Mutton/lamb > Pork	Stats SA LCS 2014/2015[2]	
Dairy	Full-cream milk	Mchiza et al. (2015)	Full-cream milk
	Full-cream milk > Low-fat milk > Condensed / evaporated milk > Milk powder	Stats SA LCS 2014/2015[2]	
Legumes	Dried beans, canned baked beans, soya products	Stats SA LCS 2014/2015[2]	Dry beans Baked beans canned Peanut butter
Vegetables	Green leafy vegetables > Tomatoes > Onion > Cabbages	Mchiza et al. (2015)	Tomato Cabbage Onion Pumpkin Carrot
	Tomatoes > Onions > Cabbage > Spinach > Carrots > Pumpkin	Stats SA LCS 2014/2015[2]	
Fruit	Apples > Bananas > Oranges > Avocado > Grapes > Peach, Pear, Mangoes	Stats SA LCS 2014/2015[2]	Apple Banana Orange
Fats/oils	Cooking oil	Mchiza et al. (2015)	Plant oil Margarine
	Edible oil > Margarine > Peanut butter	Stats SA LCS 2014/2015[2]	

[1]Presented in order of importance.
[2]Statistics South African Living Conditions Survey 2015/2015 (Statistics South Africa, 2017b).

inclusion of these products could expand the possibilities of calculating food baskets with proportionally larger plant-based components in future.

3.5. Nutritional adequacy evaluation

The nutritional profile of the two BHFB's were calculated according to data from the South African Food Data System (SAFOODS) as described in the South African Medical Research Council Food Composition Tables for South Africa (SAFOODS, 2017), as well as the Kenya Food Composition Tables of 2018. Reference intake values for macro-nutrients were obtained from the Institute of Medicine (2005), with the recommended share of total energy derived from macronutrients applied (total carbohydrates: 45–65%; total fat: 20–35%; total protein: 10–35%) (Institute of Medicine, 2005). The following energy conversion factors were applied: 17 kilojoules (kJ) per gram for protein and total carbohydrates, and 37 kJ per gram for fat (Klensin et al., 1989). Reference intake values for micro-nutrients were obtained from the Institute of Medicine (2006). An adult female within the reference family was used as a reference person focus to analyze the nutritional adequacy of the South Africa BHFB's. The nutritional adequacy of the BHFB's was evaluated by comparing the nutritional profile of the baskets with intake recommendations.

3.6. Affordability assessment

To analyze the affordability of the BHFB's in the two target countries, the calculated cost of BHFB's were compared against household income from one or two household members earning a minimum wage, as well as the typical household income levels within the target countries with typical food expenditure shares also taken into consideration (see Table 4).

4. Results

4.1. A model of basic healthy eating for Kenya

Table 5 presents an overview of the composition of the Kenyan BHFB, based on the interpretation of the typical food consumption patterns in Kenya and national nutritional guidelines. The Kenya BHFB contains 31 food items within all the food categories: starch-rich foods, meat/fish/eggs, dairy, fats/oils, fruit, vegetables and legumes.

The Kenya BHFB's met 95–97% of the estimated energy requirements (EER) of an adult female. The energy derived from carbohydrates, protein and fat is within the recommended ranges. In terms of fiber, the required intake was satisfied in all the Kenya BHFB's. The Kenya national BHFB met more than 100% of the micro-nutrient requirements for Mg, P, K, Zn, Thiamine, Riboflavin, Niacin, Folate, Vitamin B12 and Vitamin C, while meeting at least 90% of more of the daily requirements for Ca, Fe, Se and Vitamin A. The Kenya urban BHFB met more than 100% of the micro-nutrient requirements for P, K, Zn, Se, Vitamin A, Thiamine, Riboflavin, Niacin, Folate, Vitamin B12 and Vitamin C, while meeting at least 90% of more of the daily requirements for Ca, Fe and Mg. The Kenya rural BHFB met more than 100% of the micro-nutrient requirements for Ca, Mg, P, K, Zn, Thiamine, Riboflavin, Folate, Vitamin B12 and Vitamin C, while meeting at least 85% or more of the daily requirements for Fe, Se, Vitamin A and Niacin.

TABLE 4 Data applied to measure BHFB affordability in South Africa and Kenya.

Country	Variable	Short description	Information source
Kenya	Minimum wage	KSh 15120 per month.	Announced by the Kenyan government on 1 May 2022 (Reuters, 2022)
	Average income	2022 (Gross National Income *per capita*): KSh 20123.	Kenya Economic Survey 2022 (Kenya National Bureau of Statistics, 2022)
	Household income distribution	Lower income group (71% of households): total monthly household expenditure of less than KSh 77900 (inflation-adjusted to 2022 levels). Middle income group (25% of households): total monthly household expenditure of KSh 77900 to KSh 184400 (2022 estimate). Upper income group (4% of households): total monthly household expenditure of more than KSh 184,400 (2022 estimate).	Kenya Economic Survey 2022 (Kenya National Bureau of Statistics, 2022)
	Typical food expenditure shares	IFPRI estimations of food expenditure shares: Poor households: 63%; Non-poor households: 41%.	IFPRI (Breisinger et al., 2022)
		National food expenditure share: 54%.	Kenya integrated Household Budget survey 2015/2016
South Africa	Minimum wage	R23.19 per hour. Monthly household income implications: Household income of R4 020 from a single wage earner and R8 040 from two wage earners.	South African Government (2022)
	Average income	Average monthly earnings paid to employees in the formal non-agricultural sector: R24 813 per person in August 2022.	Stats SA Quarterly employment statistics (September 2022) (Statistics South Africa, 2022b)
	Household income distribution	Socio-economic Measurement (SEM) segments' population distribution and income levels in 2021 (more detail presented in the results section of this paper).	All Product Survey of the Marketing Research Foundation South Africa (2022)
	Typical food expenditure shares	Typical food expenditure shares: • Low-income households (least affluent 30% of households): 33% • Lower middle-income households (30% of households): 29%. • Upper middle-income households (20% of households): 19%. • Affluent households (most affluent 20% of households): 8%.	Stats SA Living Conditions Survey (2014/2015) (Statistics South Africa, 2022b)

From the perspective of micro-nutrients of concern in Kenya [as reported in the Kenya national micronutrient survey of 2011 (Kenya Medical Research Institute et al., 2011)], the Kenya BHFB's developed in this project could supply more than 100% the daily needs for Zinc and Folate, and at least 90% or more of the daily needs for Iron and Vitamin A.

In January 2023 the cost of the Kenyan BHFB for the reference family of four amounted to KHs (Kenyan Shilling) 33800 (US$ 270), with the largest cost contribution from animal-source foods followed by starch-rich foods as shown in Figure 4. If the ration of meat/fish/eggs to legumes in the Kenyan BHFB is changed from 1:1 to 1:2 (i.e., a more plant-based basket) the January 2023 cost of the Kenyan BHFB could be reduced by approximately 15%. Thus, a more plant-based eating pattern could contribute to households' ability to afford basic healthy eating in Kenya.

Table 6 explores the affordability of the Kenyan national BHFB for January 2023. The BHFB is not affordable to households with a dual minimum wage income or households earning two average salaries.

A household with income at the lower end of the middle-income spectrum will have to spend 43% of their income on food to purchase the BHFB. This food expenditure share is close to the 41% food expenditure indicated by the International Food Policy Research Institute (IFPRI) (Breisinger et al., 2022) for non-poor households in Kenya.

If the reference household wanted to purchase the BHFB in January 2023 with a 54% food expenditure share (i.e., the national average food expenditure share) the household would require a total monthly income of approximately KSh62 600 (US$500) – representing a household income only approximately 20% below the upper-limit of the lower-income household bracket. With 71% of households classified with the lower-income bracket it could be argued that the bulk of lower-income households will not be able to afford the BHFB.

The challenge of healthy diets in Kenya was also confirmed by Mohamed et al. (2021) who concluded that more than half of households in Kenya only met two out of nine healthy diet recommendations (total fat 15–30% of total energy and total dietary fiber 25 g/day or more), with 84% of households only achieving four or less of the healthy eating guidelines. Only 21% of households attained a total protein intake of 10–15% of total energy and only 45% of households managed to consume fruits and vegetables of 400 g/day or more.

TABLE 5 Composition of the national BHFB for Kenya.

Food group	% of total single serving units in BHFB	Food item	% of total single serving units within food group
Starch-rich foods	25%	Maize meal	50%
		Rice	22%
		Plantain	8%
		Potato	10%
		Bread	10%
Meat, fish & eggs	5%	Beef meat	25%
		Chicken meat	25%
		Fish	25%
		Eggs	15%
		Goat meat	5%
		Pork	5%
Dairy	7%	Cow milk (fresh, full-cream)	100%
Fats/oils	20%	Vegetable oil	33%
		Sunflower oil	33%
		Margarine	33%
Fruit	7%	Banana	50%
		Mango	25%
		Orange	5%
		Avocado	10%
		Pineapple	5%
		Papaya	5%
Vegetables	11%	Kale	15%
		Tomato	30%
		Cabbage	30%
		Spinach	15%
		Onion	5%
		Carrot	5%
Legumes	5%	Beans	47%
		Green grams/ Pigeon peas/ Cowpeas	47%
		Garden peas	6%
Sugar	20%	Granular sugar (white sugar)	100%

Source: Project results.

4.2. A model of basic healthy eating for South Africa

Table 7 presents an overview of the composition of the South African BHFB, based on the interpretation of the typical food consumption patterns in South Africa and national nutritional guidelines. The BHFB contains 24 food items within all the food categories: starch-rich foods, meat/fish/eggs, dairy, fats/oils, fruit, vegetables and legumes. The differences in the composition of the BHFB models for South Africa and Kenya are mainly rooted in:

1. Different typical food intake patterns within the various food groups;
2. The nature of the reference group used to analyze typical food intake (low-income consumers in the case of South Africa and the average population in the case of Kenya);
3. In the case of the South African BHFB model the availability of historical time series data was also a significant factor leading to a smaller number of basket items compared to the Kenya BHFB.

The South African BHFB met 97–101% of the estimated energy requirements (EER) of an adult female. The energy derived from carbohydrates, protein and fat is within the recommended ranges for all three baskets. The South Africa national BHFB met more than 100% of the micro-nutrient requirements for P, K, Zn, Cu, Mn and vitamins A, B1, B2, B3, B12, B5, B7, C, E and folate, while meeting 81% of iron requirements, 86% for calcium and 91% for magnesium. The South Africa BHFB that are more plant-based met more than 100% of the micro-nutrient requirements for Mg, P, K, Zn, Cu, Mn and vitamins A, B1, B2, B3, B12, B5, B7, C, E and folate, while meeting 81% of the daily requirements for iron and 87% for calcium. Both baskets were low in vitamin D.

According to a consensus study report of the Academy of Science of South Africa (2013) micro-nutrients of concern in South Africa include vitamin A, vitamin D, folate and the minerals iron and zinc. The South Africa BHFB's developed in this project could supply more than 100% the daily needs for zinc, vitamin A and folate, and at 71–81% of the daily needs for iron.

In December 2022 (latest month for available Stats SA food retail prices) the cost of the South African BHFB for the reference family of four amounted to R (South African Rand) 4715 (US$ 262). The largest cost contributions came from animal-source foods (meat/fish/eggs & dairy) (55% contribution), followed by vegetables (15%), fruit (10%) and starch-rich foods (9%), with smaller contributions from legumes (5%), fats / oils (4%) and sugar (1%).

If the ratio of meat/fish/eggs to legumes in the South African BHFB is changed from 1:1 to 1:2 (i.e., a more plant-based basket) the December 2022 cost of the South African BHFB could be reduced by approximately 15%. Thus, similar to Kenya, a more plant-based eating pattern could contribute to households' ability to afford basic healthy eating in South Africa.

In December 2022, the South African reference household with four members, with two members earning the minimum wage, had to spend approximately 58% of income to afford basic healthy eating in the form of the BHFB. If such a household could benefit from government child support grants [R480 (US$ 24)/child/month (Western Cape Government, South Africa, 2022)], combined with receiving meals at school within the South African National School Nutrition Programme (South African Government, 2023), such a household had to spend approximately 45% of income to afford basic healthy eating. According to the Stats SA LCS 2014/2015 (Statistics South Africa, 2017b) the least affluent 30% of households allocated 33% of total expenditure to food implying that a food expenditure share of 45% is beyond the financial reach of a household with this type of income typology.

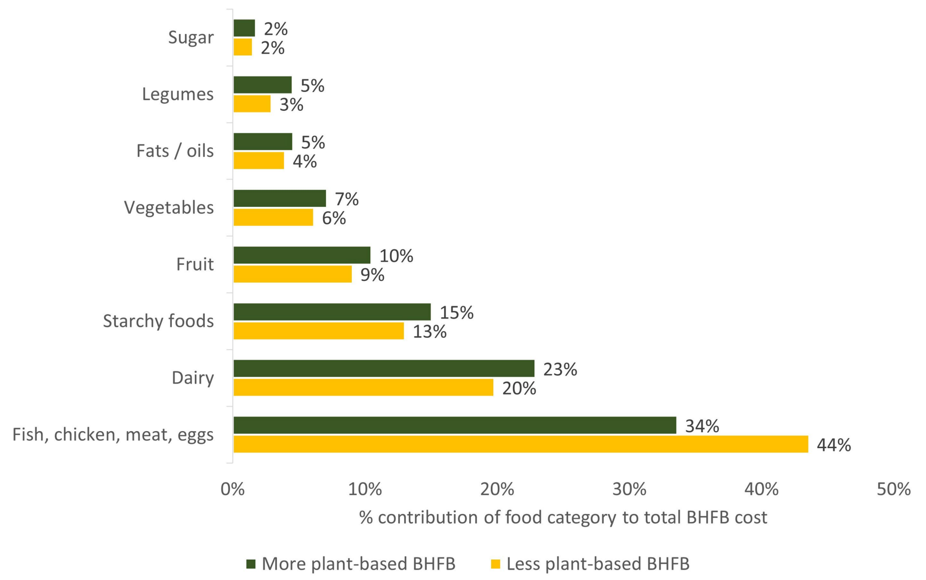

FIGURE 4
Food category cost contributions within the nation Kenyan BHFB (Source: Project results). BHFB, Basic healthy food basket.

TABLE 6 The affordability of the Kenyan national BHFB (KSh 33800 in January 2023).

Income level/scenario	% of expenditure allocated to food to purchase BHFB	Comments
KSh30 240 [Dual minimum wage income KSh15 120 × 2]	112%	With a dual minimum wage income the reference household will not be able to afford the BHFB, not even if all their income is allocated to food purchasing.
KSh40 246 [Dual average income Ksh 20123 × 2]	84%	With a dual source average income level the reference household will have to spend 84% of their income on food to purchase the BHFB.
KSh77 900 [Transition household income level between lower-income and middle-income households]	43%	A household with income at the lower end of the middle-income spectrum will have to spend 43% of their income on food to purchase the BHFB.
KSh184 400 [Transition household income level between middle-income and upper-income households]	18%	A household with income at the end of the middle-income spectrum will have to spend 18% of their income on food to purchase the BHFB.

Source: Project results.

For an alternative perspective on the affordability of healthy eating in South Africa, a reference household with a 33% food expenditure share will have to earn approximately R13 400 (US$ 733) per month to afford the BHFB (see the gray income line in Figure 5), or R 9574 (US$532) per month if also receiving child support grants and school meals within the NSNP (see the red income line in Figure 5). According to the South African income distribution reported by BFAP (2022) based on the SEM (Socio-economic Measurement) segmentation tool of the Marketing Research Foundation, these required income levels implies that approximately 64% of households (i.e., SEM 1 to SEM 6 with income levels below the gray line) cannot afford basic healthy eating (without additional support from child support grants and school meals). In the case where the impact of child support grants and school meals are taken into consideration, Figure 5 illustrates that 52% if households (i.e., SEM 1 to SEM 5 with income levels below the red line) will not be able to afford basic healthy eating. Thus, child support grants and school meals could increase the share of households that could afford basic healthy eating from approximately 36–48% of South African households.

5. Discussion

In this study the main objective was to develop Basic Healthy Food Basket (BHFB) models for South Africa and Kenya to evaluate the cost and affordability of basic healthy eating. The methodology relied on a number of key considerations (i.e., 'building blocks'): household demographic, household income, typical food intake patterns, nationally monitored food retail prices and official country-specific nutrient intake and food consumption guidelines. Suitable food composition data was applied to evaluate the nutritional adequacy of the BHFB models.

In December 2022/January 2023 the cost of the BHFB's for the reference family of four amounted to US$ 270 in Kenya and US$262 in South Africa, potentially excluding more than half of households in Kenya and South Africa from basic healthy eating from an affordability perspective. However, with mounting pressure on households from factors such as income pressure, as well as high and rising food, many more households could rapidly move into a space where basic healthy eating will not be affordable.

TABLE 7 Composition of the national BHFB for South Africa.

Food group	% of total single serving units in BHFB	Food item	% of total single serving units within food group
Starch-rich foods	33%	Maize meal (fortified, super)	40%
		Brown bread	25%
		Rice	25%
		Potatoes	5%
		Wheat flour (cake flour)	5%
Meat, fish, eggs	9%	Chicken meat (IQF portions)	60%
		Beef mince	10%
		Eggs	20%
		Fish (canned pilchards)	10%
Dairy	9%	Milk (fresh, full-cream)	100%
Fat, oil	27%	Plant oil (sunflower oil)	88%
		Margarine	11%
		Peanut butter	1%
Fruit	9%	Apple	34%
		Banana	36%
		Orange	30%
Vegetables	15%	Tomato	35%
		Cabbage	35%
		Onion	20%
		Pumpkin	5%
		Carrot	5%
Sugar	27%	Sugar (white sugar)	100%
Legumes	4%	Dry beans	80%
		Baked beans canned	20%

Source: Project results.

The inclusion of a larger selection of more expensive food items in the BHFB's to improve dietary diversity will also have a negative impact on the affordability of the basket. Another factors that could have a negative impact on the affordability of healthy eating relates to food waste. Even though the BHFB model assumes zero waste at household level, food waste is a reality at household level. In developing countries the most significant food waste occurs from the farm to the retailer, with a lesser contribution of consumer waste. In contrast consumer-level food waste has a dominant contribution in first world countries (FAO, 2019). According to the World Wildlife Foundation (WWF) (2017) total food waste in South Africa is estimated at 10 metric tons *per annum* (approximately 33% of average annual production), with the largest proportion of waste occurring from the farm to the retailer. Household-level food waste (representing the focus of this study) contributed an estimated 5% to total food waste in the value chain [World Wildlife Foundation (WWF), 2017]. Critical thinking and appropriate future research are needed on the relevant intervention levels in value chains and potential intervention strategies to curb food waste effectively in the South African context.

Even though the costing of the national BHFB models is designed to be based on nationally monitored food retail prices, it could be argued that households might lower the cost of the BHFB by engaging in actions such as 'shopping around' for special offerings, selective bulk purchasing to utilize economies of scale discounts and switching to less expensive brands. Taking South Africa is an example, a hypothetical 20% reduction in the cost of the BHFB though the application of these actions will enable approximately 10% more of households to afford basic healthy eating. However, more than 40% of households will still not being able to afford the BHFB despite best efforts from households to optimize the value-for-money in their food spending.

According to the FAO (2012), sustainable diets are defined as "those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources." Considering the affordability impact of potential movements to 'more plant-based' BHFB's (i.e., proportionally less animal-source foods and proportionally more legumes as a plant-based protein source) the study indicated a reduction of about 15% in the BHFB cost in both countries. Thus, these results suggest that food intake patterns with an increased focus on legumes as a source of plant-based protein could help to improve the affordability of basic healthy eating. However, it is also important to consider consumer acceptability in this context from various perspectives, including sensory acceptability, cultural acceptability, and the available time for food preparation (Alcorta et al., 2021; Tyndall et al., 2022). Future research should focus on the development and application BHFB models addressing both basic nutrition needs as well as optimal sustainability objectives.

5.1. Reflecting on the building blocks of BHFB's

The design of BHFB models, as applied in this study, relies on the availability of accurate and representative input data pertaining to typical household size, typical household composition, household income levels, typical food intake patterns, nationally monitored food retail prices, official country-specific nutrient intake and food consumption guidelines, as well as suitable food composition data.

5.1.1. Typical household characteristics

The identification of typical household characteristics in terms of household size and composition is a critical 'building block' of BHFB's. The compilation and publication of such data are usually performed by national statistical agencies such as Stats SA and the Kenya National Bureau of Statistics. Data should ideally be nationally representative, regularly updated and recent, and should be available at a national average level, for rural vs. urban households and for households within different geographical regions within a country. Especially in the case of Kenya these data sources dated back to 2015/2016 and 2019, creating the need for more recent official data on household characteristics.

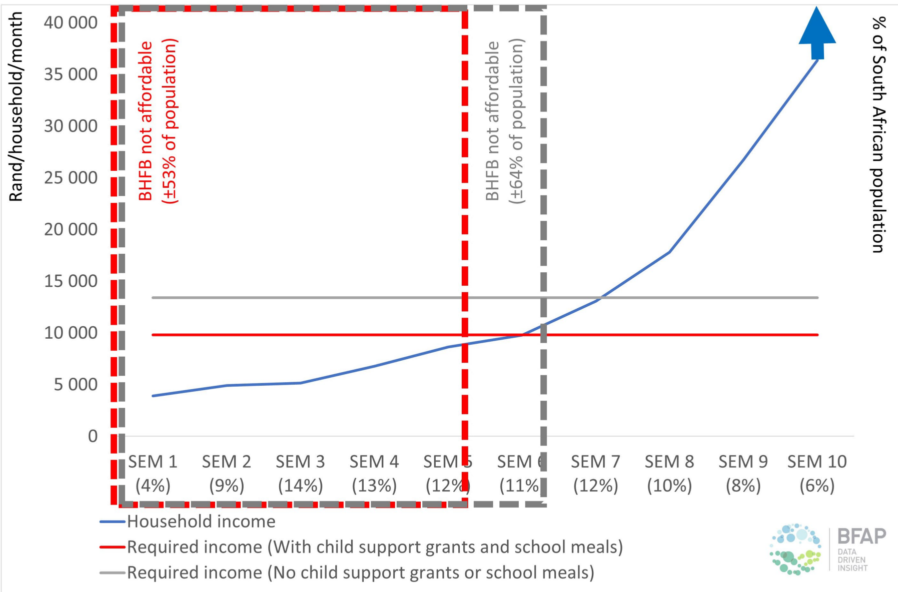

FIGURE 5
The affordability of the South African national BHFB within the socio-economic spectrum in 2022 [Sources: SEM distribution and income levels from the Marketing All Product Survey of the Marketing Research Foundation South Africa (2022)]. SEM, Socio-economic Measurement Segment; BHFB, Basic Healthy Food Basket.

5.1.2. Household income

Evaluating the affordability of BHFB's requires household income data that is detailed, regularly updated, and socio-economically disaggregated. Ideally nationally representative household income data per expenditure decile (ED) (where each ED represents 10% of households in the country) should be gathered and released annually or at least every 2 years to optimize food affordability calculations. This aspect requires attention in both Kenya and South Africa.

5.1.3. Food intake

Food intake data (applied to identify typical food choices feeding into the design of BHFB's), should ideally be based on nationally representative food intake studies, incorporating disaggregation in terms of income groups, rural vs. urban consumers and different geographical regions. However, the cost of such studies often prohibits the regular gathering and release of such datasets. In this study food intake data was obtained from sources such as household-level expenditure studies, food expenditure / intake studies in specific locations and national-level FAOSTAT data. The gathering and release of more regular detailed socio-economically disaggregate household-level food expenditure data (for various levels such as national, rural/urban and main geographic sub-regions) will make a significant contribution to improve the study of food intake dynamics over time in the target countries. Interaction with experts in the target countries also revealed the existence of food intake variations between regions / provinces / counties in the target countries. However, due to current data limitations further research will be needed to explore the geographically disaggregated food intake patterns in the target countries in a time-effective and cost-effective manner – and to supplement the available data in years when no 'big data' national studies are available.

5.1.4. Food retail price data

Ideally, for the optimal application in the context of BHFB's, official national food retail price data should be gathered and released monthly, avoiding time lags, covering a wide range of relevant food items and cover national average food prices as well as geographically disaggregated data. The availability of such data in a time-series format allows for the more accurate monitoring of food inflation and the affordability of healthy eating over time. The potential of monitoring online food retail prices in the target countries could also be investigated, to serve as a source of more timely food retail price data and as an 'early warning' system for food price movements. Based on the outcomes of this study, it is recommended that the product coverage of official food retail price monitoring activities in the two target countries should be expanded.

In South Africa the food retail price monitoring activities of Stats SA are comprehensive and cover a wide range of food items from all food categories (as presented in the methodology section of this paper). Within the fats / oils food category it is recommended that different types of plant oils should be monitored, including foods such as sunflower oil, canola oil, cooking oil (mixed content) and olive oil. A more comprehensive selection of legumes should also be monitored, e.g., specific types of dried and canned beans (such as split peas, lentils, samp and beans mix, sugar beans, white beans, speckled beans, kidney beans and sugar beans), as well as a more comprehensive selection of soya-based foods, e.g., soya beans, soya 'mince' (budget meat alternative product). The inclusion of these products could expand the possibilities of calculating food baskets with proportionally larger plant-based components in future consisting of product variety within the legumes food category.

In Kenya, public domain access to the comprehensive database of monthly food retail prices monitored by the Kenya National Bureau of Statistics (on a national level as well as for sub-regions) is critical for future actions toward monitoring the affordability of basic healthy eating in Kenya on a regular basis. Certain food items could also be added to monthly food retail price monitoring activities in Kenya, including plantain / cooking bananas, brown bread, dominant cuts / product options of chicken meat, dominant cuts of pork, beef mince, fish (Tilapia and Nile perch), sunflower oil, margarine., pineapple, papaya, pigeon peas and canned garden peas.

5.2. An improved understanding of consumers

From a consumer perspective, future research should establish a better understanding of consumers' awareness and understanding of healthy eating, as well as the factors preventing them from acquiring and consuming a healthy diet. The availability of healthy food choices should also be investigated. Research on these topics should ideally be done at national and regional levels, as well as in rural and urban locations to add maximum value. Based on these outcomes, consumer education campaigns could be formulated and rolled out to advise consumers regarding healthy food choices taking into consideration what is available, affordable and culturally acceptable in the area of residence. Furthermore, consumer education could also address aspects such as a better understanding of the nutrition transition and the negative health impacts associated with it. Helping consumers understand the correct portion sizes and the relative affordability of these portions for recommended food items – which should be updated and published monthly to help consumers make the best of available food budgets.

Improving the practical interpretation and implementation of food-based dietary guidelines by consumers from all socio-economic sub-groups could also be prioritized. For example, this could be done by designing example eating patterns, stating the number of food guide units needed per day from the various food group based on the energy requirements of individuals (an example of this was published in the South African Nutrition Week 2012), taking into consideration typical food choices of consumer sub-groups. Along with well-explained food guide unit quantities, such a tool can help consumers to adopt food-based dietary guidelines within their household in a practical manner. Furthermore, building upon the establishment of food labeling and marketing practices that are not misleading and adhere to legislative requirements, consumer education can help consumers to make more informed healthy food decisions.

5.3. Conclusion and policy outlook

Policy actions to improve the affordability of healthy eating often focus on the household income and food price components. Policy actions aimed at increasing household income levels (with a particular focus on vulnerable population segments) can help to relieve consumer debt, inequality and poverty (The Pietermaritzburg Economic Justice and Dignity Group (PMBEJD), 2016; Saskatchewan Food Costing Task Group, 2017; Rakotoniaina, 2018). Such policies could for example focus on increased household income through higher minimum wages, child support grants and old-age pensions. The complexity of raising household income levels should not be underestimated, when we consider the broader economic and fiscal implications of such actions, as well as the wide range of factors that could potentially affect household income, such as the number of income earners, the health of income earners (mental and physical), education levels, living location (e.g., rural versus urban) (Reardon et al., 2000; Alves, 2012; Statistics South Africa, 2017a).

When we shift the focus to food price interventions it is critical to keep in mind that food prices are affected by numerous complex factors, such as "political, economic, socio-cultural and environmental factors at the local, national and international levels" (Lee et al., 2013). For example, in recent months severe and persistent electricity loadshedding has caused upward pressure on food inflation due to direct costs (e.g., fuel expenses to operate electricity generators during load shedding) as well as indirect costs [e.g., the increased occurrence of food waste and spoilage within food supply chains (BFAP, 2023)]. Consequently, the ease in global commodity prices, is not currently reflected in South African food inflation dynamics.

Taxation can be used to increase the cost (with the aim to reduce the popularity) of less-desirable food options like sugar-rich soft drinks [e.g., implemented in countries like South Africa (National Treasury, South Africa, 2016)], France and the United States of America (Brownell et al., 2009; Villanueva, 2011). Lee et al. (2013) emphasized the importance of evaluating the health outcomes of such interventions. A second example of taxation to affect food prices pertains to the association between fast-food (take-away food) intake and the global prevalence of obesity (Zobel et al., 2016). In 2011 Hungary implemented a 'junk food tax' on "food high in salt, sugar and caffeine" (Bíró, 2015) which was observed to decrease the consumption of processed food and improve eating patterns particularly for lower income households.

The first example of policy action aimed at improving the affordability of healthy eating involves the exemption of certain food products from value added tax (VAT) (Powell and Chaloupka, 2009; Lee et al., 2013; Assefa et al., 2016). In South Africa based on the Value-added Tax Act of 1991 (South African Revenue Service, 2019) a selection of widely consumed food items (samp, maize meal, rice, brown bread, maize rice, dried maize, brown wheaten meal, bread flour and cake flour) is exempted from VAT (National Treasury, South Africa, 2018). Temple and Steyn (2009) argued that the VAT exempted food items in South Africa could be expanded to include other healthy food options with "a low and intermediate cost of dietary energy and a low energy density," such as oats. The Pietermaritzburg Economic Justice and Dignity Group (PMBEJD) (2016) suggested that chicken portions should also be added to the list of VAT exempted food items as chicken portions are the dominant meat source for households in South Africa.

Policy actions aimed at improving the affordability of healthy eating can also rely on subsidies targeting vulnerable groups to impact food affordability (Sassi et al., 2009; Lee et al., 2013). In the United States of America food stamps have been in use since 1939 as part of the Supplemental Nutrition Assistance Program (USDA, 2018). In the UK the Healthy Start scheme has been active since 2006 (Crawley and Dodds, 2018). An example of a policy measure targeting vulnerable groups is the Farmers Market Nutrition Program of the Massachusetts Department of Agriculture in the United States of America (Massachusetts Department of Agricultural Resources, 2019). In this scheme coupons to buy fresh fruit and vegetables at farmer markets in the state are given to vulnerable women (pregnant and breastfeeding), children and the elderly. Webber et al. (1995) observed an increase of approximately 30% in the quantity of fresh fruit and vegetables purchased by these participating households.

From a more general health perspective the South African DoH is involved in numerous policy initiatives. For example, legislation to decrease the mean salt intake of the population to less than 5 g per day has been implemented through a two stage approach (effective dates were 30 June 2016 and 30 June 2019) [Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972), Regulations relating to the reduction of sodium in certain foodstuffs' (R.214), 20 March 2013, DoH, National Department of Health, South Africa, 2013b]. A second example relates to the mandatory fortification of the main staples in South Africa started in 2003, with the current list of fortified foods including maize meal, wheat flour for white-and brown bread and cake flour (National Gazettes, No. 39776 of 03 March, 2016, as part of the Foodstuffs, Cosmetics and Disinfectants Act (54/1972): Regulations relating to the Fortification of certain Foodstuffs) (National Department of Health, South Africa, 2016). When we consider the potential substitution of maize meal with rice it is recommended that the mandatory fortification of rice should be applied in the South Africa context.

The increasing emphasis on the importance of sustainability in food choices (Willett et al., 2019) can prompt the future revision of the current food-based dietary guidelines in countries like Kenya and South Africa, to incorporate sustainable food choice considerations. Such recommendations should be based on sound scientific evidence in the national food and socio-economic context. Furthermore, an increased focus on the consumption of food that is not only affordable but also sustainable, will have significant implications for farming practices and supply chain systems in South Africa.

Data and trends regarding the affordability of basis healthy eating could contribute to the ultimate improvement in food-and nutrition security by backing and informing policy decisions. Thus, it is recommended that suitable organizations could also engage in the monthly calculation and publication of the cost and affordability of basic healthy eating in the particular country and provide context regarding the dominant factors driving food prices for that time period. For example, the BFAP Food Inflation Brief as an example of such an initiative released monthly within the South African context to a diverse audience of role-players (BFAP, 2023).

It is important to keep in mind that the improvement of the affordability of healthy eating in South Africa has no simple solution, but would require a complex, multi-dimensional strategy involving both the public sector (e.g., appropriate policies and legislation) and the private sector. Private sector contributions could include the application of technology to develop foods which are affordable and healthy (Ronquest-Ross et al., 2015), as well as the potential role of retailers to make healthy food such as fresh fruit and vegetables more affordable to consumers by initiatives such as bulk discounts when a variety of healthy products are purchased. Follow-up research should include a comprehensive review of actions undertaken around the world to improve the affordability of healthy eating, combined with research to investigate the viability of policy options at multiple levels (e.g., fiscal, nutritional, consumer and industry levels) in the South African context.

Robust, up-to-date, nationally representative food intake data is critical to enable the design and implementation of timely policy interventions to address the nutritional challenges (Van Heerden and Schönfeldt, 2011). In the absence of regularly updated food intake data in countries such as Kenya and South Africa, one possible solution could be to derive food intake data from food expenditure data, to fill this data gap. The development, testing and implementation of a 'rapid assessment' methodology to keep tabs on consumers' food consumption patterns, that is time and cost effective, could be critical in tough economic times with limited funding available for conventional nationally representative (and expensive) food intake studies.

To further improve the research findings and expand BHFB approach to a level with maximum practical relevance, further in-country testing is recommended. This relates specifically to the investigation of food intake patterns within different regions / provinces / counties in Kenya and South Africa to better understand consumers' disaggregated food intake patterns. More detailed data on food preferences could then enable the compilation and application of region-specific basic healthy food baskets and could also help to align food price monitoring activities to develop regional food prices in addition to national average food prices on a monthly basis.

Efforts to improve the nutritional status of a population, also through the improved affordability of healthy eating, should always be cognisant of socio-economic complexity and diversity. Various sub-segments could be facing unique nutritional challenges. Affluent consumers have the luxury to demand food attributes in line with their needs for aspects such as indulgence, health / wellness and innovative food solutions to assist them with time pressure in their daily lives and their social aspirations such as sustainability. With less-desirable lifestyle choices and over-nutrition, some individuals in this segment face challenges controlling weight (particularly overweight and obesity) and the subsequent development of NCDs such as diabetes and coronary heart disease. At the lower end of the spectrum numerous households cannot even afford purchasing foods in order to follow a healthy eating pattern, resulting in monotonous diets with large volumes of affordable staples and a preference for inexpensive, energy dense and often micronutrient-poor foods. The occurrence of overweight and obesity increases the risk to develop NCDs. At the same time under-nutrition (evident for example in the prevalence of childhood stunting and micronutrient deficiencies in children, females and vulnerable groups) often pose another major challenge for less affluent individuals.

Improving the affordability of healthy eating in countries like Kenya and South Africa requires a complex combination of multiple interventions involving public and private sector role-players with a broad range of interventions aimed at consumers, food production and processing systems. With significant input cost pressure at farm-level combined with dualism that is also pertinent in the farming sector in South Africa, comprising of a combination of commercial and small-scale farmers, the complexity of the policy intervention and actions required to produce affordable and healthy food become even more prominent. Working toward improved food systems and a healthier population will require passion, skill, innovative thinking, solid science backing and a strong desire to make a difference – from all role-players in the supply chain spanning from farm to fork.

Data availability statement

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

Author contributions

HV, FM, and HS contributed to the conception and design of the study. HV gathered data, performed data analysis, constructed the models, and wrote up the manuscript. All authors contributed to the manuscript revision, read, and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Gaps and opportunities in research on food systems; a micro-institutional analysis of the University of Nairobi

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Research conducted on food systems by higher institutions can contribute to sustainable food security and nutrition at a local level and reduce the impact of societal challenges such as malnutrition. Unfortunately, malnutrition itself manifests as hidden hunger causing unintended consequences such as illness negatively affecting economic progress. Traditionally, research in agriculture has not taken a food systems approach which is looking at challenges of food systems from farm to fork (all stages from production to consumption). Therefore, as we embrace the compelling call to transition from agriculture to food systems research approaches, mapping studies at a local level are needed. However, studies on food systems have been carried out at a macro (global or regional level), a micro-perspective investigation is needed to inform future research. A systematic review on existing literature (journals and thesis) was conducted to identify gaps and opportunities in research on food systems undertaken by researchers at the University of Nairobi. Information collected included; 1. institutions (faculties and department at the university, national policy, and international institutions collaborating with university of Nairobi), 2. crop types (cereals, legumes, vegetables, roots and tubers, and nuts), 3. food systems activities (production, postharvest, processing, and preservation, value addition and branding, consuming foods, input and output markets, obtaining nutrients as well as logistics and distribution) driving research on food systems. The contribution of each of the components (institutions, food systems activity and crop type) was also investigated through citation scores. The findings show that low research outputs on food systems were generated by the university of Nairobi compared to selected universities in Africa and across the globe. Research was focused on carbohydrate rich crops (maize, sorghum, cassava, irish potato, sweet potato, and rice) as compared to protective bioactive vitamin crops (vegetables, mango, and beans). This demonstrated low crop diversity and dietary quality. Research priority was given mainly to maize compared to traditional crops such as sorghum, African Leafy Vegetables, cassava and millets. Faculties such as health, science and technology, engineering, and humanities were involved in research in food systems in addition to agriculture, a potential indication of transdisciplinary research. Additionally, there was more collaborative research between university of Nairobi with institutions at a global level than with local institutions. The involvement of policy institutions in research was low, mainly restricted to the discipline of agriculture, production food system activity and in a few crops such as maize, cassava, and medicinal plants. Disparities in research existed along the food systems activities as more attention was focused on production activities. Other food system activities such as harvesting, processing and preservation, consumption, value addition and branding, input and output markets, as well as logistics and distribution activities, received low research priority. Each component (food system activity, crop type and institution) demonstrated contribution to sustainable food security as shown by citation scores. The findings demonstrate skewed focus in food systems research at the university of Nairobi. Agricultural research investment within institutions of higher learning will need to consider all food systems activities, under-researched crops and collaborations that advance transdisciplinary studies to promote inclusive contribution of food systems to food security at a local level. Further studies can focus on developing frameworks to advance transdisciplinary research.

KEYWORDS

micro-institutional, food systems, crops, transdisciplinary research, traditional crops

Background information

Recent developments in agricultural research have seen improvements in crop productivity and a reduction in food loss and waste (Valoppi et al., 2021). Despite these improvements, societal problems manifested as malnutrition, hidden hunger and obesity continue to plague the world (IPBES, 2019). These problems are highly felt in Sub-Saharan Africa. Currently, the prevalence of malnutrition cases in Sub-Saharan Africa stands at 29% compared to a global estimate of 21% (UNICEF, 2020). Climate change, dwindling natural resources and emerging pandemics will likely exacerbate these problems. An estimated 100 million people in Africa faced a crisis, emergency, or catastrophic levels of food insecurity in 2021 (Rwamasirabo, 2021; Sibanda and Mwamakamba, 2021). This number is expected to grow as a further 20 million more people will soon join the number because of the effects of the COVID-19 pandemic (Rwamasirabo, 2021; Sibanda and Mwamakamba, 2021). There is an urgent need for research to deliver sustainable solutions to these problems and also ensure food security and nutrition to the increasing human population which is expected to rise to 9 billion people by 2050, especially in Sub-Saharan where much of the population increase will likely occur.

The recent discourse in research has revolved around the application of food systems to enhance sustainable food security and nutrition (Ruben et al., 2019; Dekeyser et al., 2020; Borman et al., 2022). A key characteristic of food systems is the extensive linkages and interdependencies between components within the system. This implies that all the components along the food systems value chain involving growing and harvesting agricultural products, processing, packaging, transporting, selling, consuming, and the disposal of waste food and packaging are included (Benton and Thompson, 2016). Food systems help determine efficiency and identify externalities, shocks, and hotspots that require interventions (Alarcon et al., 2021). The study of food systems involves an analysis of components, linkages, activities, and factors (Von Braun et al., 2021). Food systems analysis can therefore assist in understanding food security and nutrition challenges, shaping research and policy, and providing strategic interventions to help solve societal challenges at a global, regional, national, and local level (Borman et al., 2022). However, food systems analysis is yet to provide solutions to these challenges. This is because studies on food systems have focused mainly on a particular activity along the food system, e.g., production (Duressa, 2018; Holka and Bieńkowski, 2020; Cairns et al., 2021) or processing and packaging (Okech et al., 2016; Beinah and Kunyanga, 2020; Malavi et al., 2021) and on addressing a single problem. An inclusive analysis of all components in a food system is needed to enhance the benefits.

Food systems research on under-utilized traditional or indigenous crops can positively contribute to sustainable food security and nutrition owing to the numerous nutritional benefits of the crops. Traditional are crops that were introduced a long time ago and have been naturalized in certain geographic regions (Akinola et al., 2021). Indigenous are crops that have origin within a certain geographic region and are not defined by a set of time (Akinola et al., 2021). Traditional or indigenous terms are synonymously used in literature to include crops such as sorghum (*Sorghum bicolor*), pearl millet *(Pennisetum glaucum)*, cassava (*Manihot esculenta*), sweet potatoes (*Ipomoea batatas*), nightshades (*Solanum* spp), marula (*Sclerocarya birrea*), and Bambara groundnut (*Vigna subterranean*), among others. The crops have dense macro- and micronutrients content (Mibei et al., 2016; Ngugi et al., 2016; Ontita et al., 2016; Ali et al., 2021); can effectively provide solutions to the double malnutrition challenge experienced on the African continent, and proponents have recommended the need to intensify research on traditional crops. However, research has put more focus on crops such as maize, wheat and rice (Mondo et al., 2018; Mwizerwa et al., 2018; Gitari et al., 2019; Odingo, 2019; Owade et al., 2019; Ichami et al., 2020; Jekayinoluwa et al., 2020; Mukami et al., 2020; Malavi et al., 2021; Wagaba et al., 2021). As a result, many of the traditional food crops remain undocumented, and the few documented crops have not been exploited sufficiently to attain their full potential considering all the activities along the food system value chain (Sibanda and Mwamakamba, 2021). This has resulted in low consumption and marketability of these crops. The low consumption of traditional crops has been attributed to factors such as household annual income, household size, farm size, culture, gender, and employment status (Kathure et al., 2019). The high marketability value of traditional crops is yet to enhance income and improve livelihoods. Marketing data shows that few farmers participate in commercialization of indigenous crops. A study by Zondi et al. (2022) shows that 20% of farmers producing traditional crops in South Africa participate in marketing of these crops. Similarly, only 20% of farmers are reported to participate in marketing of traditional crops in Kenya, Mozambique and Malawi (Moyo et al., 2022). This can be attributed to several factors such as a lack of market information, gender, off-farm income and weak value chain linkages (Zondi et al., 2022). Institutional involvement, especially at the local level, in research on traditional crops can promote production, commercialization and utilization of these crops (Lugo-Morin, 2020; Makate, 2020). However, institutional involvement in the promotion of traditional crops is low. Within the African continent, the Africa Vegetable Breeding Consortium (AVBC) established by the World Vegetable Center is involved in promoting the production of traditional crops such as *Amaranthus* (Ochieng et al., 2019). Within the southern and central parts of Africa, the Diversity International's African Leafy Vegetable program conducted in Botswana, Cameroon, Kenya, Senegal, and Zimbabwe has promoted the breeding and production of seed (Ruth et al., 2021). The South African Department of Agriculture, Forestry and Fisheries (DAFF) has developed a National Strategy on Indigenous Food Crops to support research and technology development of these crops (DAFF, 2011). In Eastern Africa, the East Africa Seed Company, World Vegetable Center, University of Nairobi, Jomo Kenyatta University of Agriculture and Technology (JKUAT) and Kenya Agricultural and Livestock Research Organization (KALRO) are involved in promoting the production and commercialization of traditional crops (Ochieng et al., 2019). Inclusion of these crops in food systems in addition to maize, rice, and wheat can contribute to sustainable food security.

Rethinking and reinventing research and development interventions in food systems using new approaches such as transdisciplinary could also contribute to food security and nutrition (Alarcon et al., 2021). Transdisciplinary is a participatory research approach where participants from science and society work closely together to identify challenges to complex societal problems (Berger-González et al., 2016). The core tenet of transdisciplinary research is its focus on shared problems and the active input of different practitioners as different goals and ambitions are simultaneously pursued (Clancy, 2017). Multiple stakeholders from science and non-science fields within a wide range of disciplines are involved which leads to better feedback and linkages of research to policy and practice (Pineo et al., 2021). Transdisciplinary research is increasingly being used in the health field to solve complex problems (Arenas-Monreal et al., 2015; Berger-González et al., 2016; Chastin et al., 2016; Fam, 2016; Black et al., 2019; Pineo et al., 2021; Ilangovan et al., 2022). The application of transdisciplinary research in food systems is yet to gain traction as only a few studies exist with collaboration across different disciplines (Claasen and Lemke, 2015; Kimondo et al., 2015; Kariuki et al., 2018).

It is against this backdrop, that research and development interventions in food systems need to be inclusive, integrate under-researched crops, and apply transdisciplinary approaches to enhance food security and nutrition. More important is for institutions, such as universities, conducting studies on food systems to understand priority areas of research and development (Committee on World Food Security, 2017). Universities are an important component of research as they are endowed with human resources, infrastructure and research funds (Lancho-Barrantes and Cantu-Ortiz, 2021). They also carry out capacity development, are sources of innovation, and take part in knowledge transfer. They have the capacity to undertake research and provide solutions toward sustainable food systems. However, mapping studies on food systems to identify gaps and opportunities that can play a significant role in providing direction, within local institutions such as universities, are largely missing (Alarcon et al., 2021). More often, studies on food systems mapping are available at a macro (global and regional level) (Valoppi et al., 2021; Bokelmann et al., 2022; Woodhill et al., 2022), hence a micro perspective investigation is needed to inform research and development priorities in food systems. Micro in this context refers to internal units (departments and faculties) and external organizations collaborating in research within an institution.

The study undertook a micro-institutional mapping exercise on research on food systems at the University of Nairobi (UoN). The main objective of the study was to map the studies that have been carried out on food systems at the UoN and identify gaps as well as opportunities for future research. The specific objectives were to use studies published by the UoN to; 1. map institutions undertaking research on food systems, 2. identify activities driving research on food systems, 3. identify crop types driving research on food systems, and 4. quantify the impact of studies on food systems on sustainable food security and nutrition (number citations, visibility, policy citations, reads, and social media mentions).

Materials and methods

The study institution

Within the East African region, Kenya was considered for benchmarking research outputs on food systems due to research performance and economic growth. The research performance broadly represents the status of research within East Africa. A mapping exercise was conducted at the University of Nairobi (UoN), Kenya, to identify studies on food systems. The university ranks the highest in research and capacity development in Kenya according to the Times Higher Education (THE) (Hongbo et al., 2021) and has higher research outputs produced compared to other institutions in the country. The research outputs broadly represent the research status on food systems in Kenya. The UoN comprises six colleges located across Nairobi city. The colleges include; the Colleges of Agriculture and Veterinary Sciences, Architecture and Engineering, Biological and Physical Sciences, Education and External Studies, Health Sciences, and Humanities and Social Sciences. The organogram for the UoN is shown in Appendix 1. These colleges uniquely place the university as a core institution to advance research in food systems. With more investment in research, it is important that the university responds to the challenges of food security and nutrition by delivering research that encompasses solutions from a wide range of disciplines.

Benchmarking research output

The research outputs collected were the number of publications. The study adopted and customized the systematic review process guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyzes (PRISMA) method as shown in Figure 1 (Tawfik et al., 2019). The PRISMA is a robust method that ensures the transparent and complete reporting of systematic reviews and meta-analyzes and has mostly been applied in the health sciences (Liberati et al., 2009). The method has four key stages which include; identification, screening, eligibility, and inclusion (Liberati et al., 2009).

The identification stage involved a preliminary search of articles contained in the PubMed, Science Direct, and Google Scholar databases focusing on food systems. According to PRISMA guidelines articles included in the study should have themes that are of global relevance (Tawfik et al., 2019). The terms "food system," "food security," and "nutrition" were included in the initial identification stage to ensure the selected articles focused on global needs. The search string used was to improve the search criteria and included the relevant articles, the descriptors "AND," "OR" and specific food systems crops such as "maize," "beans," "millet," and "finger millet," among others. The screening of articles was performed using titles and abstracts. During the screening phase, full articles were downloaded and the abstracts and titles of the articles were reviewed to identify; the context of the study, objectives, authors, type of food systems studied, geographic coverage, and activities driving food systems. Duplicate articles were removed.

The eligibility phase included defining the inclusion and exclusion criteria. The inclusion criteria were; research articles on food systems conducted between 2010 and 2021, articles having geographic coverage within Africa, and online articles under the UoN repository. All crops were included in the study to help understand the trends in research on traditional crops versus other crops. The search was then narrowed down to the UoN repository. A manual search to select research studies on crops was performed. Theses and dissertation articles were included. Abstract-only articles and pay-to-access journals were excluded.

Formulating the research questions

Formulation of the research questions was guided by the Food Systems Research Network for Africa (FSNet-Africa) Framework (FSNET, 2021; Figure 2). The FSNet framework comprises many components among them the drivers, actors, institutions, food systems components, and food systems outcomes/impacts (Figure 1). The framework was used because of its ability to capture multi-dimensional aspects along the food systems value chain. In this context, the framework was used to describe and identify activities driving research on food systems at the UoN. These activities included; input and output markets, logistics and production, innovation and branding, production and processing, consuming food, and obtaining nutrients. The actors and the institutions involved in research studies on food systems were also identified. The research questions are shown in text Box 1. Actors are the activities, the people and other organisms involved in the food chain. Institutions in this case are both internal (faculties and departments) and external organizations collaborating in research with university of Nairobi (international universities, research centers, national policy and national universities).

Data extraction

After identifying the eligible articles, a systematic review process for every article was conducted. Themes were delineated using the abductive method (Conaty, 2021). The information shown in Table 1 was extracted.

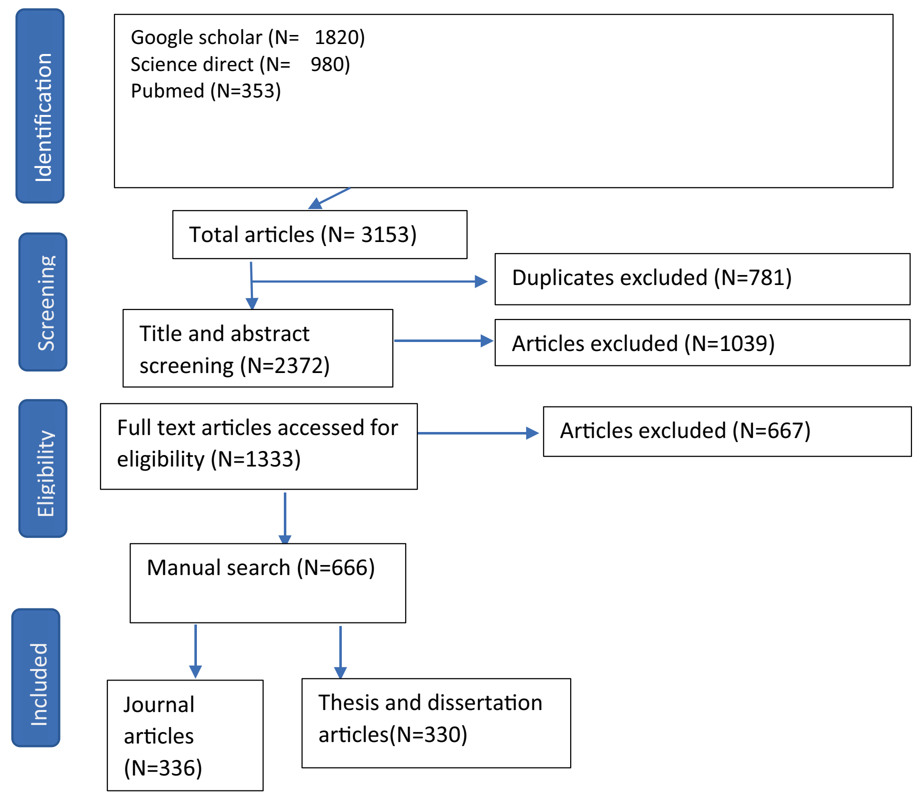

FIGURE 1
The Preferred Reporting Items for Systematic Reviews and Meta-Analyzes (PRISMA) showing the identification, screening, eligibility and inclusion process for the articles. Source; (Tawfik et al., 2019).

10.3389/fsufs.2023.1125094

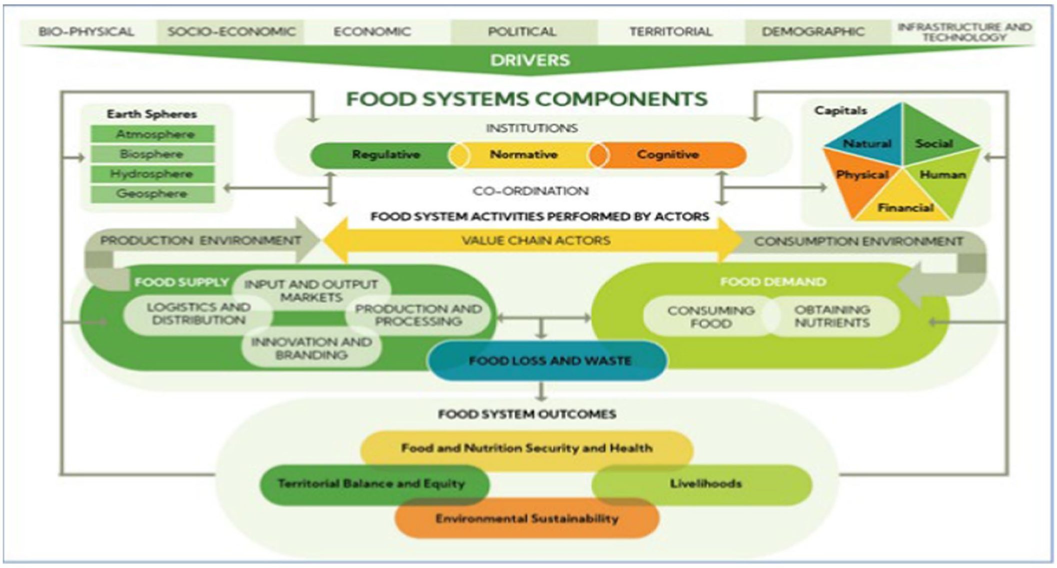

FIGURE 2
The conceptual framework guiding formulation of research questions. Source; (FSNET, 2021).

BOX 1 Research questions guiding the study

The following research questions were used to identify departments, faculties, institutions, and actors involved in research on food systems.

- Which departments/faculties/research centers/units are driving food systems related research?
- Which departments/faculties/research centers/units are collaborating in research studies on food systems?
- Which external institutions (policy, universities, research centers) are involved in research on food systems?
- Which departments/faculties/research centers/units at UoN have the potential to drive the agenda of Sustainable food systems even though they may not have done research in that area?
- Which activities (production and processing, innovation and branding, food loss and waste, consuming foods, obtaining nutrients) are driving research on food systems?
- How is research on food systems at UoN contributing toward sustainable food systems locally, nationally, and globally?

Data analysis

The data were entered into an Excel spreadsheet, coded and exported to STATA software for analysis. Descriptive statistics were obtained to summarize the collected data. Regression models were constructed to analyze the effect of the collected variables on the contribution of research studies on food systems toward sustainable food security and nutrition. According to Ebrahim et al. (2014), the citation score is a measures of research impact. The citation scores were collected from three search engines namely, Google Scholar, ResearchGate, and Plum Analytics. In this study, citation score was used as the dependent variable regressed against multiple explanatory variables which included; faculty, food systems activities, crops, and collaborations. The regression models were implemented using the generalized linear model (Muller, 2012).

Results

Descriptive statistics

A total of 666 articles from the UoN were systematically reviewed. Journal and thesis articles comprised 51% (336) and 49% (330) of the total articles, respectively. The faculties of agriculture, science and technology, and health had the highest percentage of journal and thesis articles ($p < 0.001$) on crops (Table 2). The business, veterinary and education faculties had the least percentage of articles with research on crops (Table 2). A higher percentage of journal articles appeared under the faculties of science and technology, health, and engineering compared to thesis articles. In contrast, a higher percentage of thesis articles appeared under the agriculture, social and education faculties compared to journal articles.

A higher percentage of male researchers were involved in research for both the journal and thesis articles. This can be attributed to a higher number of male researchers compared to female within the university.

A chi-square test showed a highly significant correlation ($p < 0.001$) between the activities driving research on crops and article type (journal and thesis). Most of the journal articles had research outputs on production, obtaining nutrients, harvesting, processing, and preservation activities along the food systems value chain (Table 2). The thesis articles focused on value addition and branding. The least researched activities were input and output markets as well as logistics and distribution (Table 2).

A higher percentage of articles had collaborated with outside institutions on researched focused on crops. The chi-square test showed

TABLE 1 Nature and type of information extracted from the articles.

Information	Nature of information extracted
Internal institutions within the university	Faculties and department at the university as shown in Appendix Figure 1
Collaborating institutions	Local and international universities, research centers, policy and development institutions
Article type	Journal article or thesis
Thesis type	Bachelor's, Master's, Doctoral
Geographic coverage	Region and country of study
Year of article publication	Collected between 2010 and 2021
Article authors	First author, second author and other authors
Gender of authors	Gender of all authors that were involved in research first author, second, third, fourth and other authors
Title of article	Title of article containing the term food system or food security and nutrition or name of any cereal, root and tuber, vegetables, pulses, fruits and nuts under study.
Type of crops	Cereals (maize, sorghum, millet, rice, wheat, etc.); Legumes (beans, cow pea, soya beans, etc.); Root and tuber (sweet potatoes, cassava, yams, arrow roots, and irish potatoes); Vegetables (African traditional vegetables, and exotic vegetables); Cash crops (tea, coffee, and pyrethrum); Fruits (mango, avocado, paw paw, and oranges); Medicinal plants, Herbs and oil crops such as flax seed and sesame.
Types of traditional crops	Cereals (sorghum, millet etc.); Legumes (cow pea, soya beans, etc.); Root and tuber (sweet potatoes, cassava, yams, arrow roots); Vegetables (African traditional vegetables); Fruits (Baobab, Marula, kei-apple, monkey orange, mabola-plums, wild loquat, wild medlibar); Medicinal plants, Herbs, oil crops such as flax seed and sesame.
Activities driving research	Activities along the food systems value chain (production, harvesting and processing, input and output markets, logistics and distribution, obtaining nutrients, and consuming foods)
Product development	A new product developed from the study (mathematical model, formula, methodology, new concept, and food product)
Impact of article (article metrics)	Citation index, captures/readers, social media, policy citation

a high significance ($p < 0.001$) between outside collaborations and article type and a low significance ($p = 015$) across faculty and article type. There was no significant difference ($p = 127$) between faculty collaboration and article type. Within and across faculties, collaborations were few for both journal and thesis articles. Compared to journal articles, thesis articles had the least percentage of articles that had carried out collaborative research both outside and within faculty institutions. Very few articles had carried out studies with policy institutions (Table 2). Most articles were highly visible on Google Scholar followed by ResearchGate (Table 2). Few articles, especially theses, were visible on Plum Analytics.

Visibility of the journal articles at the faculty and department level

As shown in Table 3, journal articles under the faculties of agriculture, health, science and technology, and social sciences were highly visible in ResearchGate. However, the visibility of these articles was reduced in Plum Analytics.

The visibility of journal articles that were found under extra-mural, food science, land resources, chemistry, bioinformatics, and environmental and biosystems sciences was high in ResearchGate (Table 4). This visibility was reduced in Plum Analytics except for the extra-mural departments.

Crops driving research at the University of Nairobi

The most researched crop was maize (*Zea mays* L.) followed by medicinal plants, African leafy vegetables, beans (*Phaseolus vulgaris* L.), cassava (*Manihot esculenta*), and sorghum (*Sorghum bicolor*) as shown in Figure 3. On the other hand, guava (*Psidium guajava* L.), passion fruit (*Passiflora edulis*), peanut (*Arachis hypogaea*), finger millet (*Eleusine coracana* L.), apple (*Malus domestica*), capsicum (*Capsicum annuum*), chickpea (*Cicer arietinum*), cotton (*Gossypium herbaceum*), green gram (*Vigna radiata*), lablab (*Lablab purpureus*), paw paw (*Asimina triloba*), and tobacco (*Nicotiana tabacum*) were the least researched crops.

Most crops had been researched under the faculty of Agriculture except medicinal plants (Figure 4). A high percentage of articles on medicinal plants were found under the faculty of Health. Sugarcane was also highly researched at the faculty of Business.

Figure 5 shows research on crops along the food systems value chain activities. Maize was the only crop that was researched along all seven food systems activities. African leafy vegetables and other vegetables (kales, tomatoes, cabbage, and lettuce) were researched on six of the seven food systems activities. Guava, pearl millet, apple, capsicum, chickpea, cotton, green grams, lablab, paw paw and tobacco were researched on one activity.

Involvement of policy institution on researched crops at the University of Nairobi

Only 9% (59 of 666) of the articles collaborated with policy institutions. There was no statistically significance difference between faculty and policy institutions, activity and policy institutions as well as food system versus policy institution. The faculty of agriculture had the highest percentage of research articles that had collaborated with policy institutions, followed by the faculties of science and technology,

TABLE 2 The percentage and number of faculty, researchers by gender, food system activities, collaborations and visibility of research articles on food systems at the University of Nairobi.

		Overall		Journal article		Thesis article	
		%	*N*	%	*N*	%	*N*
Faculty	Agriculture	58	390	56	190	61**	200
	Science and technology	15	98	16**	52	14	46
	Health	10	65	15**	49	5	16
	Social	6	37	5	17	6	20
	Engineering	5	36	6**	20	5	16
	Education	4	29	2	5	7**	24
	Veterinary	1	8	1	3	2	5
	Business	1	3	0	0	1	3
Gender of researchers	Male	60	642	59	324	61	316
	Female	40	430	41	226	39	202
Activities driving research	Production	58	391	57	191	61**	200
	Obtaining nutrients	14	91	20**	68	7	23
	Harvesting, processing, preservation	12	81	10	35	14**	46
	Consuming food	6	37	10**	33	1	4
	Value addition and branding	5	32	0	0	10**	32
	Input and output markets	5	30	2	8	7**	22
	Logistics and distribution	1	2	0.3	1	0.3	1
Outside collaboration	Yes	52	345	76**	256	27	89
	No	48	320	24	80	73	240
Within faculty collaboration	Yes	9	57	10	32	8	25
	No	91	609	90	304	92	305
Across faculty collaboration	Yes	9	57	14	47	3	10
	No	91	609	86	289	97	320
Collaboration (Policy)	Yes	9	59	17	58	1	1
	No	91	607	83	278	99	329
Google visibility	Visible	99	661	98	331	100	330
	Not Visible	1	5	2	5	0	0
ResearchGate visibility	Visible	44	292	86**	286	2	6
	Not Visible	56	372	14	46	98	324
Plum Analytics visibility	Visible	36	241	72**	94	1	1
	Not Visible	64	N	28	240	99	329

The chi-square test show ** significant results. The comparison was column-wise (journal and thesis articles).

TABLE 3 Visibility in ResearchGate and Plum Analytics search engines for journal articles from different faculties at the University of Nairobi.

	ResearchGate		Plum Analytics	
Faculty	Visible	Not visible	Visible	Not visible
Agriculture	92*	8	79*	21
Engineering	70*	30	55*	45
Education	20	80	20	80
Health	81*	19	67*	33
Science and Technology	87*	13	69*	31
Social Sciences	71*	29	53*	47

The * represent articles that were highly visible (above 50%) in ResearchGate and Plum Analytics. Comparison was within the subject (visible and not visible) for ResearchGate and Plum Analytics.

TABLE 4 Visibility in ResearchGate and Plum Analytics search engines for journal articles from different departments at the University of Nairobi.

	ResearchGate		Plum Analytics	
	Visible	Not visible	Visible	Not visible
Plant science	45	55	38	62
Food science	62*	38	56*	44
Land resource	61*	39	55*	45
Agricultural economics	32	68	23	77
Chemistry	59*	41	55*	44
Bioinformatics	50*	50	42	48
Environment and biosystems	50*	50	33	67
Extra-mural	100*	0	100*	0
Economics	29	71	18	82
Pharmacology and pharmacosis	32	68	24	76

The * represent articles that were highly visible (above 50%) in ResearchGate and Plum Analytics. Comparison was within the subject (visible and not visible) for ResearchGate and Plum Analytics.

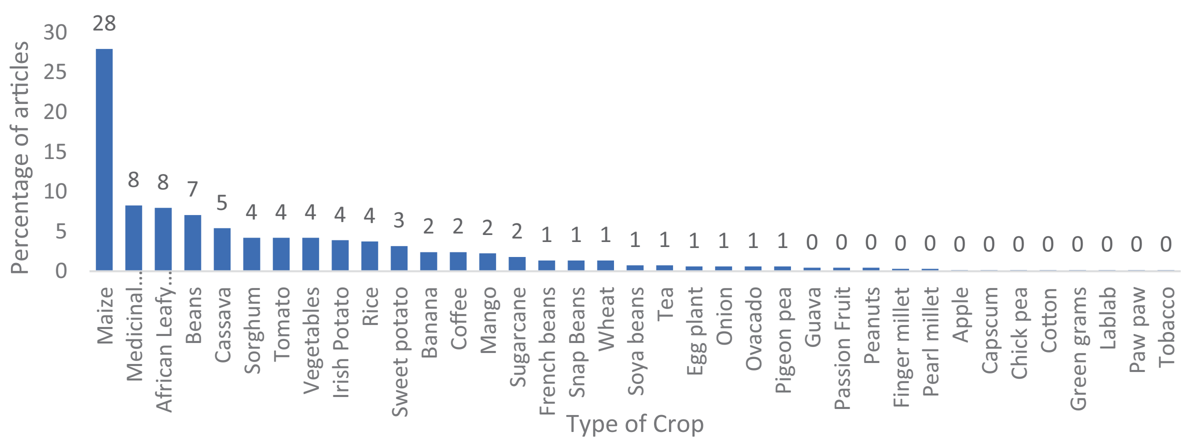

FIGURE 3
The percentage of researched and under-research crops at the University of Nairobi.

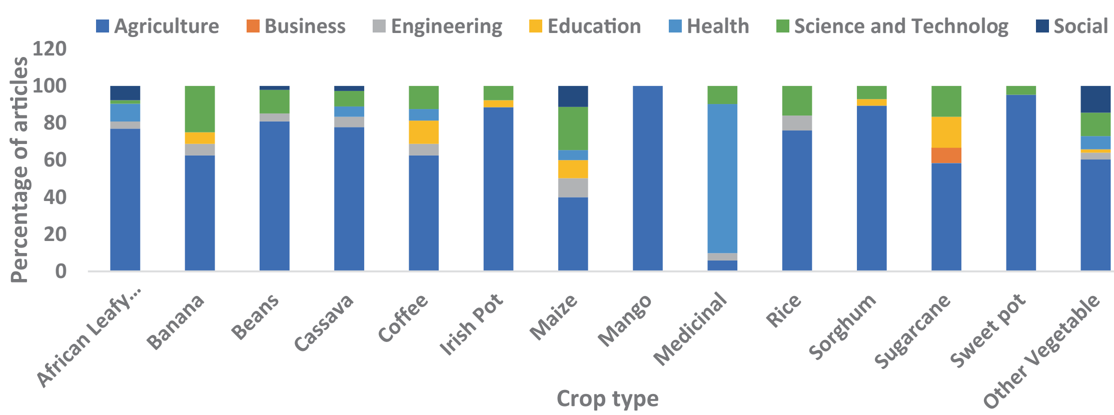

FIGURE 4
The percentage of commonly researched crops under different faculties at the University of Nairobi.

health and engineering (Figure 6). The faculties of business, education, and social science did not have any research articles where policy institutions were involved.

The production activity which entailed field management practices such as land preparation, planting, fertilizer application, weeding, pest and disease management, irrigation among others had

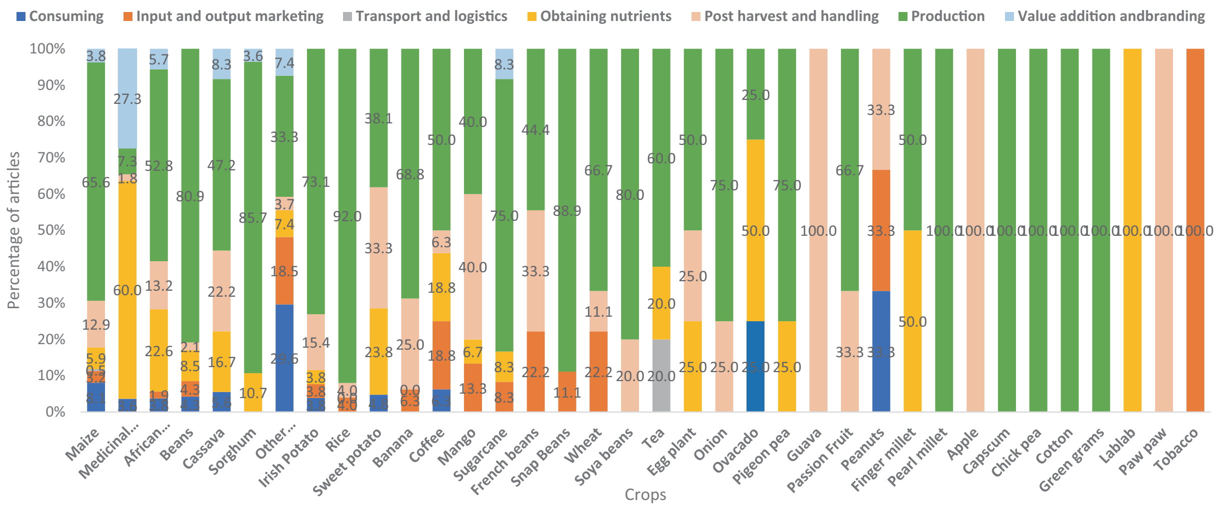

FIGURE 5
Percentage of articles with research on crops along the food systems value chain activities at the University of Nairobi.

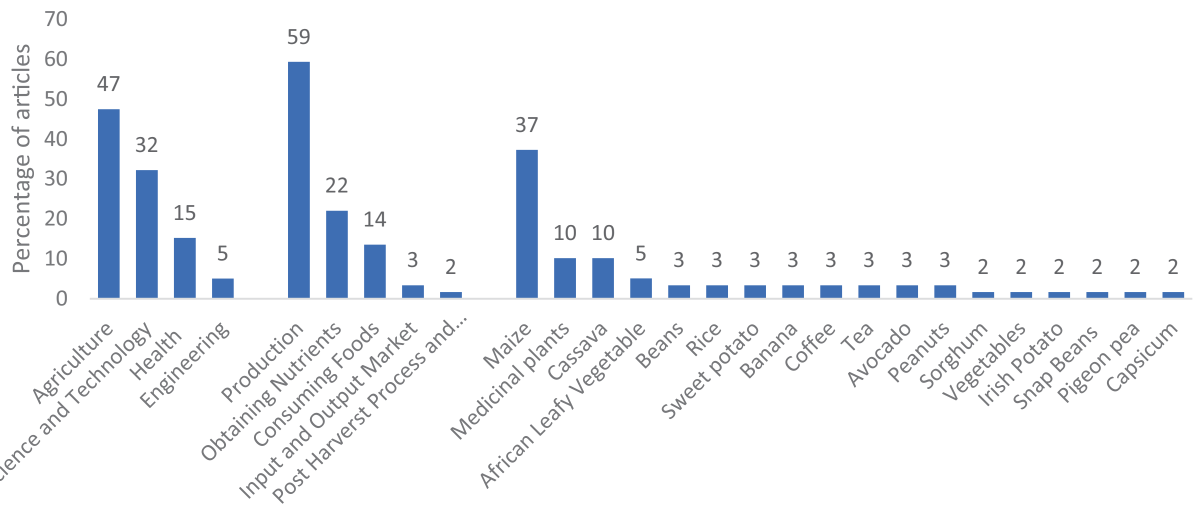

FIGURE 6
Percentage of articles which collaborated with policy institutions by faculty, food systems activity, and crop type at the University of Nairobi. Chi-square test between faculty, food system activity and food system each versus policy institution showed p values of 0.409, 0.696 and 0.613, respectively.

the highest percentage of research articles involving policy institutions. The post-harvest activity had the least percentage of articles while the logistics and distribution as well as value addition and branding did not have any studies where policy institutions were involved.

A higher percentage of articles on maize had collaborated with policy institutions. Crops such as African Leafy Vegetables, bananas, beans, coffee, rice, sweet potato, Irish potato, sorghum, and other vegetables had few articles that had collaborated with policy institutions (Figure 6). Descriptive statistics is shown in Appendix Table 1.

Impact of research on food systems

The mean, minimum and maximum values for Google Scholar, ResearchGate, and Plum Analytics are shown in Table 5. There was a significant difference ($p < 0.0001$) in google citations between journal and thesis articles. The mean citation under Google Scholar was higher for journal articles compared to ResearchGate and Plum Analytics. The mean citation for thesis articles was lower compared to journal articles. The few thesis articles that were identified under ResearchGate had a high mean citation compared to journal articles. The mean and maximum value for article readership under ResearchGate was higher compared to Plum Analytics ($p < 0.0001$; Table 5).

Table 6 shows the influence of different faculty on Google Scholar citation scores for journal and thesis articles. Journal articles under the faculties of health, agriculture, science and technology, education, and social science highly influenced Google Scholar citation scores as shown by the significant p values and the positive coefficient values. Thesis articles under the faculty of education had a strong

TABLE 5 Minimum, maximum, and mean value of citation scores, reads, social media scores and policy use from Google Scholar, ResearchGate and Plum Analytics for journal articles and theses published by the University of Nairobi.

	Journal article				Theses			
	Mean	Min	Max	N	Mean	Min	Max	N
Google Scholar citation	14*	0	438	331	2	0	77	329
ResearchGate citation	12	0	386	289	18	0	75	6
Plum Analytics citation	12	0	762	233	0	0	0	1
ResearchGate reads	490*	0	12,686	289	1,134	18	2,438	6
Plum Analytics reads	47*	0	1,358	233	0	0	0	1
Plum Analytics social media	24	0	416	72	.	.	.	0
Policy use	2	1	5	22	.	.	.	0

The "..." indicate no computation because the articles were not visible, * show significance difference between journal and thesis articles (column-wise comparison).

TABLE 6 Effect of faculty on google citation scores for journal and thesis articles at the University of Nairobi.

	Journal article						Thesis					
Faculty	Coef.	Std. Err.	z	P > z	95% Conf. Int		Coef.	Std. Err.	z	P > z	95% Conf. Int	
Agriculture	2.42*	0.02	111.6	0.000	2.38	2.46	0.56*	0.05	10.6	0.000	0.46	0.67
Engineering	2.67*	0.06	44.5	0.000	2.55	2.79	0.28	0.50	0.6	0.565	−0.69	1.26
Education	1.52*	0.20	7.3	0.000	1.11	1.93	2.07*	0.08	23.4	0.000	1.89	2.24
Health	3.10*	0.03	101.3	0.000	3.04	3.16	−0.28	0.23	−1.2	0.222	−0.75	0.17
Science and Technology	2.95*	0.03	92.5	0.000	2.89	3.01	0.00	0.25	0.0	1.000	−0.49	0.49
Social science	2.57*	0.06	38.6	0.000	2.44	2.70	0.26*	0.12	2.1	0.040	0.01	0.51

Coef. stands for coefficient, conf. Int is confidence interval. The contribution of faculty was measured as citation scores under Google Scholar. The coefficient values show the magnitude of contribution if for example 1 unit of research is added by faculty. *Depicts significant results. The comparison was along rows (between faculty) for journal and thesis articles at 95% statistical test.

effect on google citation scores as shown by the highly significant value of p and high positive coefficient. Thesis articles under the faculties of agriculture and social science had a low influence on Google Scholar citations. Generally, the influence of different faculties on Google Scholar for journal articles was higher compared to thesis articles as shown by the high p and positive coefficient values.

Table 7 shows the effect of the different departments on google citations for journal and thesis articles. Journal articles under the departments of environment and biosystems, food science, pharmacology and pharmacosis, economics, land resource, chemistry, bioinformatics, plant science, and agricultural economics significantly affected Google Scholar citations ($p = 0.0001$) in the listed order. While the order of influence on Google Scholar for thesis articles was as follows; environment and biosystems, agricultural economics, economics, land resource, and plant science influenced Google Scholar citations. Both journal and thesis articles under the department of environment and biosystems engineering had a high influence on Google Scholar citations as shown by the significant *p* values and high coefficient value in Table 7. Fewer departments for thesis articles influenced Google citations compared to journal articles as shown by significant p values.

Table 8 shows the effect of food systems activities on Google Scholar citations for journal and thesis articles. The contribution of food systems activities on Google Scholar citation for journal articles was high compared to thesis articles as shown by the significant *p* values and coefficients. Consuming foods and input and output activities under journal and thesis articles had a high influence on citation scores as shown by the significant *p* values and positive high coefficient values. Other activities that showed an influence on citation scores for journal articles included; obtaining nutrients, production, input and output markets, and post-harvest, processing and preservation. For thesis articles, production activity also influenced Google Scholar citations.

Table 9 shows the effect of crops on Google Scholar citation scores. Journal articles with medicinal plants, maize, Irish potatoes, vegetables, sugarcane, sweet potato, cassava, and African Leafy Vegetables were highly cited under Google Scholar as shown by significant *p*-values and high coefficients (Table 9). While thesis articles that had mango, maize, and banana as the study crop were more cited under Google Scholar. There was a high citation for crops under journal articles as shown by the high coefficient values than thesis articles.

The effect of collaborations with outside institutions on citations scores for journal articles was higher compared to thesis articles as shown by the high coefficient values and significant results ($p = 0.0001$) as shown in Table 10. Within faculty and across faculty

TABLE 7 Effect of department on citation scores from Google Scholar for journal and thesis articles at the University of Nairobi.

	Journal article						Thesis					
Department	Coef.	Std. error	z	P > |z|	[95% Conf. Interval]		Coef.	Std. Error	z	P > z	[95% Conf. Interval]	
Plant science	1.39*	0.04	34.9	0.000	1.31	1.47	0.15*	0.08	1.9	0.057	0.00	0.29
Food science	2.93*	0.03	102.2	0.000	2.88	2.99	−0.26	0.20	−1.25	0.21	−0.66	0.14
Land resource	1.90*	0.05	39.2	0.000	1.80	1.99	0.38*	0.16	2.3	0.021	0.06	0.70
Agricultural economics	0.75*	0.11	7.13	0.000	0.54	0.96	1.09*	0.09	11.6	0.000	0.90	1.27
Chemistry	1.77*	0.07	27.1	0.000	1.64	1.89	0.26	0.30	0.9	0.386	−0.33	0.86
Bioinformatics	1.56*	0.11	14.0	0.000	1.34	1.77	−0.22	0.50	−0.5	0.655	−1.20	0.76
Environment and biosystems	3.05*	0.06	48.4	0.000	2.93	3.17	3.19*	0.09	35.0	0.000	3.01	3.37
Extra-mural							0.00	0.20	0.0	1.000	−0.38	0.38
Economics	2.22*	0.15	15.0	0.000	1.93	2.51	0.51*	0.22	2.3	0.022	0.07	0.95
Pharmacology and pharmacosis	2.54*	0.07	36.4	0.000	2.41	2.68	0.08	0.28	0.3	0.773	−0.46	0.62

The contribution was measured as citation scores under Google Scholar. The coefficient values show the magnitude of contribution if for example 1 unit of research was added by department. *Depicts significant results between department (Row-wise comparison) for journal articles, similarly for thesis articles. The comparison was along rows (between department) for journal and thesis articles at 95% statistical test.

TABLE 8 The effect of food systems activities on Google Scholar citations for journal and thesis articles at the University of Nairobi.

	Journal article						Thesis					
Activity	Coef.	Std. Err.	z	P > z	95% Conf. Int		Coef.	Std. Err.	z	P > z	95% Conf. Int	
Consuming food	3.43*	0.03	110.2	0.000	3.37	3.49	-	-	-	-	-	-
Input and output markets	2.19*	0.11	18.6	0.000	1.96	2.42	1.28*	0.11	11.4	0.000	1.06	1.50
Logistics and distribution	0.69	0.70	1.0	0.327	−0.69	2.07	-	-	-	-	-	-
Obtaining nutrients	3.06*	0.02	115.4	0.000	3.01	3.11	0.27	0.18	1.5	0.146	−0.09	0.62
Postharvest, process preservation	2.18*	0.05	38.5	0.000	2.07	2.29	0.04	0.15	0.3	0.768	0.34	0.25
Production	2.30*	0.02	100.0	0.000	2.25	2.34	0.56	0.05	10.5	0.000	0.46	0.67
Value addition and branding	-	-	-	-	-	-	1.06*	0.10	10.1	0.000	0.85	1.26

The contribution was measured as citation scores under Google Scholar. The coefficient values show the magnitude of contribution if for example 1 unit of research added by an activity. *Depicts significant results between activities (Row-wise comparison) for journal articles similarly for thesis articles. The comparison was along rows (between activity) for journal and thesis articles at 95% statistical test.

collaborations for thesis articles had a higher influence on Google Scholar citation scores compared to journal articles as shown by the coefficient values.

Most articles with collaboration were found within the East Africa as shown in Figure 7. There was also more collaboration in Europe and North America compared to other geographic regions within Africa.

The collaborations led to wider coverage of topics of interest as shown in Figure 8. There was more focus on topics such as Nanotechnology, Food loss and food waste, Value chain analysis, Agro-ecological zoning and adoption when collaborations were within Africa. With collaborations outside Africa, the topics of focus included; Dietary related diseases, Nutrient uptake, Food biofortification, Food safety, Soil health, Herbal medicine, Crop modeling and Peri-urban and urban food systems.

Discussion

Institutions driving research in food systems

Mapping studies across the globe have shown the application of research on food systems from higher institutions to achieving national objectives and the United Nation Sustainable Development Goals (SDGs). Cleveland and Jay (2020) demonstrated the importance of integrating climate and food policies at University of California-United States. Migliorini et al. (2020) showed the significance of student's knowledge on food systems in influencing consumption patterns across higher education institutions in Europe. Nelles et al. (2022) discussed the contribution of higher education and agri-food systems to the SDGs from Chulalongkorn

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TABLE 9 The effect of different crops on Google Scholar citation scores for journal and thesis articles at the University of Nairobi.

	Journal article						Thesis article					
Crop	Coef.	Std. Err.	z	P > z	95% Conf. Int		Coef.	Std. Err.	z	P > z	95% Conf. Int	
African leafy vegetables	2.26*	0.59	3.9	0.000	1.11	3.41	0.55	0.8	0.73	0.464	−0.93	2.03
Banana	2.02	1.36	1.5	0.137	−0.65	4.69	−1.95	16.7	−0.12	0.907	−34.62	30.73
Bean	1.70	1.37	1.2	0.214	−0.98	4.38	1.06*	0.4	2.58	0.010	0.26	1.87
Cassava	2.32*	0.62	3.8	0.000	1.11	3.53	−0.69	3.6	−0.19	0.849	−7.82	6.44
Coffee	2.08	1.46	1.4	0.154	−0.78	4.94	0.80	0.9	0.84	0.398	−1.05	2.65
Irish potato	2.98*	0.42	7.1	0.000	2.15	3.80	0.51	1.1	0.47	0.640	−1.63	2.65
Maize	2.99*	0.18	16.5	0.000	2.64	3.35	0.79*	0.3	2.9	0.004	0.26	1.32
Mango	2.26	1.22	1.9	0.064	−0.13	4.65	1.61*	0.4	3.61	0.000	0.74	2.48
Medicinal plants	3.23*	0.20	16.2	0.000	2.84	3.63	0.60	0.8	0.72	0.473	−1.04	2.24
Rice	1.64	1.66	1.0	0.323	−1.62	4.89	−0.69	3.6	−0.19	0.849	−7.82	6.44
Sorghum	1.36	2.50	0.5	0.587	−3.54	6.27	−0.13	1.7	−0.07	0.942	−3.52	3.27
Sugarcane	2.50*	1.13	2.2	0.027	0.28	4.72	0.00	2.4	0	1.000	−4.67	4.67
Sweet potato	2.38*	0.82	2.9	0.004	0.77	3.99	−0.41	3.2	−0.13	0.898	−6.58	5.77
Other vegetables	2.60*	0.51	5.0	0.000	1.59	3.60	0.69	1.1	0.62	0.534	−1.49	2.88

The contribution was measured as citation scores under Google Scholar. The coefficient values show the magnitude of contribution if for example 1 unit of research added by crop *Show significant results between crops (row-wise comparison) for journal articles similarly for thesis articles. The comparison was along rows (between crops) for journal and thesis articles at 95% statistical test.

TABLE 10 The influence of collaboration on Google citations for journal articles and theses at the University of Nairobi.

	Journal article						Thesis					
Collaborations	Coef.	Std. Err.	z	P > z	95% Conf. Int.		Coef.	Std. Err.	z	P > z	95% Conf. Int.	
Outside collaborations	2.82*	0.01	162.8	0.000	2.78	2.85	0.81*	0.07	11.0	0.000	0.67	0.96
Faculty collaborations	0.10	0.06	1.7	0.08	0.23	0.01	0.68*	0.23	2.9	0.003	1.14	0.22
Across-faculty collaborations	0.33*	0.04	7.1	0.000	0.43	0.24	0.62*	0.21	2.8	0.004	0.19	1.05

The contribution was measured as citation scores under Google Scholar. The coefficient values show the magnitude of contribution if for example 1 unit of research added by collaborations. *Show significant results for collaborations (Row-wise comparison) for journal articles similarly for thesis articles. The comparison was along rows (collaboration) for journal and thesis articles at 95% statistical test.

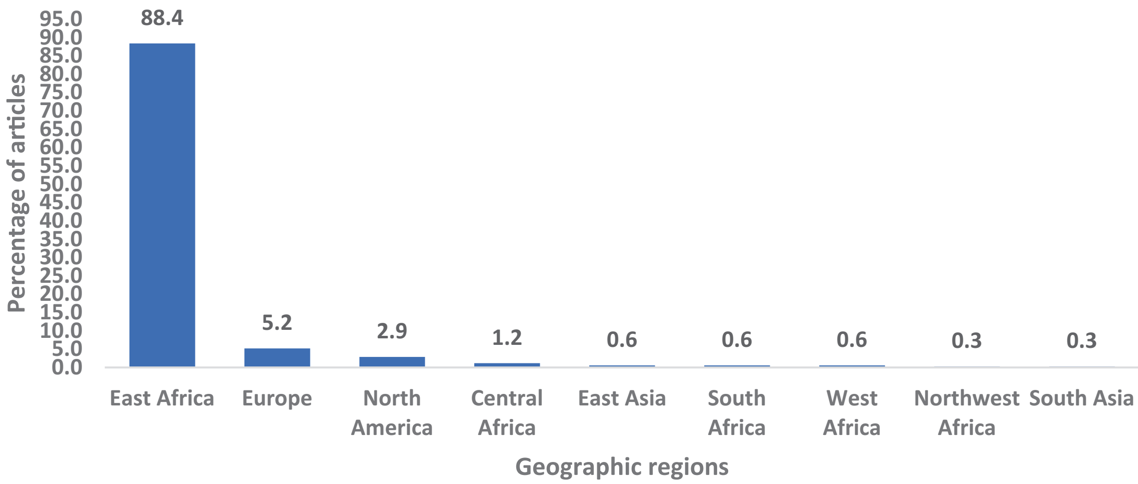

FIGURE 7
Percentage of articles with collaborations within and outside Africa at the University of Nairobi.

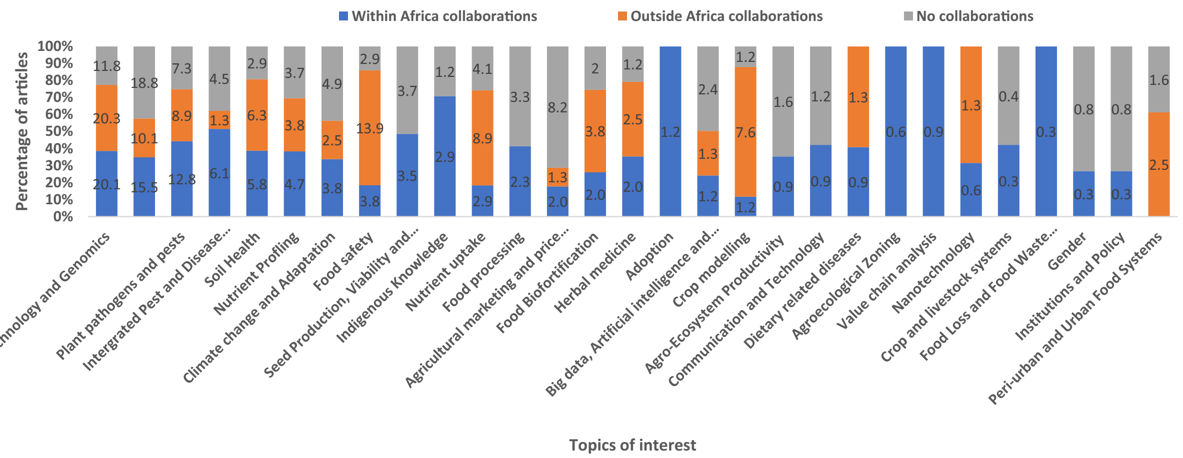

FIGURE 8
Percentage of articles showing topics of interest with collaborations (within and outside Africa) and with no collaboration at the University of Nairobi.

University, Thailand. Fox (2017) explored linkages in research and innovation, teaching and learning, outreach and engagement as well as resource stewardship to enhance food systems contribution in Ohio University-USA. A food systems dialogs by vice chancellors of higher education institutions across four geographic regions in Africa (southern, northern, eastern and western) identified information and technology, big data, policy, and practice as enablers of food systems transformation (Pretorius and Schönfeldt, 2023). The present investigation conducted a micro-institutional study (faculties and departments at the UoN) to understand the status of research studies and contribution to food systems. The study contributes to the current research discourse by identifying gaps and opportunities on research in food systems conducted by the university. The findings can help institutions of higher learning to improve food systems research and contribution to national development and the SDGs.

The current study showed low research outputs in food systems generated by the UoN compared to selected universities within Africa; Cape Town, Bostwana, Edward Mondlane, Mauritius, Ghana and Makerere (Cloete et al., 2018) and around the globe; Michigan, Cornell, Jiangsu, Oxford, Washington (Hongbo et al., 2021). This can be attributed to financial, infrastructural and human resource challenges which disincentivize researchers from conducting research (Cloete et al., 2018). The low research outputs have implications on the contribution of the institution to sustainable food security and development at the national and continental level. Sebola (2023) has also shown low research outputs and low contribution of research from universities to the South African national development goals from different disciplines such as economic management and sciences, life sciences, physical sciences, engineering and built environment, agriculture, mathematics and ICT, and military sciences.

There was low intra-institution collaboration within the UoN which can be attributed to reduced research funding (Tables 2, 10). Pouris and Ho (2014) also found low collaborative research within institutions attributed to low funding. Collaborations between local institutions has been shown to positively contribute to learning, thus contributing solutions to local problems (Van der Wouden and Youn, 2023). Low collaborations within the same institution (within and across faculty collaborations) was an indication of the low contribution of research on food systems to sustainable food security and nutrition locally. Challenges facing food systems are complex and require multifaceted solutions that are reflective of viewpoints from different disciplines. The low collaboration within the same faculty showed that research on food systems was conducted homogenously that is by single discipline. This implies that studies are focused on addressing a single problem and recommendations provided toward solving challenges of food systems are one dimensional. The contribution of research on food systems under the faculties of science and technology, health, social science and engineering, which was equal to the faculty of agriculture (Table 6), is an indication of the multiplier effect institutions can have on food systems if intra-institutional collaboration in research is enhanced. Therefore, fast tracking toward transdisciplinary research within local institutions is crucial for enhancing solutions to the challenges of food security and nutrition.

There was wider coverage on topics of interest with collaborations within and outside Africa (Figure 8). There was increased focus on topics such as Nanotechnology, Food loss and food waste, Value chain analysis, Agro-ecology zoning, Dietary related diseases, Nutrient uptake, Food biofortification, Food safety, Soil health, Herbal medicine, Crop modeling and Peri-urban and urban food systems. Haysom et al. (2019) has shown the benefits of collaboration between Europe and African institution in peri-urban and urban food systems in solving wicked problems. Food safety on increased uptake of dietary acrylamide among potato consumers has been investigated between African and European institutions (Abong et al., 2020). Dietary related diseases were also investigated in a collaborative study between American and African institutions (Neumann et al., 2013). Collaborations in research on food systems within and beyond Africa demonstrated a wider scope in research topics to solve challenges at the regional, continental and global level. The high collaborations between local and international institutions can be attributed to funding opportunities from international donors (Cloete et al., 2018). The limited funds within local universities has resulted in researchers relying on donor funding. As shown from the current study, there was a wider scope of focus on topical issues. However, donor dependent funding might have implications on the research focus as there is a tendency for studies to focus more on objectives that are inclined toward donor funding or collaborating institution purposes. The researchers may have limited control over the priority areas and often lack agency to introduce areas of focus that are reflective of local needs. Hence, there should be due consideration to include the local institutions objectives.

The contribution of research on food systems on policy formulation and implementation was low (Table 5). This could be attributed to low collaboration in research on food systems with policy institutions. Kushitor et al. (2022) has also shown a disjoint in the contribution of research and policy on food systems. The findings also show that a few disciplines; agriculture, science and technology, and health engaged in research studies with policy institutions. This has implications for policy formulation which is likely to be inclined toward the core areas of research along these disciplines which include production and health (Lind and Reeves, 2021). The low involvement of policy institutions in research studies conducted by the faculties of engineering, business, education and social sciences demonstrated low policy formulations that would improve research along core areas under these disciplines. These areas include; innovations, marketing, social and behavioral aspects. The involvement of policy institutions in research along the production, obtaining nutrients and consuming foods activities implied that policy formulation was likely to be done along these activities. Activities such as harvesting, processing and preservation, input and output markets, value addition and branding, logistics, and distribution lagged behind in policy formulation. Additionally, the involvement of policy institutions in research studies focused on maize indicated that policies to improve the production of maize were likely to be formulated (Grote et al., 2021). Other crops, such as beans, rice, sweet potatoes, and sorghum would likely receive less policy attention.

Food systems activities driving research on crops

Food systems where there is efficiency and coordination along the value chain activities from production to consumption has been deemed as one way of achieving sustainable food and nutrition security (Alexander et al., 2017). The findings of this study indicate gaps along the food systems value chain activities as most research studies were focused on production activity. Few articles focused on obtaining nutrients, post-harvest and processing, despite the high contribution of these activities as shown in Table 8. Little attention was focused on logistics and distribution, value addition and branding activities which reduced the impact of research on these activities (Table 8). The findings of the study also show integrated research on maize focusing on all the food systems activities (Figure 6), while crops such as guava, pearl millet, apple, capsicum, chickpea, cotton, green grams, lablab, paw paw, and tobacco received less attention along the food systems activities. The findings therefore demonstrated an imbalance along the food systems value chain for crops. This has reduced the contribution of these crops to sustainable food security. Ng'endo and Connor (2022) has also shown imbalances in food systems due to policies, food waste, food injustice, and undernutrition and recommended geographic specific strategies to achieve sustainable food systems. All food systems activities are important and ensure there is efficiency and coordination along the chain to connect production and consumption. The logistics and distribution activity enables connectivity with different territories and geographic regions creating a balance in the production and delivery of food products. Inefficiency along the logistics and distribution activity has been shown to increase food loss and create food insecurity (Horton et al., 2019). Additionally, increased production without proper post-harvest handling and value addition as well as branding results in reduced returns and income levels among producers (Docherty, 2012). Inclusively studying the food systems activities is therefore needed to enhance the benefits of crops grown in Africa namely; nutrient provision, income generation, industrial use, therapeutics, food loss and waste, among others (Horton et al., 2019).

Crops driving research

Crop diversity has been associated with dietary quality and quantity (Nicholson et al., 2021). The high frequency of research outputs on carbohydrate foods (maize, sorghum, cassava, Irish potato, sweet potato, and rice) than vitamin (vegetables and mango) and protein (beans) foods (Figure 3) demonstrate low crop diversity. This is contributing to low dietary quality and quantity; a situation that is increasing the food insecurity challenge. Manners and Van Etten (2018) also found high investment in high carbohydrate output foods compared to traditional crops like sweet potato. The high focus on maize and less attention paid to other crops indicates a rise in excessive intensification (monoculture) farming systems and erosion of biodiversity (Munialo et al., 2019; Bokelmann et al., 2022). Studies have pointed to the need to shift diets from animal to plant protein diets (beans) in order to reduce Greenhouse Gas emissions resulting from livestock as a mitigation toward climate change effects (Tilman et al., 2011; Benton and Thompson, 2016). Less research studies on leguminous crops as found in the present study shows the low contribution of research to reducing the impacts of climate change besides soil and water conservation measures. The high coefficient values (Table 9) for articles on medicinal plants, maize, Irish potato, vegetables, sugarcane, sweet potato, and sugarcane showed the high contribution of these crops to food security.

The role of traditional crops is multifaceted and include; dietary diversity, income generation, soil and water conservation, building resilience to climate change, among other uses (Sousa and Raizada, 2020). African Leafy Vegetables such as cowpea (*Vigna unguiculata*), amaranth (*Amaranthus* spp.), black nightshade (*Solanum* spp.), and spider plant (*Cleome gynandra*) among others, contain macro- and micronutrients that may not be available in other foods crops such as maize (Munialo et al., 2015; Owade et al., 2019; Sousa and Raizada, 2020). These nutrients are important for maintaining human health and building resistance against diseases. African Leafy Vegetables have also been shown to generate income on many smallholder farms (Pichop et al., 2016; Francesco and Knaepen, 2019). Apart from the dietary diversity and income generation, sorghum, cassava, ALVs, finger millet, and chickpea have been shown to have high capacity for climate change adaptability (Kinama and Ndiema, 2019; Beinah and Kunyanga, 2020). Despite the fact that Africa is home to approximately 400 traditional crops, as shown from the current study only a few crops are being studied at the UoN (Figures 3, 4). Focusing research on only a few crops implies that traditional crops are not being exploited to attain their full potential along the food systems value chain.

Opportunities for future research

The findings of these studies have identified gaps in research on food systems conducted at the UoN. Gaps exist within the institution, along the food systems activities and specific crops. These findings are important to guide research direction within institutions of higher learning and other research institutions. Opportunities exist in collaborative and transdisciplinary research, increasing visibility of research conducted, targeting specific under-utilized crop and food systems activities that have lagged behind.

Collaborative and transdisciplinary research

Traditionally, studies on food systems have predominantly involved institutions from the natural sciences. The findings of this study indicate that other disciplines such as health, engineering, and humanities are slowly being involved in research on food systems, a potential indication of transdisciplinary research. Building sustainable food systems requires a multidimensional approach that visualizes a food system as whole rather than separate entities (Bortoletti and Lomax, 2019). The involvement of many actors, across disciplines and industries is crucial. Leveraging on areas that have worked with collaborative research between local and global institutions could make a significant advancement in enhancing local collaborations. Priority areas that will advance transdisciplinary and collaborative research will include; building a database of researchers from different disciplines with interest in studying food systems. This will facilitate the connection of researchers across disciplines, institutions, countries and regions to conduct cutting edge research on food systems. Transdisciplinary research should also be supported by the development of frameworks that take into account the roles, trust, power relations, agency, communication, diversity in language, and working styles among the different actors. Michel (2019), has shown the success in implementation of collaborative research studies among heterogenous actors using a micro-institutional framework that builds on common perspectives. Building a common ground of understanding on a shared purpose and objectives among the different actors and disciplines is needed to improve the contribution of research to sustainable food systems. Capacity enhancement to enhance novel conceptual and methodological approaches that synthesize and extend discipline-specific perspectives, theories, methods, and translational strategies to yield innovative solutions among researchers is fundamental. Competency building among researchers on transdisciplinary approaches is needed. Research institutions are constrained by funding, human resources, a lack of state-of-the-art equipment, research facilities and pilot plants. The involvement of governments and funding institutions in supporting funding is also critical in advancing transdisciplinary research. The development of indices to measure transdisciplinary research outputs and its impact of food systems is also needed.

Increasing visibility of research articles

Increasing visibility and perceptibility is important to enhancing the impact of research articles (Ebrahim et al., 2014). The findings of this study have shown that the visibility of research findings in several search engines such as Google Scholar, ResearchGate and Plum Analytics contributed to increased citation. The visibility of journal articles in Google Scholar, ResearchGate and Plum Analytics was high compared to thesis articles which were mostly visible in Google Scholar. This resulted in a higher impact for journal articles compared to thesis articles. As efforts are made to improve research on food systems, consideration to increase the visibility of the findings to multiple stakeholders is important. Emphasis should be placed on increasing visibility of thesis articles that are produced by students as they contain rich information that should be exploited. Other than search engines, social media platforms such as LinkedIn, Twitter and media stations such TV and radio among others are platforms that can be used to enhance the visibility of the findings. Additionally, creating dialogs with stakeholders including scientists, policy makers, industry players, development agencies, and farmers at different levels can increase the visibility and usability of research findings. This will require that the information is synthesized to simple comprehensible messages.

Research along the food systems activities

The findings of this study show that activities such as input and output markets, logistics and distribution and value addition and branding as well as consuming foods lagged behind in research. All the food systems activities should be considered to improve efficiency. Promoting transdisciplinary research between agricultural and business/economic institutions together with industry players will help reduce inefficiencies that exist along the input and output markets activity. Collaborative research between agricultural and engineering sciences is needed to improve efficiencies along the logistics and distribution as well as the value addition and branding activities. Opportunities also exist in research studies between the agricultural and social sciences.

Traditional crops

Despite the fact that the African continent contain more than 400 traditional crop species, the findings of this study showed that very few crops (15) were commonly researched, with maize being the most intensively researched crop. The findings show that traditional crops were not adequately studied along the food systems value chain. These has resulted in traditional crops not being fully exploited to attain their full potential leading to low impact of the crops to sustainable food systems. Traditional crops have been branded super foods that can transform the continents food status and contribute to sustainable food security (Bokelmann et al., 2022). New research perspectives that bring out the value of these crops are needed. Transdisciplinary research along the traditional crops value chain activity will contribute to unleashing the potential of the crops. Collaboration among different disciplines will approach research from a multi-dimensional angle that created solutions to complex challenges. Promoting transdisciplinary research with global institutions will also help exploit traditional crops beyond local usability.

Policy formulation

Policy formulation is integral to food systems and help advance reforms that improve the impact of research findings. Due to the complexity of food systems, policy formulation along each food system activity is crucial. Formulating policies that account for systematic interactions between the different institutions, food systems activities and specific crops is important to help unleash the potential of these crops hence the need to increase the involvement of policy institutions in research.

Conclusion and recommendations

The study conducted a micro-institutional analysis review exercise on research on food systems at the University of Nairobi, Kenya. The aim was to identify institutions, activities, and crops driving research on food systems at the university. Low research outputs on food systems when compared to other similar institutions across the globe were observed. There was more collaborative research between local and global institutions than within local institutions. Disparities in research existed along the food systems value chain with more focus on production activity and little on post-harvest processing and preservation together with obtaining nutrients activities. Most activities; consuming foods, value addition and branding, input and output markets as well as logistics and distribution activities received less attention. There was high focus on carbohydrate rich foods (maize, sorghum, cassava, Irish potato, sweet potato, and rice) compared to vitamin (vegetables, and mango) and protein rich (beans) foods. The involvement of policy institutions in research studies on food systems was low and inclined to specific disciplines, value chain activities and few crops. Gaps along the mentioned components contributed to reduce the impact of research on food systems toward sustainable food security and nutrition with the input of thesis articles produced by students being less than journal articles. The findings also showed that disciplines such as health, science and technology, engineering and humanities were involved in research in addition to agricultural disciplines, a potential indication of transdisciplinary research, at the UoN. The study suggests for future research to close the gaps in research within local institutions, along food systems activities, policy, crops to increase the relevance toward sustainable food security. Increasing research funding by government is needed to foster intra-institutional collaborations, and transdisciplinary research on under-researched crops. Creation of awareness among researchers on the importance of intra-institutional research and collaboration with policy institutions and industry is also needed as well as increasing the visibility of the findings through media platforms. Further studies can focus on developing frameworks to advance transdisciplinary research.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

SM and LS idea conception. SM developed the theory and performed the computations. CO, JL, OW, JM, JN methodology verification. CO and LS supervised the findings of this work. AD and SM proof reading and editing. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1125094/full#supplementary-material

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Predictors of micronutrient deficiency among children aged 6–23 months in Ethiopia: a machine learning approach

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Introduction: Micronutrient (MN) deficiencies are a major public health problem in developing countries including Ethiopia, leading to childhood morbidity and mortality. Effective implementation of programs aimed at reducing MN deficiencies requires an understanding of the important drivers of suboptimal MN intake. Therefore, this study aimed to identify important predictors of MN deficiency among children aged 6–23 months in Ethiopia using machine learning algorithms.

Methods: This study employed data from the 2019 Ethiopia Mini Demographic and Health Survey (2019 EMDHS) and included a sample of 1,455 children aged 6–23 months for analysis. Machine Learning (ML) methods including, Support Vector Machine (SVM), Logistic Regression (LR), Random Forest (RF), Neural Network (NN), and Naïve Bayes (NB) were used to prioritize risk factors for MN deficiency prediction. Performance metrics including accuracy, sensitivity, specificity, and Area Under the Receiver Operating Characteristic (AUROC) curves were used to evaluate model prediction performance.

Results: The prediction performance of the RF model was the best performing ML model in predicting child MN deficiency, with an AUROC of 80.01% and accuracy of 72.41% in the test data. The RF algorithm identified the eastern region of Ethiopia, poorest wealth index, no maternal education, lack of media exposure, home delivery, and younger child age as the top prioritized risk factors in their order of importance for MN deficiency prediction.

Conclusion: The RF algorithm outperformed other ML algorithms in predicting child MN deficiency in Ethiopia. Based on the findings of this study, improving women's education, increasing exposure to mass media, introducing MN-rich foods in early childhood, enhancing access to health services, and targeted intervention in the eastern region are strongly recommended to significantly reduce child MN deficiency.

KEYWORDS
machine learning, child micronutrient deficiency, AUROC, spatial variation, Ethiopia

1 Introduction

Micronutrient (MN) deficiencies are a major public health problem around the world, contributing to childhood morbidity and mortality. The burden of this problem is disproportionately high in low- and middle-income countries, particularly in Sub-Saharan Africa, including Ethiopia (1, 2). MN deficiencies mainly occur when people lack access to MN-rich foods like fruits, vegetables, animal products, and fortified foods. MN deficiencies lower immune capabilities and increase the overall risk of infection-related mortality, particularly diarrhea, measles, malaria, and pneumonia, which are among the world's top ten leading causes of death (1, 3). MNs are only minimally required; however, their lack in the diet has a severe impact on the survival and development of children. Furthermore, MN deficiency contributes to stunting, wasting, weakened immunity, and delays in cognitive development (1, 3, 4).

Vitamin A (VA) and Iron are essential micronutrients that are crucial for the growth and development of children and their deficiency causes significant public health problem in children (5). Iron deficiency is a primary cause of anemia and has serious health consequences for both women and children. VA plays an important role in maintaining the epithelial tissue in the body. Its severe deficiency causes eye damage and is the leading cause of preventable childhood blindness. Moreover, VA deficiency increases the severity of infections such as measles and diarrheal disease in children and slows recovery from illness. It is common in dry environments where fresh fruits and vegetables are not readily available (3).

According to the 2019 United Nations Children's Fund report, 340 million children globally suffered from hidden hunger as a result of MN deficiency (6). In Africa, less than one-third and one-half of children aged between 6 and 23 months met the minimum criteria for dietary diversity and meal frequency, respectively. According to the 2019 Ethiopian Mini Demographic Health Survey (EMDHS) report, the consumption of foods rich in VA and iron, which are the major MN deficiency indicators, remains low among young children in Ethiopia. Thirty-nine percent of children aged 6–23 months consumed foods rich in VA during the 24 h before the interview, whereas 24% consumed iron-rich foods (3).

Empirical studies have identified several factors associated with insufficient minimum dietary diversity, including limited access to media such as newspapers, magazines, and radio; lower education level of fathers; fewer antenatal care visits; younger child age; working in agriculture, and poorest household wealth index (1, 4, 6–8). However, the typical logistic and multilevel models employed in these studies were unable to identify the most important predictors. Identifying predictors of MN deficiency and taking corrective action are critical in reducing MN deficiency. Prioritizing predictors based on their contribution in predicting MN deficiency will be cost effective and simple to implement but has not yet been considered. Machine learning (ML) algorithms, which intersects statistical learning and artificial intelligence research, are used to explore large amounts of data to discover unknown patterns or relationships and show the share of predictors for a particular problem (9, 10). In addition, ML helps to develop predictive models and the selection of the most important predictors.

Hence, the ML algorithm is the ideal candidate statistical model for addressing these statistical modeling issues. These models have demonstrated high performance in solving classification problems compared to the conventional statistical models applied to select the most important predictors. The availability of diverse alternative models to be selected as the best fit for a predictive model is one of the most important features behind the use of ML algorithms. Among others, the five widely used ML models considered in this study are Support Vector Machine (SVM), Logistic Regression (LR), Neural Network (NN), Random Forest (RF), and Naïve Bayes (NB) (9–14).

The most significant predictors of MN deficiency were determined after evaluating these multiple models and choosing the model that best fit the data under consideration in this study. This enables health professionals, policy designers and implementers, and interventions geared towards addressing challenges posed by MN deficiency to concentrate their efforts on the most reliable predictors and take corrective actions. To the best of our knowledge, no previous study has used ML modeling to determine the factors that predict MN deficiency in Ethiopia and other East African nations. The main objective of this study was to identify the most important predictors of childhood MN deficiency in Ethiopia by evaluating various ML algorithms that most accurately and efficiently predict micronutrient deficiency.

2 Materials and methods

2.1 Data source and sampling procedure

This analysis involved the Ethiopia Mini Demographic and Health Survey (EMDHS), which was collected through a nationally representative, cross-sectional, and household-based survey conducted in Ethiopia in 2019. The data collection used a two-stage cluster sampling design with stratification into urban and rural regions. Twenty-one sampling strata were obtained after stratifying each region into urban and rural areas. In the first stage, 305 Enumeration Areas (EAs) (93 urban EAs and 212 rural EAs) were chosen with a probability proportional to the EA size in each stratum. In the second stage, 30 households were randomly selected from each EA using an equal probability method from the fresh list of households, resulting in a total of 8,663 households with 1,463 children aged 6–23 months (3).

2.2 Study variables and measurements

2.2.1 Outcome variable

The outcome variable in this study was the MN deficiency status of children aged 6–23 months, which was derived based on the MN intake status from respondents' report. It was mainly computed from the VA and Iron rich foods consumed in the last 24 h prior to the data collection among children aged 6–23 months. We classified children's MN deficiency status into two groups: "Yes" outcomes if the respondent reported that the child did not consume any of the minimum recommended MNs, and "No" outcomes if the child had consumed at least one of the minimum recommended MNs (1).

A child was grouped in the MN deficient category in VA if he or she had not consumed any of the seven VA-rich foods in the 24 h prior to the data collection. The seven VA rich foods include: i. eggs; ii. meat (beef, hog, lamb, or chicken); iii. Pumpkin, carrots, and squash; iv. any dark green leafy vegetables; v. mangoes, papayas, and other fruits containing VA; vi. liver, heart, and other organs; and vii. Fish or shellfish. Similarly, a child was deemed MN deficient in Iron if she or he did not eat anything from the four food groups that were high in Iron: eggs, meat (beef, hog, lamb, or chicken), liver, heart, and other organs, fish, or shellfish. Hence, in this study, the MN deficiency status of the child was determined as MN deficient if the child was MN deficient in both groups (VA and Iron) and labeled "Yes" and "No" otherwise. The outcome variable is MN deficiency (Y), which is defined for an individual child as:

$$y_i = \begin{cases} 1, \text{if a child i had received none of the minimum recomended MNs} \\ 0, \text{if a child i had eaten atleast one of the minimum recomended MNs} \end{cases}$$

2.2.2 Predictors in the model

The MN deficiency predictor variables or features included in the models were child age in months, age of mothers, number of children under five, mother's education, antenatal care (ANC) visit, postnatal care (PNC) visit, health check after delivery, place of delivery, current pregnancy status, currently breastfeeding, wealth index, region, place of residence, and media exposure (See details in Table 1). Moreover, the administrative region shapefiles were used to investigate the spatial variation in the prevalence of child MN deficiency.

2.2.3 Feature selection

Feature selection is a critical step in predicting and interpreting high-dimensional datasets. We employed the Recursive Feature Elimination (RFE) method as a feature selection technique that uses a wrapper approach to select the most relevant features for a given ML model by recursively removing features from the dataset and training the model on the remaining features until the desired number of features is obtained (15). RFE is a valuable tool for identifying the most important features of MN deficiency in children and improving the predictive power of our ML models. Therefore, ML algorithms were applied to determine their predictive power and identify the most important determinants of child MN deficiency.

TABLE 1 The description of the predictor variables considered in the analysis.

Variables	Descriptions
Maternal level characteristics	
Mother's education	No education, primary, secondary, higher
Age of mothers	15–24, 25–34, 35–49 (Mothers current age)
Number of under five children	1, 2, 3 or more
Community level characteristics	
Place of residence	Urban/Rural
Media exposure	No/Yes
Wealth index	Poorest, poorer, middle, richer, richest
Region	Tigray, Afar, Amhara, Oromia, Somali, Benshangul, SNNPR, Gambela, Harari, Addis Ababa, Dire Dawa
Obstetric characteristics	
Antenatal care (ANC) visit	No visit, 1–3, >=4
Postnatal care (PNC) visit	No/Yes
Health check after delivery	No/Yes
Current pregnancy status	No or unsure/Yes
Place of delivery	Home/health facility
Child level characteristics	
Child age in months	6–8, 9–11,12–17, 18–23 (Child age in months)
Currently breastfeeding	No/Yes

2.3 Machine learning methods

Machine Learning (ML) methods that were used in this study include SVM, LR, NN, RF, and NB. ML models have been used to rank relevant predictors of MN deficiency and to identify important predictors of health outcomes and other variables of interest.

We used the R programming language (version 4.2.2) and R packages sf (16), caret (17), and pROC (18) for data preprocessing and analysis. The performance of the ML algorithms was evaluated using metrics such as accuracy and the Area Under the Receiver Operating Characteristic curve (AUROC).

In this study, we employed ML approaches by randomly dividing the dataset into two sets: 80% of it for the training set and 20% for the test set. The training set was used to train the model and the test set was used to evaluate the performance of the model. Standard ML accuracy measures were used to evaluate the prediction power of popular supervised ML algorithms, including SVM (13), LR (11, 14), NN (11–14, 19), RF (10–14, 20, 21), and NB (19). The ML algorithms were trained based on 10-fold cross-validation to optimize models. The overall pipeline of this study is shown in Figure 1. Figure 1 depicts the ML approach for predicting MN deficiency using EMDHS data. The approach involves several steps, including data collection, preprocessing, data cleaning and encoding, feature selection, building and evaluating ML algorithms, and comparing the performance of different models. The best-performing model was then used to predict MN deficiency. Following this approach, this study aimed to develop accurate and reliable predictive models that can inform public health policies and promote child development in Ethiopia.

Support Vector Machine (SVM) is a supervised ML model used for regression and classification that creates a hyperplane or set of hyperplanes in a high- or infinite-dimensional space. The objective is to maximize the margin between the nearest training points or support vectors of each class and the separating hyperplane. The best separation border is represented by the hyperplane with the largest available margin. To conduct linear separation, data must be transformed into higher dimensions using kernel functions. Non-linear classification tasks can be successfully completed using SVM, which is successful on complicated issues with little training data because of its generalization capabilities (22).

Logistic Regression (LR) is a statistical machine learning algorithm for binary classification problems that models the probability of an input data point belonging to a particular class. LR applies a logistic sigmoid function to the weighted sum of input predictors to estimate the probabilities, then thresholds the output to make a binary prediction. Moreover, it assumes a linear relationship between the log-odds of the outcome and the input predictors and can handle numerous predictor variables. It does not require linear

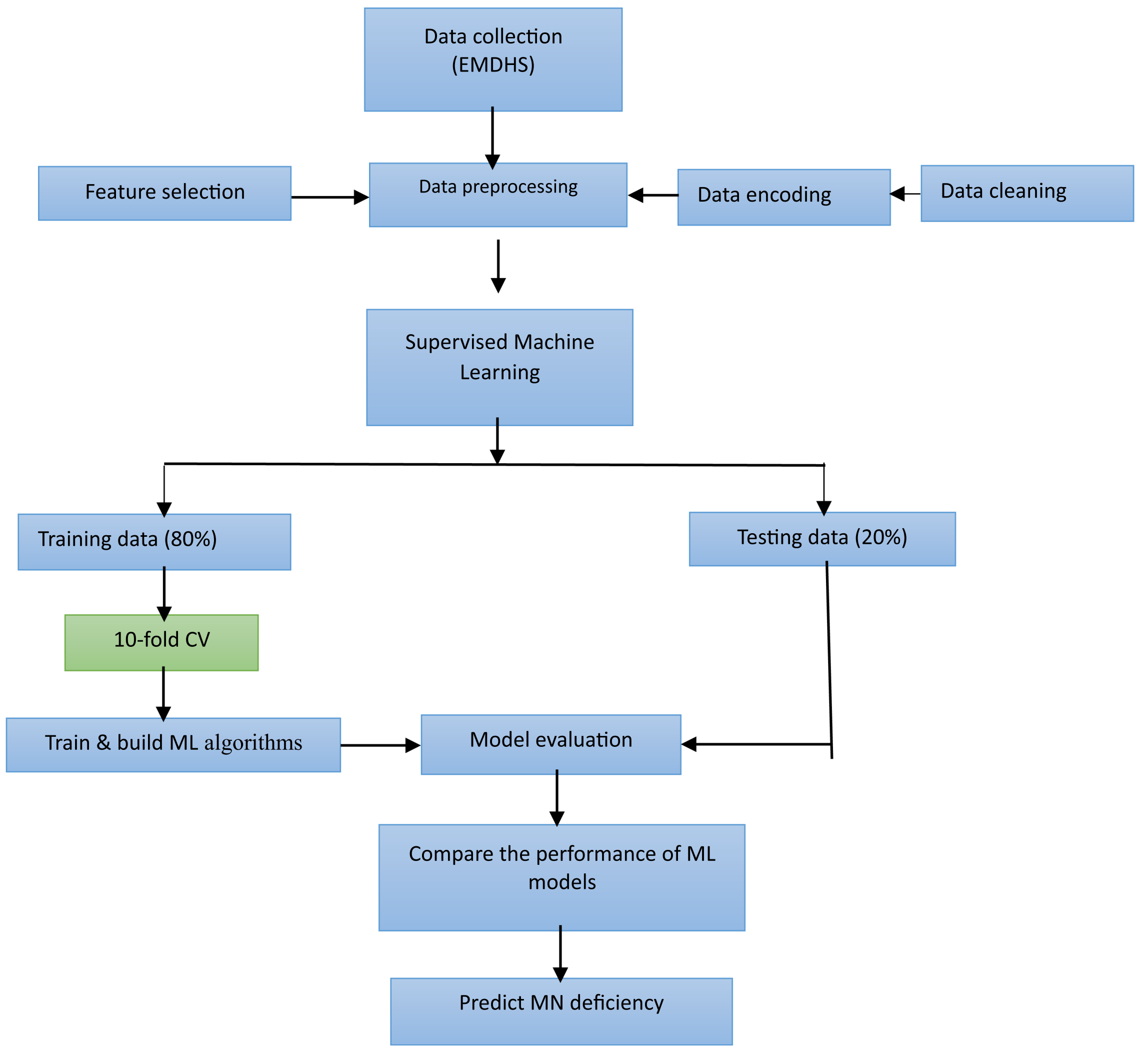

FIGURE 1
Flow chart of Machine learning approach.

relationships between dependent and independent variables, and penalization can control overfitting. The interpretability of model coefficients and probabilities makes logistic regression a popular starting classifier for machine learning applications involving binary prediction (23, 24).

The Random Forest (RF) is a popular algorithm for supervised ML that is used to solve classification and regression issues. It generates decision trees from randomly chosen data samples, gets predictions from each tree, and uses a majority vote to determine the optimal solution. RF also ranks the significance of each predictor using the mean decrease in accuracy (24–26).

The Neural Network (NN), also known as an Artificial Neural Network (ANN), is an ML model that uses a network of functions to recognize and translate a data input of one form into a desired output. The notion of NN was based on the biology of humans and how neurons work together in the human brain to understand information from the senses. NNs learn from labeled training data by adjusting the connection weights between layers of simple processing units, which enables them to model complex nonlinear relationships for applications in prediction, classification, and clustering (24, 27).

Naive Bayes (NB) is a supervised machine learning algorithm classifier based on Bayes' theorem with independence assumptions between the features that simplifies the computation needed to estimate likelihood and posterior probability, making Naive Bayes a fast, scalable classifier that tends to perform very well on a variety of data despite its simplicity and restrictive assumptions (28).

2.4 Model performance evaluation

Different model performance metrics, including precision, recall or sensitivity, specificity, accuracy, F1 score, Receiver Operating Characteristics (ROC) curves, and ROC Area Under the Curve (ROC AUC) scores, were used to compare the performance of ML models or classifiers (24, 29).

A confusion matrix for binary classification is a two-by-two matrix that displays the values of True Positives (TP), False Negatives (FN), False Positives (FP), and True Negatives (TN) resulting from the predicted classes of data. By analyzing the confusion matrix, we can calculate various performance metrics such as recall (or sensitivity), specificity, and accuracy. The TP and TN represent correct classifications by the model, whereas FN and FP are incorrect predictions.

Recall (sensitivity) also called True Positive Rate (TPR) measures how many of the positive samples are captured by the positive predictions

$$TPR = \frac{TP}{(TP + FN)}$$

Specificity is another performance metric used in binary classification that measures the proportion of negative samples that are correctly identified by the model. Specifically, it measures the ability of the model to correctly predict negative samples as negative.

$$Specificity = \frac{TN}{(TN + FP)}$$

Accuracy is a commonly used performance metric in binary classification that measures the proportion of samples that are correctly classified by the model out of all the samples it has predicted. It is calculated as:

$$Accuracy = \frac{(TP + TN)}{(TP + FP + TN + FN)}$$

Precision also called positive predictive value (PPV) measures how many of the samples predicted as positive are actually positive.

$$Precision = \frac{TP}{(TP + FP)}$$

The F_1 score is the harmonic mean of precision and recall

$$F_1 = \frac{2}{\left(\frac{1}{Precision} + \frac{1}{Recall}\right)} = \frac{TP}{\left(TP + (FN + FP)/2\right)}$$

The Receiver Operating Characteristic (ROC) curve is another standard tool used with binary classifiers, which plots sensitivity versus (1 − specificity). Measuring the Area Under the Curve (AUC) is one method of comparing classifiers. AUC provides an aggregated value that illustrates the likelihood that each ML algorithm will accurately classify a random sample. The better the classifier, the more closely the ROC curve will hug the top left corner (24, 30).

3 Results

3.1 Descriptive results

Data from 1,455 children aged 6 to 23 months were included in the analysis to assess the MN deficiency status in Ethiopia. Overall, 62.1% of them had not received any of the minimum recommended micronutrients and were therefore MN deficient. According to Table 2, the prevalence of MN deficiency was significantly higher among children whose mothers had no education (70.53%) compared to those with higher education (36.53%).

The prevalence of MN deficiency decreases as the child's age increases, with the lowest percentage of deficiency found in the 18–23 month age group (47.97%). MN deficiency is also significantly prevalent among children whose mothers have no media exposure (67.95%) compared to those with media exposure (47.43%). The results also suggest that as the wealth quintile increases, the prevalence of MN deficiency decreases, with the lowest percentage of deficiency found in the richest wealth quintile (47.12%) and the highest in the poorest (80.3%). The prevalence of MN deficiency also varies widely across regions, with the highest percentage of deficiency found in the Somali region (98.20%) and the lowest percentage of deficiency found in the Gambela region (42.94%) (Table 2).

According to Table 2, children whose mothers did not attend any ANC visits were more likely to have a MN deficiency (73.49%), compared to mothers who attended 1–3 ANC visits (60.70%) and those attended 4 or more visits (53.85%). Additionally, households with three or more children are more likely to experience a MN deficit (78.84%) than households with one or two children (59.81 and 57.3%, respectively).

3.2 Spatial distribution of childhood MN deficiency

As per the findings presented in Figure 2, the spatial variation of childhood MN deficiency was most prevalent in Somali, Afar, and Amhara regions, while Gambela, Addis Ababa, and Southern Nations, Nationalities, and Peoples (SNNP) were the least affected regions. The findings suggest that the eastern part of Ethiopia, which includes the Somali and Afar regions, and the Amhara region were severely affected by MN deficiency.

3.3 Predictive algorithms for child micronutrient deficiency

The Recursive Feature Elimination (RFE) method was used to identify the features required to develop the ML algorithms on the training dataset. The results showed that RF had a relatively higher accuracy of 72.41% (95% CI: 66.89, 77.48), indicating its ability to correctly classify positive and negative cases. RF also achieved an AUROC of 80.01, suggesting good discriminative ability in distinguishing between positive and negative cases. The NPV of RF was found 69.23%, indicating its effectiveness in correctly identifying children without micronutrient deficiency. Additionally, the F1 score of RF was 79.59, indicating a balanced performance in terms of precision and recall, while NN had a slightly lower AUROC (79.84%) and accuracy (71.03%) compared to RF. Moreover, RF has the highest sensitivity (86.67%), meaning 86.67% of the children who are actually MN deficient are correctly identified by the model. In comparison to the other classifiers, Generalized Linear Model (GLM) had a slightly lower accuracy (70.69%) compared to RF, NN, and SVM and a relatively high AUROC score of 79.53% next to RF and NN. However,

TABLE 2 Weighted prevalence and chi-square statistics of MN deficiency by demographic and other characteristics among children aged 6–23 months in Ethiopia ($n = 1,455$).

Predictors	Non-MN deficient (%)	MN deficient (%)	Chi square test statistic	*p* values
Region			126.37	0.000
Tigray	52.24	47.76		
Afar	16.63	83.37		
Amhara	29.53	70.47		
Oromia	42.07	57.93		
Somali	1.80	98.20		
Benishangul	47.52	52.48		
SNNPR	49.58	50.42		
Gambela	57.06	42.94		
Harari	45.81	54.19		
Addis Adaba	56.92	43.08		
Dire Dawa	43.18	56.82		
Place of residence			2.4024	0.121
Urban	47.81	52.19		
Rural	35.99	64.01		
Media exposure			7.8064	0.005
No	32.05	67.95		
Yes	52.57	47.43		
Number of under 5 children			12.199	0.002
1	40.19	59.81		
2	42.63	57.37		
3 or more	21.16	78.84		
Wealth index			28.89	0.000
Poorest	19.71	80.29		
Poorer	38.89	61.11		
Middle	38.47	61.53		
Richer	46.23	53.77		
Richest	52.88	47.12		
Current pregnant			1.053	0.305
No or unsure	39.79	60.21		
Yes	31.83	68.17		
Currently breastfeeding			0.298	0.5852
No	35.29	64.71		
Yes	40.03	59.97		
Maternal age			1.9302	0.381
15–24	38.67	61.33		
25–34	42.17	57.83		
35–49	32.75	67.25		
Maternal education level			23.465	0.000
No education	29.47	70.53		
Primary	44.84	55.16		
Secondary	48.20	51.80		
Higher	63.47	36.53		

(Continued)

TABLE 2 (Continued)

Predictors	Non-MN deficient (%)	MN deficient (%)	Chi square test statistic	*p* values
ANC visit			8.49	0.014
No visit	26.51	73.49		
1–3 visits	39.30	60.70		
>=4 visits	46.15	53.85		
Place delivery			0.44	0.51
Home	36.17	63.83		
Health facility	41.75	58.25		
Health check after delivery			0.83	0.363
No	38.58	61.42		
Yes	45.94	54.06		
PNC check			0.52	0.47
No	38.52	61.48		
Yes	44.55	55.45		
Child age in months			13.46	0.003
6–8	28.07	71.93		
9–11	33.55	66.45		
12–17	36.88	63.12		
18–23	52.03	47.97		

MN, micronutrient; ANC, antenatal care; PNC, postnatal care; SNNPR, Southern Nations Nationalities and People Region.

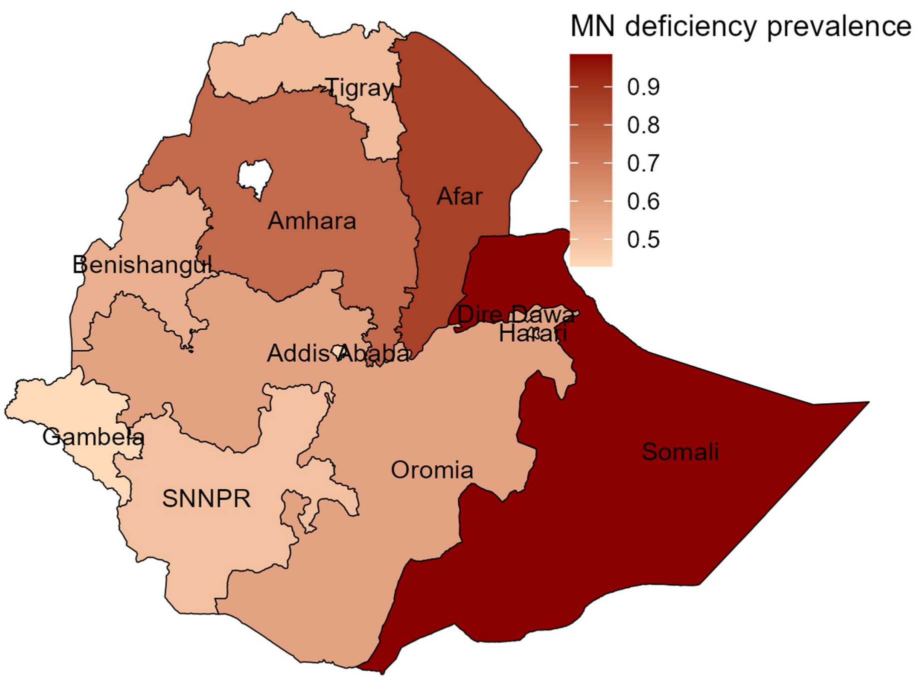

FIGURE 2
Spatial variations in MN deficiency by administrative regions in Ethiopia, EMDHS, 2019.

its sensitivity score of 80% was lower than those of RF and SVM. Finally, RF had the highest AUROC score (80.01%), whereas NB had the lowest (78.18%) (Figure 3). Based solely on the results presented in Table 3, RF, NN, and SVM were the top-performing algorithms, respectively, in terms of accuracy (Table 3). Thus, among all the algorithms utilized in our investigation, the RF algorithm performed the best in predicting the MN-deficient status of the cases, as evidenced by performance measures.

3.4 The important predictors of micronutrient deficiency

The model evaluation findings, as discussed above, demonstrated that the random forest classifier was the best classifier in terms of accuracy and area under the receiver operating characteristics (AUROC) curve. Based on the most accurate classifier (RF), the top important predictors are presented according to their mean decrease accuracy (MDA) (Figure 4). Among the proposed predictors, the Somali region, the poorest wealth index, no maternal education, no media exposure, home delivery, the Afar region, and children aged 6–8 months were the top important predictors in their order of importance for MN deficiency among children aged 6–23 months in Ethiopia.

3.5 Spatial mapping of actual vs. predicted childhood MN deficiency prevalence

The spatial variation in Figures 5A,B depicts the actual and predicted prevalence of childhood MN deficiency for each region in the test data, respectively. To predict the regional prevalence of MN deficiency, our best predictive model (RF) was employed. Upon visual inspection of the map, we observed that while some discrepancies existed between a few regions, the overall patterns of the observed prevalence were consistent with the predicted prevalence of child MN deficiency. This suggests that our predictive model (RF) was reliable and can be used to predict the childhood MN deficiency prevalence in areas where data are lacking.

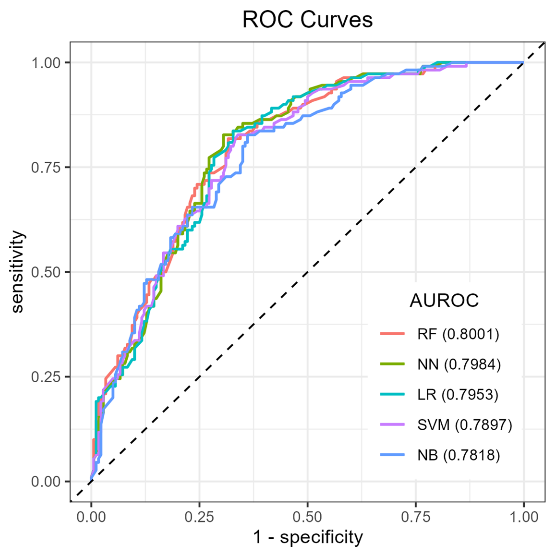

FIGURE 3
ROC curve for machine learning models in predicting childhood micronutrient deficiency. ROC, receiver operating characteristic; AUROC: area under the receiver operating characteristics.

3.6 Classical logistic regression analysis

In contrast to the machine learning models, the traditional logistic regression model provides interpretable odds ratios for each predictor. Based on the results presented in Table 4, the region where the child lives, wealth index, maternal education level, and child age in months were found to be significant predictors of micronutrient deficiency among children aged 6–23 months in Ethiopia. Specifically, children living in the Somali and Afar region had 31.20 and 4.75 times higher odds of MN deficiency, respectively, compared to children in the SNNP region. Children in the poorest wealth index category had 4.75 times higher odds of micronutrient deficiency compared to children in the richest wealth index category. Moreover, the study found that a lower maternal education level and a younger child's age were significantly associated with higher odds of micronutrient deficiency in children. Specifically, no education, primary, and secondary education in mothers were associated with 2.50, 1.96, and 1.91 times higher odds, respectively, compared to higher education. Children aged 6–11 months had 1.78 times higher odds of MN deficiency compared to those aged 18–23 months (Table 4).

4 Discussion

In this study, we found that children aged 6–23 months had a significant prevalence of MN deficiency, which accounted for 62.1% of children in Ethiopia. This finding highlights the highest MN deficiency compared with other studies conducted in East Africa (31), including Ethiopia (1). The difference in results can be explained by the influence of sample size because the current survey was a mini-demographic survey. Moreover, we found strong associations between certain demographic and socio-economic factors and the

TABLE 3 Model evaluation metrics for all ML models as evaluated on the test data.

ML algorithms	Accuracy (95% CI) (%)	Sensitivity (recall) (%)	Specificity (%)	Precision (PPV) (%)	NPV (%)	F1-score (%)	AUROC (%)
SVM	71.03 (65.44, 76.19)	84.44	49.09	73.08	65.85	78.35	78.98
GLM	70.69 (65.09, 75.87)	80.00	55.45	74.61	62.89	77.21	79.53
RF	72.41 (66.89, 77.48)	86.67	55.45	73.58	69.23	79.59	80.01
NN	71.03 (65.44, 76.19)	80.00	56.36	75.00	63.27	77.42	79.84
NB	67.93 (62.22, 73.27)	57.78	84.55	85.95	55.03	69.10	78.18

ML, machine learning; GLM, generalized linear model; SVM, support vector machine; RF, random forest; NN, neural network; NB, Naive Bayes; PPV, positive predictive value; NPV, negative predictive value; AUROC, area under the receiver operating characteristic curve.

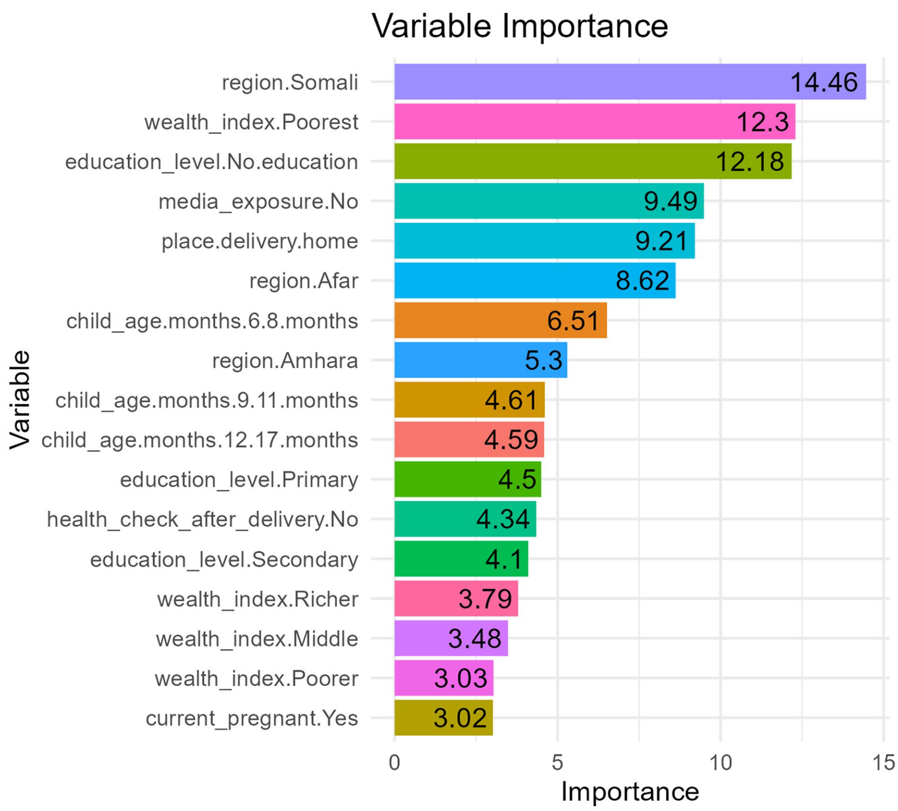

FIGURE 4
Variable importance from random forest.

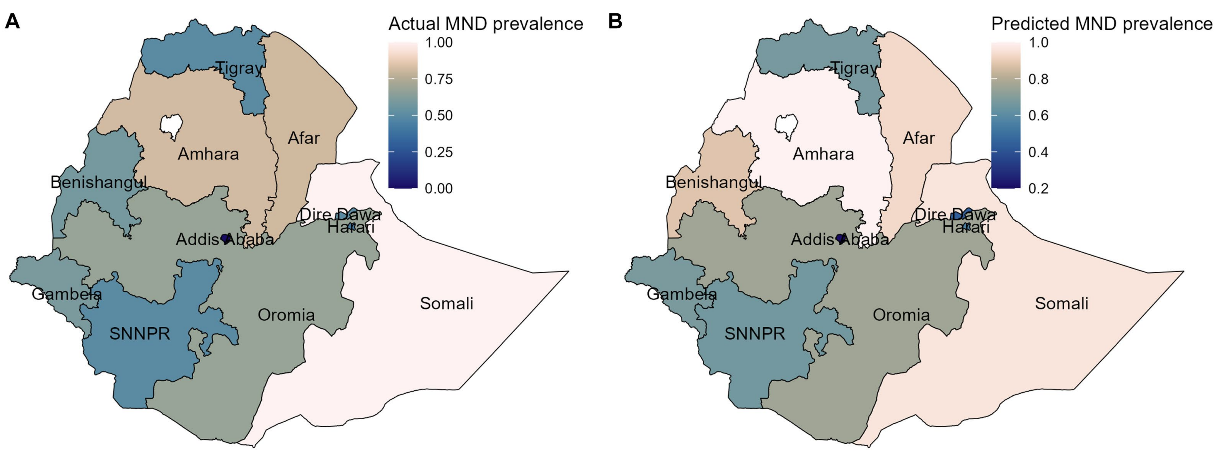

FIGURE 5
The spatial distribution of the actual **(A)**, and predicted **(B)** of MN deficiency prevalence on the test data. MND, micronutrient deficiency.

prevalence of micronutrient deficiency, such as poverty, lack of media exposure, young age, low maternal education, and larger household size. This finding is consistent with other studies in this area (1, 32, 33).

The findings of this study also showed considerable variations in MN deficiency among children across Ethiopian regions, as illustrated in the spatial map. MN deficiency is most prevalent in the eastern regions, such as Somalia and Afar, and in Amhara region, but least prevalent in the south-west, southern, and central regions in Gambella, SNNP, and Addis Ababa, respectively. Evidence of similar geographical variabilities in MN deficiency has been shown (1, 31, 34). These findings highlight the need for targeted interventions that address the specific needs of different population groups in the eastern regions of Ethiopia.

TABLE 4 Logistic regression model results for factors associated with child MN deficiency (based on training data).

Characteristics	Adjusted odds ratio (AOR)	Confidence interval (CI)		*p* value
		Lower	Upper	
(Intercept)	0.13	0.06	0.29	0.000
Region				
Tigray	1.30	0.75	2.28	0.351
Afar	4.75	2.46	9.55	0.000
Amhara	2.53	1.48	4.36	0.001
Oromia	1.30	0.79	2.15	0.296
Somali	31.20	9.02	197.20	0.000
Benishangul	1.08	0.63	1.88	0.771
Gambela	0.58	0.32	1.04	0.070
Harari	1.66	0.91	3.04	0.100
Addis Adaba	1.94	0.99	3.81	0.053
Dire Dawa	1.78	0.96	3.34	0.071
SNNP (Ref)				
Media exposure				
No	1.39	1.00	1.95	0.053
Yes (Ref)				
Wealth index				
Poorest	1.81	1.09	3.01	0.021
Poorer	1.11	0.69	1.78	0.666
Middle	1.17	0.73	1.88	0.525
Richest	1.01	0.62	1.64	0.968
Richer (Ref)				
Current pregnant				
No (Ref)				
Yes	1.61	0.92	2.90	0.102
Education level				
No education	2.50	1.40	4.52	0.002
Primary	1.96	1.13	3.45	0.018
Secondary	1.91	1.02	3.62	0.045
Higher (Ref)				
Place of delivery				
Home	1.18	0.85	1.62	0.322
Health center (Ref)				
Health check after delivery				
No	1.37	0.91	2.05	0.133
Yes (Ref)				
Child age in months				
6–8	2.77	1.84	4.19	0.000
9–11	2.32	1.54	3.54	0.000
12–17	1.75	1.26	2.43	0.001
18–23 (Ref)				

AOR, adjusted odds ratio; CI, confidence interval; Ref, reference category.

In terms of predictive ML algorithms, the random forest algorithm was found to have the highest accuracy and AUROC score for predicting micronutrient deficiency. However, it is worth noting that while the logistic regression algorithm (GLM) had slightly lower accuracy compared to other algorithms such as NN, RF, and SVM, its advantage lies in producing more interpretable results in terms of the predictors estimated in the algorithm. Numerous machine learning (ML) approaches have been applied to health issues, including nutritional status (11, 14, 21, 35), asthma risk prediction (20), and childhood anemia (9). These studies have demonstrated high-quality and valid predictions, highlighting the potential of the ML approach in predicting health outcomes. Findings from the RF classifier reveal that the Somali region, the poorest wealth index, children of mothers who have no education, children whose mothers have no media exposure, home delivery, the Afar region, and children aged 6–8 months were the top important variables in their order of importance for predicting MN deficiency among children aged 6–23 months in Ethiopia (1, 31, 32).

The findings of this study indicated that the poorest household wealth index was an important predictor of child MN deficiency. This aligns with evidence that poverty and the poorest wealth index status contribute to childhood MN deficiency (31, 33). Children from low-income households often have limited access to nutritious food, which can lead to deficiencies in essential micronutrients. The implications of these findings highlight the need for targeted interventions aimed at addressing MN deficiency in low-income households. Besides, this study finds that home delivery was a significant risk factor for micronutrient deficiency. This suggests that women who give birth at home may not receive the same level of support and education on proper nutrition and infant care that they would receive in a healthcare facility (36).

Likewise, the significance of a child's age in predicting micronutrient deficiency has been well documented in the literature (1, 31, 33), which supports the results of this study. Additionally, it seems that children aged 6 to 11 months are more vulnerable to micronutrient deficiencies. These findings suggest that there is a strong association between child age and micronutrient deficiency, with younger children being at a higher risk of deficiency. This highlights the importance of early interventions to promote optimal nutrition and prevent micronutrient deficiency in infants and young children in Ethiopia.

Furthermore, the results indicate that a lack of maternal education increases the risk of childhood micronutrient deficiency. Conversely, children of educated women have significantly lower rates of micronutrient deficiency (31, 33). These findings have important implications for addressing child micronutrient deficiency and further emphasize the need to improve women's education in developing countries to promote better outcomes for children's micronutrient status. Moreover, the findings indicate that parents who lack media exposure are also important predictors of childhood micronutrient deficiency, which is consistent with previous research conducted in India (35). This indicates that parental access to media can play a significant role in promoting good nutritional outcomes for children.

Additionally, this study investigated the spatial variation of the actual and predicted prevalence of MN deficiency using RF model, which highlighted the overall patterns of the observed prevalence that were consistent with the predicted prevalence of MN deficiency in children. This suggests that our predictive model (RF) was reliable and can be used to predict the prevalence of childhood MN deficiency in areas where data is lacking.

Moreover, the findings from the best-performing ML model (RF) are largely consistent with the traditional logistic regression analysis. Both the eastern region where the child lives, the wealth index, maternal education level, and child age in months were found to be significant predictors of micronutrient deficiency among children aged 6–23 months in Ethiopia. However, home delivery and media exposure emerged as important predictors in the ML models but not in conventional logistic regression. This suggests that the ML models may reveal previously unknown insights beyond traditional logistic regression approaches. Specifically, ML models could identify new influential variables for policy decision making that are missed by standard statistical methods (37). While the core findings aligned, ML provided the additional benefit of highlighting novel and potentially crucial MN deficiency factors not captured by traditional logistic regression.

5 Conclusion

The aim of this study was to evaluate the effectiveness of various ML algorithms and identify the most accurate and efficient algorithm for predicting micronutrient deficiencies. Accuracy and AUROC were used to evaluate the predictive power of the ML algorithms. The random forest algorithm was identified as the best model, achieving an accuracy of 72.41% and an AUROC of 80.01% on the test data. Thus, the Somali region, the poorest wealth index, children of uneducated moms, children whose parents have no media exposure, home delivery, the Afar region, and children aged 6–8 months were found to be the most important predictors of child MN deficits in their order of importance. Furthermore, the findings demonstrated considerable regional variations in the frequency of child MN deficit, particularly in Ethiopia's eastern region. Although the RF model and traditional logistic regression model displayed more similar important predictors, the RF model was able to discover some crucial predictors that the conventional logistic regression model had missed. As a result, our model may provide better policy suggestions for children with MN deficiency. These findings underscore the importance of socioeconomic and spatial factors in the incidence of micronutrient deficiencies among Ethiopian children. Addressing these issues may result in better health outcomes for children within an age category of 6–23 months. The regional variation in the prevalence of MN deficiency emphasizes the need for targeted interventions that account for differences in the prevalence and risk factors of micronutrient deficiencies across different regions in Ethiopia.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://www.dhsprogram.com/Data/.

Ethics statement

This research has obtained approval to access the Datasets. Subsequent to the submission and request of the study concept, consent was granted by the Data Archivist of The Demographic and Health Surveys (DHS) Program. All data used adhere to the ethical standards of research. Furthermore, the data was managed in accordance with the Helsinki Declaration of the World Medical Association.

Author contributions

LGG: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Investigation, Software, Validation, Visualization, Writing – original draft. EYD: Conceptualization, Data curation, Methodology, Validation, Visualization, Writing – review & editing. JAY: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Diet quality and nutritional status of HIV-exposed children aged between 6 and 18 months in the Greater Accra Region of Ghana

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Introduction: HIV-exposed children, even when uninfected, have a greater risk of malnutrition than unexposed counterparts. WHO guidelines recommend children aged 6–23 months be fed a variety of foods to meet nutrient requirements. This study aimed to determine infant and young child feeding (IYCF) practices among HIV-exposed children under 2 years old enrolled in a dietary intervention and to explore correlates of the IYCF indicators and associations between IYCF and nutritional status.

Methodology: Six hundred and eighty mother–child pairs were recruited from 19 health facilities from the Greater Accra Region. The sociodemographic data, anthropometry, hemoglobin, and dietary intake were recorded.

Results: Ninety-five percent of HIV-positive mothers breastfed their babies, and 53% initiated breastfeeding in a timely manner. Around one in five mothers (21%) introduced liquids other than breastmilk to their children within the first 2 days of birth, and only around one in four children (26%) aged 12–23 months had received breast milk on the day before assessment. Ninety-three percent of babies between 6 and 8 months had been introduced to solid, semi-solid, or soft foods. Eighteen percent of children reached the threshold for Minimum Dietary Diversity (MDD) by eating from over five of eight food groups. Fifty-four percent received Minimum Meal Frequency (MMF), eating between 2 and 4 meals in a day. Eleven percent received the Minimum Acceptable Diet (MAD). Thirty-two percent were anemic. Underweight and stunting were 12 and 11%, respectively. Children of mothers aged 31–40 years were more likely to meet the MDD and MAD [OR = 2.8, 95%CI (1.185, 6.519), $p < 0.05$ and OR = 2.8, 95%CI (1.256, 6.279), $p < 0.05$] compared to children of mothers aged 30 years or less or aged above 40 years. Children from households earning more than GHS 500 were more likely to meet MMF than those from households earning less. No associations were found between IYCF and nutritional status.

Conclusion: Findings highlight the need for nutrition programs to educate HIV-exposed children's caregivers on optimal feeding practices. The importance of continued breastfeeding and dietary diversity needs to be highlighted. Affordable, iron-rich foods should be promoted. Special attention should be paid to younger, less educated, and lower socioeconomic status mothers.

KEYWORDS
diet quality, HIV-exposed children, IYCF, dietary intake, sub-Saharan Africa

Introduction

Adequate nutrition is necessary for the growth and development of all children, and every child has the right to good nutrition according to the 'Convention on the Rights of the Child' (Verhellen, 2000). The first 1,000 days of life are crucial for growth, and optimum nutrition is required in this window to reduce morbidity and mortality and to foster development (WHO and UNICEF, 2021). The World Health Organization reported in 2021 that globally, undernutrition is associated with 45% of child deaths. In 2020, 149 million children under 5 were estimated to be stunted, 45 million were estimated to be wasted, and 38.9 million were overweight or obese (WHO and UNICEF, 2021). Ghana made significant progress between 2008 and 2018 in reducing stunting and anemia in under-fives from 28 to 18% and 76 to 66%, respectively (Ghana Statistical Service GSS, Ghana Health Service GHS, Macro ICF, 2009; Ghana Statistical Service (GSS), 2015; Aryeetey et al., 2022). Children born to HIV-infected mothers are at higher risk of malnutrition compared to those born to HIV-uninfected mothers, even when they themselves are uninfected (McHenry et al., 2019; Yirga et al., 2019).

Globally, approximately 1.8 million children 0–14 years and 1.8 million adolescents 10–19 years were living with HIV in 2017, of whom more than 85% lived in sub-Saharan Africa (Enane et al., 2018). In Ghana, 42,000 children and adolescents aged 0–19 years were living with HIV in 2018 (UNICEF, 2021). Young children usually get infected with HIV through their mothers during pregnancy, labor, or delivery or through breastfeeding; mother-to-child transmission (MTCT) (World Health Organization, 2004). Maternal factors that may lead to an increased risk of HIV transmission include high maternal viral load, maternal malnutrition, vaginal delivery as opposed to planned cesarean section, and oral disease in the baby during breastfeeding (JICA, 2014). Widely implemented policies to prevent mother-to-child transmission include the provision of HIV-positive mothers with lifelong antiretroviral drugs to reduce the transmission through breast milk and recommendations to exclusively breastfeed for 6 months, breastfeed for at least 12 months, and continue breastfeeding for up to 24 months or longer (similar to the general population) while being fully supported for antiretroviral therapy (ART) adherence. It is recommended that when mothers decide to stop breastfeeding at any time, they should do so gradually within 1 month, not abruptly, and feed safe and appropriate food after breastfeeding stops (World Health Organization, 2016). Mothers or infants who have been receiving ARV drug prophylaxis should continue prophylaxis for 1 week after breastfeeding is fully stopped. Stopping breastfeeding abruptly is not advised as there seems to be no benefit of doing so for HIV-free survival at 24 months (Kuhn et al., 2008) or milk HIV RNA viral load (Phiri et al., 2006; Filteau, 2009). On the contrary, it does not give room for psychological adjustment for mother and child and also puts the mother at increased risk of mastitis. Although challenges still exist to the prevention of mother-to-child transmission program coverage in low- and middle-income countries, there has been considerable success, and there are now globally over 15 million children who are HIV-exposed and uninfected (HEU), 90% of whom live in sub-Saharan Africa (Prendergast and Evans, 2023). The fact remains, however, that HIV-exposed children, regardless of their HIV status, are at greater risk of malnutrition and, consequently, to an extent, slower motor and cognitive development than their HIV-unexposed counterparts (Sint et al., 2013; Abu-Raya et al., 2016).

HIV exposure *in utero* and early life has been linked to immune abnormalities, which are thought to have a negative effect on the child's response to infection and T cell-dependent antigens during routine vaccination in early life (Afran et al., 2014). In addition, most antiretroviral drugs cross the placenta (Venhoff and Walker, 2006) and have been linked to biological alterations in babies with varying effects on infant health. Third, HIV-1-infected mothers are at increased risk of co-infections, which can harm the health of their babies *in utero* or after birth. In resource-poor settings, frequent infections such as malaria and measles, together with malnutrition and poor socioeconomic circumstances, make it harder for HIV-exposed infants to recover from these early insults (Glennie et al., 2010), particularly in HIV-affected households, and may contribute to a vicious cycle of malnutrition and infections. Moreover, HIV-infected mothers are more likely to have low birthweight children compared to their uninfected counterparts (Bailey et al., 1999; Marinda et al., 2007), predisposing them to higher rates of morbidity and mortality (Lawn et al., 2005). Optimal feeding practices are of utmost importance to meet the nutritional needs of this vulnerable group.

Infant and young child feeding (IYCF) practices most importantly affect the nutritional status of children under 2 years of age. Early initiation of breastfeeding (within an hour of birth), exclusive breastfeeding for the first 6 months of life, and introduction of nutritionally adequate and safe complementary foods at 6 months together with continued breastfeeding up to 2 years or beyond is recommended by WHO and UNICEF (Pan American Health Organization, 2003; World Health Organization, 2003). Globally, only about 44% of infants below 6 months were exclusively breastfed over the period of 2015 to 2020 (WHO and UNICEF, 2021). In Ghana, the prevalence of exclusive breastfeeding, as reported by the Ghana Demographic Health Survey (GDHS) in 2015, was 52%, with the median duration of exclusive breastfeeding being about 4 months (Ghana Statistical Service (GSS), 2015).

The WHO recommends that children aged between 6 and 23 months of age should be fed from at least 5 out of a total of 8 food groups (breast milk; grains, roots and tubers; legumes and nuts; dairy products; flesh foods; eggs; Vitamin-A rich fruits and vegetables; and other fruits and vegetables) daily. They also recommend that breastfed infants aged 6–8 months should receive at least two feedings of solid, semi-solid, or soft foods, and those aged 9–23 months should receive at least three of such feeds. Non-breastfed children aged 6–23 months should receive at least four of such feeds or milk feeds, of which at least one must be a solid, semi-solid, or soft feed.

In a joint report, WHO and UNICEF outlined indicators for assessing these IYCF breastfeeding and complementary feeding practices (WHO and UNICEF, 2021). Those of interest to this study are listed and defined next. The infant and young child ever breastfed (EvBF) indicator is defined as the percentage of children born in the last 24 months who were ever breastfed. This indicator is useful for assessing the overall acceptance of breastfeeding. The infant and young child early initiation of breastfeeding (EIBF) is defined as the percentage of children born in the last 24 months who were put to the breast within 1 h of birth. Infant and young children exclusively breastfed for the first 2 days after birth (EBF2D) is defined as the percentage of children born in the last 24 months who were fed exclusively with breast milk for the first 2 days after birth. Continued breastfeeding between 12 and 23 months (CBF) is defined as the percentage of children 12–23 months of age who were fed breast milk during the previous day and replaced previous indicators that assessed breastfeeding at 1 year and 2 years of age.

The infant and young child minimum dietary diversity (MDD) is defined as the percentage of children 6–23 months of age who consumed foods and beverages from at least five out of eight defined food groups during the previous day. MDD is the most widely used maternal and child health (MCH) dietary metric and is routinely collected in studies in low- and middle-income countries (Miller et al., 2020). Infant and young child minimum meal frequency (MMF) is defined as the percentage of children 6–23 months of age who consumed solid, semi-solid, or soft foods (but also including milk feeds for non-breastfed children) at least the minimum number of times recommended during the previous day. For breastfeeding children, the infant and young children's minimum acceptable diet (MAD) is defined as receiving at least the minimum dietary diversity and minimum meal frequency for their age during the previous day, and for non-breastfed children, receiving at least the minimum dietary diversity and minimum meal frequency for their age during the previous day as well as at least two milk feeds. The Multiple Indicator Cluster Surveys (MICS), 2017/2018 in Ghana, reported that nationally, 41% of children aged 6–23 months met minimum meal frequency (MMF) and 29% met minimum dietary diversity (MDD), while 12% had minimum adequate diet (MAD) (Ghana Statistical Service (GSS), 2018).

Any factors associated with poor feeding practices hold importance in addressing the issue of malnutrition. It is therefore necessary to obtain information on IYCF feeding indicators in HIV-exposed children and their associated factors to guide the relevant policies and intervention studies. This study therefore aimed to determine infant and young child feeding practices among HIV-exposed children under 2 years old enrolled in a dietary intervention study and to identify the household, maternal, and child factors associated with the IYCF indicators measured. We also explored the relationships between IYCF indicators and nutritional status measured by anthropometry and anemia status.

Materials and methods

Study design and population

This study is a secondary analysis using the baseline data from a randomized controlled trial that aimed to examine the effectiveness of a 6-month soy-based supplementation intervention called KOKOPlus in improving nutritional status and child development among HIV-exposed children aged 6–18 months in Accra. It ran from August 2021 to July 2022. HIV-positive mother–child dyads who attended antiretroviral clinics in the Greater Accra Region were enrolled. The size of the sample was estimated for the larger supplementation trial at 590 with reference to the study by Prendergast et al., (2019), which recorded a 0.26 change in length for age z scores (LAZ) in a randomized control trial given significance level and power risks of 0.05 and 0.80, respectively. A predicted drop-out rate of 10% during follow-up was considered, bringing the final sample size to 649.

Recruitment into this study took place at adult antiretroviral and Child HIV Clinics at Korle-Bu Teaching Hospital, The Greater Accra Regional Hospital, Princess Marie Louise Children's Hospital, Ledzokuku-Krowor Municipal Assembly (LEKMA) Hospital, Shai-Osudoku District Hospital, Tema General Hospital, Tema Polyclinic, Ashaiman Polyclinic, Manhean Polyclinic, Pentecost Hospital-Madina, Madina Polyclinic Kekele, Weija Gbawe Municipal Hospital, Ga West Municipal Hospital-Amasaman, Ga North Municipal Hospital-Ofankor, Kaneshie Polyclinic, Mamprobi Polyclinic, Maamobi General Hospital, Legon Hospital, and Achimota Hospital. A database of HIV-positive mothers with children between 6 and 18 months of age was compiled from hospital records. Eligible mothers were contacted by phone or in person during clinic attendance and were invited to participate in the study. After mothers had agreed to participate in the study and completed informed consent forms, they were randomized to receive the intervention.

Eligibility for participation in the study included HIV-positive mothers and their children between 6 and 18 months of age attending antiretroviral clinics (ART) and child HIV clinics. Excluded were mothers who declined to participate in the study, children with severe acute malnutrition, children on hospital admission, and children with diagnosed or apparent congenital conditions that negatively affect the child's ability to eat and/or grow.

Ethical approval was obtained from three institutions: Institutional Review Board of Noguchi Memorial Institute for Medical Research (Federalwide Assurance 00001824, NMIMR-IRB CPN 058–20/21) and Ghana Health Service Ethics Review Committee and Korle-Bu Teaching Hospital Institutional Review Board (KTH-IRB).

Data collection and analyses

Data collection took place at the HIV Clinics at the health facilities enumerated above. Supplementary Table S1 shows the data collected and the time points.

Infant and young child feeding data

The WHO/UNICEF questionnaire to assess infant and young child feeding practices collected information on breastfeeding practices, the timing of initiation of complementary feeding, parental recall of the child's diet in the previous 24-h period, and meal frequency (WHO and UNICEF, 2021).

The IYCF indicators

Ever breastfed (EvBF): Percentage of children who were ever breastfed. Mothers were asked if their children were ever breastfed.

Early initiation of breastfeeding (EIBF): Percentage of children who were put to the breast within 1 h of birth.

Exclusively breastfed for the first 2 days after birth (EBF2D): Percentage of children who were fed exclusively with breast milk for the first 2 days after birth.

Exclusive breastfeeding is breastfeeding with no other food or drink, not even water. Thus, in this study, we did not include the exclusive breastfeeding rate for infants aged 0 to 6 months because we recruited study participants aged between 6 and 18 months.

Continued breastfeeding 12–23 months (CBF): Percentage of children 12–23 months of age who were fed breast milk during the previous day and night.

Introduction of solid, semi-solid, or soft foods 6–8 months: Percentage of infants 6–8 months of age who consumed solid, semi-solid, or soft foods during the previous day. The indicator was calculated based on a question that asked mothers about foods fed to the infant the day before during the day or at night.

Minimum dietary diversity 6–23 months (MDD): Percentage of children 6–18 months of age who consumed foods and beverages from at least five out of eight defined food groups during the previous day. group 1: breast milk; group 2: grains, roots, and tubers and plantain; group 3: pulses (beans, peas, and lentils), nuts, and seeds; group 4: dairy products (milk, infant formula, yogurt, and cheese); group 5: flesh foods (meat, fish, poultry, and organ meats); group 6: eggs; group 7: vitamin-A rich fruits and vegetables; group 8: other fruits and vegetables. Responses to questions about breastfeeding and other liquid intake were used to account for breast milk intake and other liquids, respectively. Mothers were asked to recall foods using a list-based approach. They were asked about the intake of foods from a list of 16 food groups eaten yesterday during the day or night. To calculate the dietary diversity score, the 16 food groups were categorized into eight food groups (WHO and UNICEF, 2021).

Minimum meal frequency 6–23 months (MMF): Percentage of children who consumed solid, semi-solid, or soft foods (including milk feeds for non-breastfed children) the minimum number of times or more during the previous day. The minimum number of times was calculated as two feeds of solid, semi-solid, or soft foods for breastfed infants aged 6–8 months; three feeds of solid, semi-solid, or soft foods for breastfed children aged 9–18 months; and four feeds of solid, semi-solid, or soft foods or milk feeds for non-breastfed children aged 6–28 months whereby at least one of the four feeds must be a solid, semi-solid, or soft feed. For breastfed children, this indicator was based on questions on the intake of breast milk and solid and semi-solid foods. For non-breastfed infants, the use of milk feeds was taken into account. The numerator for breastfed was children 6–18 months of age recruited into the study who consumed solids, semi-solids, or soft foods the minimum number of times during the previous day. For non-breastfed children, it was children 6–18 months of age recruited into the study who consumed at least four solid, semi-solid, or soft foods feeds or milk feeds during the previous day, with at least one of the four being a solid, semi-solid, or soft food feed.

Minimum acceptable diet 6–23 months (MAD) was computed as the percentage of children 6–18 months of age recruited into the study who consumed a minimum acceptable diet during the previous day and achieved the minimum meal frequency as well.

Sociodemographic data

Data on sociodemographics, household conditions, and mother's information were collected using a household questionnaire. All questionnaires were administered at the clinic electronically using Computer Assisted Personal Interview (CAPI) technology.

Household food security was assessed with an 8-item food insecurity questionnaire comprising questions that inquire about various aspects of food access, affordability, and availability, providing a comprehensive measure of a household's vulnerability to food insecurity (Bickel et al., 2000; Coleman-Jensen et al., 2019).

Anthropometry

All anthropometric measurements for children and their mothers were taken twice (and were repeated if they differed by more than 5 mm), and the mean values of the measurements were computed and used in the analysis. Anthropometric measurements were done in accordance with WHO guidelines (WHO and UNICEF, 2019). Recumbent length was measured for all the children using an infantometer since the children were below 2 years of age. The mother's height was recorded using a height meter. Weight was measured using the Tanita Electronic WB-100A/WB-110A Remote Display Version scale. Tared weighing was done for the children since they were unable to stand on their own. The scale was switched on, and when the reading was 0.0 kg, the mother was asked to mount the scale barefoot, wearing only light clothing. They were asked to stand still in the middle of the scale until their weight was displayed and recorded. After the weight appeared on the display, she remained standing on the scale while it was reset to zero. The child was then given to her, and the child's weight was recorded.

Nutritional status

For the children, weight-for-age, weight-for-length, and length-for-age were determined using the WHO AnthroPlus Software. Length-for-age < -2 standard deviations from the median of the WHO child growth standards was categorized as stunting. Underweight was categorized as weight-for-age < -2 SD, wasting as weight-for-length < -2 SD, and overweight as weight-for-length/height < -2 SD. Mother's body mass index (BMI): Body Mass Index (BMI) was used as one of the markers of nutritional status of the mothers and was calculated using the measured mother's weight in kg and height in meters. BMI was calculated as kg/m^2: Underweight BMI is less than 18.5, normal BMI is between 18.5 and less than 25.0, overweight BMI is between 25 and less than 30, and obese BMI is above 30.

Hemoglobin measurement

Children's hemoglobin levels were tested using a Hemocue® Hb 301 device according to the manufacturer's user guidelines and WHO guidelines on drawing blood (WHO, 2010).

Anemia status

Children with a hemoglobin concentration of less than or equal to 110 grams per deciliter (g/dl) were classified as anemic (WHO, 2011).

Household food security

A food insecurity experience scale was adopted. This questionnaire asked about the household's experience in the last 12 months. This is an 8-item tool to assess household food security status comprising questions about various aspects of food access, affordability, and availability, providing a comprehensive measure of a household's vulnerability to food insecurity. The responses were scored to categorize households into different levels of food security as follows: less than 3: food secure; 4–5: mildly food insecure; and 6–8: severely food insecure. Mild and severe food insecurities were combined as food insecure (Ghana Statistical Service GSS, Ghana Health Service GHS, Macro ICF, 2009).

Statistical analyses

Data were cleaned, and analysis was conducted using Stata version 16 (StataCorp. 2019. Stata Statistical Software: Release 16. College Station, TX: StataCorp LLC). The Shapiro–Wilk Test was used to test for normality. All values were normally distributed except for the mother's age. The median for the mother's age was 33 compared to the mean of 32.7, hence the categorization of the mother's age for the logistic regression. Descriptive statistics (means and standard deviations) were calculated for continuous variables, and categorical variables were reported as frequencies and percentages. For bivariate analysis, statistical associations between the various IYCF indicators and sociodemographic variables (mother's age, mother's level of education, mother's employment status, household income, mothers' BMI, and household food insecurity) were tested for statistical significance using the Chi-square test. For multivariate analyses, all predictor variables were initially put in the model, and the goodness-of-fit was assessed using the Likelihood Ratio (LR) test. When the value of p associated with the LR test was less than 0.05, a predictor variable with the largest value of p was dropped from the model. Predictor variables with the highest value of p were dropped until the model recorded an LR test associated with a value of p of less than 0.05. The level of statistical significance was set at $p < 0.05$. The odds ratios with 95% confidence intervals were derived from the adjusted logistic regression models, which were used to determine the predictors of IYCF indicators among HIV-exposed children.

Results

Sociodemographic characteristics of mothers of HIV-exposed children

Table 1 shows the sociodemographic characteristics of the mothers. The mean age of the mothers was 33 years, with the majority (58%) of them within the ages of 31 to 40 years. Secondary school education was the highest level reached but not necessarily completed for most mothers (70%). Seventy percent of them were employed, and 81% were married or living with their spouses. The Akan ethnic group formed the majority, and almost 90% of mothers were Christians. For the nutritional status of the mothers, their mean weight was 69 kg; 39% of them had normal BMIs, 58.7% were overweight, and 2% were underweight. The average household size was 4, with at least one child under 5 years. The majority of them stayed in compound houses (63%) and used water closets (WC) as their main toilet facility (49%). More than half of the women had a household income greater than GH¢500 ($42, GH¢1.00 is approximately $0.08). The minimum daily wage in 2022 (GH¢13.53) translates to GH¢419 per month, which was rounded to Gh¢500 (Kuhn et al., 2008). More women were from households that were food insecure (57%) than secure (43%).

TABLE 1 Characteristics of mothers, their children, and the households of HIV-exposed children aged 6–18 months from the antiretroviral clinics and HIV clinics in the Greater Accra Region.

Characteristics	Number	Percentage
Mothers' characteristics		
Age: mean (SD)	33 (5.5)	
15-30 yrs	223	34.4
31-40 yrs	376	58.0
Above 40 yrs	49	7.6
Highest level of education (%)		
No education	52	8.0
Primary	87	14.6
Secondary	449	75.3
Tertiary	60	10.1
Employment status (%)		
Unemployed	193	29.8
Marital Status (%)		
Never in union	93	14.4
Married/living with partner	525	81.0
Widowed/divorced/separated	30	4.6
Ethnicity (%)		
Akan	225	34.7
Ga/Dangme	133	20.5
Ewe	166	25.6
Other	124	19.1
Religion (%)		
Christian	567	87.5
Islam	78	12.0
Other	3	0.5
Weight: mean (SD)	69.1 (17.2)	
Height: mean (SD)	159.4 (7.5)	
BMI: mean (SD)	27.0 (5.8)	
Underweight	13	2.1
Normal	248	39.2
Overweight	203	32.1
Obese	168	26.6
Household characteristics		
Household size: mean (SD)	4.4 (1.6)	
Children under 5 years: mean (SD)	1.4 (0.6)	
Dwelling		
Separate house	167	25.8
Compound house	410	63.3
Container/uncompleted building	71	11.0

(Continued)

TABLE 1 (Continued)

Characteristics	Number	Percentage
Toilet facility		
Free range	29	4.5
WC	318	49.1
Pit/KVIP	126	19.4
Public toilet	175	27.0
Household income		
Less than gh500 (USD42)	167	36.0
Household food insecurity		
Food secure	280	43.2
Children's characteristics		
Age: mean (SD)	10.8 (3.8)	
6–12 months	410	63.3
13–15 months	140	21.6
16–18 months	98	15.1
Sex		
Female	322	49.7
Weight: mean (SD)	8.3 (1.4)	
Length: mean (SD)	72.0 (5.4)	
WAZ: mean (SD)	−0.664 (1.2)	
Underweight	76	11.7
HAZ: mean (SD)	−0.469 (1.4)	
Stunted	71	11.0
WHZ: mean (SD)	−0.514 (1.3)	
Wasted	61	9.4
HB: mean (SD)	10.2 (1.6)	
Anemic	205	31.8

BMI, body mass index; WAZ, weight-for-age *z* score; HAZ, height-for-age *z* score; WHZ, weight-for-height *z* score; HB, hemoglobin.

Characteristics of HIV-exposed children

The characteristics of the HIV-exposed children are also presented in Table 1. The mean age of the children was 10.8 months, with more than half (63%) of them within the age of 6–12 months. There was a balance between male representation among the children; 12% of the children were underweight, 11% were stunted, 9% were wasted, and 32% were anemic.

Infant and young child feeding practices

A descriptive summary of the IYCF practices of study participants is shown in Table 2. Almost all children (95%) had ever been breastfed, with more than half (53%) initiating breastfeeding within the first hour of delivery. The majority (79.0%) had exclusively breastfed for the first 2 days after birth. Almost all the infants (92%) between 6 and 8 months of age had been introduced to solid, semi-solid, or soft foods. Around one in four (26%) of the participants continued to breastfeed their children beyond 12 months.

TABLE 2 Infant and young children feeding practices among HIV-exposed children aged 6–18 months from the antiretroviral clinics and HIV clinics in the Greater Accra Region.

IYCF Indicators	Yes *n* (%)
Ever breastfed (EvBF)	615 (95.4)
Early initiation of breastfeeding (EIBF)	321 (53.2)
Exclusive breastfeeding for the first 2 days (EBF2D)	486 (79.0)
Continued breastfeeding (CBF)	67 (25.9)
Introduction of solid, semi-solid, or soft foods 6–8 months	217 (92.7)
Minimum meal frequency (MMF)	361 (54.3)
Minimum dietary diversity (MDD)	126 (18.7)
Minimum acceptable diet (MAD)	71 (10.6)

Only 19% of the children attained the minimum dietary diversity, and 11% attained the minimum acceptable diet. However, more than half (54%) of the children met the minimum meal frequency.

Factors associated with IYCF breastfeeding indicators

Factors found to be associated with IYCF breastfeeding indicators after bivariate analyses are presented in Table 3. Mothers who were married or living with a partner had higher rates of ever breastfeeding ($p < 0.05$) than those who were widowed, divorced, or separated and those who had never been in a union. Mothers' education was important, and those who had reached secondary education had the highest rates of continued breastfeeding between 12 and 18 months ($p < 0.01$), followed by primary, tertiary, and no education.

Factors associated with IYCF complementary feeding indicators

Table 4 presents the results of bivariate analyses and shows associations of other IYCF indicators for complementary feeding with sociodemographic characteristics. MDD and MAD were associated with the mother's age ($p < 0.01$), with a greater percentage of children of mothers in the 31–40 years group attaining MDD and MAD compared to those of mothers aged 15–30 years and mothers above 40 years. Children of employed mothers had higher rates of attainment of MDD ($p < 0.05$), MMF ($p < 0.01$), and MAD ($p < 0.01$) than children of unemployed mothers and children from households with household income greater than Ghc500 were more likely to attain MMF than those from households with household income less than Ghc 500 ($p < 0.05$). In addition, children from food-secure homes were more likely to attain MDD than those from food-insecure homes ($p < 0.01$).

Predictors of IYCF breastfeeding and complementary feeding

Logistic regression models were run to find predictors of IYCF practices. None of the breastfeeding indicator models were significant.

TABLE 3 Factors associated with IYCF breastfeeding indicators in HIV-exposed children aged 6–18 months from the antiretroviral clinics and HIV clinics in the Greater Accra Region.

	EvBF	EIBF	EBF2D	CBF
	n (%)	*n* (%)	*n* (%)	*n* (%)
Mother's age				
15-30 yrs	216 (35.1)	109 (34.0)	43 (33.3)	25 (37.3)
31-40 yrs	354 (57.6)	193 (60.1)	74 (57.4)	39 (58.2)
Above 40 yrs	45 (7.3)	19 (5.9)	12 (9.3)	3 (4.5)
Highest level of education				
None	48 (7.8)	22 (6.9)	13 (10.1)	3 (4.5)**
Primary	85 (13.8)	52 (16.2)	12 (9.3)	16 (23.9)
Secondary	427 (69.4)	225 (70.1)	88 (68.2)	42 (62.7)
Tertiary	55 (8.9)	22 (6.9)	16 (12.4)	6 (9.0)
Employment status				
Unemployed	185 (30.1)	94 (29.3)	38 (29.5)	14 (20.9)
Employed	430 (69.9)	227 (70.7)	91 (70.5)	53 (79.1)
Marital Status				
Never in union	86 (14.0) *	45 (14.0)	18 (14.0)	12 (17.9)
Married/living with partner	503 (81.8)	260 (81.0)	106 (82.2)	51 (76.1)
Widowed/ divorced/ separated	26 (4.2)	16 (5.0)	5 (3.9)	4 (6.0)
Mother's BMI				
Underweight	12 (2.0)	7 (2.2)	4 (3.2)	1 (1.5)
Normal	235 (39.0)	127 (40.2)	47 (37.3)	26 (40.0)
Overweight	195 (32.4)	110 (34.8)	33 (26.2)	23 (35.4)
Obese	160 (26.6)	72 (22.8)	42 (33.3)	15 (23.1)
Household income				
<=gh500	154 (35.2)	74 (32.9)	37 (39.0)	21 (50.0)
Greater than gh500	283 (64.8)	151 (67.1)	58 (61.1)	21 (50.0)
Household food insecurity				
Food secure	261 (42.4)	128 (39.9)	51 (39.5)	22 (32.8)
Food insecure	354 (57.6)	193 (60.1)	78 (60.5)	45 (67.2)

Chi-square analyses. EvBF, ever breastfed; EIBF, early initiation of breastfeeding; EBF2D, exclusively breastfed for the first 2 days after birth; CBF, continued breastfeeding 12–18 months; ISSSF, introduction of solid and semi-solid foods; BMI, body mass index, *p*-value (***$p < 0.001$; **$p < 0.01$; *$p < 0.05$).

Table 5 shows the results for complementary IYCF practices. Compared to mothers 15–30 years of age, children born to mothers between the ages of 31 and 40 years were twice as likely to have a diverse diet [AOR 2.1 (1.14, 3.85), $p < 0.01$] and three times as likely to achieve the minimum acceptable diet [AOR 3.0 (1.52, 5.92), $p < 0.001$], and those born to mothers above age 40 years had an even greater likelihood of attaining MDD [AOR 2.8 (1.11, 7.2), $p < 0.05$] compared to mothers 15–30 years. In addition, compared with children of mothers with no education, children of mothers who had some tertiary education were more than 5 times as likely to attain MDD [AOR 5.4 (1.1, 26.1), $p < 0.05$]. Children of employed mothers were more than one and a half times as likely to attain MMF compared to their counterparts whose mothers were unemployed [AOR 1.6 (1.1, 7.2), $p < 0.05$]. Coming from a household with income greater than GH¢500 gave a child 60% increased odds of attaining MMF [AOR 1.6 (1.01, 2.33), $p < 0.05$] compared to households with income less than GH¢500 while children from food insecure homes were 50% less likely to achieve MDD when compared to those from food secure households [AOR 0.5 (0.31, 0.86), $p < 0.01$].

Association between IYCF indicators and nutritional status

Bivariate analyses showed no significant associations between IYCF indicators and nutritional status (Table 6); however, multiple logistic regression with nutritional indices as continuous rather than categorical variables showed some statistically significant associations between IYCF and nutritional status. Attained MDD was associated with 20% less Hb [AOR 0.8 (0.71, 0.99), $p < 0.05$], and MMF was negatively associated with WHZ [AOR 0.8 (0.72, 0.98), $p < 0.05$] (Table 7).

Discussion

This cross-sectional study sought to determine infant and young child feeding practices among HIV-exposed children under 2 years of age enrolled in a dietary intervention study, to explore factors associated with the IYCF indicators and to explore any associations between IYCF indicators and the children's nutritional status. According to the last GDHS (Ghana Statistical Service (GSS), 2015), the national EvBF rate was 98% of last-born children born in the preceding 2 years, and 56% were breastfed within an hour of birth. Our results reveal comparable breastfeeding practices amongst our population of children born to HIV-positive mothers, with an EvBF rate of 95% and EIBF at 53%.

Although a significant association was lost between marital status and EvBF after multivariate analyses, the bivariate analyses showed a positive association of breastfeeding with marital or relationship stability ($p < 0.05$). Living with a partner could mean that mothers have more support from a significant other for their own, as well as their child's care, including breastfeeding (Renata et al., 2022). Having said that, we note that breastfeeding was universal in our population (95%), which is typical of the cultural norm of breastfeeding in Ghana. This is similar to findings in Nigeria (Umeobieri et al., 2018) and Kenya, where the lack of male involvement has been cited as a barrier to breastfeeding (Samburu et al., 2021), and in South Africa, HIV-positive women who attempted breastfeeding had better social support and HIV-related social support (Remmert et al., 2020).

Mother's education positively influenced continued breastfeeding after 12 months ($p < 0.01$). Only 5% of non-educated mothers breastfed beyond 12 months. Sociodemographic factors such as the education of HIV-positive mothers have been documented to influence maternal knowledge, attitudes, and practices. Mother's education has been reported to facilitate understanding and adherence to recommendations (Renata et al., 2022). A retrospective cohort study of sociodemographic factors that enhance breastfeeding uptake in HIV-positive women using DHS surveys from multiple sub-Saharan African countries found that women with the highest levels of

TABLE 4 Factors associated with IYCF complementary feeding indicators of HIV-exposed children aged 6–18 months from the antiretroviral clinics and HIV clinics in the Greater Accra Region.

	ISSSF at 6–8 month	Minimum meal frequency	Minimum dietary diversity	Minimum acceptable diet
	n (%)	*n* (%)	*n* (%)	*n* (%)
Mother's age				
15-30 yrs	81 (37.3)	110 (31.9)	15 (20.8)**	11 (16.2)**
31-40 yrs	121 (55.8)	206 (59.7)	49 (68.1)	53 (77.9)
Above 40 yrs	15 (6.9)	29 (8.4)	8 (11.1)	4 (5.9)
Highest level of education				
None	18 (8.3)	21 (6.1)	2 (2.8)	3 (4.4)
Primary	34 (15.7)	43 (12.5)	10 (13.9)	10 (14.7)
Secondary	145 (66.8)	249 (72.2)	49 (68.1)	44 (64.7)
Tertiary	20 (9.2)	32 (9.3)	11 (15.3)	11 (16.2)
Employment status				
Unemployed	75 (34.6)	88 (25.5)**	14 (19.4)*	13 (19.1)**
Employed	142 (65.4)	257 (74.5)	58 (80.6)	55 (80.9)
Marital Status				
Never in union	28 (12.9)	52 (15.1)	8 (11.1)	11 (16.2)
Married/living with partner	181 (83.4)	276 (80.0)	61 (84.7)	55 (80.9)
Widowed/divorced/separated	8 (3.7)	17 (4.9)	3 (4.2)	2 (2.9)
Mother's BMI				
Underweight	4 (1.2)	5 (1.5)	2 (2.9)	0 (0.0)
Normal	85 (40.1)	134 (39.8)	23 (33.3)	20 (30.3)
Overweight	66 (31.1)	104 (30.9)	28 (40.6)	30 (45.5)
Obese	57 (26.9)	94 (27.9)	16 (23.2)	16 (24.2)
Household income				
<=gh500	48 (32.0)	80 (31.4)*	17 (37.8)	15 (32.6)
Greater than gh500	102 (68.0)	175 (68.6)	28 (62.2)	31 (67.4)
Household food insecurity				
Food secure	110 (50.7)	151 (43.8)	42 (58.3)**	34 (50.0)
Food insecure	107 (49.3)	194 (56.2)	30 (41.7)	34 (50.0)

Chi-square analyses. ISSSF: introduction of solid and semi-solid foods, BMI: Body mass index, *p*-value (**$p < 0.01$, *$p < 0.05$).

education and those without partner support were less likely to breastfeed (Caldwell et al., 2023).

A study in Uganda that looked at the morbidity of HIV-exposed children found that at 6 months, 12 months, and 24 months, the proportion of children breastfeeding was consistently lower for HIV-exposed than for HIV-unexposed children; at 6 months of age, 84.4% vs. 99.7% ($p < 0.0001$); at 12 months of age, 29% vs. 99% ($p < 0.001$); and at 24 months of age, 0 vs. 24.4% ($p < 0.0001$) (Marquez et al., 2014). While mothers living with HIV tend to avoid stigmatization by practicing breastfeeding norms such as initiating breastfeeding (Oguta et al., 2004; Oladokun et al., 2010; Tariq et al., 2016; Umeobieri et al., 2018), their fear of transmitting the virus to their children may cause them to stop breastfeeding earlier than their non-HIV counterparts (Fadnes et al., 2009; Flax et al., 2017; Anderson et al., 2021). HIV-exposed children are less likely to be breastfed after 12 months compared to their unexposed counterparts, as observed in Botswana and Uganda (Muhangi et al., 2013; Chalashika et al., 2017).

For IYCF complementary feeding practices, 2017/2018 MICS reported that nationally, 41% of the children met minimum meal frequency (MMF), 29% met minimum dietary diversity (MDD), and 12% had minimum adequate diet (MAD) (Ghana Statistical Service (GSS), 2018). Intake of MDD was higher among children from wealthier households, with high levels of maternal education, and in urban areas. In addition, mothers within the age bracket of 31 to 40 years were more likely to meet MAD (Ghana Statistical Service (GSS), 2018). Almost all infants in our study between 6 months and 8 months (93%) had been introduced to solid, semi-solid, or soft foods compared to the national rate of 79% (Ghana Statistical Service (GSS), 2018). The higher percentage of mothers who had introduced complementary foods at this stage could be an indication that mothers in our study were more inclined to cease breastfeeding after 6 months, possibly to reduce the chances of MTCT.

While MMF was higher in our study than nationally (54% vs. 41%), MDD was much lower than national rates (19% vs. 29%), and

TABLE 5 Predictors of complementary IYCF indicators among HIV-exposed children aged 6–18 months from the antiretroviral clinics and HIV clinics in the Greater Accra Region.

	Minimum meal frequency	Minimum dietary diversity	Minimum acceptable diet
	AOR [95% CI]	AOR [95% CI]	AOR [95% CI]
Mother's age			
15-30 yrs		Ref	Ref
31-40 yrs		2.1 [1.1, 3.8]**	3.0 [1.5, 5.9]***
Above 40 yrs		2.8 [1.1, 7.2]*	1.6 [0.5, 5.5]
Highest level of education			
None		Ref	Ref
Primary		3.7 [0.8, 17.8]	2.1 [0.5, 8.0]
Secondary		3.3 [0.8, 14.2]	1.8 [0.530, 6.0]
Tertiary		5.4 [1.1, 26.1] *	3.6 [0.9,13.9]
Employment status			
Unemployed	Ref		Ref
Employed	1.6 [1.0, 2.3]*		1.7 [0.9, 3.2]
Household income			
Less than gh500 (USD42)	Ref		
Greater than gh500	1.6 [1.1, 2.3]*		
Household food insecurity			
Food secure		Ref	
Food insecure		0.5 [0.3, 0.9]**	

Multiple logistic regression. AOR, adjusted odds ratio; CI, confidence interval; Ref, reference group; p-value (***p < 0.001; **p < 0.01; *p < 0.05).

MAD was received by a similar proportion (11% vs. 12%). Although meals may have been frequent enough, they were not diverse enough for the majority of the children. These were children of mothers who were attending ART clinics and who would receive nutrition education from time to time. This could account for more frequent meals than the general population; however, they may have had fewer resources and been less food secure than the general population to provide the necessary diversity in meals for their children, resulting in similar MAD rates. Bivariate analyses showed that MMF was significantly and positively associated with mothers' employment (p < 0.01) and household income (p < 0.05), and these associations remained strong in the logistic regression, showing that the availability of more financial resources likely translates to greater frequency of feeding (Table 5).

MDD showed a significant and positive association with mothers' age, employment, and household food security in bivariate analyses, and only the association with employment was lost with multivariate analyses. An additional positive association was discovered with tertiary education after logistic regression analyses. Better household food security meant that there were resources available to feed children a more diverse diet. It is also possible that a better understanding of IYCF recommendations on feeding a diverse diet, leading to better practice, comes with age and experience and is facilitated by higher education. In line with our findings, food insecurity has been found to make it difficult for HIV-positive mothers to follow complementary feeding guidelines (Flax et al., 2016).

Bivariate analyses showed that MAD was positively and significantly associated with mothers' age and employment, but after multiple logistic regression, only the mother's age was significantly associated with MAD. Mothers between the ages of 31 and 40 years were the most likely to feed their children diverse diets compared to those in the 15–30 age bracket. There could be a number of reasons for this. While the 31–40 years age group may have the benefit of learning more from experience than the youngest age group, they may be more actively and gainfully employed than the above 40 age group and, therefore, have more financial empowerment to access a more diverse diet for their children. This finding is in line with the Ghana 2017/18 MICS report (Ghana Statistical Service (GSS), 2018).

Standard DHS data of Sub-Saharan African countries conducted between 2010 and 2020 were analyzed to determine the minimum acceptable diet (MAD) intake and its associated factors among children aged 6–23 months. Results showed that factors such as achievement of secondary education and higher for the women, being employed, having media exposure, richest household wealth, breastfed child, rural residence, and living in upper middle-income country were significantly associated with MAD (Belay et al., 2022). Studies on IYCF in HIV-exposed children have been conducted in Ethiopia (Haile et al., 2015; Esubalew et al., 2018; Yisak et al., 2020), Malawi (Flax et al., 2016), and Uganda (Kumbakulu et al., 2022), with MAD rates ranging from 40% in Malawi to 34% in Ethiopia, with a myriad of associated factors. These include mothers' education sometimes acting as a negative or positive predictor of IYCF, inadequate information about infant feeding acting as a barrier to good practice, household wealth and media exposure as positive factors for good IYCF practice. A study conducted among HIV-positive mothers in the Manya-Krobo Municipality of Ghana reported that factors such as being married or in a stable relationship, having a supportive partner, adhering to ART, age of mother, education on IYCF received from the health facilities and influence of the media impacted the IYCF practices (Tofoatsi, 2005).

Ghana has a high burden of child undernutrition (Boah et al., 2019). Nationally, the rates of underweight stunting and wasting in children under 5 years in Ghana are 13, 18, and 7%, respectively (Ghana Statistical Service (GSS), 2018). The prevalence of underweight in this study population, 12%, was similar to the national prevalence, as was the prevalence of wasting (9%). Stunting, however, was lower in our population at 11%. We acknowledge that the national figures are for under-fives while our study population is under 2 years of age. It could be, however, that given a few more years, the stunting rates in our sample may approach the national figure as stunting is an indicator of long-term malnutrition, and malnutrition has been associated with the child's age in Ghana (Boah et al., 2019). The rates of stunting and wasting observed in this study are of medium public health importance, and the rate of underweight is of high public health importance (De Onis et al., 2019).

Anemia was highly prevalent in our study population (32%) but lower compared to the national prevalence of 66% in under-fives (Ghana Statistical Service (GSS), 2015) which is considered to be a severe public health problem (World Health Organization, 2020). This difference could be due to the fact that the mothers in our study have regular access to healthcare and may have more regular checks for low

TABLE 6 Association between IYCF breastfeeding and complementary feeding indicators and nutritional status of HIV-exposed children aged 6–18 months from the antiretroviral clinics and HIV clinics in the Greater Accra Region.

	WAZ	HAZ	WHZ	HB
	Underweight	Stunted	Wasted	Anemic
EBF [a] (Yes)	71 (11.5)	67 (10.9)	58 (9.4)	192 (31.3)
(No)	5 (16.7)	4 (13.3)	3 (10.0)	12 (42.9)
EIBF [a] (Yes)	40 (12.5)	33 (10.3)	34 (10.6)	114 (35.5)
(No)	31 (10.5)	34 (11.6)	24 (8.2)	78 (26.7)
EBF2D [a] (Yes)	15 (11.6)	13 (10.1)	12 (9.3)	35 (27.3)
(No)	56 (11.5)	54 (11.1)	46 (9.5)	157 (32.4)
CBF [a] (Yes)	12 (17.9)	13 (19.4)	8 (11.9)	16 (23.9)
(No)	24 (12.5)	24 (12.5)	21 (10.9)	61 (31.9)
ISSF at 6–8 months [a] (Yes)	18 (8.3)	17 (7.8)	16 (7.4)	67 (31.2)
(No)	0 (0.0)	0 (0.0)	1 (5.9)	7 (41.2)
Minimum dietary diversity [a] (Yes)	6 (8.3)	5 (6.9)	6 (8.3)	18 (25.4)
(No)	70 (12.2)	66 (11.5)	55 (9.6)	187 (32.6)
Minimum meal frequency [a] (Yes)	41 (11.9)	32 (9.3)	37 (10.7)	112 (32.8)
(No)	33 (11.2)	37 (12.5)	22 (7.6)	91 (31.0)
Minimum acceptable diet [a] (Yes)	8 (11.8)	7 (10.3)	7 (10.3)	17 (25.4)
(No)	68 (11.8)	63 (10.9)	54 (9.4)	187 (32.6)

Chi-square analyses. EBF, ever breastfed; EIBF, early initiation of breastfeeding; EBF2D, exclusively breastfed for the first 2 days after birth; CBF, continued breastfeeding 12–18 months; ISSSF, introduction of solid and semi-solid foods; [a] *p*-values showed no statistical significance; Yes, followed IYCF recommendations; No, did not follow IYCF recommendation.

Hb and iron supplementation than the general population, especially when their children are unwell. In sub-Saharan Africa, risk factors for anemia are age, birth order, sex, comorbidities (such as fever, diarrhea, and acute respiratory infection), malnutrition or stunting, maternal education, maternal age, mother's anemia status, household wealth, and place of residence (Obasohan et al., 2020). In Ghana, anemia in children is associated with monotonous diets, poor feeding habits during weaning periods, and meals that lack iron, vitamins, and other essential nutrients. Children from poorer and larger households are at higher risk of anemia (Aheto et al., 2023). Lower maternal education, maternal unemployment, and lower household wealth index are the sociodemographic factors most commonly associated with infant undernutrition in sub-Saharan Africa (Chola et al., 2020).

Our study failed to find any meaningful associations between IYCF indicators and nutritional status. Multiple logistic regression with indices of nutritional status treated as continuous variables showed an inverse relationship between MMF and WHZ and between MMD and anemia, which was contrary to expectation. These contrary results may be due to the fact that IYCF indicators were based on a single 24-h recall, which is not representative of habitual food intake. Current nutritional status is a result of habitual food intake, among other factors. The possibility of recall and response bias with regard to IYCF indicators also cannot be ruled out. A study by Saaka et al. in Northern Ghana also found that apart from timely initiation of complementary feeding at 6 months, none of the WHO recommended IYCF indicators, including minimum dietary diversity, minimum meal frequency, and minimum acceptable diet, were associated with HAZ scores of infants 6–23 months of age (Saaka et al., 2015). Some studies, however, have found associations between adequate IYCF practices, especially minimum dietary diversity, and the growth of children. In sub-Saharan Africa, limited MMD has been associated with stunting (Aboagye et al., 2021). A study in 21 countries, including 12 in Africa, found that minimum infant dietary diversity is the IYCF complementary feeding indicator most consistently associated with positive growth patterns (Onyango et al., 2014).

Strengths and limitations of study

This study has contributed to filling the gaps in IYCF of HIV-exposed infants as there are few such studies, especially in sub–Saharan Africa. In addition, we used the most recent WHO/UNICEF IYCF indicators to assess HIV-exposed children based on current feeding recommendations for IYCF in the context of HIV. Our participant age range of 6–18 months, however, was not fully aligned with the target age group for IYCF complementary feeding indicators, which is 6–24 months. Comparisons with national figures for malnutrition, which are usually based on children 0–5 years, were also a limitation. Another limitation of our study is the fact that it failed to identify expected significant associations between IYCF and nutritional status. Measures of habitual intake would have been more useful.

Conclusion

Breastfeeding is nearly universal among HIV-positive women and is associated with mothers' education and marital status. Continued breastfeeding between 12 and 24 months is not practiced by 75% of HIV-positive mothers. Earlier cessation than recommended could be due to concerns about transmitting the virus. There is a need for more education and support for breastfeeding beyond 12 months, with special attention given to those with low education. Malnutrition rates were of medium (HAZ and WHZ) and high (WAZ) public health significance, and anemia was of moderate public health concern. There is an urgent need for a national focus on improving IYCF and the nutritional status of HIV-exposed children, as this is a vulnerable group. Health workers should be given relevant training in IYCF in the context of HIV infection to assist HIV mothers through regular nutrition education. Affordable iron-rich foods need to be highlighted. In addition, since MDD was significantly associated with food security, market-based interventions that increase the availability and affordability of nutritious foods should be considered. Social support programs for vulnerable households that subsidize nutrient-rich foods, especially iron-rich foods, could improve their IYCF practices.

TABLE 7 Association of IYCF indicators with nutritional status of HIV-exposed children aged 6–18 months from the antiretroviral clinics and HIV clinics in the Greater Accra Region.

	WAZ	HAZ	WHZ	HB
	AOR [95% CI]	AOR [95% CI]	AOR [95% CI]	AOR [95% CI]
EvBF	1.3 [0.925, 1.780]	1.0 [0.761, 1.349]	1.6 [1.126, 2.264]	0.8 [0.611, 1.023]
EIBF	0.9 [0.818, 1.087]	0.9 [0.863, 1.142]	1.0 [0.866, 1.175]	1.0 [0.921, 1.170]
EBF2D	1.1 [0.858, 1.300]	1.0 [0.841, 1.180]	1.1 [0.918, 1.245]	0.9 [0.800, 1.024]
CBF	0.8 [0.560, 1.107]	0.7 [0.536, 0.917]	1.1 [0.819, 1.478]	0.9 [0.742, 1.143]
Minimum meal frequency	1.1 [0.874, 1.223]	1.2 [1.040, 1.381]	0.8 [0.716, 0.983]*	0.9 [0.834, 1.059]
Minimum dietary diversity	1.1 [0.865, 1.317]	1.1 [0.938, 1.328]	0.9 [0.766, 1.145]	0.8 [0.714, 0.989] *
Minimum acceptable diet	1.2 [0.960, 1.477]	1.2 [0.976, 1.403]	1.1 [0.870, 1.299]	0.9 [0.761, 1.061]

Multiple logistic regression. EvBF, ever breastfed, EIBF: early initiation of breastfeeding; EBF2D, exclusively breastfed for the first 2 days after birth; CBF, continued breastfeeding 12–18 months; WAZ, weight-for-age *z* score; HAZ, height-for-age *z* score; WHZ, weight-for-height *z* score; HB, hemoglobin; AOR, adjusted odds ratio; CI, confidence interval, *p*-value (***$p < 0.001$;**$p < 0.01$, *$p < 0.05$).

Special attention should be paid to younger, less educated, and lower socioeconomic status mothers.

HIV infection coupled with ART exposure affects the maternal gestational environment and can also affect the immune system of the exposed children, making them vulnerable to poor nutritional status right from birth. There is a paucity of information on the dietary intake of HIV-exposed children. This study aimed to determine infant and young children's feeding practices among HIV-exposed children under 2 years by measuring indicators outlined in a recent joint report by WHO and UNICEF (2021). The indicators of interest in this study were the introduction to solids, semi-solids, and soft foods, minimum dietary diversity (MDD), minimum meal frequency (MMF), and minimum acceptable diet (MAD). Our study also determined the correlates of the IYCF indicators measured.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

This study involving human subjects was approved by the Institutional Review Board of Noguchi Memorial Institute for Medical Research, University of Ghana (Federalwide Assurance 00001824, NMIMR-IRB CPN 058–20/21), Ghana Health Service Ethics Review Committee and Korle-Bu Teaching Hospital Institutional Review Board (KTH-IRB). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

GF, FY, GT, GA, and BB designed the research. GF, BB, GT, GA, VA, PP, JD, and MN conducted the research. BB analyzed the data. GF and BB interpreted the data. MA, BB, and GF wrote the article. GF and FY provided the critical revision of the manuscript for important intellectual content. All authors have read and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1251611/full#supplementary-material

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