

Exploring indigenous fruits and vegetables with potential cardiometabolic health benefits: Understanding barriers and facilitators to consumption

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Abstract

Indigenous Fruits and Vegetables (IFV) may offer sustainable remedy for the surging cardiometabolic dysfunction in sub-Saharan Africa. In Uganda consumption of IFV is pervasively low, despite a rich diversity. Our study aimed to catalogue IFV reputed for cardiometabolic benefits as well as understand the determinants of consumption. We collected data around the Greater Kampala Metropolitan Area (GKMA) through Focus Group Discussions (FGD), Key Informant Interviews (KII) and market surveys. Participants for the FGD were recruited from the general population while for KII, farmers, ethnobotanists, nutritionists, herbalists, and health workers were interviewed. We conducted surveys in supermarkets and open-air markets together with explorative interviews with market vendors. Discussions were audio recorded, transcribed verbatim and analysed thematically. We performed phenolic characterisation of the identified IFV using Phenol-Explorer and PhytoHub databases. Eleven FGD (84 participants), 19 KII, and 12 food market surveys were conducted. Participants ages ranged from 19 to 80 years. Three out of the 11 FGD were conducted among younger adults (19–34 years). *Tamarindus indica*, *Cleome gynandra*, *Solanum anguivi*, and *Hibiscus sabdariffa* were most cited as potent against cardiometabolic dysfunctions. *T. indica* had the highest levels of total polyphenols. Consumption was influenced by the sensory appeal, awareness of health benefits, seasonality and social misconceptions whereby IFV are considered food for the poor or linked to food insecurity. Other barriers to IFV consumption were observed to be low food preparation skills, food safety concerns, and the diversity of fast foods. Young adults had low knowledge of IFV and were less willing to consume IFV. Food market survey revealed a scarcity of fresh and processed IFV. Our study revealed that several IFV may have beneficial cardiometabolic benefits, but consumption is impeded by several food environment constraints.

1. Introduction

Indigenous foods represent a large genetic diversity of ruderals and conventionally farmed food species. These foods constitute a bedrock for food diversity and food security and are a symbol of cultural identity in sub-Saharan Africa (SSA) [1–3]. The Food and Agriculture Organization (FAO) of the United Nations has described indigenous foods as “foods that indigenous people have access to locally, without having to purchase them, and within traditional knowledge and the natural environment from farming or wild harvesting” [4]. The term African indigenous vegetables was then coined to refer to “all categories of plants whose leaves, fruits or roots are acceptable and used as vegetables by rural and urban communities through custom, habit and tradition” [5].

In order to accelerate food system transformation and enhance the achievement of Sustainable Development Goals (SDGs), the EAT-Lancet Commission proposed a planetary health diet consisting of more plant-based foods and minimal animal-source foods [6]. The proposition is in part, a countermeasure to the increasing suboptimal cardiometabolic health and a lever to optimize environmental sustainability. The SSA is experiencing an increase in the suboptimal cardiometabolic health largely due to the predominance of low-quality carbohydrate-based diets with minimal fruits and vegetables, and a steadily rising fast food culture [7–9].

Beyond conventional nutrition, Indigenous Fruits and Vegetables (IFV) possess bioactive elements reputed for health promoting benefits [10–13]. The wealth of bioactive ingredients motivates the use of these foods as complementary therapy for cardiometabolic dysfunction [13–16]. Evidence from human trials, shows that many of these foods either whole or extract, are potent against glucose dysregulation, high blood pressure, dyslipidaemia, central obesity, vascular dysfunction, and inflammations [17–20]. The efficacy of IFV is attributed to the abundance of polyphenols that they contain [13, 21].

The health benefits notwithstanding, the consumption of fruits and vegetables remains generally low in Low- and Middle-Income Countries (LMICs) [22–25]. For example, despite the rich diversity of IFV in Uganda [26], 27% of Ugandans do not consume any fruit or vegetable in a week while 88% never meet the WHO recommendation of at least 400 g/person/day of fruits and vegetables [27]. The neglect of IFV is a salient threat that could lead to their extinction [28, 29]. It is noteworthy that 86.4% of the IFV in Uganda have been lost in the period 1989 to-date [26, 30, 31]. Amidst the progression in suboptimal cardiometabolic health among Ugandans [23, 27, 32], IFV are envisaged to offer sustainable remedy as adjuvant therapies if underpinned scientific evidence. This study explored the diversity of IFV locally claimed to have potential cardiometabolic health benefits, and the determinants of consumption of these foods. The study also characterised the polyphenols of the identified foods as an initial step towards evaluating their therapeutic potential.

2. Methodology

This study is reported following the Consolidated Criteria for Reporting Qualitative research (COREQ) [33]. A three-pronged approach was used. A schematic overview of the different steps of this study is shown in Fig. 1. The first step involved conceptualization of indigenous foods in the context of Uganda through the review of grey literature and Delphi rounds with experts. In the second step, we held Focus Groups Discussion (FGD), and Key Informant Interviews (KII) to catalogue IFV with potential cardiometabolic benefits and document the barriers and facilitators to consumption. Lastly, we conducted a cross-validation for step 2. Cross validation involved market surveys to determine the diversity, availability, price of IFV and also understand the demographics of the regular consumers of IFV. Additionally, we performed a phenolic characterization of the identified IFV to gain scientific insight into the potential cardiometabolic benefits. The study was approved by the Uganda National Council of Science and Technology (HS2248ES) and the study was performed in accordance with the ethical standards as laid down in the Declaration of Helsinki and all participants gave informed written consent to participate in this study. The study complied with the 1989 International Union for Conservation of Nature guidelines on research involving species at risk of extinction, with special reference to scientific collecting of threatened species.

2.1. Conceptualization of indigenous food in Uganda

We conducted a review of the grey literature of IFV reputed for cardiometabolic benefits in Uganda. A systematic search of grey literature was performed in Google using the following keywords: ('Food system' AND 'Uganda' AND 'environment' AND 'biodiversity' AND 'nutrition' AND 'culture' AND 'traditional knowledge' AND 'rural' AND 'food for traditional medicine' AND 'trade' AND 'wild food' AND 'food for hunger' AND 'neglected plants' AND 'indigenous food'). In

this electronic search, organisations that extensively provided material relevant to our study were the Natural Chemotherapeutic Research Institute (NCRI), Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), National Agricultural Research Organisation (NARO), National Council of Traditional Healers and Herbalists Associations (NACOTHA), and the National Environment Management Authority (NEMA). These organisations were physically visited to access such material as reports, theses, magazines and pamphlets that could not be obtained through electronic searches. Subsequently, in multiple Delphi rounds [34], a panel of 12 experts from the fields of health, botany, herbal medicine, nutrition, and food policy agreed on the definition of indigenous food in the context of Uganda, listed examples of IFV and the ascribed cardiometabolic benefits. The agreed upon definitions were used to validate responses of FGD and KII while examples of IFV generated were incorporated into the compiled list of IFV.

2.2 Focus Group Discussion and Key informant interviews

2.2.1 Study design and participants

This study used a generic qualitative interpretative research design. The study involved adult men and women (≥ 18 years) from the Greater Kampala Metropolitan Area (GKMA) regardless of their health status. FGD participants were recruited from the general population with the help of community mobilizers, health facilities, and agricultural extension workers. Key informants were drawn from NCRI, National Crops Resources Research Institute (NaCRRI), Plant Genetic Resource Centre (PGRC), NACOTHA, Health service, academia, freelance-herbalists, and district agricultural extension services. Participants were recruited using purposive and snowballing sampling techniques.

2.2.2 Theoretical framework

Food consumption behaviour can be explained by an array of complex interaction of intertwined factors both at individual and environmental levels conceptualized through theoretical models [35–37]. We used a modified theoretical framework premised on the Theory of Planned Behaviour and specific constructs from the Social Cognitive Theory, Health Belief Model, Precautionary Adoption Process Model, and social support theory. The modified theoretical framework, **supplementary figure** was necessary because no theory can solely describe a given behaviour [38]. The model guided the development of the questioning framework and analysis of FGD and KII. Further details of the development of this modified model have been published elsewhere [39].

2.2.3 Data collection

The investigator moderated the FGD and KII assisted by a silent observer who took notes on non-verbal individual behaviour and group interactions. Using semi-structured questioning routes, open-ended questions were followed up by more specific probes to clarify and extend responses. The discussions were audio-recorded and lasted between 60 and 90 minutes. FGD and KII were conducted in English, and Luganda (local language in central Uganda). Before the start of each focus group, the moderator explained to the participants the reasons for conducting the FGD/KII. Participants received refreshments and transport refund as an incentive for their participation. In order to obtain age-related opinions and allow freedom of expression during the FGD, participants were grouped into two different age categories: young adults (18–34 years) and the elderly (≥ 35 years).

2.2.4 Data analysis

Audio recordings were transcribed verbatim, translated into English for the FGDs and KII conducted in Luganda, and cross-checked by two researchers. Using the thematic content data analysis, two investigators independently read the transcripts and developed the initial coding framework. The framework was discussed among the two researchers to identify similarities and contrasts. In case of disagreements on the coding, a third researcher was consulted. The resultant codebook was used to work through all the transcripts. NVivo software (version 12.0) was used to support the data coding process. Generated codes from all transcripts were organised together into a second coding framework. Codes with overlapping content were grouped into categories. The categories of codes were then grouped into themes using the theoretical framework to generate the final codebook. Two researchers synchronised the final coding frameworks which was then shared with the third researcher. Inclusion of factors was based on the frequency, and specificity. The non-verbal behaviour and group interactions were equally considered. The interaction of these themes was shaped by three ecological levels: intra-individual, sociocultural, and environmental levels and therefore findings are reported accordingly. Both FGD and KII factors are presented together except where views were divergent. The most commonly used IFV for adjuvant cardiometabolic therapies were determined by the frequency of citation in both FGD and KII.

2.3 Cross-validation

2.3.1 Market survey

Six open-air food markets and six supermarkets were purposively selected around GKMA. Open-air food markets were Mukono, Seeta, Kireka, Kajjansi, ST. Balikuddembe (Owino), and Nakasero. We collected data through transect walks. In addition, in each market three vendors selling at least 10 different IFV were selected for a structured interview. The themes of the interview included pricing, seasonality of IFV, the demographics of the ardent customers of IFV, the variations in sales at the different times of the day, storage techniques, and knowledge of potential cardiometabolic benefits of IFV they sell. Further, vendors were asked to report on the customers' perceptions of IFV relative to other exotic fruits and vegetable varieties. Availability of IFV in open-air food markets is reported as the proportion of surveyed food stalls selling a given indigenous fruit or vegetable in each market location. In the supermarkets we registered all food products containing indigenous fruits or vegetables as either principal products or ingredients in another product, pricing, nutrition information, and health claims included on the product package. Comparison of prices of IFV between the open-air food markets and supermarkets was not feasible due to large variations in the weight and form of IFV.

2.3.2 Phenolic characterisation of IFV

The polyphenolic characterisation was done in two steps. First, taxonomic classification and proofing of both local and scientific names of the identified IFV. The compiled list of the local name and a photograph of each IFV was reviewed by a herbarium specialist for taxonomy. The specialist also identified

potential availability of other varieties of given species. Correctness of scientific names was checked using the International Plant Names Index database [40]. In the second step, we searched in databases such as Phenol Explorer [41] and PhytoHub [42] to determine the polyphenolic composition of the identified IFV.

3. Results

After 11 FGD and 19 KII were conducted, no new themes were emerging. Each focus group ranged between 6 and 8 people and altogether totalled to 84 participants with a mean age of 43 years. Three out of the 11 FGD were conducted among younger adults. The socio-demographic characteristics of participants are presented in Table 1.

Table 1
Socio-demographic characteristics of participants of both focus group discussions and key informant interviews.

Parameter	Participants in FGD (n = 84)		Participants in KII (n = 19)	
	n	%	n	%
Gender				
Male	30	35.7	12	63.2
Female	54	64.3	7	36.8
Age				
18–34 years	32	38.1	4	21.1
≥35 years	52	61.9	15	78.9
Employment status				
Employed	55	65.5	19	100
Not employed	29	34.5	0	0
Marital status[#]				
Single	25	31.3	4	21
Married	44	55	14	73.7
Widowed	11	13.7	1	5.3
Education Level				
None	14	16.7	0	0
Primary level certificate	23	27.4	1	5.2
Secondary level certificate	27	32.1	1	5.3
University/tertiary	20	23.8	17	89.5
Region of origin				
Central	49	58.3	10	52.6
Eastern	19	22.6	3	15.8
Western	10	11.9	3	15.8
Northern	6	7.2	3	15.8
Household size				
Single person household	11	13.1	3	15.8
Multiple-person household	73	86.9	16	84.2
Average monthly income (\$)	56 ^a		1,191 ^b	
KII, Key Informant Interview; FGD, Focus Group Discussion; [#] n = 80 for FGD participants (4 participants did not disclose their education background); ^a n = 60 FGD participants (24 participants did not disclose their income); ^b n = 13 KII participants (6 participants did not disclose their income).				

3.1 Identified IFV species and the ascribed cardiometabolic benefits

A total of 64 IFV species were identified, (Table 2) and these were either farmed or gathered from the wild. *Tamarindus indica* Linn. (tamarind), *Cleome gynandra* Linn. (spider plant), *Solanum anguivi* Lam. (bitter berries), *Hibiscus sabdariffa* Linn. (hibiscus) were most frequently cited IFV used as adjuvant therapies for cardiometabolic dysfunction.

Table 2
Indigenous fruits and vegetables reported to treat cardiometabolic risks around Central Uganda

No	English Name	Local name	Scientific Name/botanical name	Plant part(s) used	Preparation/preservation methods	Reported Cardiometabolic Benefits	Source	Regional
1	Pawpaw	Amapapaali	Carica papaya	Fruits	Eaten fresh, juiced		Wild, and cultivated	All regions
2	Alligator pepper	Amatungulu	Aframomum angustifolium	Fruits	Fruits are eaten fresh or can be crashed, water added, and the mixture is filtered to make a juice	Diabetes, high blood pressure, hypercholesterolemia	Wild	Central
3	Egg plant	Biringanya	Solanum melongena	Fruits and Leaves	The fruits are reduced in size and cooked. The soup and the fruits are consumed. • The leaves are crashed, water is added and then the solution is filtered. • The leaves are reduced in size, shade dried and reduced further to a powder that can be reconstituted with water	Diabetes	Cultivated	All regions
4	Rhus	Bukwansokwanso	Rhus vulgaris	Fruits	Eaten fresh		Wild	Central West and East
5	Amaranthus spinach	Ddodo	Amaranthus dubius	Leaves	Steamed and boiled, fried	Diabetes, hypertension	Wild, and cultivated	All regions
6	Amaranthus spinach	Ddodo wamagwa	Amaranthus spinosus	Leaves	Boiled, steamed	Diabetes, hypertension	Wild	Central
7	Amaranthus spinach	Ebbugga eryaannamusayi	Amaranthus lividus	Leaves	Boiled, steamed		Wild	Central
8	Pumpkin shoots	Ebigujju	Cucurbita maxima	Fruits	Boiled		Cultivated	All regions
9	Cho-cho/Chayote	Ebisusuuti	Sechium edule	Leaves, Fruits	Boiled	Diabetes	Cultivated	Central
10	Cowpea	Eggobe	Vigna unguiculata	Leaves	Boiled, steamed		Cultivated	Central East North
11	African spider herb	Ejjobyo	Cleome gynandra	Leaves	Boiled, steamed, fried	Diabetes, hypercholesterolemia, high blood pressure	Wild, and cultivated	All regions
12	Mulberries	Enkenene	Morus rubra	Fruits	Eaten fresh		Wild	East Central West
13	Prickly tree hibiscus	Ekilenke	Hibiscus diversifolius	Leaves, Flowers	Boiled, dried			North and east
14	Tree tomato	Ekinyaanya	Cyphomandra betacea	Fruits	Eaten fresh		Wild, and cultivated	Central west East
15	Turmeric	Ekinzaali ekiganda	Curcuma longa	Roots	Boiled, dried, powdered	Diabetes, weight reduction	Cultivated	North East

No	English Name	Local name	Scientific Name/botanical name	Plant part(s) used	Preparation/preservation methods	Reported Cardiometabolic Benefits	Source	Regional
16	Soursop	Ekitafeeri	Annona muricata	Fruits and Leaves	Fruits are eaten when ripe or reduced, crushed and expressed to make juice • The leaves are reduced in size shade dried and reduced further to a powder that can be reconstituted with water. • Leaves may also be crashed fresh, mixed with water and then filtered to make a debris free solution	Diabetes	Cultivated	Central
17	Amaranthus spinach	Embooge	Amaranthus graecizans	Leaves	Boiled, steamed		Wild	All regions
18	Mangoes	Emiyembe	Mangifera indica	Fruits	Eaten fresh/juiced		Wild, and cultivated	East Central
19	Bush candle	Empafu	Canarium schweinfurthii	Fruits	Boiled		Wild	Central
20	Wild Date Palm	Empirivuma	Phoenix reclinata	Seeds	The seeds are dried, roasted and then crashed into powder. The powder can be reconstituted with water. Or the seeds may be crashed after drying without roasting them.	Diabetes, high blood pressure	Wild	Central
21	Vine spinach/Malabar spinach	Enderema	Basella alba	Leaves	Boiled		Cultivated	All regions
22	Pomegranates	Enkomamawanga	Punica granatum	Fruits	Eaten fresh	Diabetes and stroke	Wild	Central
23	Tamarind	Enkooge	Tamarindus indica	Fruits, Seeds, Barks, Leaves	Fruits are juiced, Seeds are powdered	High blood pressure, cholesterol lowering, Diabetes	Wild	Central and East
24	Loquat	Ensaali	Eriobotrya japonica	Fruits	Eaten fresh		Wild	Central West East
25	Black nightshade	Ensugga enzirugavu	Solanum nigrum	Leaves	Boiled, steamed	Diabetes, hypercholesterolemia, high blood pressure	Wild	Central West
26	Pumpkin	Ensujju	Cucurbita maxima	Fruits	Fruit is reduced in size and crushed. After water is added and the juice is filtered off.	Diabetes	Cultivated	Central West East
27	Desert date	Entende	Balanites aegyptiaca	Fruits	Boiled and dried		Cultivated	East North South
28	Scarlet eggplant	Entula enganda	Solanum gilo	Fruits	Boiled, steamed	High blood pressure, Diabetes	Cultivated	All regions
29	Gooseberry	Entuntunu	Physalis peruviana	Fruits	Eaten fresh	High blood pressure	Wild, and cultivated	Central East West
30	Jack fruit	Ffene	Artocarpus heterophyllus	Seeds/fruit	The seeds are dried and crashed into a powder. The powder is reconstituted with water, Eaten fresh	Diabetes, hypertension	Wild, and cultivated	All regions
31	Hibiscus	Hibiscus	Hibiscus sabdariffa	Calyx, Leaves	Dried, powdered, infusions, sprinkled on tea, juiced	Diabetes, hypertension, dyslipidaemia	Cultivated	All regions

Plant names (Scientific names) according to the International Plant Names Database

No	English Name	Local name	Scientific Name/botanical name	Plant part(s) used	Preparation/preservation methods	Reported Cardiometabolic Benefits	Source	Region
32	Java plum	Jambula	Syzygium cumini	Seeds and fruits	Fruits are cooked and consumed, leaving the seeds behind • The seeds are dried and crashed into a paste. The paste is reconstituted with water and filtered to make a solution	Diabetes, High blood pressure	Wild	Central East West
33	Chillies	Kamulali	Capsicum annum	Fruits	Dried, eaten fresh, boiled		Wild, and cultivated	Central
34	Chillies	Kamulali	Capsicum frutescens	Fruits	Dried, eaten fresh, boiled		Wild, and cultivated	Central
35	Bitter berries	Katunkuma	Solanum anguivi	Fruits	Fruits can be crushed, mixed with water and filtered • Fruits can be dried, pounded into a powder and reconstituted with water and then filtered • Fruits can be cooked and eaten	Diabetes, high blood pressure, hypercholesterolemia	Wild, and cultivated	Central
38	African ebony/Jackal berry	Kumi	Diospyros mespiliformis	Fruits	Eaten fresh		Wild	North West North west
39	Pigeon peas	Lapena (Luo)	Cajanus cajan	Seeds	Boiled		Cultivated	North and West
40	Sweet potato leaves	Malagala	Ipomoea batatas	Leaves	Steamed		Cultivated	All regions
41	Hibiscus spp	Malakwang	Hibiscus cannabinus	Leaves	Boiled	Cholesterol lowering	Cultivated	North
42	Bamboo shoots	Malewa	Bambusa vulgaris	Leaves	Boiled, steamed or pasted		Cultivated	East
43	Guava	Mapeera	Psidium guajava	Fruits	Eaten fresh/juiced		Wild, and cultivated	All regions
44	Wild medlar	Matugunda	Vangueria madagascariensis	Fruits	Eaten fresh		Wild	East West Central
45	Bambara nuts	Mpande	Vigna subterranea	Seeds	Steamed/boiled		Cultivated	All regions
46	Cinnamon	Mudalasini	Cinnamomum verum	Leaves and Barks	Boiled	Diabetes, high blood pressure	Wild	All regions
47	African basil	Mujaaja	Ocimum gratissimum	Leaves	Boiled		Wild	Central West East
48	Black plum	Munywamazzi	Vitex doniana	Fruits	Eaten fresh		Wild	Central West East West
49	Jute	Mutere	Corchorus olitorius	Leaves	Boiled, steamed		Wild	West North East
50	Carandas plum	Muyonza	Carissa carandas	Fruits	Eaten fruit		Wild	All regions
51	Star fruit	Muzadibu	Averrhoa carambola	Fruits	Eaten fresh, juiced	Diabetes	Wild	All regions
52	African bread fruit	Muzinda	Treculia africana	Fruits	Juiced, eaten fresh		Wild	West and Central

Plant names (Scientific names) according to the International Plant Names Database

No	English Name	Local name	Scientific Name/botanical name	Plant part(s) used	Preparation/preservation methods	Reported Cardiometabolic Benefits	Source	Regional consumption
53	Scarlet eggplant	Nakati	Solanum aethiopicum	Leaves	Boiled, steamed, fried	Cholesterol lowering, diabetes, high blood pressure	Cultivated	All regions
54	Small tomato	Nniina	Lycopersicon esculentum	Fruits	Boiled	Diabetic neuropathy	Wild, and cultivated	All regions
55	Ginger root	Ntangawuzi	Zingiber officinale	Roots	Boiled		Cultivated	Central, West, East
56	Mushrooms	Obutiko obubaala	Agaricus bisporus	Whole	Steamed/boiled/dried of fresh		Wild, and cultivated	All regions
57	Passion fruit	Obutunda obuganda	Passiflora edulis	Fruits	Juiced, eaten fresh	Lowering blood sugar, heart diseases	Wild, and cultivated	East, Central
58	Lima beans	Obuyindiyindi	Phaseolus lunatus	Seeds	Boiled		Wild, and cultivated	Central, East, West
59	Okra	Okra	Hibiscus esculentus/ Abelmoschus esculentus	Fruits	Boiled	Control inflammation	Cultivated	North, Central, West
60	White's Ginger	Omulondo	Mondia whitei	Roots	The roots are crashed, water added and then filtered to make a clear solution • The roots may be chewed directly	Diabetes, hypertension	Wild	Central
61	Avocado	Ovakado	Persea americana	Seeds	The seeds are dried and crashed into a powder. The powder is reconstituted with water	Diabetes, hypertension	Cultivated	All regions
62	Cassava leaves	Sombe	Manihot esculenta	Leaves	Boiled		Cultivated	All regions
63	Cocoyam/Taro leaves	Ttimpa	Colocasia esculenta	Leaves	Boiled, steamed		Wild, and cultivated	All regions
64	Shea butter tree	Yaa (Achoi)	Vitellaria paradoxa	Fruits and seeds	Add to food for flavour		Wild	West, North
Plant names (Scientific names) according to the International Plant Names Database								

3.2 Barriers and facilitators to consumption of IFV

Altogether, 38 factors and 19 themes were drawn from FGD and KII as barriers and facilitators to the consumption of IFV, supplementary table 1 and 2. A summary of these factors and the frequency of citation is presented in Table 3.

Table 3
A summary of the barriers and facilitators for the consumption of indigenous fruits and vegetables

Ecological levels	Categories of factors	Frequency of citation
Intra-individual level	Food safety concerns (pesticide/herbicide residues, microbial contamination, aflatoxin)	FGD (1,4,6–8), KII (3–5,9&16)
	Financial considerations (limited budget to be spent on food)	FGD (1–11)
	Sensory appeal (colour, taste, texture...)	FGD (1–11), KII (6&11)
	Physiological attributes (IFV are associated with low satiety)	FGD (3&8)
	Knowledge of potential cardiometabolic health benefits	FGD (1–8)
	Convenience and time implications of food preparation	FGD (1, 9–11)
	Nutrition knowledge, and food preparation skills	FGD (1–11), KII (4–10)
Socio-cultural norms	<i>Injunctive norms</i>	
	IFV are food for the poor, medicine not food, food for the elderly, a symbol for backwardness, food for village people, food during food scarcity	FGD (1–11)
	IFV are associated with witchcraft, superstition	FGD (1,3&8)
	IFV are associated with weight loss	FGD (1,4,7)
	<i>Descriptive norms</i>	
	Food taboos, foods linked to tribes	FGD (1,3,8), KII (16–19)
	Increased drive towards nutrition for longevity	FGD (1,7), KII (1–19)
Environmental factors	<i>Physical food environment</i>	
	Scarcity of IFV, proximity to food market, seasonality of IFV	FGD (1,2,5,6,8–11)
	Limited availability of ready-to-eat IFV	FGD (2–5)
	<i>Social food environment</i>	
	Family size	1–8,10
	Family composition	1–8,10
	Peer influence	1,9–11
	Influence of women and children	1,2,6–8
	<i>Information environment</i>	
	Health claims related to IFV	KII 5, 6, 10, 13 &14.
	Food adverts related fast foods	KII 15, 17&18
FGD, focus group discussion; IFV, indigenous fruits and vegetables; KII, key informant interview.		
Supplementary figure: The modified theoretical framework that guided the development of the questioning framework and analysis of focus group discussions and key informant interviews.		

3.2.1 Intra-individual factors

Food safety concerns. Participants expressed chemical and microbiological food safety concerns. Chemical food safety concerns included pesticide residues and metal debris in powdered IFV. Indigenous vegetables usually grow as ruderals or cultivated in polluted areas and are often vended under unhygienic conditions. There were also concerns about the influx of genetically modified fruits and vegetables.

“These indigenous vegetables often grow in very unhygienic places for instance in sewage polluted areas, then you find vendors selling them in very unhygienic conditions, you can imagine a vegetable stall mounted above an open drainage channel”, FGD 9

“.... from having our indigenous foods turned into genetically modified variants to the uncontrolled use of all sorts of agricultural chemicals, certainly death is on our doorsteps. Everything is sprayed, even at the point of harvesting”, KII 3,4&16.

It was stressed that the observed rudimentary drying and storage practices of IFV may expose them to mycotoxin attack.

“...the way these herbalists and farmers handle these products after harvesting for example, you find them drying hibiscus calyxes, katunkuma or ggobe on bare ground, no quality control on storage moisture or temperature, all this could attract mycotoxins and aflatoxins”, KII 5&9

Financial considerations. Participants perceived that IFV are expensive and cannot be prioritized given the limited financial resources.

"Absolutely! without doubt we don't really eat what we would want, finances dictate what we choose to eat, we can't spend the little money we have got on fruits and vegetables, we can only buy energy dense foods. IFV are quite costly from the market", FGD 1–11

Behavioural beliefs

Psychological and physiological perceptions. Participants indicated that IFV are mostly tasteless or bitter and not as visually appealing as their preferred fast foods. Preference was high for exotic fruits and vegetables owing to their reportedly superior sensory attributes.

"Bitter berries, spider plant, cherry tomatoes.... have a bitter taste, so I wouldn't eat them, I prefer meat, fries and if you go out you can't order for IFV, you just want to eat tastier fast foods because they even look nice," FGD 9&10, KII 6&11.

Furthermore, participants highlighted that IFV are low in satiety, and unsuitable for manual work hence priority is given to energy-dense staples.

"We work at a construction site, we dig, these jobs require a lot of energy.. We choose posho and cassava to provide the energy throughout the day. So, we cannot choose IFV, those indigenous foods can only be snacks or tea accompaniments" FGD 3&8

However, participants involved in sports activities indicated that they regularly eat IFV to boost their performance.

Knowledge of cardiometabolic risks. Participants acknowledged the rising trend of cardiovascular diseases which they largely attributed to unhealthful eating. However, healthful eating was misconstrued to only mean moderate intake of fats, soda and alcohol with very little attention to fruits and vegetables.

Potential cardiometabolic health benefits. Participants drew a link between consumption of IFV and prevention of cardiometabolic risks. The older participants referred to some of the IFV as direct remedies for overweight, diabetes and hypertension.

"When our parents ate these foods, they lived longer and healthy but nowadays we see young people with diabetes and heart diseases, overweight. Foods like katunkuma, jjobyo and all those bitter vegetables can't allow accumulation of body fat but young people don't care all they want fast foods..... we are surely dying" FGD 1, 2&3.

Convenience and time implications

The difficulty in preparation of IFV was heavily cited as an impediment for their consumption. Some indigenous vegetables like lima beans and pigeon peas take a long time to cook, which is an inconvenience especially in the case of busy schedules. Moreover, participants noted the limited supply of safe ready to eat/prepacked IFV.

Nutrition knowledge, and food preparation skills. Vegetables like bitter berries, spider plant were cited as difficult to prepare in a way that makes them palatable. Preparation methods that were cited included boiling, frying, steaming, grinding, sun drying, and seldomly pasting. Participants expressed that traditional methods formerly used to prepare most indigenous vegetables are no longer convenient. Frying has replaced boiling and steaming. In a nutshell, vegetable preparation skills were limited and vegetables were reported to be cooked for abnormally longer periods.

"For us indigenous vegetables are not just simply vegetables, there's a cultural dimension to them. For example, there's a traditional way of preparing them which involves wrapping vegetables in a banana leaf and steaming them on top of the main food, unfortunately, all that is lost now, currently people use plastic bags and polyester sacks but mostly they simply fry. This makes me sad", FGD 1, 6, 7&8.

"... the way you prepare them matters. These self-styled herbalists may not understand, but the bioactivity of phytochemicals in food is influenced by processing methods, for example, the effect of heat, pH among other factors, so if these processing conditions are not controlled, the phytochemicals could be affected", KII 4.

Equipping women with food preparation skills was identified as a key facilitator for the consumption of IFV. Women reported to be the meal planners of their households but often lack skills to make palatable vegetables from foods deemed unpleasant.

"... why I think the focus of sensitization should be on women is because they are the meal planners of the homes, and if they don't have the knowledge of the health benefits of these foods or skills to prepare them in a better way, then we won't eat them", KII 10.

3.2.2 Social-cultural norms

Injunctive norms

IFV were associated with several sociocultural misconceptions. For example, IFV were regarded as food for the poor and low social class people. Young adults considered IFV as a symbol of backwardness, food for older adults and medicine for certain ailments.

"If the neighbors see you eating katunkuma, cherry tomatoes, jjobyo, nsugga... they will laugh at you saying that the poverty at your house stinks. One day I packed these foods for my children for school, but their peers mocked them, saying they are very poor, backward and eating medicine for old people", FGD 1.

Participants regarded IFV as a coping strategy for food insecurity.

"... these are foods we eat when we don't have anything else to eat, as for me, if I see people eating these foods, it's an indication that hunger, and poverty have struck", FGD 8

Participants reported certain cultural beliefs where IFV are associated with witchcraft and superstitions, or only consumed on particular cultural ceremonies.

"..... you see, some fruits like jackfruits are thought to be resting places for ancestral spirits, steamed unripe indigenous bananas and mushrooms are used for cleansing after the birth of twins, jjobyo induces labor pains, while rosary peas are used for love charms. If you eat meat or fish together with yams/yam leaves as vegetables, the yams in your garden will all die", FGD 3&8.

Some IFV like bitter berries, spider plant, hibiscus and black night shade were linked to weight loss or prevention of weight gain. Participants expressed a positive perception for large body sizes which they linked to health and prosperity.

"... those foods can make you lose weight or if you eat them regularly, or you won't gain weight. I can't imagine myself losing weight, in fact I always want to add weight to look good because when you lose weight people think you are poor or have health problems", FGD 1.

Descriptive norms. Participants concurred that there is an entrenched custom that inclines people to only eat what they grew up eating; traditionally, the main course meal consists of carbohydrate-based staples with a spoonful of vegetables. Some IFV were culturally connected to specific tribes, and other tribes are reluctant to consume them.

"In the central here, food is carbohydrate-staples and occasionally little vegetables at the side..... but the Luos eat a lot of vegetables, then you have vegetables like malakwang, okra, otigo which are culturally for the Luos, also the way they cook their vegetables like pasting with pea nuts, Hmmm all these are alien to our culture", FGD 1&3.

The existence of food taboos was presented as another barrier.

"We have clans in Buganda and each clan has a totem, so you find some indigenous vegetables like aaah Kkobe, Butiko and Empindi that means for the people belonging to these clan such foods are taboos", FGD 8.

The increased drive towards nutrition for longevity among the elites was reportedly increasing the demand for IFV.

"My clients are scared of the raging cardiovascular diseases and are seeking remedy in natural foods especially these indigenous foods; katunkuma, pomegranates, tamarind, jjobyo... everyone wants to live a longer disease-free life, so I always say why take synthetic food supplements when we have these foods here", KII 16.

3.2.3 Environmental factors

The environmental factors were shaped by both physical and social food environments.

Physical food environment. Participants reported scarcity of IFV and ubiquitous availability of the exotic fruits and vegetables in urban areas. Main sources of IFV were open-air food markets, however, the availability and diversity of IFV were reported to be erratic along the day. The food markets were said to be far away from residences, yet IFV are almost unavailable in the supermarkets.

"Hmmm IFV are so rare, maybe they exist in villages but here in town, markets rarely have them except very early in the morning or late in the evening. But also, markets are far from us, you basically need a taxi or bodaboda to reach there, that is already money spent", FGD 2&6.

There is minimal availability of ready-to-eat IFV reportedly because the drive towards processing of IFV is still low. Restaurants do not always prepare IFV, as there is a social preference for fast foods and exotic fruit and vegetable varieties such as apples, grapes, French beans and melons. Most IFV are still gathered as ruderals from the wild and efforts to conventionally farm these foods are still inadequate. Participants concurred that there are some varieties of IFV which are at present scarce or totally non-existent in their locality. Participants showed that growing IFV is hampered by lack of land and knowledge of urban/backyard gardening, and good quality seeds.

"We used to collect IFV from forests and swamps where naturally they grow, these places have been cleared for settlement and industrial activities...., now if you want a fruit like Ttungulu you can't find it. Maybe if we had space and seeds we could grow them at home but it's hard because they aren't adapted to conventional farming conditions", FGD 2-5.

Seasonality of IFV was cited as a key determinant of consumption.

"... definitely most of these indigenous vegetables are seasonal and are more available/ accessible during rainy seasons, if they are out of season, usually the prices are so high you cannot afford them", FGD 1, 2&8.

Social food environment. It was discussed that family size and composition, influence of children, women's influence, and peer influence are instrumental determinants of IFV consumption.

In multi-person households, priority was given to presumably more satisfying foods such as carbohydrate staples.

"... we are about seven people in the house, so with the little money we have to spend on food, priority is given to more satisfying foods like posho. You cannot start spending on IFV because they cannot make people feel full", FGD 4.

Participants from single-person households reported often choosing for ready-to-eat street foods.

"I am alone in my house, so I choose for ready to eat street foods like potato chips, sausages, soda..., I can't start cooking or making juice", FGD 10.

Food choices were also dictated by what children like to eat.

"Children don't like such foods, some think IFV are foods for the elderly for example my children don't eat bitter berries, jjobyo, so it's hard to eat it when they are just looking on, so we end up entirely not buying these foods", FGD 1&3.

Women's role and influence. It was reported that culturally women are responsible for meal planning and preparation, men do not cook or decide on what should be cooked and how it should be cooked.

"What the wife cooks is that we eat, in our culture men don't go to the kitchen or plan what is cooked at home. Women will always cook the way they were also taught by their mothers. Besides, our wives get annoyed when we tell them to prepare vegetables at home because they feel we have become so poor", FGD 8.

Peer influence. Younger adults cited being influenced by their friends to frequent fast food outlets, while the elderly claimed to learn from each other's dietary aspects such as reducing the intake of fried foods and eating fruits and vegetables regularly.

"...I learned how to vary my dishes and not eat the same food all the time, not to prepare food without greens, to eat some fruits during breakfast from my neighbour while friends teach us to eat boiled foods instead of frying all the time", FGD 1.

Information environment. Participants reported obtaining information on the cardiometabolic benefits of IFV from herbalists, older adults, testimonies of previous users, and NCD hospital clinics. Younger adults particularly claimed to receive such information through social media. However, participants demonstrated difficulty in verifying the authenticity of the shared information.

"There so many self-styled herbalists and nutritionists nowadays giving all sorts of health and nutritional advice, promoting some IFV and forbidding others, making all sorts of health claims, it is actually sad that you will also find these baseless claims on some food products in supermarket shelves and our people are not protected from this harmful information", KII 5, 6, 10, 13 &14.

It was noted that adverts on billboards, and mainstream media mainly promote fast foods and fizzy drinks.

"...I personally feel our people would make attempts for example to drink the juice from let's say hibiscus or tamarind if there was a deliberate effort by the media to promote these foods, but all the adverts you see are promoting soda brands and synthetic drinks", KII 15, 17&18.

3.3 Cross-validation

With regard to the phenolic composition, identified IFV had varying concentrations and diversity of classes of polyphenols. *Tamarindus indica* fruits had the highest levels of total polyphenols, followed by *Hibiscus sabdariffa*, supplementary table 3.

In the supermarkets, only 5 (Tamarind, Bitter berries, Hibiscus, and Pomegranates) fresh IFV were identified. Mainly, exotic vegetables and fruits could be identified across the surveyed supermarkets. Supermarkets had a number of products processed from IFV and these were majorly wines, vegetable powders, tea infusions, juice blends, kombucha, and porridge formulations essentially from such foods as Hibiscus, Tamarind, Bitter berries, Okra, Amaranthus, Avocado seeds, Pigeon peas, and Pumpkin seeds. The prices of IFV based products were 3 to 4 folds higher than their raw forms.

In the open-air food markets, only 21 out of the 64 IFV that were cited during FGD and KII were identified, supplementary table 4. The availability and diversity of IFV varied erratically along the day with peaks in the morning and evening. Hibiscus, Tamarind, Amaranthus varieties, Pigeon peas, and Scarlet eggplant were the most common IFV. Pomegranates, Spider plant, Alligator pepper, and Chayote were scarce while Java plum, Black night shade, and Cherry tomatoes were totally unavailable. The interviewed vendors reported that older adults were particularly the most frequent buyers of these foods while the younger adults were ardent buyers of exotic varieties. Peak sale hours were early morning and late evening. In terms of food handling, no specialised structures were observed, IFV were vended on open stalls with no cooling system and very often, exposed to the sun.

4. Discussion

The findings showed a fair understanding of the interface between consumption of IFV and prevention of cardiometabolic risks. Although several IFV were linked to potential cardiometabolic benefits, *Tamarindus indica* fruits were the most popular potential adjuvant therapy for cardiometabolic disturbances. Interestingly, the phenolic profile of *Tamarindus indica* fruits relative to other identified IFV, seems to be commensurate with its purported health benefits. The main hinderances of IFV consumption were financial limitations, convenience and time barriers, food safety concerns, food and nutrition knowledge, physical food environment, food skills and self-efficacy, sociocultural norms, and physiological and psychological satisfaction. A cross check for the market availability and diversity of IFV revealed a scarcity of such food items both as fresh and processed. From a conceptual viewpoint, the study is in tandem with current National Biodiversity Strategies and Action Plan that seeks to conserve indigenous plant genetic resources [29] by raising awareness of the potential health benefits of neglected IFV. The study contributes to the global agenda of improving diets and preventing obesity and diet-related NCDs in LMIC by placing emphasis on safe and sustainable healthy food systems, the so-called planetary healthy diets [43]. This will accelerate the attainment of SDG 3 and 13, which are ensuring good health and wellbeing; environmental sustainability.

Generally, food safety is a key deterrent of consumption of IFV. In particular, indigenous vegetables are regarded as ruderals growing in polluted places [44, 45]. Moreover, there is empirical evidence of the presence of high pesticide residues on Ugandan fruits and vegetables [46, 47]. Postharvest handling systems

for IFV are still substandard, for example, drying vegetables on bare ground, poor storage and vending are precursors of food mycotoxin contamination. Particularly, aflatoxin contamination in fruits and vegetables is a rampant threat in SSA [48, 49].

Sociocultural norms, where IFV are regarded as food for the poor or weeds, and associated with several myths affect consumption. The work of [39, 50] corroborate our findings that vegetables are generally regarded as food for the poor. Consumption of IFV was said to promote weight loss or hamper weight gain. Findings have revealed a culturally entrenched affinity for a large body size in SSA as an indicator of health and prosperity [39, 50]. This health-beauty paradox is a potential impediment to the consumption of IFV. In several SSA communities, food consumption relates to many sociocultural practices and connotations that are often restrictive [2, 51, 52].

Physiological and psychological satisfaction is influenced by satiety, food sensory attributes, and peer influence. Findings from SSA show that multi-person households are more focused on providing foods with high satiety and desirable to children [50]. Single persons not only presented proneness to eating out of home but were also more likely to be influenced by their peers into eating fast foods. Emotional satisfaction was linked to consumption of fast foods while IFV were considered not tasty and visually unappealing even after cooking. In the wake of nutrition transition, eating from fast food outlets is perceived to be emotionally satisfying especially to young adults [39]. It is imperative to note that the high value attached to energy dense foods across SSA compounded by the bitter taste and peculiar colour of IFV are a mainstay hindrance to the consumption of IFV [2, 50]. On a positive note participants reported learning from each other the health benefits of foods like *Solanum anguivi*, *Cleome gynandra*, *Tamarindus indica*, *Hibiscus sabdariffa* during community group meetings. [24], highlighted the importance of community structures as instrumental conduits of nutrition knowledge.

Food choices were largely influenced by financial status and convenience rather than health considerations. Although it was widely reported that IFV are particularly expensive, the general fruit and vegetable consumption culture among Ugandans is far from optimal [23–25]. It is tempting to assume that a good financial status would predict healthful eating, however, our findings corroborate earlier reports from Uganda [39], and Tanzania [53] that a higher financial status may instead trigger unhealthy food choices. Across SSA, a low financial status increases the propensity to consume only carbohydrate staple-based diet devoid of fruits and vegetables [50]. This seems to invalidate the traditionally engrained assertion that IFV are foods for the poor. Further, some indigenous vegetables take hours to prepare making them unsuitable in the face of convenience [2]. Moreover, the hard-to-cook effect of some indigenous vegetables poses a sustainability challenge through increased demand for fuel.

The claim that IFV have inferior sensory appeal is a salient hindrance to consumption. However, such claims could reaffirm the fact that low food skills and self-efficacy often mediate the exclusion of healthy foods on account of their unpleasant taste [2, 54]. Alienating indigenous foods pursuant to their inferior taste has been reported especially among young adults in South Africa [2]. Participants from northern Uganda reiterated that simple innovations such as pasting with peanut butter could ameliorate the taste of indigenous vegetables. Such simple innovations to offset unpalatable tastes have also been reported in Ghana [55]. It has been shown that training sessions built around the concept of food literacy can improve food skills and self-efficacy and consequently increase fruit and vegetable intake [24]. Noteworthy, the traditional culinary and preservation practices where vegetables are customarily steamed for long hours, uncontrolled drying, roasting among others could be detrimental to the integrity and functionality of phytochemicals [56, 57].

The scarcity of IFV is a barrier to their consumption. Previous studies have documented an apparent food desert in Uganda and SSA [2, 39, 58], where only 62.2 kg and 105.5 kg of fruits and vegetables are available person per year for Uganda and the entire African region, respectively [25]. This threshold is short of the WHO and FAO recommendation of 146 kg/person/year [58]. The scarcity can be attributed to the seasonality of IFV [59], as well as the ubiquitous presence of exotic varieties in the retail food environment [29]. The inherent characteristics of IFV such as low yields and long growth periods among others often discourage large scale production [2, 60, 61]. Moreover, there is little doubt that commercialization of fruits and vegetables has coincided with the desire to cultivate exotic species with superior agronomic qualities [62].

Regarding information on IFV, the study revealed an array of scientifically unsubstantiated health claims related to IFV. We observed age-related disparities in the knowledge of IFV. Culturally, the older adults are the custodians of knowledge about indigenous food, which cascades to younger generations over time. However, lifestyle changes marked by rapid urbanisation have caused a shift in nutrition patterns, the so-called nutrition transition [63]. Consequently, such indigenous knowledge has plummeted among the young adults [2]. Hence in our study, younger adults were less enthusiastic about IFV. The age-related difference in knowledge of IFV could be critical to the development of age-tailored intervention to increase the consumption of IFV.

Study strength and limitations

The study employed a modified theoretical framework as a basis for the design of questioning routes for both KII and FGD. The combination of multiple health behavioural theories has been advocated as no single theory can solely describe behaviour [38]. The use of probes in the questioning route allowed for flexibility to capture new emerging themes. The inclusion of food market surveys was an essential component to validate some of the claims from FGDs regarding availability and diversity of IFV. However, the time of the study could have influenced the findings of the market survey since seasonal variation has a huge bearing on food availability and diversity [59, 64]. Polyphenolic profiling of IFV was not fully complete since a large diversity of IFV have not yet been characterised hence unavailable in the databases used.

Conclusion and recommendations

Consumption of IFV is influenced by a plethora of intra-individual, sociocultural and environmental factors. At intra-individual, there is need to improve food knowledge, skills and self-efficacy to prepare culturally acceptable diets involving IFV through community base culinary workshops. There is need to underpin cardiometabolic health claims associated with IFV through clinical trials. At environmental level, there is need to stimulate production of IFV by empowering communities with skills of backyard farming. In addition, the food market chain of IFV needs to be streamlined to ensure safety of IFV.

Declarations

Data availability

The datasets of this study are available upon reasonable request from the corresponding author.

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Conflict of interest statement.

The authors have no competing interests to declare that are relevant to the content of this article.

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Author's contributions

TK, PY and CM designed the study. TK, MB, PO contacted and recruited study participants. TK, MB and EVD conducted the study. TK, PY, CM, BVDS and EVD transcribed, crosschecked interview transcripts, coded and conducted data analysis. TK wrote the first draft of the manuscript. All authors reviewed the final draft and approved the publication of this work.

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Figures

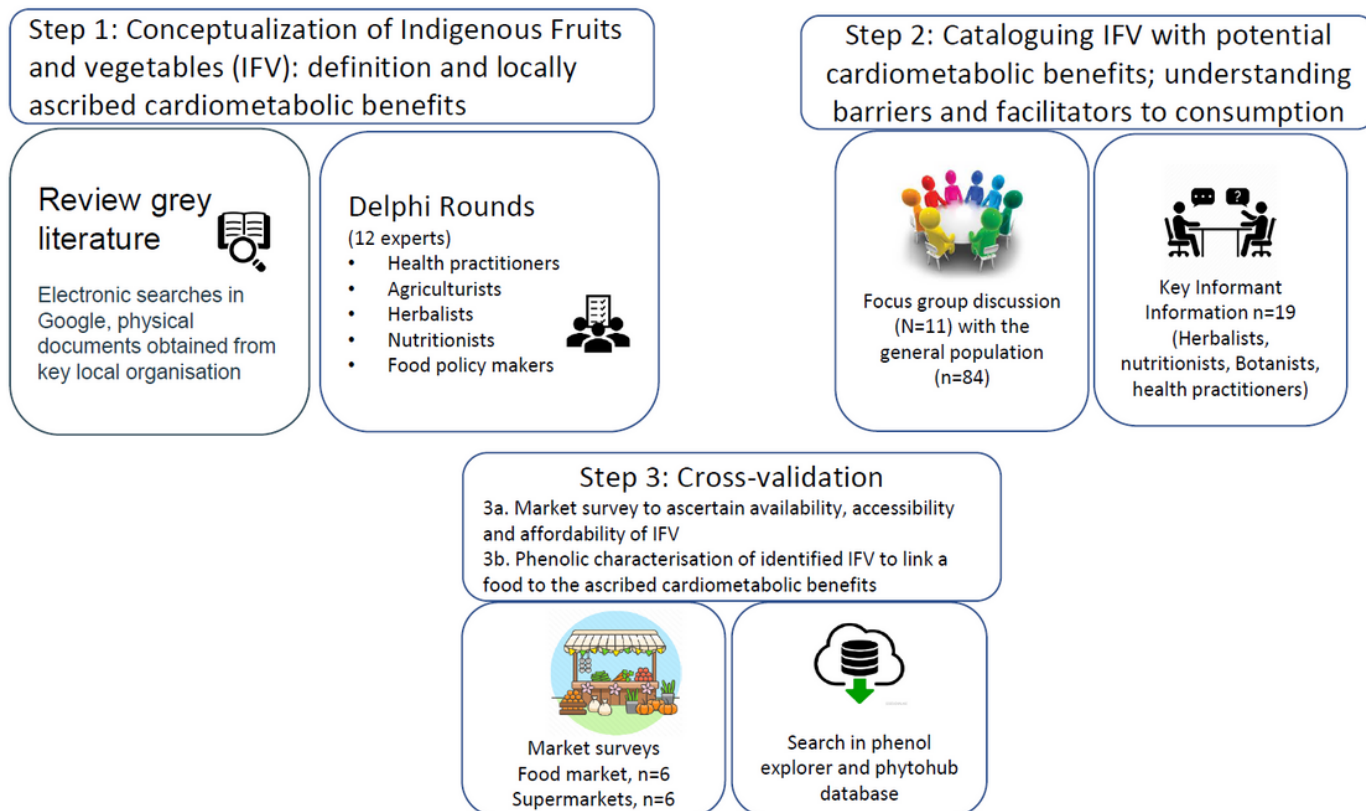


Figure 1

A schematic overview of the different steps followed to conduct the study.

Supplementary Files

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