LOCAL, TRADITIONAL AND INDIGENOUS FOOD SYSTEMS IN THE 21ST CENTURY TO COMBAT OBESITY, UNDERNUTRITION AND CLIMATE CHANGE,
2nd Edition

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LOCAL, TRADITIONAL AND INDIGENOUS FOOD SYSTEMS IN THE 21ST CENTURY TO COMBAT OBESITY, UNDERNUTRITION AND CLIMATE CHANGE, 2nd Edition

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Editorial: Local, traditional and indigenous food systems in the 21st century to combat obesity, undernutrition and climate change

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Editorial on the Research Topic
Local, traditional and indigenous food systems in the 21st century to combat obesity, undernutrition and climate change

Traditional and indigenous food systems have existed for centuries and were in balance with local food supplies, globally. However, between the mid 20th and early 21st century the green revolution dramatically altered food production, which in turn affected the inclusivity of traditional production systems within food systems and subsequently, traditional dietary intakes. Industrialized food systems, with the aid of global processing, distribution and marketing channels have helped in transforming grains and edible oils into increasingly processed food products as well as animal feed. This change was accompanied by lifestyle changes and spurred a global nutrition transition. Today the world faces a global syndemic of obesity, undernutrition, and climate change. A new call to action to create food systems that nourish people and sustain the planet is needed. Modern food systems have evolved to a point where the cost of a healthy diet is five times greater than the cost of a diet that meets dietary energy requirements from the least costly food products; cereals (FAO et al., 2022). The downside of this approach are diets that are devoid of essential micronutrients and food biodiversity required for health and food production systems that are a major source of global greenhouse gas (GHG) emissions and an unsustainable use of natural resources. Traditional and indigenous food systems have long been recognized as systems that can both support good human nutrition as well as maintain a balance with nature. Our food systems need to be reoriented to be more compatible with the natural environments in which we live and more reliant on a wide range of food biodiversity to meet our nutritional needs. In 2010, the Food and Agriculture Organization defined Sustainable Diets as *"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"* (Burlingame and Dernini, 2012).

Traditional and indigenous food systems have existed for centuries and can offer some pathways forward to mitigating the challenges of obesity, undernutrition and climate change. Traditional food systems are characterized as systems oriented toward use of diversified plant, animal and fish species with place-based distribution and marketing channels and geographically defined consumer base. Indigenous peoples were often the custodians of traditional food systems.

There is an underutilized knowledge base around traditional and indigenous food systems. This includes the knowledge of nutritious species, traditional culinary preparations, and cultural practices. Greater agricultural production of underutilized species can result in more sustainable agricultural and food systems which can also help improve livelihoods and food security. Traditional and indigenous cultural practices with respect to both land and water management, as well as culinary practices, contribute to both sustainable food production and consumption. These practices require a greater evidence base in order to be incorporated into public health nutrition initiatives related to improving dietary quality, such as food-based dietary guidelines for example. An increased focus on the importance of local, traditional, and indigenous food systems and nutrition could therefore help countries to improve human nutrition and, ideally, help mitigate the global syndemic of obesity, undernutrition, and climate change. There are 12 articles published in this special issue that consist of 7 original research papers, two systematic reviews, one mini review, one policy and practice review and one perspective piece. Here follows a brief summary of how each one of these articles has made a unique contribution to documenting diverse local food systems and promoting elements within them that can help improve nutrition and health—both human and planetary—in various ways including the livelihood development of knowledge holders.

In a perspective piece, Burkhart et al. call for the revitalization of local, traditional bananas in the Pacific Islands to help improve the diet and health outcomes in these populations. Traditional banana cultivars have been found to have higher amounts of carotenoids than the most commonly consumed Cavendish banana cultivar. The subsequent revitalization of these banana cultivars can also simultaneously support local food systems and livelihoods in these areas.

Merchant et al. utilized participatory research methods to assess, amongst adult male and female farmers in Western Kenya, familiarity of African Indigenous Vegetables (AIVs), consumption, and related barriers and facilitators of consuming AIVs, and favorite recipes for cooking AIVs. Results demonstrated that farmers were cooking AIVs, and also highlighted barriers and facilitators of consuming AIVs. In addition, participants were asked to list their most preferred AIVs in terms of both production and consumption preferences. Seasonal differences were either a facilitator or a barrier to AIV availability and thus, consumption. The authors call for policies that simultaneously promote increased farmers' access to key inputs for AIV production and behavior change programs to support increased consumption.

Bokelmann et al. use the HORTINLEA project which engaged small holder farmers in collaborative research for the purpose of promoting production of local vegetables. The project took place in Kenya and was focused on small-holder farmers and small enterprises to generate strategies and support the decision making processes that could lead to improvements in local vegetable value chains to improve food and nutrition security. Market access, especially to urban informal markets was noted as one of the most promising opportunities for small-scale producers to expand their market share. In order for this strategy to be successful investments in market hygiene and storage and better rural to urban access are needed. Opportunities to improve consumption of African Indigenous Vegetables (AIVs) were found across multiple pathways leading to food and nutrition security, including own consumption, increased income and women's empowerment and each pathway has merit for inclusion in a holistic strategy. From a value chain perspective, gains in efficiency can come through reducing vegetable loss, that occurs both from pests and disease as well as post-harvest deterioration. Solutions explored included improved vegetable seed and cooling and storage technologies. The final area considered for upgrading the AIV value chain to benefit small holder farmers in Kenya was through financial support to producer organizations and other forms of collective action, especially for women-owned enterprise.

Ahmed et al. focused on the importance of wild food environments, where communities can procure cultivated and wild foods from within their surroundings. They surveyed 182 adult informants in the state of Montana in the United States of America, divided between urban and rural counties. Over half of these participants reported hunting or foraging on a weekly basis; the majority of which incorporated the foraged wild edible plants and hunted wildlife into homemade recipes. Overall, participants shared myriad environmental concerns that could negatively impact the positive benefits of wild food environments, including changes in weather patterns, land-use and water quality. In parallel with greater conservation efforts and place-based education on wild food procurement, more research is needed to discern how climate change is specifically impacting wild food environments.

Kuhnlein and Chotiboriboon highlight why and how to strengthen Indigenous Peoples food systems using examples from the Nuxalk Nation in British Columbia, Canada and the Pwo Karen People of Sanephong Community, Thailand. They define Traditional Food Systems of Indigenous Peoples as all foods within the particular culture that are available from local natural resources and culturally accepted, including the sociocultural meanings, acquisition and processing techniques, use, biological composition and nutritional consequences for the people using the food. The people of the Nuxalk Nation inhabit the Bella Coola valley, in a food system where the river and tributaries provided many habitats and food diversity, including five species of Pacific salmon, sea foods, game (rarely found), tree foods, root foods, and a variety of wild fruits and greens. The paper highlights the nutritional and cultural value of the eulachon (Thaleichthys pacificus Richardson) fish species, valued for oil, meat and culturally important food, provided as gifts and shared among community members. However the use of traditional food species by Nuxalkmc has been gradually declining. Interviews with three generations of Nuxalk women shows gradually decreasing use of game, berries, greens, roots, and sea foods, with less impact on river fish. A more severe downturn in local food resources was noted in the more recent past (1980 to 2009) due to a decline in fish species. A systematic

attempt to preserve and revive the Nuxalk food system began in the 1980s and continues to document, retain and use traditional biocultural knowledge for long-term nutrition and health benefits for Nuxalkmc.

Using South Africa as the setting, where erosion of traditional knowledge and use of indigenous and traditional foods has occurred for sorghum, Pereira and Hawkes trace this nutrient dense and resilient traditional food crop through the food system of South Africa. They identify five key entry points ranging from increasing affordability through trade and tax adjustments to increasing consumer appeal. They note a particular need to remove value added tax applied unequally to sorghum as compared to maize and to increasing consumer appeal through innovative product development and inclusion of sorghum in public procurement schemes, such as school meals. The South African government has identified sorghum as a crop of interest due to the nutritional and agroecological potential. The authors conclude with suggesting a cross-country learning exchange to exchange lessons learned on how to proactively engage across sectors and stakeholders within the food system to revitalize traditional grain crops that are both nutrient dense and climate resilient.

Ekesa et al. explore access to and utilization of wild foods in the Teso and Acholi sub-regions of Uganda. Using a series of focus group discussions with men and women (grouped separately) and the four cell mapping method, participants assessed current (2017) and past (before 1997) availability, consumption, sale, and purchase of wild foods in their communities considering dimensions such as (i) large and small areas of availability; (ii) many and few households; and (iii) more and less frequently consumed, sold or purchased. The study confirmed that wild foods still play a major role within the food systems of the two regions, with over 100 species mentioned, but that species availability has decreased over time for most species, especially animal source foods due to loss of habitat and hunting restrictions. A few communities reported greater availability of wild fruits now as compared to in the past. Fewer species were reported as being consumed, purchased and sold now as compared to the past, largely due to restrictions on hunting wild animals and habitat destruction. The reasons most frequently cited for continued reliance on wild foods were that they were convenient to harvest (grew commonly near homes), were considered local seasonal delicacies, were popular with children and were affordable. In contrast, habitat loss, rarity and expense were the most commonly cited reasons for few households consuming infrequently. The authors conclude with a call to valorize the social and cultural aspects related to wild foods.

Wang and Mashford-Pringle address the nutrition status and dietary practices of "ethnic minority groups" in China through a literature review. The authors found that, of all fifty-five ethnic minority groups in China, only fifteen have representative dietary intake data reported, only seven have data on both, nutrition status and dietary practices and there are no studies for ten of them (representing more than 800.000 inhabitants). The probability for an ethnic minority to be considered a research subject is related to the population size of the group, as well as with their uniqueness in a specific region. On the substantive content of the research reviewed, ethnic minorities in China suffer from a double-burden of malnutrition and consume unbalanced diets.

Gutierrez et al. investigated the Kumiai community in San José de la Zorra in Baja California, Mexico, near the Guadalupe Valley to better understand if their traditional food system persists at present. They found that the current Kumiai diet is substantially different and less nutritious from the traditional diet, rich in cultivated foods such as bitter acorn and watercress, they once consumed. However, the Kumiai still prefer cooking with a wood stove and will still have family traditional meals with acorn-based recipes, amongst other locally based ingredients. The current existence of traditional food system knowledge within the Kumiai community offers solutions for both the health of its people and its natural resources.

del Valle M. et al. conducted a literature review based on the following question: "How can food governance transform food systems to ensure better access to sustainable diets?." The authors conclude that from the food governance lens it is key to ensure that food systems are sustainable and resilient to crisis. In this, food governance is necessary to have more equitable relationships between the actors involved in food systems. An additional finding is that the concept of agriculture governance, although very relevant to promote an agricultural sector more committed to nutrition and sustainability, has still been scarcely explored. Another aspect that needs to be more developed is the socio-cultural dimension of sustainability. The concept of agency can be useful to advance a better understanding and thus, inclusion of the socio-cultural dimension of sustainability.

Sobhani et al. assess and compare the sustainability dimensions of the usual Iranian dietary intakes with sustainable optimal diets based on Iranian, Mediterranean, and vegetarian food-based dietary guidelines (FBDGs). The authors found that the Iranian food-based dietary guidelines have improved in terms of sustainability though the years. They also show that substituting the usual Iranian dietary intake with the optimal diet of other FBDGs could lead to very relevant reductions on environmental footprints (water, carbon and land), as well as in cost. In this, the Mediterranean diet was the one with higher improvements in costs, sustainability and nutrition.

Marchant et al. study the potential of blood-fleshed peach, a heritage cultivar, to support livelihood opportunities in local agriculture in Chile. Ethnographic research using a citizen science approach was used to map the geographic distribution of blood peach in regions of Chile and farmers familiar with blood peach responded to questions on common uses and properties. These findings were complimented with laboratory analysis focused on the antioxidant and polyphenols in fresh blood peach. The geographic distribution was wide, suggesting that blood peach is adaptable to a range of climatic conditions. Farmers interviewed often recalled childhood memories of consuming this fruit, but that the cultivar is now in decline. Some reasons for this are the delicate nature of this cultivar which bruises easily and therefore is difficult to transport and market widely and the current trend in Chile for fruit production aimed at the international export market. There is also a loss of cultural knowledge, with younger generations not recognizing this cultivar in the market and therefore not purchasing the fruit. The antioxidant activity of the blood-fleshed peach is higher than that of white and yellow commercially produced cultivars. The research team subsequently has helped the formation of a community association interested in

protecting the Chilean blood-peach and promoting it's production and consumption locally. There are several products that given the high antioxidant property have the potential of reaching health conscious consumers, especially if supported by chefs, restaurants and food entrepreneurs. Success for this cultivar will be linked to rural territories that are interested in promoting the conservation of this cultivar based on the social and economic benefits that can be gained.

The post-COVID food and nutrition security outlook shows an increase in hunger and food insecurity, exacerbated by the economic aftershocks of COVID and increasing global inflation. Related to low global dietary diversity and diet quality, diet-related health costs are projected to reach USD 1.3 trillion per year by 2030 (FAO et al., 2022). Therefore, we hope that the 12 scholarly articles in this special Research Topic focused on local and traditional food systems will positively contribute solutions toward mitigating the concomitant climate and health crises the world is facing.

Author contributions

RK drafted the introduction and conclusion sections of the text, wrote summaries for the articles she worked on when the Research Topic was in progress, and compiled and revised all authors' contributions into the final version of the manuscript. GK contributed to both the introduction and conclusion sections of the text, wrote summaries for the articles she worked on when the Research Topic was in progress, and provided feedback on the draft manuscript. SB wrote summaries for the articles she worked on when the Research Topic was in progress. All authors contributed to the article and approved the submitted version.

Conflict of interest

GK was employed by Global Alliance for Improved Nutrition.

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.

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PERSPECTIVE
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Realizing the Potential of Neglected and Underutilized Bananas in Improving Diets for Nutrition and Health Outcomes in the Pacific Islands

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Pacific Island countries are undergoing rapid food system transformation. This has led to a deterioration in diet quality with decreased consumption of traditional, fresh foods, and increasing consumption of imported, ultra-processed foods. Consequently, the triple burden of malnutrition is a now a major issue in the region. It is estimated that Vitamin A deficiency (VAD) is widespread, particularly in Kiribati, Vanuatu, and Solomon Islands. Rates of overweight, obesity, and diet-related non-communicable disease (DR-NCD) are high. Increasing consumption of local, traditional fruits and vegetables, particularly those that have high nutritional value like Pacific Island bananas, could play an important role in improving diets and health outcomes of Pacific Islander populations. Many of the banana cultivars found in the Pacific Islands region are high in carotenoids, an important precursor to Vitamin A. Fe'i bananas, such as Utin lap, have been shown to contain much higher amounts of carotenoids than that of the commonly consumed Cavendish banana. As a traditional, starchy staple food, bananas are a good source of carbohydrate, including resistant starch, with small amounts of protein and little fat. These characteristics also lend themselves to being part of a healthy diet. The promotion of neglected and underutilized banana cultivars in the Pacific region provides a food-based and low-cost solution that simultaneously supports healthy diets and good nutrition, local farming systems and livelihood opportunities. However, to realize this potential, more work is required to understand the availability of nutrient rich banana in the region, current consumption patterns and drivers of consumption.

Keywords: Oceania, food systems, fruit, livelihoods, local food, traditional food

INTRODUCTION

Diets in areas of the Pacific Islands (P.I) have changed dramatically since World War II (Englberger et al., 2003b), with rapid food system transformation underway. Local, traditional foods have been somewhat replaced by an increased reliance on imported, highly processed foods (Englberger et al., 2003b; FAO, 2018; Horsey et al., 2019; Santos et al., 2019; Sievert et al., 2019; Medina Hidalgo et al., 2020; Vogliano et al., 2021b). Diet quality has decreased with reduced consumption of traditional, fresh foods, and increasing consumption of store-bought foods, particularly rice and nutrient poor ultra-processed foods. This appears to have contributed to increased rates of chronic disease and a heavy triple burden of malnutrition. Many P.I are experiencing high rates of both under- and over-nutrition.

Undernutrition is a significant issue in the P.I (FAO et al., 2021), with some of the highest rates globally for stunting, wasting and micronutrient deficiency. The prevalence of stunting in children (under 5 years of age) in the region is 41.4% (FAO et al., 2021), and wasting 9% (FAO et al., 2021). Vitamin A Deficiency (VAD) is estimated to be widespread across the region, particularly in Kiribati, Vanuatu and Solomon Islands (Schaumberg et al., 1995). Vitamin A deficiency is a major cause of morbidity, mortality and blindness among children. Many of the foods now imported into P.I., including refined flours, sugar, white rice and ultra-processed foods (i.e., biscuits, instant noodles), are poor sources of Vitamin A and compound the issues related to overnutrition and diet related non-communicable diseases (DR-NCDs). Additionally, Vitamin A supplementation coverage is low, with less than a third of children reached in Solomon Islands and Vanuatu (UNICEF, 2018).

Overnutrition is also a significant health issue in the region. Many imported, ultra-processed foods are high in energy (kilojoules) but provide very little nutrient value. Rates of obesity are high, with >50% of the adult population (over 18 years) reported as obese in many countries, including Nauru (61%), Marshall Islands (52.9%), Cook Islands (55.9%), Palau (55.3%), Tuvalu (51.6%) and Niue (50%) (FAO et al., 2021). Obesity is a risk factor for many non-communicable diseases (NCDs), adverse health outcomes and mortality. In the P.I. on average, over a quarter of adults have diabetes and NCDs are responsible for around 70% of deaths (World Bank, 2014).

Increasing fruit and vegetable consumption can play an important role in improving diets and health outcomes (FAO, 2020b). Banana, a traditional staple food of the P.I. region (Englberger et al., 2003b, 2006a,b; Nelson et al., 2006) has potential to improve some of the major health issues facing these populations, including VAD and DR-NCDs. Food is intrinsically linked to culture and livelihoods in the P.I, so identifying local, traditional and culturally acceptable foods that are high in Vitamin A/provitamin A carotenoids (Englberger et al., 2006a) is an important step toward addressing undernutrition. Increasing consumption of fruits, like banana, that are nutrient rich, low in energy (kilojoules), and high in fiber can also play an important role in improving health and weight status (Lindström et al., 2006; Slavin and Green, 2007; Brownlee et al., 2017).

Prior to the early 2000s, there was little understanding of the nutrient value of P.I bananas. A substantial body of research and community-based advocacy led by the late Dr Lois Englberger (Englberger et al., 2003a,c, 2006a,b, 2010) showed P.I bananas to have high levels of carotenoids, particularly β-carotene, with higher amounts found in those with deeper-colored flesh (Englberger et al., 2003a,c, 2006a). The Karat, a Fe'i banana (of the Australimusa series), has been the focus of much of this work and has been proposed to play a role in alleviating VAD in the region (Englberger et al., 2006a). Despite being traditional custodians of this genetic resource, the P.I have not yet seen significant investment in research and development to improve the availability and utilization of Fe'i banana, yet there is increasing attention and demand for these naturally occurring vitamin A rich bananas in East Africa (Fongar et al., 2020).

Given 2021 was the International Year of Fruits and Vegetables (FAO, 2020b), it is timely to renew interest in local bananas as part of a nutritious diet in the P.I. In this perspective, we aim to strengthen the call for realizing the potential of local, traditional bananas in improving diets and health outcomes in P.I populations by highlighting key nutritional characteristics of banana with a focus on carotenoids and resistant starch.

BOTANY AND TRADITIONAL USE

The Musa genus, thought to have originated in South East Asia (Englberger et al., 2006b), contains many cultivars of banana (Englberger et al., 2006b; Sardos et al., 2018), divided into Musa and Callimusa (Häkkinen, 2013; Janssens et al., 2016; Sardos et al., 2018). Edible bananas, the most popular being Cavendish (AAA) (Buah et al., 2016; Sardos et al., 2018) and Plantain (AAB) (Buah et al., 2016; Sardos et al., 2018), have either genome A (based on M. acuminata Colla) (Englberger et al., 2006b), A with B [B designated as M. balbisiana Colla (Englberger et al., 2006b)] as seen in Pome and Silk bananas, or A with S (Sardos et al., 2018). The range of diploidic, triploidic, and tetraploidic hybrid varieties available result in different composition and properties of the banana (Stover, 1987).

Banana plants, a climacteric fruit (Mohapatra et al., 2011), usually grow between 2 and 9 m high, with a bunch of fruit, pseudostem with leaves and a base rhizome, with suckers and roots (Daniells et al., 2011). The plant flowers at any time of the year, with maturation of the fruit taking between 2 and 6 months (Daniells et al., 2011). Forming the bunch of fruit is the female basal flower clusters (Daniells et al., 2011). Bunch size and finger length depend on the variety, as well as environmental conditions (Daniells et al., 2011).

In the P.I region, bananas are typically grown for domestic use and are considered a traditional staple food (Englberger et al., 2003b, 2006a,b; Nelson et al., 2006). Banana and plantain production has been steadily increasing over time in the Pacific Islands, with 1,332,961 tons produced in Melanesia, Polynesia

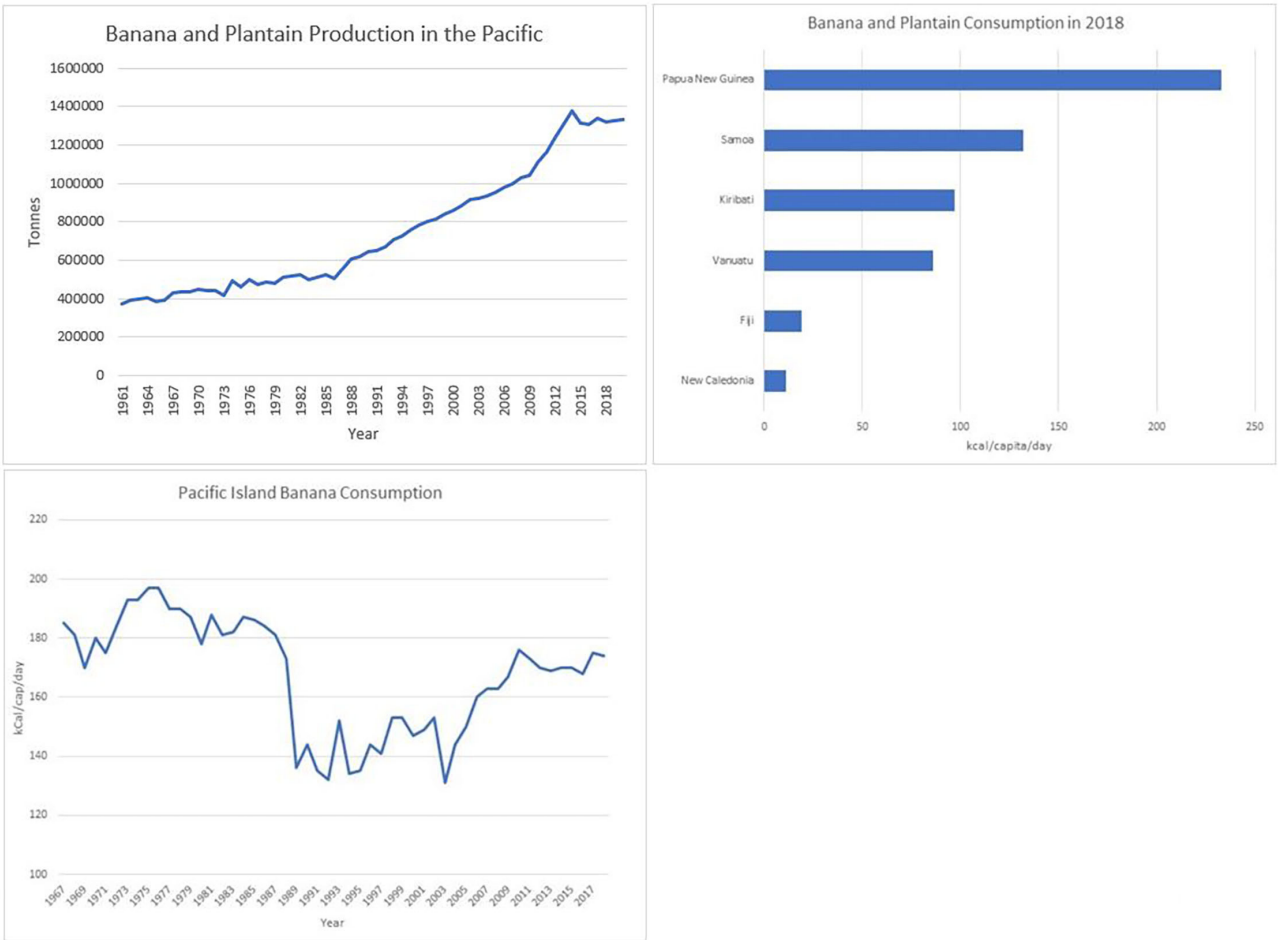

FIGURE 1 | Banana production and consumption in the P.I region. Source: FAOSTAT Food Balance Sheets—calculated by authors.

and Micronesia in 2020 (**Figure 1**), however no information is available to understand production yields of different banana cultivars. Bananas from the Fe'i classification are mostly found throughout the P.I region (Sharrock, 2001; Englberger et al., 2006b), including in the Cook Islands, Federated States of Micronesia, Fiji, Papua New Guinea, Samoa, Solomon Islands, and Tonga (MacDaniels, 1947; Daniells, 1995; Sharrock, 2001; Englberger et al., 2006a; Sardos et al., 2018). They are considered to be highly nutritious but are less studied than other types of banana (Sardos et al., 2018). Fe'i bananas grow in an erect bunch and have richly colored pink to purple/violet sap (Sharrock, 2001; Englberger et al., 2006a,b). Known as banana, plantain, cooking banana and dessert banana in this region, common names vary depending on area/location (Nelson et al., 2006).

Pacific Islanders use banana fruit in green, ripe, or half-ripe stages (Englberger et al., 2006a; Daniells et al., 2011), raw (usually as a snack), or cooked (usually for a meal) (Englberger et al., 2003b, 2006a; Nelson et al., 2006; Sardos et al., 2018) (see **Figure 2**). They are used to produce beverages (vinegar, beer, and wine) (Nelson et al., 2006), and for medicinal (Nelson et al., 2006; Daniells et al., 2011; Pereira and Maraschin, 2015; Sardos et al., 2018), ornamental (Sharrock, 2001; Daniells et al., 2011; Sardos et al., 2018) and cultural purposes (Sardos et al., 2018). The banana flower, also known as a bud or bell, can also be consumed (Daniells et al., 2011).

Different cultivars have different levels of status in communities, depending on their use and location. For example, Karat is considered of low value in Yap (Federated States of Micronesia) but of high value in Pohnpei (another State within the Federated States of Micronesia), where it has been used traditionally as food for weaning children (Demory, 1976; Englberger et al., 2003b, 2006a). Local bananas have also played an important role in ensuring food security. For example, traditionally in Vanuatu, unripe bananas have been preserved for over 2 years using the "Mara Technique" for cyclone season and associated periods of food insecurity (APTC and DFAT, 2014). While these micronutrient rich cultivars have and could further play a role in the diets of Pacific Islanders, they are

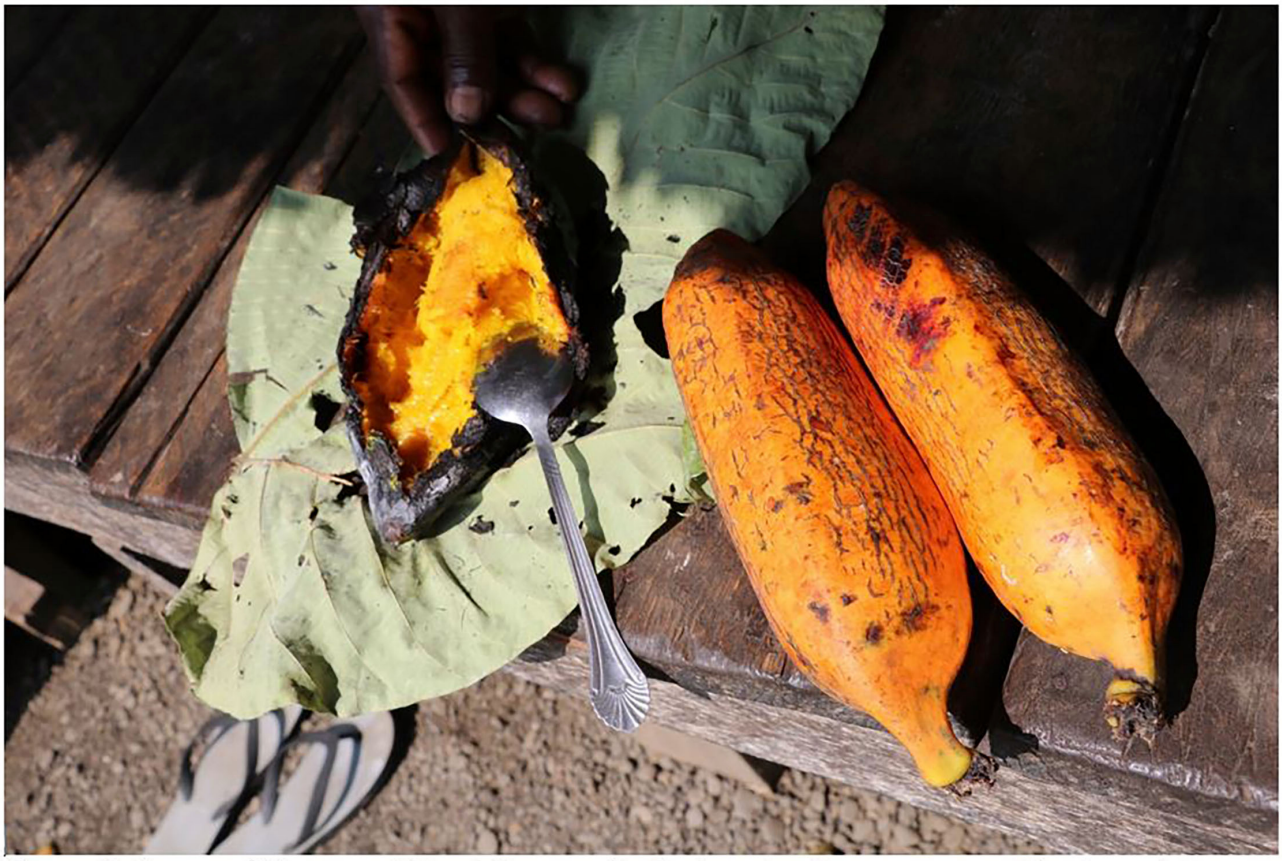

FIGURE 2 | Image of Solomon Islands banana. Left: A cooked banana opened to show rich colored flesh. Right: Fresh, unpeeled banana (Image courtesy Jessica E. Raneri, 2021).

underutilized and could be considered the "forgotten" crop of the Pacific.

NUTRIENT COMPOSITION

As a starchy staple food, bananas are a good source of carbohydrate, with small amounts of protein and little fat (Dignan et al., 2004). Bananas, in general, contain a range of micronutrients, including potassium, magnesium, and sodium and a diverse range of high value bioactive compounds. Bananas are an important food for reaching B1 nutrient adequacy in the Solomon Islands (Troubat et al., 2021). Bananas are particularly rich in antioxidants, including phenolics, carotenoids, ascorbic acid, flavonoids, and biogenic amines (Singh et al., 2016), all important for human health. The high antioxidant capacity of bananas increases as the fruit matures (Singh et al., 2016; Vu et al., 2019).

Banana is not typically considered as a source of Vitamin A, most likely because of the low levels of provitamin A carotenoid content reported in common cultivars such as Cavendish (Englberger et al., 2006b). Research to date, however, suggests that many of the banana cultivars found in the P.I region are high in carotenoids (Englberger et al., 2003a,c, 2006a,b, 2010), an important precursor to Vitamin A (Gilbert, 2001), supporting the consideration of these local, traditional foods as an opportunity to improve nutrition and health outcomes. For example, Fe'i bananas have been shown to contain up to 8508 μg of β-Carotene per 100g (Utin Iap) (Englberger et al., 2006a). In comparison, common cultivars such as Williams (Cavendish, found widely throughout the World) contain ∼50–64 μg of trans β-Carotene per 100 g (Englberger et al., 2006b; **Table 1**).

A health promoting component of fruits and vegetables is dietary fiber. Derived from plants including banana, dietary fiber is resistant to digestion and absorption in the small intestine, this important class of carbohydrates promotes beneficial physiological effects (Lockyer and Nugent, 2017), and provides further evidence for the potential role of banana in improving health. In humans, through the process of enzymatic digestion, starch chains are broken down into glucose units which are absorbed, however, a proportion of starch is not always entirely digested nor absorbed by the body (Sajilata et al., 2006; Lockyer and Nugent, 2017). This property of some starchy foods is referred to as resistant starch (RS) and

TABLE 1 | Carotenoid composition of selected *Musa* found in Pacific Islands.

Classification[a]	Descriptive information			Carotenoid content, presented as μg per 100 g of edible portion			
	Local name of cultivar	Source	Flesh color (numerical score)[b]	β carotene	α carotene	β carotene equivalents[c]	Total carotenoids[d]
Fe'i	*Utin lap**	Pohnpei (FSM)	Orange (15)	8,508	N/R	8,508	N/R
	*Utimwas**	Pohnpei (FSM)	Orange (14)	278–7,200	91–1,800	324–8,100	N/R
	*Aibwo/Suria***	Makira (Solomon Islands)	Yellow—orange (10, 12, 14[e])	2,574–5,945	1,517–2,358	3,331–7,124	4,185–9,400
	Fagufagu[f]*	Makira (Solomon Islands)	Yellow—orange (most 8, some 15 in center)	3,428	1,524	4,190	5,054
	*Karat**	Pohnpei (FSM)	Yellow—orange (8)	960–2,230	455	960–2,473	4,230
	*Gatagata/Vudito***	Guadalcanal (Solomon Islands)	Yellow—Orange (10, 13)	447–695	42–79	468–734	489–774
	*Toraka Parao***	Makira (Solomon Islands)	Yellow—Orange (most 10, some 14 in center)	526	250	651	776
	*Baubaunio***[f]*	Makira (Solomon Islands)	Light yellow (1)	332	249	457	581
	*Warowaro***	Makira (Solomon Islands)	Yellow (most 4, some 8 in center)	166	<2	167	1,444
AAB; Maia Maoli Popoulu	*Karat en lap**	Pohnpei (FSM)	Yellow (4)	720	510	980	1,470
	*Tangrat**	Yap (FSM)	Yellow (2)	220–460	140–250	290–585	400–790
	*Peleu**	Pohnpei (FSM)	Yellow (4)	420	240	540	810
	*Huki Matawa***	Guadalcanal (Solomon Islands)	Yellow (4)	296	293	443	589
AAB; Maia Maoli Populu-like	*Iemwahn**	Pohnpei (FSM)	Yellow (3)	430–1,209	188–602	524–1,510	N/R
AAB; Mysore	*Utin Pihsi**	Pohnpei (FSM)	White <1 (slightly deeper color in center of flesh)	38	24	50	N/R
AAB; Plantain	*Mangat en Saipahn**	FSM (Pohnpei)	Yellow (9)	550–4,799	342–3,408	721–6,503	N/R
AAB; Pome	*Lady Finger****	South Johnstone (Australia)[g]	Yellow	95[h]	132	178	N/R
	*Preisihl**	Pohnpei (FSM)	White <1	44	25	57	N/R
AAB; Silk	*Utin Menihle**	Pohnpei (FSM)	White <1	128	N/R	128	N/R
AA; Sucrier	*Kudud**	Pohnpei (FSM)	Yellow (2)	315	192	411	N/R
AAA; na	*Ropa***	Makira (Solomon Islands)	Yellow (5)	1,324	3,682	3,165	5,218
AAA: Cavendish	*Williams****	South Johnstone (Australia)[g]	Yellow (no number)	50–64[h]	93–123	104–134	N/R
	*Saena***	Guadalcanal (Solomon Islands)	White <1	58	79	98	137

**Englberger et al. (2006a).*

***Englberger et al. (2010).*

****Englberger et al. (2006b). N/R, Not reported; na, not known. [a]Samples classified by Stover and Simmons; [b]using the DSM Yolk color fan, [c]estimate of β carotene equivalents: Content of b-carotene plus one-half of the content of a-carotene and b-cryptoxanthin; [d]estimated by calculating total peak areas recorded in the chromatograms (using the response factor of b-carotene); [e]range of yellow orange (12) and (most 10, some 14 in center); [f]half ripe; [g]provided for comparison, sample obtained from Australia; [h]reported as trans β carotene.*

is considered a type of dietary fiber. There are five types of RS, including Resistant Starch type 2, whereby the starch is ungelatinized and in a granular form, for example in grains, potatoes, pulses, and green bananas (Lockyer and Nugent, 2017). Resistant starch resists breakdown in the small intestine and arrives intact in the large intestine, where it is fermented by residing bacteria (Lockyer and Nugent, 2017). The production of short chain fatty acids through microbial fermentation provides various physiological benefits, including greater insulin sensitivity and colonic cancer prevention (McNabney and Henagan, 2017).

However, most food sources of starch are not eaten in their raw form, for example potato or rice, as they unable to be digested and are unappealing for consumption in the raw form. Banana, a starch-rich food that can be eaten raw and is a good source of RS, is an exception to this (Jiang et al., 2015; Wang et al., 2015). While traditional staple foods of the region are typically starchy root crops, like taro and cassava, imported rice, mainly white, is now widely consumed in the region. Interestingly, there is some evidence that rice is linked to diabetes prevalence (Hu et al., 2012). The fiber and starch content of banana have been shown to have protective properties for preventing diabetes, as well as being a low GI food to help with diabetes management (Hermansen et al., 1992). This suggests that substituting local bananas in place of white rice could potentially assist with diabetes management. Additionally, consuming more local bananas could displace ultra-processed foods, which are also associated with adverse health outcomes, including cardiovascular and metabolic diseases (Monteiro et al., 2019).

CURRENT CONSUMPTION PATTERNS

Dietary intake data is limited for the P.I, with most available consumption data obtained from household income and expenditure surveys. In the absence of specific P.I nutrient reference values (SPC, 2018), there is a reliance on International nutrient reference values for interpretation of adequate intake, for example 300 μg Retinol Equivalents/day for adults (WHO and FAO., 2004). When data is available, banana is often aggregated into food groups of fruit and/or roots and tubers. From the data available, the relative importance of banana to overall daily energy intake (DAI) varies across the region and within countries. In Solomon Islands, cooking banana intake averaged 76 g/capita/day and contributed to 5% of DAI (Troubat et al., 2021). However, a subregional study showed banana consumption more broadly (including dessert banana) ranged from contributing nearly a quarter (21%) of DAI in rural inlands (Vogliano et al., 2021b), to just 7% in a rural coastal region (Vogliano et al., 2021a). In Vanuatu, banana is the second most consumed food after rice, at about 172 g/day contributing 8.5% of daily energy (Vanuatu National Statistics Office, 2021). In the Marshall Islands, between 32 and 45% of households consume bananas with higher consumption in rural areas (EPPSO et al., 2021). Data from the (FAO, 2020a), indicate that on average across the PI, bananas now contribute 174 kCal/capita/day, having decreased 16% from the average between 1967–1988 and 1989–2018 (**Figure 1**).

OPPORTUNITIES TO INCREASE CONSUMPTION

While Pacific Islanders currently consume bananas in a variety of ways (Englberger et al., 2003b, 2006a; Nelson et al., 2006; Sardos et al., 2018) there are opportunities for other banana-based food products to be included in diets, potentially increasing consumption.

Banana can be processed in various ways, including as dried banana, banana flour, banana crisps, and banana jam, however these are not common in the P.I region (Daniells et al., 2011). To date, there appears to be small scale processing of banana in some areas of the region, such as Fiji and Samoa, but little published literature on the process(es) used and products developed. Daniells et al. (2011) suggest that processing banana at a farm or community level could provide opportunities to reduce waste, transform fruit into more "valuable" items and promote increased consumption through greater availability of banana-containing items.

Green banana products are of increasing interest because of their nutritional composition and potential health benefits (Falcomer et al., 2019). Green banana provides a good source of dietary fiber, vitamins, and minerals and many bioactive compounds (Falcomer et al., 2019). The RS content of green banana flour (∼74%) makes this an acceptable, and more nutritious, substitute for wheat flour in bread and pasta (Gomes et al., 2016).

Increased promotion of the value of local, nutritious foods to communities, and individuals also provides an opportunity to increase consumption of local bananas. The "Let's Go Local" campaign, started in the Federated States of Micronesia, is one example of a successful program (Englberger, 2011). There are also opportunities to integrate knowledge of local, traditional foods, including banana, in school curriculum and extra-curriculum activities (Burkhart et al., 2022), to teach children how to produce, prepare, and to eat local bananas. Furthermore, this can support children to understand the value these foods, not only from a health perspective, but also for local livelihoods and food sovereignty.

DISCUSSION

Despite their potential, P.I banana cultivars remain neglected and underutilized in the region, particularly in the context of domestic commercial trade. There is decreased reliance on banana and other traditional staple foods, in favor of imported options, including rice and wheat-based food products in the region. High in nutrients and fiber, local bananas can play a role in ensuring P.I populations consume more fruit and could help to alleviate some of the nutrition related health outcomes currently seen in the region. Local P.I bananas are relatively unique in their nutrient profile. The main cultivar produced and consumed globally is the Cavendish banana, which contains relatively

fewer nutrients, especially carotenoids, compared to some of the more nutrient dense cultivars available in the P.I. Besides health benefits, promoting and using locally produced foods like bananas can positively impact livelihoods and communities through increased domestic production.

The high levels of carotenoids found in P.I bananas suggest they can play a significant role in improving nutrition related health outcomes in this population, including for VAD. In developing countries, a large proportion of vitamin A consumption is from vegetable sources (Borges et al., 2019). This is in the form of provitamin A carotenoids, which are ultimately converted into vitamin A (retinol). In the P.I region, animal source foods (ASF), which are a source of retinol, are consumed, but not to the same extent as seen in developed countries. Several factors likely restrict consumption of ASF, including availability, cost/affordability and cultural practices and values (Englberger et al., 2003b; Bottcher et al., 2021). Across the Pacific many Governments include vitamin A supplementation policy as part of their health and nutrition strategies, however given the logistical constraints of disseminating a government wide supplementation program in the region, because of the rural and remote geographies of the P.I, vitamin A supplementation coverage is low (UNICEF, 2018).

As a good source of resistant starch, bananas could also improve digestive health and play a role in mediating type II diabetes and other DR-NCDs. However, to realize the potential health benefits associated with nutrient rich banana PI banana, there is a concurrent need to ensure crop accessibility and consumption. Apart from Dr. Lois Englberger's work in the late 1990s and early 2000s, there has been very little published literature in this area within the Pacific context. Much of the recent literature on P.I banana has centered around the Pacific Community's Center for Pacific Crops and Trees' (SPC-CePaCT) banana genetic resource program (Taylor, 2005; Gwabu et al., 2007; Palanivel and Shah, 2021) and studies to further document regional biodiversity (Kagy et al., 2016; Sachter-Smith and Sardos, 2021a,b). However, there is a dearth of information on P.I banana local consumer accessibility, consumption patterns, and associated drivers.

Consumer accessibility of P.I banana will also necessitate sustainable and semi-commercial scale production, distribution and market-trading. Some P.I banana cultivars have slow growth (Englberger et al., 2006a; Daniells et al., 2011), and often experience increased susceptibility to pests and diseases (Ploetz et al., 2007). As the popular Cavendish is under threat from Panama disease (Dita et al., 2018), there is significant interest in finding alternative cultivars. Further work to explore the characteristics of local P.I bananas is warranted to understand their susceptibility to disease and pest threats and their potential to be cultivated more widely. Englberger et al. (2003b, 2006a) noted that some Musa cultivars used in their work were rare, particularly Utin Iap and Utimwas, two of those with the highest β-Carotene levels, suggesting that there may be limited availability of these for local communities. Compounding accessibility and production constraints, much of the P.I region also experiences significant and recurring environmental challenges, for example tropical cyclones, which can adversely impact production and distribution of food, including banana (Magee et al., 2016). Further work to understand current availability, from a potential local consumer perspective, would be a productive starting point for understanding the potential contribution of P.I banana to healthy diets and resilience in the region.

Current food composition data, and the absence of regionally specific nutrient reference values, constrains our understanding of the contribution of P.I. banana to diets in the region. Food composition tables need to acknowledge the rich diversity available in bananas, and as such, the importance of capturing cultivar information in both food composition tables and during dietary intake assessments. The FAO/INFOODS Food composition Database for Biodiversity contains 59 different varieties of banana (FAO, 2017), however, the most recent published Food Composition Tables for the Pacific (FAO SPC., 2020) only includes three entries for banana: common (Cavendish), cooking and banana (generic) which is mainly derived from the Australian Food database (AUSNUT, AUSNUT). There is a clear need to improve the diversity of bananas included in regional food composition tables, to both better measure the contribution of these bananas in diets, but also help to build awareness around their relative contribution to nutritional intake compared to common cultivars. More work is needed to understand acceptability of banana in local diets, and well as highlighting the benefits of consuming this food in various settings. Similarly, dietary intakes methods and tools, similar to what was used by Vogliano et al. (2021a), are needed to ensure they are adapted to capture biodiversity level information, given the contribution of food diversity to diet quality (Lachat et al., 2018).

Pacific Island bananas have the potential to play an important role in improving food sovereignty and food and nutrition security in this region. As the Pacific region moves on from the COVID-19 pandemic, during which many Pacific populations returned to more subsistence forms of living, there has been discussion about opportunities to re-set food systems and revitalizing traditional foods and farming to improve the resilience of Pacific food systems. The timing may now be more conducive to supporting a newfound return to such traditional banana preservation and consumption practices, whilst levering on highly nutritious varieties offering potential health benefits.

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/s.

AUTHOR CONTRIBUTIONS

SB and JR conceptualized the work. All authors contributed to the draft and revisions of the final manuscript.

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Barriers and Facilitators in Preparation and Consumption of African Indigenous Vegetables: A Qualitative Exploration From Kenya

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Malnutrition and food security continue to be major concerns in sub-Saharan Africa (SSA). In Western Kenya, it is estimated that the double burden of malnutrition impacts 19% of adults and 13–17% of households. One potential solution to help address the concern is increased consumption of nutrient-dense African Indigenous Vegetables (AIVs). The objectives of this study were to: (i) document current methods used for preparation and consumption of AIVs; (ii) identify barriers and facilitators of AIVs consumption and preparation; and (iii) identify a package of interventions to increase the consumption of AIVs to promote healthy diets. This study used qualitative data collected from 145 individual farmers (78 female and 67 male) in 14 focus group discussions (FGDs) using a semi-structured survey instrument. Most farmers reported that they prepared AIVs using the traditional method of boiling and/or pan-cooking with oil, tomato, and onion. However, there were large discrepancies between reported cooking times, with some as little as 1–5 min and others as long as 2 h. This is of importance as longer cooking times may decrease the overall nutritional quality of the final dish. In addition, there were seasonal differences in the reported barriers and facilitators relative to the preparation and consumption of AIVs implying that the barriers are situational and could be modified through context-specific interventions delivered seasonally to help mitigate such barriers. Key barriers were lack of availability and limited affordability, due to an increase cost, of AIVs during the dry season, poor taste and monotonous diets, and perceived negative health outcomes (e.g., ulcers, skin rashes). Key facilitators included availability and affordability during peak-season and particularly when self-produced, ease of preparation, and beneficial health attributes (e.g., build blood, contains vitamins and minerals). To promote healthy diets within at risk-populations in Western Kenya, the findings suggest several interventions to promote the preparation and consumption of AIVs. These include improved household production to subsequently improve affordability and availability of AIVs, improved cooking methods

and recipes that excite the family members to consume these dishes with AIVs, and the promotion of the beneficial heath attributes of AIVs while actively dispelling any perceived negative health consequences of their consumption.

Keywords: consumption, food choice, healthy diets, Indigenous Vegetables, nutrition education, malnutrition, recipes, sustainability

INTRODUCTION

Malnutrition measured by stunting increased by 30% between 1990 and 2013 and thus remains relatively high in sub-Saharan Africa (SSA) (FAO, 2021). Moreover, food system shocks such as the COVID-19 pandemic have exacerbated undernutrition (FAO, 2021). It is estimated that in 2020, one in five individuals faced hunger in Africa, an increase of 3 percentage points as compared to previous years (FAO, 2021). It is common that such communities experience more than one form of malnutrition and the co-existence of undernutrition and overweight/obesity is often referred to as the double burden of malnutrition (DB) (Popkin et al., 2012). In parts of SSA, the DB has been attributed to nutrition transitions (Kimani-Murage et al., 2015; Ajayi et al., 2016), where urbanization, economic growth, and dietary shifts and changes in physical activity patterns, increase the prevalence of malnutrition (Raschke-Cheema and Cheema, 2008; Popkin et al., 2012; Rousham et al., 2020). It is currently estimated that in Western Kenya, DB is found in 19% of adults and 13–17% of households (Fongar et al., 2019). Such findings provide a compelling reason to ensure that agricultural and nutrition behavior change interventions as well as policy work toward increasing micronutrient intake without increasing caloric intake within populations that are already consuming sufficient energy.

African Indigenous Vegetables (AIVs) are an underutilized source of micro and macro-nutrients that can contribute to a healthy diet. AIVs are defined as vegetables that either originated in Africa or have a long history of cultivation and domestication to the conditions and are acceptable through custom, habit, or tradition (Ambrose-Oji, 2009; Towns and Shackleton, 2018). AIVs such as African nightshade (*Solanum scabrum*), spider plant (*Cleome gynandra*), amaranth (*Amaranthus* spp.), and cowpea leaves (*Vigna unguiculata*), are culturally accepted (Weller et al., 2015; Hoffman et al., 2018; Hunter et al., 2019; Simon et al., 2020, 2021), nutrient dense (Abukutsa-Onyango et al., 2010; Kamga et al., 2013) vegetables that may offer a partial solution to addressing malnutrition in SSA by contributing to micro and macro-nutrient intakes without introducing excess calories. Furthermore, AIVs are adapted to the local environmental conditions (Abukutsa-Onyango, 2010; Muhanji et al., 2011; Hunter et al., 2019) and some are even considered "survivor plants" due to their tolerance to temperature and precipitation extremes posing them as a sustainably produced and a climate resilient food source of micro and macro-nutrients (Chivenge et al., 2015; Stöber et al., 2017). Nutrition-sensitive agriculture programs attempt to increase the availability, affordability, and accessibility of nutritious foods, such as AIVs, which can contribute to a healthy diet; however, these programs may not take into consideration the broader barriers and facilitators within the external and personal food environment that may contribute to the preparation and consumption of such foods (Gillespie and Bold, 2017; Maestre et al., 2017).

There are dimensions within the external and personal food environment that may create barriers and facilitators that influence the preparation and consumption of AIVs. The external food environment includes external dimensions such as food availability, prices, vendor and product properties, and marketing and regulation within a given context; while the personal food environment includes internal dimensions such as accessibility, affordability, convenience and desirability at the individual level (Turner et al., 2017). Research suggests that AIVs need to be available, affordable (Muhanji et al., 2011), desirable, and palatable/tasty (Hartmann et al., 2013) in order for increased household adoption and consumption.

Increased consumption of AIVs (Kamga et al., 2013; Neugart et al., 2017) and thoughtful preparation techniques that maximize taste and flavor while preserving nutrition (Yang and Tsou, 2006; Mepba et al., 2007) can lead to improved micronutrient intake and subsequently improved health status amongst vulnerable populations (Ochieng et al., 2018). However, current literature is limited on the barriers and facilitators for preparation and consumption of AIVs. This study fills this gap by analyzing context specific semi-structured focus group discussions aimed to identify these barriers and facilitators. Through a qualitative exploration, the study objectives were to document current methods used for preparation and consumption of AIVs; identify barriers and facilitators of AIV preparation and consumption; and identify a package of interventions to increase the consumption of AIVs.

METHODS

Study Setting

This study was part of a larger research initiative to examine the production and consumption of AIVs in Kenya supported by the USAID Laboratory for Horticulture Innovation (Odendo et al., 2020; Simon et al., 2020, 2021). This study was conducted in four counties in Western Kenya: Bungoma, Busia, Kisumu, and Nandi. Agriculture is the main economic activity in the study counties (Recha, 2018; Welfle et al., 2020). The staple food crop is maize, often consumed as stiff porridge (*ugali*) alongside cooked leaves of AIVs (Maundu et al., 2009). These counties represent the four different regions in Western Kenya that were engaged in the larger study. However, individuals who participated in this study did not participate in the large Horticulture Innovation Lab project as the intention of this study was to gather qualitative data relative to barriers and facilitators

of preparation and consumption of AIVs without influence from recruitment or participation in the larger study.

The study applied qualitative research methodology. Qualitative research is especially appropriate for answering research questions of why something is (not) observed, assessing complex multi-component interventions, and focusing on intervention improvement (Busetto et al., 2020). For this study, qualitative approach was suitable because it was an exploratory study that sought to explain "how" and "why" a particular phenomenon or behavior (preparation and consumption of AIVs), operates in a particular context. Focus group discussions (FGDs) were used to identify the barriers and facilitators of preparation and consumption of AIVs in Western Kenya (Cooper and Endacott, 2007). A semi-structured survey instrument was designed to help in data collection. The protocol for this sub-study received ethical approval from Rutgers University, the State University of New Jersey (New Brunswick, NJ, USA) and Academic Model for Providing Access to Healthcare (Eldoret, Kenya). All study participants provided informed oral consent to participate in the study.

Study Participants

This study was conducted in May and June of 2017 and involved 145 individual farmers ($n = 78$ female and $n = 67$ male) in 14 FGDs from the four counties in Western Kenya. The study design allowed for two FGDs per sex in each of the four counties except for Busia county where a third FGD was conducted. The larger USAID study recruited a higher proportion of participants from Busia county; therefore, to represent this within the ethnographic study, a third FGD occurred in Busia. The FGDs were conducted by sex ($n = 7$ male and $n = 7$ female FGDs) to allow free communication, especially for females given the cultural gender dynamics in the communities. The FGDs ranged from 8 to 12 participants with an average of 10 participants to maximize data output and ensure that all participants had ample opportunity to participate while being conscientious of time (Tang and Davis, 1995). There was one instance of over recruitment due to word-of-mouth between neighbors (Focus Group 5); however, all participants who met the requirements were invited to stay. The total number of male and female participants in each FGD are shown in **Table 1**. Participants were randomly selected using farmer group contact lists we had gathered during our prior survey work in the region by the Kenya Agricultural and Livestock Research Organization, Kakamega Centre, Kenya (KALRO) and the Academic Model Providing Access to HealthCare (AMPATH), Eldoret, Kenya. The respondents were from communities that had prior exposure to AIVs through USAID-funded Horticulture Innovation training programs. The respondents were from households that had a man or woman [age 18–65 years) and owned a small farm or garden (defined as <1 hectare (ha)]. In addition, respondents were selected based on ease of access and proximity to other homes participating in the FGD. Horticultural farmers or commercial farmers cultivating and managing land more than 3 ha were excluded from the study. For each of the selected respondents, the spouses were also invited to participate in the FGDs.

TABLE 1 | Focus group discussions: dates, locations, and participant numbers.

Date	Location (county)	Focus group	Female participants (*n*)	Male participants (*n*)
5/29/2017	Nandi	1	9	0
		2	0	10
5/30/2017	Kisumu	3	11	0
		4	0	9
5/31/2017	Busia	5	17	0
		6	0	9
6/1/2017	Busia	7	12	0
		8	0	11
6/5/2017	Bungoma	9	11	0
		10	0	12
6/6/2017	Bungoma	11	9	0
		12	0	8
6/15/2017	Busia	13	9	0
		14	0	8
	Total participants		78	67

Data Collection

A semi-structured survey instrument was developed by Rutgers University, the State University of New Jersey (USA) in collaboration with KALRO (Kakamega Centre, Kenya) in English and then translated into the local languages. A copy of the semi-structured survey instrument can be found in the **Supplementary Material**. The FGDs took an average of 90 minutes and were led by two project team members, one acting as the FGD facilitator and the other as a notetaker. Interviews were not audio recorded due to the limitation of ability to translate and transcribe multiple local languages post survey; however, notes were taken by study team members (MO, CN, NM, and NN).

The semi-structured survey instrument contained open-ended questions in five key areas: staple foods, familiarity of AIVs, importance (or lack of) of consuming AIVs, favorite recipes for cooking AIVs, and barriers and facilitators of consuming AIVs. In addition, FGDs were asked to list their top preferred AIVs and the reasons for their preferences relative to production and consumption.

Data Processing

Immediately following each FGD members of the research team transcribed the notes from the FGD into Microsoft Word, where they were subsequently uploaded into NVivo (Version 12) for analysis. FGD participants provided common AIVs recipes and a list of their most preferred AIVs and reasons for their preferences. The responses for these two questions were aggregated, and the full range of responses were recorded.

Data Analysis

Data were open-coded and organized based on current culinary methods, and barriers and facilitators of preparation and consumption of AIVs within dimensions of the external

(e.g., availability, food price) and personal (e.g., affordability, convenience, desirability) food environments (Turner et al., 2017) as well as perceived AIV health attributes. Within each of these dimensions (e.g., availability, affordability, convenience) themes and subthemes were coded. Each of the dimensions ranged in the number of themes and subthemes with the full range presented in **Figure 1**. If discrepancies were encountered between FGDs, both perspectives were captured and reported in the data. The dimensions for this thematic framework were selected based the external and personal food environment presented in Turner et al. (2017) (e.g., affordability, availability, convenience, desirability) as well as elements of interest to the larger study (e.g., perceived health). Thematic analysis of FGDs was conducted using NVivo (Version 12) by one member of the research team following qualitative thematic exploration (Williams and Moser, 2019).

RESULTS

The results are organized into current culinary practices and perceived barriers and facilitators of the preparation and consumption of AIVs within the external and personal food environment (**Figure 1**).

Current Culinary Practices

Common Foods Consumed by Households

The FGDs identified common foods consumed within their household. All 14 focus groups reported *ugali*, a mixture of cassava, sorghum, millet, and/or maize, as the most common food consumed. The full range of reported commonly consumed foods is presented in **Figure 2**. In addition to *ugali*, respondents noted AIVs (3 female and 1 male focus group) and sweet potatoes (2 female and 1 male focus group) as commonly consumed foods. One FGD noted the most common consumed AIVs were "*spider plant, kales, slender leaf, nightshade, cowpea leaves, and African kale*" (Focus Group 1, female).

The top 8 preferred AIVs listed in alphabetical order and the full range of reasons participants prioritized these AIVs are listed in **Table 2**. When participants were asked why they preferred the various AIVs, female focus groups commonly elaborated on reasons relative to consumption noting nutrition, taste, ability to cook without additional ingredients (e.g., salt, oil), and ability to mix with other vegetables. Meanwhile, male focus groups more commonly elaborated on reasons relative to production noting sowing method (e.g., volunteer, self-propagating), inputs (e.g., fertilizer), and financial return.

Common AIVs Recipes and Frequency of Consumption

The full range of reported cooking methods and added ingredients for AIVs are listed in **Table 3**. It was noted that all of the AIVs could be cooked alone. Yet, in common practice, the AIVs were usually mixed and ingredients such as salt, milk, and groundnuts (peanuts) were added to the dishes. In addition, it was noted that ash a natural form of lye, commonly known as *munyu musherekha* in the local dialect and derived from the burning of different plants such as dried bean pods, was often added to the cooking water to soften the vegetables. However, Focus Group 12 (male) noted that, "*It becomes difficult to eat the AIVs if too much ash water is used during cooking*." Most farmers reported that AIVs were prepared using the traditional method of boiling and/or pan-cooking with oil, tomato, and onion. However, there were large discrepancies between reported cooking times, where some reported more "modern" cooking times of blanching and/or pan-cooking for 1–5 min while others reported more traditional times that range up 2 h. Some FGDs noted that the cooking time is extended when mixing different AIVs together to allow the flavors to blend.

Respondents reported that they did not set goals for consumption frequencies. It was noted that vegetables are consumed at random with no clear timetable as consumption is often dependent on seasonal availability and affordability at the market and farm. This was summarized Focus Group 8 (male), "*No goals are set, we eat AIVs depending on their availability and affordability. AIVs are cheaper during the rainy season because plenty can be found in the marked or even within the community*." However, it was noted that mothers use *"intuition to ensure that the family rotates and eats different types of vegetable through the week*" (Focus Group 13, female).

External Food Environment

Availability

Availability of AIVs can present barriers and facilitators to preparation and consumption. Respondents noted that the two main barriers to availability were seasonality and allocation of land on their farm. Focus Group 6 (male) noted that there is a "*shortage of AIVs during drought[s]*." Furthermore, seasonality can inhibit the ability to acquire the necessary ingredients to prepare complete and desired meals for household consumption as summarized by Focus Group 11 (female), *"Not all vegetables are available in each season this makes it difficult to get the required varieties for mixing*." In addition to limited availability during the dry seasons, respondents noted that a lack of availability may be attributed to low production of AIVs on the farm as summarized by Focus Group 1 (female), "*Most of the land has maize and little land is left for AIVs*." On the contrary, FGDs reported that during the growing season market availability was a facilitator for consuming AIVs. Focus Group 11 (female) noted that, "*They are found easily in the market compared to other foods*."

Food Price

Depending on seasonality, AIV food price presented barriers and facilitators for AIV preparation and consumption. In addition to availability, respondents noted that seasonality presented a barrier to the cost of AIVs during the dry seasons. Focus Group 8 (male) noted that "*when not in season especially during the dry season, most AIVs are sold expensively*." Meanwhile, during peak production season the low cost of AIVs at the market facilitated purchasing and household consumption.

Personal Food Environment

Affordability

Relative to affordability, or the ability to acquire AIVs, barrier and facilitators were reported. Off-season, affordability influenced the

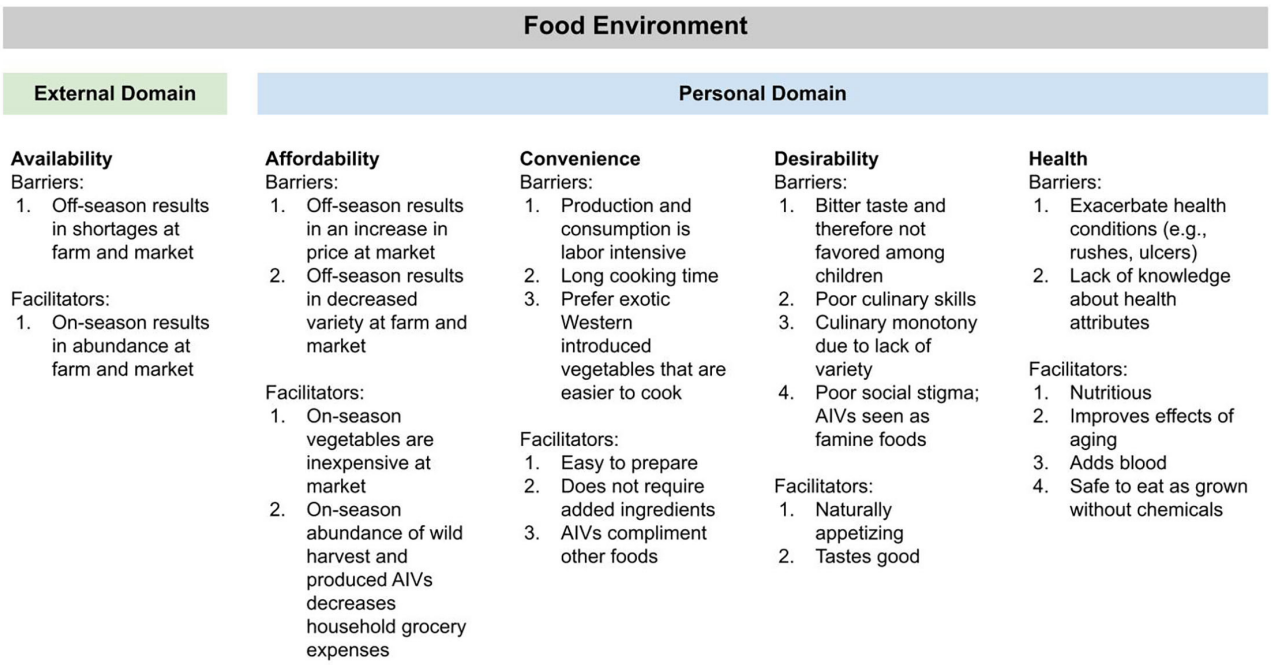

FIGURE 1 | Key barriers and facilitators to production and consumption of African Indigenous Vegetables in the external and personal food environment in Western Kenya.

variety of AIVs that are purchased for household consumption as summarized by Focus Group 13 (female), "*Financial ability is sometimes a limitation to changing the type of vegetables to be eaten*." Meanwhile, AIVs were affordable to purchase and plant in-season, particularly when AIVs are self-produced or wild-harvested. FGDs noted that AIVs are "*cheap to get and plant*," particularly if they are wild harvested (Focus Group 7, female). Due to their low production cost, this was also a "*more economical option than buying them from the market*" (Focus group 12, male). In addition, to providing readily available inexpensive nutritious leafy greens, self-production of AIVs also allowed for household finances as summarized: "*vegetables from the wild, volunteers or vegetable gardens help reduce amount of money spent on food*" (Focus Group 4, male).

Convenience

Relative to the convenience of preparing AIVs, FGDs reported both barriers and facilitators. During the FGDs, participants observed several barriers regarding the convenience of preparing AIVs. It was reported that preparing AIVs, from harvest to table is labor-intensive. Focus Group 14 (male) summarized this by saying, "*Some females pick less vegetables from the farm to avoid the long preparation time required before cooking, such as plucking the leaves and washing several times to remove soil*." It was further noted that "*the local vegetables take long to cook which discourages some people because they don't have much time to wait*" (Focus Group 13, female). Furthermore, respondents noted that when they have the economic resources, they prefer to purchase exotic vegetables or "expensive" food. Focus Group 12 (male), summarized this by saying, "*Many people prefer global vegetables because they are easy to prepare*."

There are several aspects with respect to convenience of preparation that facilitate the consumption of AIVs. Focus Group 7 (female) noted that AIVs "*can be cooked very easily with simple ingredients*," suggesting that they are easy to prepare with little to no added ingredients such as oil or meat. Furthermore, AIVs can easily compliment other foods to create a complete meal. Focus Group 11 (female) summarized this by saying, "*Vegetables is a ready food that can consumed with other food like meat to form a complete meal for the family*."

Desirability

There were differences in responses relative to the desirability of AIVs, where both barriers and facilitators were noted. FGDs provided a range of barriers related to the desirability of AIVs. Respondents indicated that some AIVs had a bitter taste, which reduced consumption particularly among children: "*Some vegetables are bitter which makes some youths and children dislike them*" (Focus Group 13, female). Furthermore, it was noted that a lack of variety results in boring and monotonous meals. This challenge was summarized by a participant from Focus Group 13 (female) who noted that, "*Cooking one type of vegetable several times make the family member loose interest hence consumption reduces*." Poor culinary skills were noted as another major challenge: "*Poor cooking skills make most of family members refuse to eat vegetables*" (Focus Group 11, female). Furthermore, AIVs carry a negative perception, which affect household consumption given that some "*believe that vegetable for the poor people*" (Focus Group 10, male).

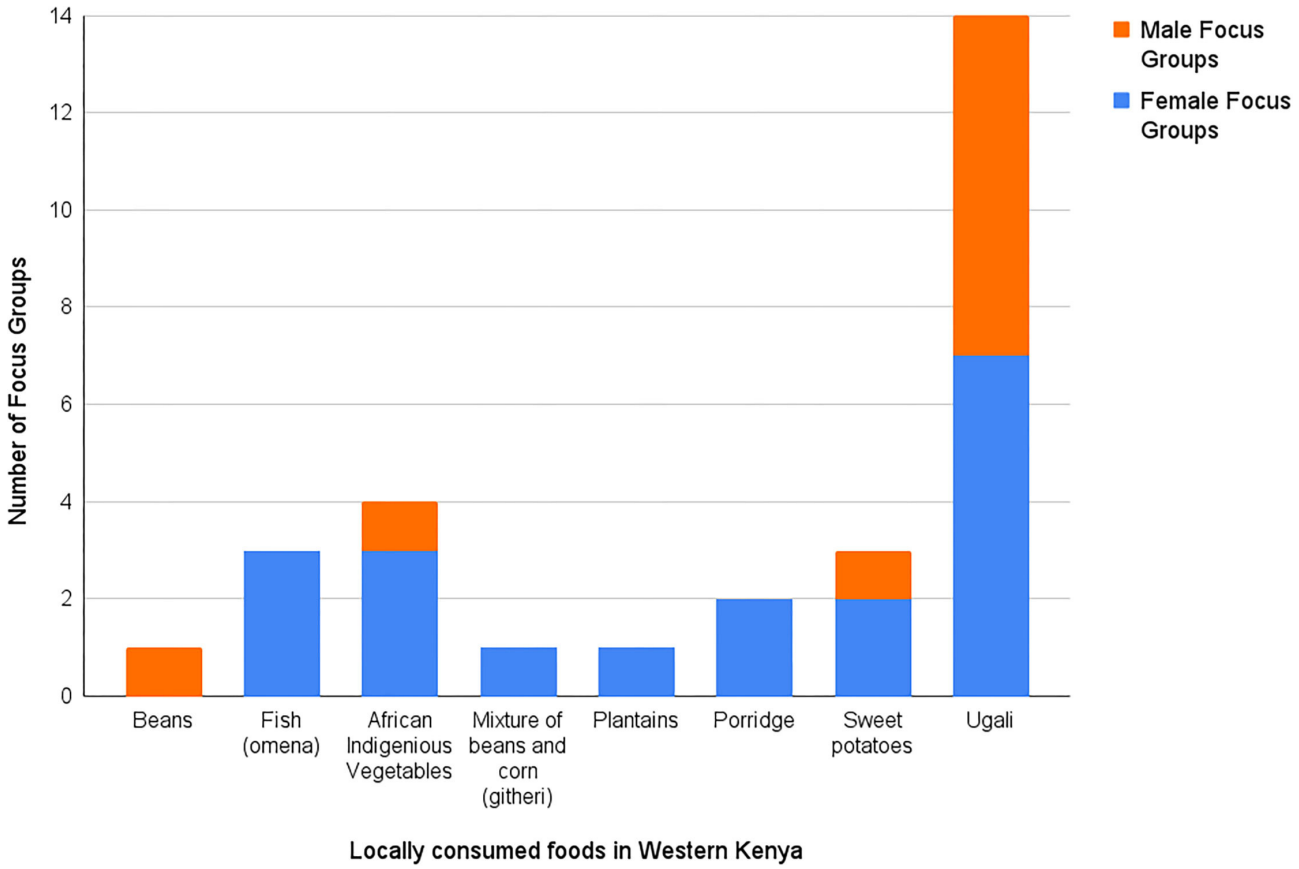

FIGURE 2 | Most commonly consumed foods as reported by male and female focus groups in Western Kenya.

Some FGDs reported facilitators relative to the desirability of AIVs. Some respondents noted that AIVs are "*naturally appetizing*" (Focus Group 14, male) and "*have a good taste*" (Focus Group 6, male). Additionally, respondents noted that eating AIVs may increase appetite for eating ugali. Furthermore, "*milk can be added to make the taste even better*" (Focus Group 6, male).

Health

Several health aspects that present barriers and facilitators to the consumption of AIVs were reported. Many respondents noted that consumption of AIVs can cause or exacerbate health conditions, particularly in the gut and digestion system (e.g., stomach upset, ulcers, and diarrhea). Focus Group 9 (female) summarized this by reporting that, "*Some people have ulcers hence preventing them from using some AIVs.*" In addition, it was noted that some AIVs can cause allergic reactions for some people when they eat AIVs as "*they get [rashes]*" (Focus Group 13, female). Some respondents noted '*oldwives tales*' regarding a few of the AIVs, notably that "*crotalaria destroys the liver*" (Focus Group 10, male). Furthermore, it was noted that a "*lack of knowledge on the importance of AIVs*" may contribute to low consumption (Focus Group 10, male).

While some FGDs noted barriers, positive health aspects that facilitate the consumption of AIVs were also reported. FGDs noted a wide variety of health components of AIVs that facilitate their consumption. Contrary to the above where respondents noted that AIVs can contribute to rashes through allergic reactions, Focus Group 13 (female), noted that AIVs, "*Cure diseases like skin [rashes*]." Moreover, respondents noted that AIVs were a "*source of health food*" (Focus Group 7, female) and noted that they were nutritious, rich in vitamins, and considered to have medicinal properties. Furthermore, it was reported that consuming AIVs may "*improve on health hence help in retarding aging effect*" (Focus Group 9, female). Some respondents were able to identify ways that AIVs impact one's general wellness, such as "*add blood and strength in the body*," (Focus Group 9, female) promoting a strong immune system, and preventing/reducing diseases such as cancer and infections. Respondents also noted other general wellness attributes such as AIVs are low in calories, increased thirst, and were safe to eat because they are planted without chemicals. Specifically, respondents were able to make note of ways that AIVs directly benefit the body such as reducing blood pressure, improving digestion, eyesight, intelligence, and memory, and settling the stomach. In addition, some respondents noted that the consumption of AIVs is important for pregnant and lactating mothers.

TABLE 2 | Top eight African Indigenous Vegetables reported by female and male focus groups and reasons for preferences relative to production and consumption.

Main AIVs with local common name(s)	Reason: production		Reason: consumption	
	Female	**Male**	**Female**	**Male**
Amaranth *(Terere/ muchicha)*	—	Seeds easy to harvest	Nutritious; easy to prepare and soft	Taste; soft; can be cooked with other AIVS, minimizes the bitterness of other AIVs
Cowpea *(Kunde)*	Suits most soil; hardy; grows fast; can regenerate for a long time after harvest and be intercropped with maize	Available seeds; easy to grow (can be grown in sack); plant without fertilizer, generally no chemicals; drought tolerant; early maturing	Can be eaten without frying when mixed with jute mallow	Taste; home consumption
Crotalaria *(Mitoo)*	Suits most soil; hardy	Early maturing	Sweet taste; can be mixed with other vegetables	Taste; cooks fast
Ethiopian Kale/mustard *(Kanzira)*	—	—	Nutritious and can be mixed with other vegetables	—
Jute mallow *(Mrenda)*	Suits most soil; hardy; regenerates for a long time after harvest	—	Can be mixed with other vegetables such as amaranth; broad leaf variety preferred for soup	—
Nightshade *(Managu)*	Can be harvested over a long time-period	Self-propagating	Nutritious; sweet taste; can be mixed with other vegetables	Taste; believed to heal stomach ulcers
Pumpkin *(Seveve)*	Regenerates for a long time after harvest	High financial returns but needs fertilizer and agrochemicals	Can be mixed with other vegetables	Increases blood; medicinal; tastes like liver
Spider plant *(Saga)*	—	Short maturation; self-propagating; Seed available; high germinate in a small portion of ground; drought tolerant	Nutritious; has good taste even when one is sick; can be fermented with milk, eaten without salt, and mixed with other vegetables	Taste; easy on stomach; cooked with no oil; good for stomach

*****Names in brackets represent a common name in Western Kenya.*

DISCUSSION

This paper sought to identify the barriers and facilitators to the preparation and consumption of AIVs from a food environment perspective. These opportunities are particularly highlighted in instances when there were seasonal differences in the reported barriers and facilitators. Low availability and low affordability of AIVs are experienced during the dry season while the AIVs are readily available and affordable when self-grown or during the rainy season. The seasonal influence of production and consumption presented in this study has also been reported in previous research (Kimiywe et al., 2007; Ambrose-Oji, 2009). For instance, daily consumption of AIVs has been reported during peak seasons and the frequency of consumption has been reported to be as low as once a week during off-seasons (Weinberger and Msuya, 2004). These seasonal fluctuations imply that the barriers to preparation and consumption of AIVs are situational and could be modified through context-specific interventions that mitigate the seasonal effects of AIV production. A package of interventions designed to promote healthy diets through an increase in the preparation and consumption of AIVs should include improved access to affordable AIVs, improved cooking methods and recipes, and the promotion of the beneficial heath attributes of AIVs while actively dispelling the perceived negative health consequences of their consumption.

Improved Availability and Affordability of AIVs Through Household Production Training

The reported barriers and facilitators to availability and affordability are tightly linked to seasonality where off-season AIV shortages and high prices were reported while in-season it was reported that AIVs were abundant and inexpensive. This seasonal fluctuation impacts household food choices and causes a decrease in household consumption of AIVs prohibiting families from meeting the recommended consumption goal of 400 g of fresh fruits and vegetables per capita daily (World Health Organization. Nutrition Unit., 2003). To meet this goal, and promote healthy diets, fresh dark, leafy greens must be available and affordable year-round. One way to ensure year-round availability and affordability is through the promotion of year-round home production and the introduction of affordable water collection systems and water management during the dry season. An intervention of this nature is particularly suitable for

TABLE 3 | Commonly added ingredients and cooking methods for African Indigenous Vegetables.

Vegetable	Added ingredients	Methods of cooking
Spider plant (*Saga)*	Salt, fermented milk (Mala) or fresh milk, sesame seeds, and cooking oil	1. Boil for 30–50 min then fry with oil or eat without frying 2. Boil for 1–2 h then fry with oil or eat without frying
Nightshade (*Managu*)	Salt, milk, onions, tomatoes, groundnuts, sesame seeds, and cooking oil	1. Boil for 1–5 min then fry with oil 2. Boil for 30–50 min then fry or eat without frying 3. Boil for 1–2 h then fry or eat without frying 4. Ferment for up to 3 days and add sour milk
Pumpkin leaves (*Seveve*)	Milk	1. Boil for 10–25 min with ash
Crotalaria (*Mitoo*)	Salt and milk	1. Boil for 15–20 min with ash liquid then fry with oil or eat without frying
Amaranth (*Terere/muchicha*)	Salt, onions, tomatoes, milk, and cooking oil	1. Boil for 15–30 min then fry with oil or eat without frying 2. Boil for 1 h then fry with oil or eat without frying 3. Fried alone for 5 min in cooking oil 4. If mixed with other AIVs boil for 1 h then fry in oil 5. *Some noted boiling with ash
Cowpea leaves (*Kunde*)	Salt, milk, groundnuts, sesame, and cooking oil	1. Boil with ash liquid for 10–30 min to soften then fry in oil for 15–45 min or eat without frying 2. If mixed with other AIVs, fry for 15–30 min after boiling

**Names in brackets represent a common name in Western Kenya.*

subsistence farmers (Musotsi et al., 2009), such as those who participated in the study. Participants noted that the core AIVs that they grew were hardy and environmentally adapted, need little to no inputs, and are easily produced (e.g., self-propagate). However, it was reported that households are not growing enough to meet household consumption demands. Promoting the production of AIVs through provision of improved seeds and good agronomic practices could increase household production and subsequently the consumption of a variety of AIVs at the household level with potential sales from surplus (Korth et al., 2014). In addition, households could be trained to preserve AIVs when they are in plenty and subsequently how to prepare preserved AIVs for household consumption. This would allow for year-round access during seasons when AIVs are not readily available in the home garden plot.

Improved Cooking Methods and Recipe Development Through Culinary Training

In addition to access, individual and household demand can impact consumption. Research suggests that culinary interventions can have positive outcomes by altering food attitude and preferences, and increasing nutrition literacy (Lautenschlager and Smith, 2007; Flynn et al., 2013; Jones et al., 2014). The FGDs noted that common barriers households face when encouraging their families to eat dark leafy greens is monotony and poor taste. In most FGDs, participants reported that they prepare AIVs using the traditional methods of boiling and/or pan-cooking the vegetables with oil, tomato, and onion but often there was a discrepancy between reported cooking times with some as long as two hours. Apart from culinary monotony, the lengthy cooking time can result in a loss of overall nutritional quality of the finished dish (Kamga et al., 2013; Gogo et al., 2017).

To minimize monotony, improve taste, and promote more frequent consumption of AIVs with higher nutrition relative to traditional cooking methods interventions should focus on recipe development and variation in preparation styles (Managa et al., 2020; Odendo et al., 2020). For example, interventions could emphasize decreased cooking time to maintain the nutritional quality and palatability of the finished dish. A study by Habwe et al. (2009) reported that cooking AIVs significantly increased the iron content compared to the raw vegetables, particularly when the dish is served with complimentary vegetables that increases the overall nutrient profile of the finished dish. In addition, Habwe et al. (2009) found that boiling the vegetables with ash, a natural form of lye, a traditional method to soften the vegetables, significantly decreased the available iron content. Moreover, while AIVs are naturally adapted to the local environment, there are still subject to seasonality (Weinberger and Msuya, 2004; Kimiywe et al., 2007; Ambrose-Oji, 2009; Gido et al., 2017). Preserving and drying AIVs could provide year-round access to nutrient dense vegetables (Owade et al., 2020). However, it is essential that households are provided nutrition and culinary education that ensure proper handling of AIVs during the drying process to ensure maximum retention of taste and flavor first as well as nutrient content. Furthermore, proper methods for rehydrating the vegetables and recipes that take into consideration the sensory attributes of the finished dish can further promote the consumption of the preserved vegetables. Context specific culinary interventions and nutrition education could promote incorporating and rotating complimentary vegetables (e.g., tomatoes, onion, carrots) and flavors (e.g., garlic and ginger) while minimizing the use of lye for preparation to maximize iron delivery. Furthermore, culinary interventions could provide education on proper postharvest preservation methods for dehydration, rehydration, and appropriate recipes to promote year-round consumption of AIVs.

Promotion of the Beneficial Health Attributes of AIVs Through Nutrition Education

In addition to providing high concentrations of essential nutrients such as iron, protein, calcium, and magnesium (Abukutsa-Onyango et al., 2010; Byrnes et al., 2017), AIVs also contain secondary plant metabolites such as carotenoids, glucosinolates, and phenolic compounds that contribute to human health (Fadl Almoulah et al., 2017; Neugart et al., 2017).

Each AIV contains a unique profile of vitamins, minerals, and plant metabolites; therefore, the consumption of a variety of these AIVs may contribute to different health benefits such as antioxidant activity and increased pro-vitamin A consumption (Fadl Almoulah et al., 2017; Neugart et al., 2017). Many of the health benefits attributed to AIVs are due to their bioactive compounds, some of which may impart a bitter, astringent, acrid flavor and impart a negative perception of AIVs (Drewnowski and Gomez-Carneros, 2000). Some FGDs responses indicated their belief that the consumption of AIVs may cause or exacerbate pre-existing health conditions. While more research is required to understand the link between consuming AIVs and anti-nutritive factors, some of these assumptions may be due to the AIVs' bitter flavor. While some of these AIVs are indeed known to contain anti-nutritive factors including glycoalkaloids, phytic acid, and oxalic acid, the concentration and type of anti-nutritive factors is complex. Genetics and the environment contribute to the levels and/or content of such compounds (Rouphael et al., 2012). In general, AIVs are healthy and highly nutritious, and it is important that nutritious intervention focus on the health benefits of AIVs and actively dispel misinformation. However, any concerns relating to the possible content of anti-nutritive compounds should be thoroughly examined as described using nightshade as an example (Yuan et al., 2017).

While a package of interventions may increase household production and consumption of nutritious AIVs, policy level change is needed for significant improvements to encourage production and availability. Improved production and subsequent consumption hinge on stability in the food environment (Jarosz, 2014; Downs et al., 2020; FAO, 2021). For example, climate variability, including shocks, or poor seed stock can cause crop failure or low yields further driving demand and price (Ochieng et al., 2019). Furthermore, political unrest or regional crises, such as the COVID-19 pandemic, may limit an individual's ability to access the markets (FAO, 2021; O'Hara and Toussaint, 2021). Hence, policy-level change that fosters an enabling environment for the production and consumption of AIVs needs to be enacted to fully address this issue. Furthermore, such policies could capitalize on the natural beneficial qualities of producing and consuming AIVs that lend themselves to a sustainable diet and food system. For example, AIVs have adapted to the local environmental conditions such as limited water supply and high temperatures often experienced in SSA (Chivenge et al., 2015; Stöber et al., 2017; Hunter et al., 2019). These highly tolerant vegetables can contribute diverse micro- and macronutrients to diets year-round and particularly during times when other, more environmentally sensitive, exotic vegetables are a challenge to produce as the costs of production is high. Moreover, when these vegetables are produced at the household level, they provide an opportunity for increased household availability of AIVs that do not require the built food environment. This could provide resilience to household diets and protect households against shocks to the food system such as those due to restricted movements of people and trade during the COVID-19 pandemic. In order for indigenous foods to thrive, policies need to champion their production and consumption. For example, Brazil has several national initiatives such as but not limited to, *National School Meals Programme* and *Food Acquisition Programme*, which mandated that school meals are partially soured from family farmers and paid an incentive for organic or agroecological produce from smallholder farmers (Hunter et al., 2019). Policies such as this can contribute to the production and consumption of traditional vegetables and may help address malnutrition concerns such as undernutrition.

LIMITATIONS

Our study was limited by our inability to audio record and transcribe verbatim the focus group discussions. While this limitation may have resulted in a loss of nuances between participants, the overall data collected fills a research gap in the current literature relative to current cooking methods and noted barriers and facilitators to AIV consumption and preparation in Western Kenya. Additionally, this study solely used qualitative data to address our research questions. A mixed-methods approach could have provided additional insight into our findings. However, we believe this this exploratory study offers a contribution to the field that is significant and critical for the development of context-specific interventions for these communities.

CONCLUSION AND RECOMMENDATIONS

An increase in the consumption of AIVs could improve micronutrient deficiencies within at-risk populations in Kenya. The AIVs are prepared using the traditional method of boiling and then pan cooking the vegetables with oil, tomato, and onion but there were large discrepancies between cooking times. There were also seasonal differences in the barriers and facilitators for the preparation and consumption of AIVs. Poor availability and low affordability of AIVs during the dry season, poor taste and monotonous diets, and perceived negative health outcomes were the key barriers. While ease of availability and affordability particularly when produced at home, ease of preparation, and beneficial health attributes were reported as facilitators. Interventions within the personal and external food environments should focus on increasing year-round availability in the home-garden through drought mitigation techniques such as water collection and storage as needed, irrigation; improved affordability through on-farm production and wild harvesting; and improved desirability, palatability, and knowledge of health benefits through culinary and nutrition education. Furthermore, this promotion may improve social outcomes by fostering a sense of biocultural pride and belonging in turn reshaping the negative social stigma associated with these "wild indigenous/traditional" nutritionally dense vegetables. There is need for policies that simultaneously promote increased farmers' access to key inputs (e.g., improved seed, fertilizers, water, and validated agronomic practices) for AIV production and support behavior change communications for increased consumption of AIVs. Future research can build

on our findings by developing and implementing context-specific interventions and conducting a rigorous evaluation of its impact.

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 Rutgers University IRB; Academic Model for Providing Access to Healthcare (Eldoret, Kenya). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

EM designed the survey instrument in concert with DH and JS, analyzed the qualitative data, and wrote the manuscript draft. MO and CN piloted and modified the survey instrument and participated in all data collection. NM and NN participated in the field survey including data collection. SD provided technical guidance and oversight on the data analysis. DH and JS oversaw the development of the survey instrument and data collection. All authors contributed to revisions of the manuscript.

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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.2022.801527/full#supplementary-material

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The Role of Indigenous Vegetables to Improve Food and Nutrition Security: Experiences From the Project HORTINLEA in Kenya (2014–2018)

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Many warning signs indicate that the food security goals formulated in 2015 will not be achieved. This situation is particularly true for the African continent. After substantial progress up to 2015, the situation has hardly improved or has worsened in many respects. In addition to the rapid population growth, the increasingly frequent long dry periods or sometimes erratic rainfall have contributed to this. In addition, current production systems have dysfunctional side effects due to increasing yield optimization and specialization. Thus, besides the associated resource degradation, it also leads to a monotonous food supply and the emergence of vitamin and mineral deficiencies (hidden hunger). A meaningful way to diversify the food supply is to cultivate and market previously underutilized species. However, they are characterized by not being known and traded globally and usually having only local importance. Accordingly, they have been widely ignored in research. Increasingly, however, there is a growing realization worldwide that these plants can make an essential contribution to food and nutrition security, especially for poorer segments of the population. Moreover, they are adapted to local conditions and are often produced with less resource input. This article aims to show how these species can be better utilized to provide nutritious food through sustainable production, using the example of African indigenous vegetables. In doing so, the impact of emerging social and ecological changes in Kenya will be considered. This source is an interdisciplinary collaborative research project, Horticultural Innovation and Learning for Improved Nutrition and Livelihood in East Africa (HORTINLEA), which was carried out in Kenya from 2014 to 2018. Many different disciplines were involved in the German-African cooperation project. The results will be brought together in this article with the help of a food-sensitive value chain approach, and the experiences gained from this project will be reflected.

Keywords: African indigenous vegetables, smallholder, nutrition-sensitive value chains, gender, climate change, urbanization, food security, post harvest management

INTRODUCTION

Problem Background of the Project

In September 2015, 192 countries approved the 2030 Development Agenda at the UN General Assembly, entitled "Changing our world: the 2030 Agenda for Sustainable Development". SDG 2 and SDG 3 occupy an important place among the 17 goals: Zero Hunger, Good Health and Wellbeing (Griggs et al., 2017). From 2000 until 2014, the number of chronically undernourished people steadily decreased. Since 2014, however, this trend has reversed. The United Nations estimates that between 720 and 811 million of the world's 7.7 billion people were suffering from hunger in 2020. More than two billion people, about a quarter of the world's population, had no regular access to nutritious and sufficient food in 2019 (Food Agriculture Organization of the United Nations, 2021). Projections for 2030 highlight that the current effort is not even close to ending malnutrition in the next decade (FAO, IFAD, UNICEF, WFP, and WHO, 2021).

Globally, about 150 million children under five are suffering from stunting in 2020. Forty-five million of these children were wasted. At the same time, about 39 million children worldwide under 5 years are overweight (United Nations Children's Fund, 2021). Childhood obesity has almost tripled worldwide since 1975 and now reaches every country in the world (Global Panel on Agriculture Food Systems for Nutrition, 2020).

On the other hand, food systems are a significant cause of environmental degradation on which they depend (High-Level Panel of Experts on Food Security Nutrition, 2019; Global Panel on Agriculture Food Systems for Nutrition, 2020; International Panel of Experts on Sustainable Food Systems, 2020). They are the most critical cause of anthropogenic greenhouse gas emissions (28% between 2007 and 2016), and agriculture alone accounts for 70% of freshwater consumption.

Sub-Saharan Africa's population continues to increase significantly. In Kenya, the strong population growth with an average annual growth rate of 2.3% (United Nations Department of Economic Social Affairs Population Dynamics, 2021) has led to increasing demand for food and increased use of natural resources. As in many African countries, Kenya's population will double by 2050. However, 36.8% of the population or more than 18 million people in Kenya, live below the poverty line of 1.9 US dollars a day. The prevalence of malnutrition is around 25% of the population and has risen again under the problematic climate conditions of recent years. Estimates by UNICEF at the end of August 2019 have revealed that around 665,000 children under the age of five are acutely malnourished (FAOSTAT, 2021).

At the same time, the rural migration and unfavorable climatic conditions led to low agricultural productivity and a shift to non-agricultural income-generating activities. As a result, the rural population, which constitutes the most significant part of the agricultural labor force, declined by 3.2% between 2008 and 2014 (Food Agriculture Organization of the United Nations; Swedish International Development Cooperation Agency, 2019). Thus, unless significant efforts are made, compliance with the commonly formulated nutrition targets is not expected in the coming years. Because of the increasing number of significant weather events caused by climate change, such as persistent drought or erratic rainfall combined with widespread flooding and political upheavals, confidence in a reliable supply has been lost (Béné, 2020). This situation makes it necessary to discuss the resilience of food systems, especially regarding food and nutrition security.

The Potential of Indigenous Crops

The precondition for good nutrition is that a variety of food is available and affordable for all people at all times. Most efforts tried to ensure food and nutrition security by intensifying production and introducing high-yielding, stress-tolerant crop varieties. However, the prevailing guiding principles of agricultural intensification do not ensure universal access to a diverse diet and, in some cases, jeopardize the long-term sustainability of the agricultural resource base (Food Agriculture Organization of the United Nations, 2017).

It also reduces ecosystem services. Biodiversity is necessary for many ecosystems functions critical for agricultural production, such as pollination, soil fertility, water quality, and genetic diversity (Hunter et al., 2020; Padulosi et al., 2021). Genetic diversity in agriculture protects the ability of species to evolve in response to changing environmental conditions and increases species resistance to diseases, pests and parasites (Padulosi et al., 2011; Capuno et al., 2015; Chivenge et al., 2015; Hunter et al., 2020; Laborde et al., 2020). Agricultural diversity also enhances the supply of foods that offer nutritional benefits (Fanzo et al., 2013). The challenge, therefore, is to protect biodiversity and preserve natural resources while producing enough food.

Kenya is endowed with agrobiodiversity, such as African Indigenous Vegetables (AIVs) (Yang and Keding, 2009; Weller et al., 2015; Akinola et al., 2020). Given the increasingly perceived importance of fresh fruits and vegetables for healthy diets and the prevention of micronutrient deficiencies and diet-related non-communicable diseases, a stronger focus on the horticulture sector is crucial (Keatinge et al., 2015; Food Agriculture Organization of the United Nations, 2017; Aiyelaagbe et al., 2018; Wopereis, 2018; Laibuni et al., 2020; N'Danikou et al., 2021). About 200 indigenous plant species are used as leafy vegetables in the country. Only a few (4) have been fully domesticated, a number (15) are semi-domesticated, while most are wild (Maundu, 2018). The challenge is to protect biodiversity and natural resources while producing enough food (Gotor and Irungu, 2010; Ebert, 2014). The literature is full of evidence of benefits associated with the production and marketing of indigenous African vegetables by smallholder farmers.

- **Contribution to healthy diets:** At the local level, excessive intensification (i.e., monoculture) risks narrowing diets, thus worsening regions' nutritional situation. Indigenous vegetables are essential sources of dietary components. They contain essential minerals and vitamins necessary for maintaining human health and strengthening resistance to disease and infection (Padulosi et al., 2013; Cogill, 2015; Keatinge et al., 2015; Neugart et al., 2017).

- **Contributing to sustainable food production and climate change adaptation:** With a view to small holdings, Ricciardi et al. (2021) illustrate that smaller farms, on average, have higher yields and greater crop and non-crop biodiversity at the farm and landscape level than larger farms. Diversifying agricultural production systems by promoting underutilized species offers opportunities to strengthen the adaptation, mitigation and resilience of both natural and socio-economic systems. Being native to the African continent, AIVs have been selected over many generations against various stressors in tropical environments, especially drought. Therefore, they have co-evolved adaptive mechanisms that ensure broad adaptation (Keatinge et al., 2018). Most of them are grown very fast after the first rainfall, and harvesting begins 3–4 weeks after germination. Unlike most exotic vegetables, AIV species do not require large amounts of fertilizer and chemicals (Shayanowako et al., 2021).
- **Contributing to improving smallholder income by production, processing and marketing:** African Indigenous Vegetables (AIV) are an integral part of the diet in many Sub-Saharan African (SSA) countries. Several publications indicate that the market for these crops will continue to grow (Ngugi et al., 2006; Pichop et al., 2016; Rampa and Knaepen, 2019). In Nairobi, for example, about 30% of all vegetables sold are AIVs grown around the city. AIVs find their way from the field to the market through various channels, and AIVs support a large number of small-scale farms along the entire value chain in urban and peri-urban areas (Weinberger and Pichop, 2009). Women are significantly involved in all chain segments, including wholesale and retail. In addition, low capital requirements for entry enable even the poorest households to participate (Weinberger et al., 2011).
- **Rural development through job creation:** Rural development has risen high on the agenda of development challenges (Altenburg, 2017; Food Agriculture Organization of the United Nations; Swedish International Development Cooperation Agency, 2019; Sumberg, 2021; Sumberg et al., 2021). Due to the lack of good prospects in rural areas, many young people migrate to growing cities. However, the development of the industrial and service sectors cannot absorb this large number, so many of these youth end up in urban slums. Therefore, creating attractive jobs in rural areas is of enormous political importance. The development of modern AIV value chains could contribute to this.
- **Acceptance through cultural embeddedness:** AIVs are an essential part of the diet of many people in Sub-Saharan Africa. Rural and urban communities traditionally accept and use them as vegetables (Weinberger, 2007). The use of many of these varieties and species abundance is based on traditional knowledge about cultivation methods and meal preparation. However, this knowledge is being lost at an alarming rate (Cernansky, 2015; Maundu, 2018).

Given these potential benefits from the production, marketing and consumption of indigenous vegetables, the question arises why it has not yet been possible to give these products a higher priority in the diets of poor rural and urban dwellers. The reasons often assumed for this are the predominantly small-scale farm structure in which production occurs. Despite some advantages of small-scale production, these farms are confronted with particular constraints and obstacles and therefore find themselves in a "poverty trap" (Ngugi et al., 2006; Gatzweiler and von Braun, 2016; Poole, 2017; International Finance Corporation, 2018). For example, access to high-quality inputs (e.g., seeds and fertilizers) is often limited due to a lack of financial resources, and investments (e.g., irrigation) cannot be made. In addition, institutional deficits result in unclear land use rights (especially near larger cities) and water use rights. Often there is a lack of knowledge to adapt to climate change and increased consumer and trade demands.

Last but not least, smallholder farmers also face many interrelated risks to their livelihoods. The occurrence of those shocks not only threatens already vulnerable food production systems, but the likelihood of those events causes some smallholder farmers to become more risk-averse and to pursue more subsistence-oriented activities, thereby perpetuating smallholder poverty (Fan and Rue, 2020; Gómez y Paloma et al., 2020).

Linked to the constraints mentioned above, the increasing division of labor in the rapidly changing value chains that take the products from the producer to the consumers in the growing cities cause part of the problems (Fan et al., 2013; Fan and Rue, 2020). For example, considerable logistical demands are associated with supplying more distant sales markets. In addition, the growing number of wholesalers and retailers is placing ever higher demands on the quality and preparation of the products, including sorting standards and, in the case of supermarket supply, certification of the processes. Finally, yet important, there are changes on the consumer side. Increasing imports and demographic changes in society, such as the migration of young, well-educated people to the cities and growing middle-class development, are associated with a change in diet (Tschirley et al., 2015; Bloem and de Pee, 2017). As a result, the knowledge of traditional vegetables' nutritional value and preparation is increasingly forgotten. Moreover, higher preparation effort is no longer well-matched with larger women's work engagement and/or childcare.

THE HORTINLEA PROJECT

This article will present results and experiences from the collaborative research project Horticultural Innovation and Learning for Improved Nutrition and Livelihood in East Africa (HORTINLEA), which focuses on promoting the production and consumption of local vegetables in Kenya and the role of smallholder farmers in this respect.

Background Information on the HORTINLEA Project

In 2013 The German Federal Ministry of Education and Research (BMBF) had launched the funding initiative "Global food security" (GlobE) to support the development

of sustainable and high-yield agriculture. Projects of the funding initiative "should follow a systemic and interdisciplinary approach: In collaboration with local partners, the situation on the ground should be analyzed before the start of the investigations and, based on this, research questions for the joint research projects should be formulated". Furthermore, projects should develop solutions tailored to local conditions and are considered both necessary and sustainable by regional partners in Africa.

In summer 2014, we organized a workshop in Nairobi to bring together the different partners and previous experiences and get to know the problems on the ground more precisely. In this workshop, existing issues and obstacles were discussed in more detail, and the expected outcomes of the overall project and the individual sub-projects were jointly articulated.

Against the background and the discussed problems, the joint project HORTINLEA aimed to investigate how small farmers and small enterprises can use the opportunities offered by producing and processing indigenous vegetables. The expected outcome of the joint research project was to generate knowledge that enables relevant decision-makers in the sector to develop better strategies and support decision-making processes that improve the nutritional situation of resource-poor households in rural and urban areas. To reach these expected results, HORTINLEA was directed toward answering the following questions:

- Promotes production and marketing to improve food and nutrition security? What future opportunities arise from the production and marketing of AIVs? (3.1)
- What are the mechanisms or pathways through which the production and marketing of AIVs contribute to food and nutrition security? (3.2)
- How can production, marketing, processing and distribution be improved so that the poorer population, in particular, can benefit? (3.3)
- How can processes of value chains for food and nutrition security be improved so that small and medium-sized enterprise can benefit from it? (3.4)

The Need for a Common Understanding of the Project: The Conceptual Framework

To fulfill this complex task, it was, on the one hand, a question of finding relevant scientific disciplines (sub-projects) and practice partners both in Germany and in Kenya for the project. At the same time, however, the challenge was to develop a "common language" and organize the cooperation of the respective sub-projects so that the results could be processed coherently and comprehensively.

A jointly developed conceptual framework is necessary to support these requirements. As value chains play a crucial role in determining food availability, affordability, quality, and acceptability, they offer opportunities to promote nutrition (Hawkes and Ruel, 2011; Humphrey and Robinson, 2015). Therefore, a starting point for our considerations was the so-called value chain approach, which has already been used for many years in development cooperation and has frequently been improved and adapted. In the discussion on inclusive value chains, the main question was whether and how the interests of resource-poor households, in particular, can be taken into account. Further discussions revolved around how other goals, such as environmental sustainability and gender equity, can be considered in value chain strategies. The value chain food and nutrition security approach goes one step further by paying particular attention to providing sufficient and healthy food and exploring pathways to achieve this goal, especially for poorer populations (Fanzo et al., 2017). The constraints may be on the demand side of the chain (e.g., low consumer demand) or the supply side (e.g., production and nutrient losses during transport) (Gelli et al., 2016).

The framework was intended to help delineate the problems to be addressed in a meaningful way and clearly define the role and obligations of the research disciplines involved. Simultaneously, this approach should support the systematic discovery of obstacles and inefficiencies of the value chains. Therefore, we have tailored it as a conceptual framework for our collaborative project (see **Figure 1**). The approach is characterized by a strong focus on market transactions and emphasizes the role of the private sector. However, the role of the public sector in creating supportive framework conditions (e.g., financing of small enterprises, reliable legal framework, and infrastructures such as advisory services and transport) and in shaping the food environment is also intensively discussed.

In our view, the value chain approach for food and nutrition security (VCFNS) offers the following advantages:

- By looking at possible pathways to improve food and nutrition security, it aims to shed light on the mechanisms through which nutritional goals can be achieved.
- It supports identifying relevant stakeholders who had to be integrated into the project for necessary changes in the value chain.
- It is forward-looking in that it considers current and future local conditions. Changes in food systems are driven by external and internal factors and feedback mechanisms between these factors. External drivers are, for example, climate change, socio-demographic developments or urbanization. Internal drivers are, for example, innovations, changing actor constellations or changing consumer behavior.
- It explicitly includes governance and infrastructure issues in the analysis. It thus also creates the prerequisite for addressing the role of politics and actors from the mesolevel (associations, lead companies in the chain).
- Last but not least, it forms a good heuristic tool allowing to detect the complex interrelationships and interdependencies in the system. Heuristics often helps practitioners to plan their interventions.

Information About the Procedure and Scope of the Examinations

Research on five AIVs [African nightshade (*Solanum scabrum*), Amaranth (*Amaranthus cruentus*), Cowpea (*Vigna unguiculata*), Ethiopian kale (*Brassica carinata*) and Spider plant (*Cleome*

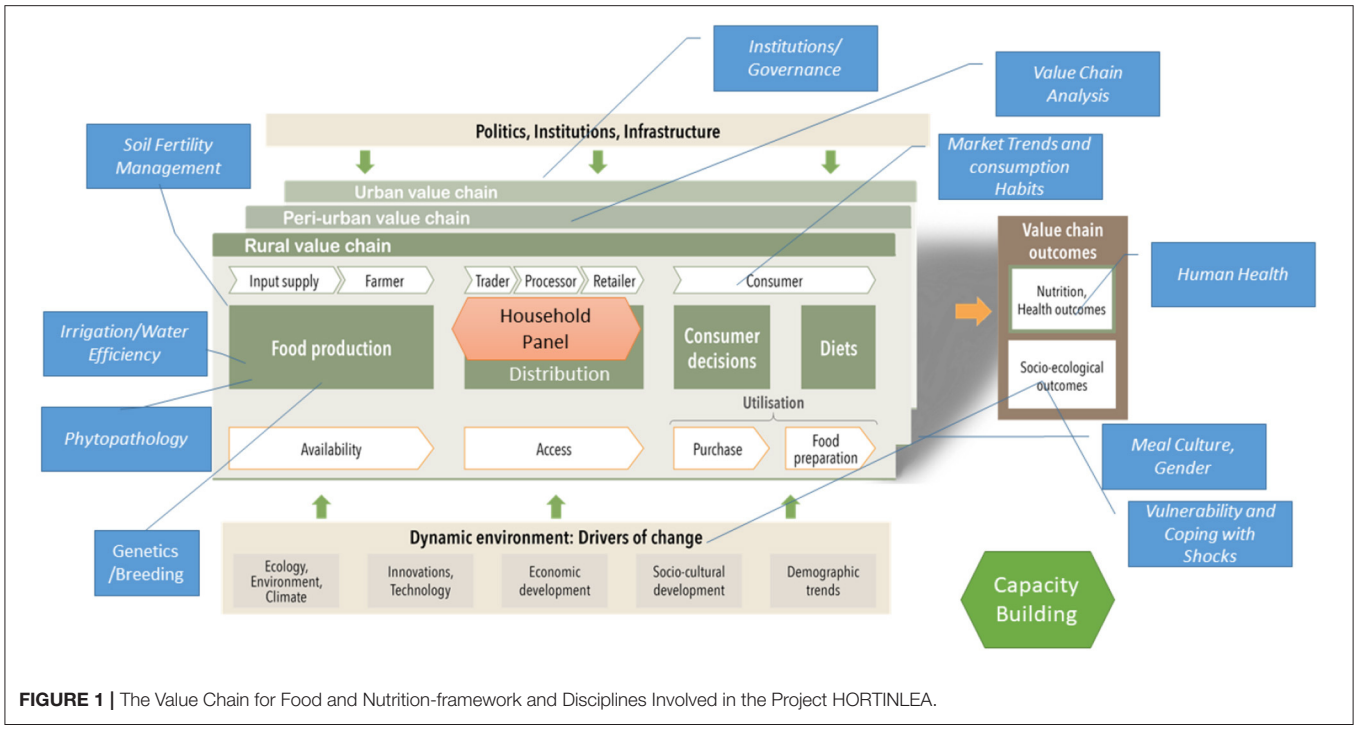

FIGURE 1 | The Value Chain for Food and Nutrition-framework and Disciplines Involved in the Project HORTINLEA.

gynandra)] was conducted to enhance relevant knowledge about these crops' production, marketing, and consumption. For the design of the HORTINLEA-project, it was essential to consider environmental and socio-economic changes and future demand. Twelve sub-projects have focused on different facets of the value chain: soil fertility, breeding opportunities and seed system, water management, pest management, post-harvest management, nutritional aspects, marketing, food preparation and processing, gender, climate change adaptation and capacity building. In the HORTINLEA project, some disciplines worked with experimental research methods, and socio-economic studies relied on qualitative and quantitative methods of empirical social research (Kebede, 2014). In many cases, actors from the sector were involved in the research process. However, there was a regular exchange of results and experiences within the research network and among the researchers involved, predominantly African PhD students. Results of individual sub-projects of the von HORTINLEA project have mainly been published disciplinary scientific journals.

RESULTS AND DISCUSSION

This article attempts to summarize results and experiences against the background of the VCFNS framework. To this end, some selected project findings and recommendations for action derived from them are summarized and discussed in light of the current literature. Attention will be paid to the threats and opportunities arising from the changing market trends and framework conditions. Subsequently, our approach will be critically reflected upon to identify existing gaps in knowledge, formulate the need for further research, and provide thoughts for implementing the results.

Benefits and Opportunities of Promoting the Production and Marketing of Indigenous Vegetables in Kenya

The debate on food security has historically focused on agricultural production and rural areas. In the last decade, however, it has become increasingly clear that supplying the urban population will be at least as necessary for Africa's food security in the future (Bloem and de Pee, 2017). Rapid urbanization focuses attention on the importance of urban agriculture for feeding the urban population. Ruel et al. show that poverty, food insecurity, and malnutrition in all its forms are widespread in cities, and the rapid rise in obesity is worrying. They call decision-makers to be better informed about this situation through research (Ruel et al., 2017). Currently, informal markets are the most important suppliers of AIVs in the cities. Predominantly, women are involved in both the production and marketing of local vegetables here. Most intermediaries buy the vegetables from the farmers to resell them in the urban markets at retail prices.

In the last decade, interest has focused on the rapid emergence of supermarkets and the resulting impact on food security and welfare (Neven and Reardon, 2008; Tschirley et al., 2010). The supermarket "revolution" presents both opportunities and challenges for small-scale farmers and consumers. On the positive side, supermarkets and modern supply chains

offer significantly improved food safety, the ability to fortify staple foods with essential vitamins and minerals, and the potential to stabilize food prices and thus contribute to food security.

The power relations between the supermarkets and the suppliers have a modular governance structure—the supermarkets do not provide technical or financial support to the farmers and therefore have limited ability to monitor the production process to ensure the quality of the vegetables (Otieno, 2019). Government policies can influence the positives and the negatives to a limited extent. However, most supermarket growth dynamics are stimulated by economic incentives, technological changes, and consumer demand. These factors are largely beyond the control of governments.

The results from HORTINLEA on the determinants of AIV farming also suggest that AIV has made the transition from a "poor man's food" to an exciting crop in Kenya (Gido et al., 2017). Generally, farmers who sell AIVs achieve a higher per capita income than farmers who do not sell AIVs. This effect increases with a higher level of commercialization. Food security of producer households significantly improved in the dimensions of access and stability, mainly through an increase in disposable income (Krause et al., 2016; Krause, 2020). However, our results show that market distance is still a barrier for most farmers producing these perishable products. As distances between production sites and urban markets were often within a day in our study, it became clear that post-harvest handling such as cold storage and reliable logistics that maintain quality would allow farmers from rural areas more sales opportunities.

While this direct income effect is already interesting for farmers and their production decisions, policymakers should also have a strong incentive to increase AIV production. Even under current production conditions, AIVs and other horticultural food crops have more substantial positive effects on rural economies than tea, coffee or maize (Krause et al., 2019a). Moreover, the growth and diversity of urban food markets allow farmers to expand their range of products, enter new consumer segments and thus increase their income. Against this background, investments by small and medium-sized enterprises in retailing, wholesaling, processing, packaging and logistics play an important role. Tschirley et al. (2014, 2015) refer to these small and medium-sized enterprises as the "hidden middle" because policymakers and researchers have often ignored them in the nutrition debate (Altenburg et al., 2016). In addition, investments in infrastructure are necessary to benefit from this growing market and enable a wider group of farmers, including women entrepreneurs, to access inputs, rural services, and extensive information. Accordingly, government and donors need to ensure that investments flow into energy, sanitation, transport and food marketing infrastructure and other urban infrastructure (Hawkes and Halliday, 2017). In addition, investments in the rural road network also consider the development of secondary towns and communities.

Conclusions 3.1 Benefits and Opportunities

In Kenya, as everywhere else in the world, the proportion of urban population is increasing. This expansion poses particular challenges for their reliable supply of healthy food. However, there are also opportunities for many small producers and other value chain actors in distributing and processing indigenous vegetables.

In recent years, the perception of the population has changed so that indigenous vegetables are no longer seen as poor men's food, but their nutritional value is increasingly recognized.

To date and for the foreseeable future, informal markets still play a dominant role in urban and rural regions. Therefore, investments in infrastructure (hygiene, storage) and fair access to these markets by smallholders could substantially contribute to improving the supply of the population. Nevertheless, in the coming years, supermarkets and supermarket chains will gain importance for supplying the growing middle class in the cities.

On the one hand, this development poses a threat to small farmers due to unequal bargaining power and increasing demands by buyers. On the other hand, however, it also provides opportunities by opening up new market segments and developing new products. To use these opportunities, investments in infrastructure as well in logistics are necessary, and value chain actors need to improve distribution processes. However, these measures also open up opportunities for job creation in rural and peri-urban areas.

Looking on Pathways to Food and Nutrition Security

The concept of value chains for food and nutrition security emphasizes that there should be a particular focus on pathways to achieve Food and Nutrition Security (Hawkes and Ruel, 2008; Herforth and Harris, 2014; Gelli et al., 2016; Maestre et al., 2017; Kennedy et al., 2018; Sharma et al., 2021).

Production for Household Self-Consumption

Production for household consumption is the most direct way to increase food availability and food security at the household level. For example, households can meet their needs for staple foods through their production while relying on markets for other products, such as fruits, vegetables or meat. Others may depend mainly on their gardens for fruits and vegetables. In this system, production to generate income plays a subservient role. With a favorable distribution of food within the household, this pathway can improve food intake and nutrition for the weaker members of the family.

However, empirical findings evaluating this pathway are very diverse. Sibhatu and Qaim systematically reviewed studies that examined linkages between production diversity, dietary diversity and nutrition in smallholder households. While most of these studies come to positive conclusions, according to them, there is little evidence that increasing agricultural production diversity is an effective strategy for improving the nutrition of smallholder families (Sibhatu and Qaim, 2018). Regardless of the crops studied, the links between increased intensification, production diversity and food security need further investigation. Furthermore, analysis of our household data in the HORTINLEA project has shown that surpluses are sold at local markets or in the neighborhood whenever possible. A significant disadvantage of this practice is that excesses are often associated with an ample

market supply and accompanying low prices. However, in highly rural areas of Kenya with little market access, less diversity in production can harm household dietary diversity (Krause et al., 2019b).

Selling the Vegetables on Markets to Generate Income

Increased market orientation brings a second path to better food security into play. In this way, income-based production becomes more critical than self-sufficiency. The results from the HORTINLEA project indicate a positive impact of focusing on commercial AIV production in terms of food security for smallholder households. The positive effects of increased commercialization of AIVs are attributed to positive income effects associated with specialization. Income becomes the critical determinant of food availability and access, while household production for subsistence plays a complementary role (Krause et al., 2019b). Farmers take their decisions about production based on the prospect of selling products on the market and the price obtained. Often, risks are perceived with the volatility of markets and opportunistic behavior. One way of limiting market risks could be maintaining and promoting kitchen gardens and small animal husbandry alongside commercial AIV production.

Favorable Retail Prices for Food

Improving production systems combined with higher yields leading to lower food prices is another way to improve nutrition for poorer populations. Increasing production puts downward pressure on food prices, especially in areas where markets are less integrated and where poor people are the primary residents. Lower prices facilitate access to food and essential nutrients for net food consumers. The tremendous inclusive power of informal markets helps explain their resilience. Low-income consumers in informal settlements and on the urban fringe can find staple foods, fresh foods, animal products, processed or prepared foods that suit their financial, time or space constraints. Informal markets also create comparative advantages for smallholder farmers. Informal traders pay cash, come to the farm and buy all qualities (Otieno, 2019).

"Inclusive growth" has become a buzzword of development agencies and governments. Therefore, it is paradoxical that "inclusive growth" initiatives focus mainly on formal markets.

Empowerment of Women

Resources and the income that women dispose of through their involvement in agriculture provide another significant pathway for household nutrition. Research on value chain development was gender-blind for a long time (Pyburn and Kruijssen, 2020).

The HORTINLEA sub-project on gender conducted qualitative studies in Kenya's Nairobi, Nakuru and Kakamega regions between 2015 and 2017 (Musotsi et al., 2018a,b). The results show that the consumption of AIVs in Kenyan households is highly gendered. Women are responsible for most of the tasks related to the preparation and cooking of AIVs. However, women also use their power to circumvent some of the stratifications they face. The interviews also illustrate that women play the leading role in the production and marketing of AIVs. Almost 60% of the interviewees in our HH-sample of 1,500 people) indicated that women are responsible for producing AIVs, and in about 57% of the sample, women are also responsible for marketing. When women are responsible for marketing AIVs, in 90% of cases, they also have control over the income generated from these sales. However, the share of income from AIVs of the total household income is relatively low, averaging 9.4%. If there are no other sources of income, women are left with a relatively small budget to spend according to their own needs. Previous studies also confirm that AIV in Kenya is still seen as a subsistence crop and traditionally a "women's crop". The situation is different in urban areas, where the share of men in AIV production is much higher, mainly attributed to the changing perception of AIV as a profitable crop (Weinberger and Pichop, 2009). The commercialization of AIV has encouraged men to cultivate and market it. As a result, they take on more lucrative functions of the AIV value chain, e.g., marketing. The research has shown that women in producer groups increase AIV production. In addition, the research has shown that women (unlike men) are proactive and more resilient in sharing their resources and less likely to compete for leadership roles.

Nevertheless, women often prefer to be in mixed producer groups. To have access to more credit, women need collateral in the form of land registered in their name. The right to and use of natural resources in society is gendered, and women in patriarchal societies often lack access to and control over natural resources and assets (Brückner, 2020). While men and women are affected differently by climate change and environmental degradation, men have more economic alternatives. To attain food security, sustainability is required not only in production but also in consumption. By sustainable consumption, we refer to the ability to meet individuals' food needs and preferences and thus to take actions that contribute to a more equitable availability of AIVs, more equitable access to knowledge about AIVs and, finally, a more equitable sharing of food-related labor.

Changes on the Consumer Side

AIVs vary enormously in their concentrations and profiles of secondary plant metabolites. In general, a mixture of AIVs can be recommended for a healthy diet, with benefits such as antioxidant activity, higher uptake of provitamin A or uptake of anti-cancer compounds (Baldermann et al., 2016; Neugart et al., 2017). However, apart from their nutritional value, they must be acceptable to consumers because of their appearance, ease of preparation and social and cultural norms given the prevailing taste, consumption habits and preparation methods. The HORTINLEA project investigated the socio-cultural practices of AIV consumption in Kenyan households (Baldermann et al., 2016; Brückner and Caglar, 2016; Musotsi et al., 2018a; Brückner, 2020). Differences in practices can help distinguish nutrient-dense foods from less nutrient-dense alternatives, but they can also pose significant acceptability problems. For example, willingness to pay will decrease if consumers and/or shoppers associate higher nutritional value with less taste or more time-consuming preparation (Gido et al., 2017; Brückner, 2020). In the HORTINLEA project, extensive research was conducted on accepting and preferred shopping

places for indigenous native vegetables (Bauhardt et al., 2015; Gido et al., 2016; Gido, 2017). They were able to show that the acceptance of these vegetables is high among both the urban and the rural populations. However, the frequency of consumption is significantly higher in rural areas (four times a week) than in urban areas (twice). Education, income and a short distance from the market favor the consumption of vegetables. However, the choice of shopping venue when buying leafy vegetable AIVs showed differences between rural and urban areas. Local open-air markets were the most preferred by rural dwellers; in contrast, urban dwellers showed the highest preference for green food markets. Although the process of urbanization in Kenya continues, Tschirley et al. (2014) assume that the "modern" sector will continue to account for far <50% of the market in the future. Also, AIVs have the inherent potential to address malnutrition, and their consumption is still limited by poor perception and lack of awareness of their nutritional benefits. To date, there are few studies on the effectiveness of information campaigns to influence the perception and acceptance of AIVs. We have identified several barriers to AIV consumption and entry points on how to overcome them.

- Younger respondents often dislike AIV. Therefore, we suggest explicitly targeting the younger generations. Here, it is crucial to give the younger generation a voice and include them in the discussion to voice their concerns and attitudes toward AIVs actively. In addition, opportunities need to be created to contact AIVs, learn about their nutritional value, importance to the environment and wellbeing, and socio-cultural significance in Kenyan food cultures. It could also be essential to work with school gardens and kitchens to develop participatory tools (workshops, training).
- There is a knowledge gap regarding the nutritional properties and preparation of AIVs. Creating and sharing knowledge about AIVs among women, men, girls, and boys are critical. Hands-on experiences in the kitchen, opportunities to taste vegetables and practice cooking techniques can be a practical starting point. The role of women in all these activities is crucial, as they can actively provide knowledge and skills about AIVs and their preparation (Brückner and Aswani, 2017).
- The time-consuming preparation of AIVs is a gendered issue (Brückner, 2020). Although women are engaged in paid employment, they do most reproductive work. Nevertheless, women are creative in managing the job assigned to them, and our research has shown that they have developed ways to work around the problem of time constraints. Their methods and indigenous knowledge (e.g., drying and preserving AIV, using AIV that takes less time) need further exploration and should be the starting point for product-based interventions. Careful, context-specific implementation is required for all these interventions and suggestions, making these strategies beneficial to those addressed in our research project.

The results of HORTINLEA in the context of meal cultures show that despite challenges in preparation, cooking and consumption, AIVs remain a core part of Kenyan households. Daily consumption in rural areas shows that consumers still prefer AIVs over exotic vegetables.

Conclusions 3.2 Looking for Pathways

The debate on food security has focused on agricultural production and rural areas. However, the concept of value chains for food and nutrition security draws attention to the fact that a better provision of healthy vegetables, especially for the poorer population, can be achieved in various ways. In analyzing the value chains, they focus on the mechanisms that can ultimately improve the food situation of more impoverished parts of the population. Subsistence farming still plays a significant role at present. In addition to farms, production takes place in home gardens and schools. It helps to increase resilience to shocks, e. g. from price fluctuations and weather events. However, sufficient and continuous supply, easy access to produce and lower prices are needed to ensure a reliable supply for the non-farming population. In this context, yield enhancements and efficiency improvements in value chains play a prominent role. This pathway should also lead to an improvement in incomes, especially for agricultural households. Women play a vital role in producing and marketing indigenous vegetables. Strengthening their role in the family and society is essential for feeding and caring for household members than for taking advantage of the opportunities available to them through the production and marketing of these vegetables. Better information and training through government campaigns and promotion can increase demand. In addition, smallholder farmers and other value chain actors need market information to adapt to changing consumer demand. All these pathways are not mutually exclusive but should be considered together. Understanding the different mechanisms that lead to the progress of the nutritional situation of poorer population groups helps avoid a too strong focus on particular problem areas within the value chain framework.

Enhancing AIV-Value Chains: Upgrading Strategies

The concept of upgrading describes how companies in the value chain move to make processes more efficient and/or shift to value-adding activities (e.g., processing), achieving higher prices, entering new markets, and increasing their income (Giuliani et al., 2005; Mitchell, 2014). In our article, we follow the proposal of Kilelu et al. for a broad-based modernization strategy to develop value chains in the smallholder agri-food sector (Kilelu et al., 2017).

Process Upgrading

Process upgrading increases production efficiency either through improvements to the production and post-harvest processes and/or improved means of production. This way is fundamental given the low productivity of AIV production in Kenya. Productivity describes how much yield a farm produces with the resources available. One reason for the low productivity is that farmers, researchers and seed companies have long neglected AIV (Cernansky, 2015; Moraza et al., 2018), resulting in significant knowledge gaps. In addition, the poor availability of inputs and poor access to capital are essential factors.

Production

The AIV producers studied in Kenya mainly use traditional production practices (Kebede and Bokelmann, 2016, 2017). They often use organic fertilizer and promote local biodiversity through their cultivation. This contributes to improving soil fertility and environmental sustainability. In addition, the use

of local seeds minimized operating costs and the cost of non-renewable inputs.

Breeding and Seed System. The growing interest in AIVs, especially among the urban population, has raised a problem. In most African countries, AIV production uses local landraces in low-input systems. Products harvested are intended for own consumption or sale in nearby towns and villages. Farm-saved seed and low availability of improved varieties predominate in production. As specific AIV-production shifts to urban areas with higher consumer demand, farmers' demand for high quality, healthy seeds and improved varieties that meet the quality requirements of urban markets is lacking.

Like other aspects of production, little attention has been paid to breeding enhanced varieties. As a result, poor seed quality remains a significant constraint to AIV (Kirigia et al., 2018) productivity. In the meantime, some improved AIV varieties are already produced by seed companies, including amaranth, African nightshade, jute mallow, kale/Ethiopian mustard, cowpea leaf spider plant (Abukutsa-Onyango, 2015; Jansen van Rensburg et al., 2015; Dinssa et al., 2016; Ayenan et al., 2021).

Seed production includes the selection of suitable plant material, harvesting and seed processing. An excellent understanding of the species' reproductive biology is also crucial to prevent contamination by other genotypes. Considerable efforts are still needed to improve the seed system and develop suitable varieties. Several projects within the framework of HORTINLEA have addressed this question (Omondi et al., 2016, 2017a,b; Menssen et al., 2017; Ronoh et al., 2018, 2019; Shilla et al., 2018). However, developing new varieties to market maturity requires considerable perseverance and institutional support, such as the World Vegetable Center.

To improve the seed system, the technical capacities of African seed and/or breeding companies would need to be strengthened, seed regulations revised, and, above all, access to seed and advice on its use improved. Investment in these measurements would help to encourage private sector investment in the vegetable seed sector (Schreinemachers et al., 2021). Depending on the regulatory framework and the level of development of the seed sector in a given intervention area, community-based and informal seed systems should be still promoted to provide access to higher quality AIV seed.

Plant Health. The production of AIVs faces several challenges, including yield losses due to viral, bacterial and fungal diseases and arthropod pests (Agbodzavu, 2019). A HORTINLEA survey in Kenya and Tanzania found several arthropods could infest AIV. Still, detailed information on the damage caused by the different pests and species identity is lacking in East Africa (Mureithi et al., 2017). Therefore, the first step toward developing sustainable integrated pest management strategies was a field study in Kenya and Tanzania to determine the specific pest species that attack AIVs. As the impact of pests and the identity of species can vary from region to region, the survey covered the main growing areas in both countries at different altitudes, i.e., from the highlands to the coastal regions. There were significant differences in the prevalence of arthropod species in the two countries, in the two growing seasons and at the different altitudes for Lepidoptera and Coleoptera species, but generally not for Homoptera pest species (Mureithi et al., 2017).

There are alternatives to chemical insecticides. Locally produced seed coatings, entomopathogenic fungi and biopesticides derived from botanicals such as neem need further development (Mweke et al., 2016, 2018; Juma et al., 2017; Agbodzavu, 2019). Together with tolerant varieties and traits and some production technologies such as soil solarisation, integrated pest management strategies are available. While not aiming at total pest eradication, alternative technologies can lead to more environmentally friendly production methods. Further work should be done on the potential of beneficial insects, breeding better lines and varieties, technologies for early detection of pest problems (e.g., pheromone traps) and training of farmers to use sustainable production techniques as essential pest control strategies.

Soil, Plant Nutrition. To take full advantage of AIVs-benefits, more knowledge about potential agronomic constraints is still needed. In this respect, one objective in HORTINLEA was to assess soil fertility status on AIV-producing farms in western Kenya and establish databases to quantify species-specific fertilizer requirements for AIV production and the input of organic C from plants into the soil (Onyuka et al., 2018). In addition, such chemical soil fertility indices were measured as the potential ability of soils to supply plants with nutrients (e.g., P, S, K, Mg, Zn) and harmful elements (Cd). To assess whether a given index value limits productivity, the data were compared with reference data for sufficiency and deficiency zones. For the study, we took soil samples from 413 fields on 150 farms in different counties in western Kenya (Kakamega and Kisii). All were characterized by intensive AIV production. Extreme acidity ($pH < 4.5$) was a problem in 27% of the fields. Low soil pH reduces the chemical availability of nutrients such as P and Mo. In addition, it can affect root growth through Al toxicity. Low root growth, in turn, can increase the vulnerability of plants to dry periods by hindering water uptake from deeper soil horizons. The application of lime is generally recommended to raise the pH of the soil. If this management approach is not practical due to supply constraints and high costs, replacing inorganic nitrogen fertilizer with animal manure and returning plant residues to the cropland can reduce acidification.

Soil organic carbon (SOC) content indicates various chemical, physical and biological processes that regulate soil fertility. The average SOC at the district level was significantly higher in Kisii (3.2% C in dry soil matter) than in Kakamega (1.7%), suggesting that natural factors, including mean annual temperature and rainfall, have a significant influence on SOC. Another reason for the higher SOC in Kisii compared to Kakamega may be

the shorter duration of agricultural use, i.e., the shorter time since forest conversion to cropland. In Kisii, SOC in all soils was higher than 1.5% C in dry soil matter, a threshold value representing sufficient SOC to maintain soil functions associated with soil fertility. In Kakamega, however, SOC was below this threshold in 47% of the soils, with the proportion of soils with critically low SOC in Mumias being exceptionally high (63% of all soils). This indicates that farmers in Kakamega should increase SOC, e.g., adding more organic C to the soil through plant residues or manure. Other management options to increase SOC include reduced tillage and reducing the frequency and duration of fallow in the crop rotation (Onyuka et al., 2018). In his thesis, Nambafu (2018) also measured value-giving and toxic element concentrations in leaves of different AIVs. He interprets it as an indicator for the nutritional value, the performance under different rates and forms of phosphorus (P) supply due to adaptation to suboptimal chemical soil conditions, and the harvest-related nutrient outflow from the soil as an index for fertilizer need.

Climate Change Adaptation. Kenya is a water-scarce country (World Bank, 2021), and only 17% of the land is productive cropland. Kenyan agriculture is mainly rain-fed; <3% of arable land is currently irrigated. The agriculture sector is the largest emitter, accounting for 33% of carbon dioxide equivalents in 2010. The Kenyan National Adaptation Plan (NCCAP) 2013–2017 envisaged initiating a low-carbon, climate-resilient development pathway through sustainable development and climate change mitigation activities (Global Center on Adaptation, 2021). In agriculture, the focus was on programs to promote irrigation, value addition through processing, weather-based crop insurance, autonomous adaptation measures based on decentralized community projects, climate information systems for farmers, improved financial support and drought-resistant seeds.

The share of greenhouse gas emissions from AIV crops is negligible concerning the agricultural sector, as greenhouse gases are primarily generated through livestock production. However, two interesting questions arise in the adaptation debate for the production of AIVs, which a HORTINLEA sub-project was able to answer (Chepkoech et al., 2018). First, the results show that climate change is present in farmers' perceptions: The household survey indicates that 67% of sample farmers (269 AIV-Farmers) are negatively affected by increasing variability of rainfall patterns and 85% by changes in temperatures (Stöber et al., 2017). The historical analysis of weather data for different agro-climatic zones shows statistically significant temperature increases in all three zones, the humid, the semi-humid and the semi-arid areas. In particular, night temperatures have increased significantly and disproportionately between 0.02 and 0.08°C per year. These are 0.7 and 2.7°C, respectively, over 1980–2014. Changes in precipitation are not significant, with a few exceptions, but variability in rainfall, unpredictability and heavy rain occurrence coupled with short dry spells are consistently mentioned.

Farmers need to adapt their farm-level management to climate change to cope with these challenges. In general, AIVs are known to be relatively unresponsive to weather influences. The HORTINLEA sub-project provides qualitative results from a hitherto completely unexplored field (Chepkoech et al., 2020). From their observations and wealth of experience, the smallholder farmers interviewed derive relatively straightforward statements. In focus group discussions, they prioritized the AIVs according to their insensitivity to extreme weather conditions. The parameters yield/growth, diseases, pests and weeds justified their decision. The spider plant and Ethiopian kale, which are very popular on the market, react relatively sensitively to heavy rain. However, cowpea, which is very resistant to drought, does not tolerate too much rain and moisture, as the fungus Protomycopsis phaeseoli infects the leaves (black spot). Therefore, it is classified by farmers in the medium tolerance group. The least sensitive AIVs include amaranth, crotalaria, vegetable jute and pumpkin leaves. These almost always succeed and generally contribute to a stable agro-ecosystem on farms. Even though consumers do not demand them as much, they play a significant role for plant hygienic reasons.

Therefore, farmers need to adapt in a context-specific manner, with agro-climatic zones, value chain character and the particular AIV species requiring different adaptation strategies. In general, the process of adaptation aims to reduce the negative impacts of climate change. Which adaptation strategies farmers ultimately choose depends primarily on the adaptive capacity of AIV farmers (Chepkoech et al., 2020). One Question relates to how common it is for smallholder farmers growing AIVs to adopt sustainable intensification practices and the socio-economic factors influencing their adoption. Agro-biodiversity strategies are widely adopted, i.e., growing multiple AIV crops per farm and manure for soil improvement. Improved irrigation methods and integrated soil fertility strategies, using organic and synthetic fertilizers as needed, are standard among only 9 to 12% of smallholders. Proximity to urban areas, access to formal markets such as restaurants, bulk buyers or supermarkets, information technologies and extension services, and membership in farmers' organizations or groups, among others, were significant factors in the adoption of sustainable farming practices (Kurgat et al., 2018a,b).

In questions about adaptation strategies with 269 smallholders, it was found that from a tested list of 26 strategies, the following five measures were the most widespread and equally distributed in all three agro-climatic zones: Manure application, more frequent weeding, the use of more pesticides, crop rotation and mixed cropping, and water with a watering can. The characteristic of widely-used adaptation strategies is that farmers can apply those with low risk and little financial input, but they are all associated with higher labor input. In contrast, the main characteristics of the five least common strategies are that they are not available on the market, not easy to implement and require financial resources, knowledge or broad networks. These include, for example, moving to the cities, taking out crop insurance or acquiring additional leased land, which is rare in Kenya. Furthermore, only a tiny proportion reported

seeking off-farm activities to adapt to climate change. This means that the adaptation portfolio as a whole is autonomous from support structures (which are still lacking) on the farm with little capital input but high labor input, and other transformative adaptation strategies are not widespread among farmers.

The results of HORTINLEA concerning agronomic topics of production and especially on the options for climate change adaptation have provided a wealth of exciting and essential results. However, it also became clear that there is still a considerable need to catch up in this context. Compared to the major crops, the need to catch up in technical production know-how is evident here.

Post-harvest and Processing

Indigenous vegetables need to preserve their valuable ingredients until consumption. Especially African indigenous leafy vegetables are highly perishable products with a short shelf life. Advanced post-harvest handling and processing are essential to ensure freshness and good quality, reduce losses and benefit from reasonable prices. However, due to the high water content, the quality of AIV deteriorates quickly. In addition, the high metabolic activity leads to high post-harvest deterioration. Despite many indications of high post-harvest losses in AIV-Value Chains, few studies have focused on quantifying them (Gogo et al., 2017b, 2018). However, reliable data on the actual extent and nature of quantitative and qualitative post-harvest losses are essential for formulating measures to address the problem. Research in the HORTINLEA project (surveys and experimental setups) to identify causes of AIV losses along the supply chain in Kenya has shown that losses at harvest to marketing can be 50%. They vary by location, supply stage and distribution and marketing dynamics. Not only is the loss of quantity harmful to upward mobility, but the loss of nutritional quality is also highly problematic. Quantitative, nutritional and economic losses varied across districts. For example, higher losses of cumulative produce, nitrogen, calcium, protein, provitamin A (carotenoids) were observed in Kakamega, while Nakuru had higher losses of potassium, magnesium, iron, and zinc (Gogo et al., 2017b, 2018).

Along with value chains, nutrients can be lost during processing, storage, distribution and/or preparation due to spoilage, improper handling or preparation methods. By breaking down the economic losses at different stages of food value chains, it can be made clear to growers and sellers how important post-harvest handling can be. Furthermore, making the economic impact of volume and quality losses visible can help to encourage the adoption of new post-harvest handling technologies, such as UV-C treatment (Gogo et al., 2018).

Enhancing affordable and easy-to-use handling, processing, and post-harvest methods for smallholder farmers on the one hand, and innovative new post-harvest technologies for supermarkets on the other are essential for ensuring the quality of AIVs in terms of providing nutritious and health-promoting ingredients, as well as reducing food losses in post-harvest (Gogo E. B., et al., 2016). For example, other research has shown that determining an optimal maturity stage or index for harvesting each AIV plant species allows for higher levels of nutrients for human consumption and/or post-harvest processing. In combination with biodegradable film packaging (PLA) bags, Modified Atmosphere Packaging (MAP) bags can significantly reduce post-harvest quality losses, preserving the shelf life, visual quality (leaf color), and nutritional and health-promoting properties of AIVs. The effect of MAP is exceptionally high under retail conditions (20°C). AIVs have an optimal shelf life at temperatures of ∼0–5°C. The spoilage of these products increases two- to three-fold with each 10°C increase in temperature (Gogo et al., 2016). The HORTINLEA project also tested easy-to-use and low-cost cooling systems, such as the evaporative cooling system using zero-energy brick coolers or evaporative charcoal coolers (Ambuko et al., 2017). Treatment of perishable AIVs with UV-C is a new approach to extend the shelf life and improve the health value of fresh horticultural crops (Gogo et al., 2017a).

There is an urgent need for more quantitative evidence on the actual extent and nature of quantitative and qualitative post-harvest losses in these nutritionally and economically valuable African leafy vegetables for smallholder farmers. Nevertheless, the results provide a starting point for optimizing efforts and strategies to deal with AIV losses. Value chains are used to establish trade linkages between rural and urban areas and achieve a win-win outcome. Rural producers benefit from higher economic returns and urban consumers from a variety of nutritious food at affordable prices. Promoting investment in modern value chain logistics is necessary to ensure supply to urban markets without loss of crop and quality. Further studies are needed on affordable, safe and easy-to-use pre-and post-harvest treatments in conjunction with farmer training to promote and sustain commercial AIV cultivation (International Finance Corporation, 2018).

Product Upgrading and Tapping Into New Markets and Discovering New Consumer Segments

Product upgrading—improving product quality and increasing consumer benefits—can be stimulated by end-market changes. Product improvement involves improving product quality (e.g., certification, safety standards, traceability) and switching to higher-value products (e.g., processing, packaging, and branding). Often it is linked to process upgrading.

In order to better assess the prospects for improved market access and the exploitation of new consumer groups, it is essential to have information on consumer behavior and emerging changes. In the project HORTINLEA, consumer surveys were also conducted to address these questions (Gido, 2017) better. Among a sample of 450 consumers in Kenya, African nightshade is the most commonly consumed, followed by amaranth and cowpea. About 2 out of 3 consumers report that the woman in the household buys the AIVs. Consumers prefer to buy from local vendors in open markets mainly because they are cheaper, closer and offer fresh vegetables. About 72% of consumers said they would buy more AIVs, having reduced prices. Most AIV markets open early in the morning and are open all day. However,

almost 80% of consumers disagree or strongly disagree that AIVs are available in sufficient quantities all year round. This is due to seasonality, dependence on rainfall, perishability and lack of suitable storage facilities. In addition, more than 85% of consumers believe that the sale of AIV in supermarkets leads to its scarcity in rural markets. Almost all consumers cook and consume AIVs at home. Most consumers get information on preparation and nutritional benefits from relatives and family members.

For various reasons, Value Chains for African indigenous vegetables offer opportunities to create sustainable and challenging jobs by opening up new markets (e.g., through convenience products), improving agricultural services, logistic services and related business models. The discussion on so-called nested markets addresses the importance of alternative market structures for rural development. Nested markets (Hebinck et al., 2015) are not organized globally. Instead, the exchange takes place at real meeting points. Van der Ploeg (2015) emphasizes the complexity of such exchange processes and that ethical and social values like product quality, human relations, territorial development, and environmental protection are linked to them (e.g., reliable relationships with schools, kindergartens, and hospitals). Here, too, the expansion and use of indigenous vegetables offer tremendous opportunities.

Value addition, such as processing (e.g., drying, blanching, and fermenting), can help address scarcity during lean seasons and mitigate the problem of high spoilage. Traditional food processing aims to maintain the supply of healthy, nutritious food throughout the year, especially in times of scarcity. Commercial food processing also seeks to generate income for the producer and seller. While most people in rural areas still rely on traditional foods for their basic needs, people in urban centers tend to buy processed and packaged foods for convenience. Today, the increasing number of women working outside the home adds to the pressure for such changes. Even people with healthy traditional diets demand external products, either as occasional delicacies, such as gas-laden drinks or as staples.

Better access to finance could help with storage and processing, as the AIV market is volatile, with prices dropping in the rainy season and skyrocketing in the dry season. In addition, more even availability throughout the year could prevent wastage and scarcity. On a less material level, knowledge about the value and preparation of AIVs is also slowly being lost, both orally and practically, especially in urban areas.

Supermarkets have the niche of those who want to consume AIVs who are willing to consume AIVs but lack the time or knowledge by selling ready to eat vegetables. This could also be an opportunity for women to exploit their expertise through cookbooks, seminars, etc. This includes functional upgrading, where producers or other actors in the chain take on new functions, such as providing inputs or services.

Conclusions 3.3 Upgrading strategies

The analyses in the HORTINLEA project have made clear that the yield differences between the farms are pretty significant and that overall productivity could be increased significantly. Furthermore, HORTINLEA could show that a large part of the harvest gets lost during transport and distribution. The project also identified ways to increase the value of the products through processing. These results create some starting points discussed under the headline process and product upgrading.

Process upgrading is about increasing the efficiency of processes and thus also productivity. Those interventions should reduce losses in the value chain (disease infestation and post-harvest losses). In this context, farmers' particular difficulties due to the changing climate need to be considered. Even if farmers have already developed specific strategies, support is required to reduce the increasingly occurring risks (e.g., water-saving irrigation, insurances).

A significant source of reduced yields is the lack of good quality seed that also meets the changing needs of younger consumers in particular. Systematic breeding is still in its infancy, therefore incentives for private breeding companies are needed. Particular yield problems result from the fact that, despite relatively high resistance, the plants are increasingly attacked by plant diseases and often suffer from nutrient deficiencies. The shortfall in yields is due to knowledge gaps and the low availability of means of production. There is a particular need for support through extension services and long-term systematic research.

At least as serious problems occur after harvesting. In addition to yield losses, the loss of essential ingredients during transport and distribution is a particular concern. Adapted technologies in cooling, storage facilities at markets, packaging and improved infrastructures would be necessary to better serve urban markets.

So far, little use has been made of the opportunities to meet the changing needs of urban dwellers, and especially of women through processed products (e.g., convenience) and at the same time to bridge periods of low supply during dry periods.

Improving the Coordination—The Role of Governance and Collective Action

The value created in the nutrient-rich food value chain needs to be distributed to the chain actors involved to provide incentives for sustained cooperation. The functioning of the overall system depends on the actions of each actor. Economic power is a crucial determinant of the distribution of benefits and can lead to disincentives without an appropriate legal and policy environment. Price-cost spreads are an indicator of benefit distribution. In our view, a fair distribution of benefits is, therefore, a prerequisite for the upgrading strategies described below.

In recent years, promotional campaigns by research institutions and public authorities have led to an increased demand for AIVs, especially among urban consumers. These efforts have led to a more extensive and diversified sales market in urban areas. It also provides smallholders with the opportunity to participate in value chains with higher margins. However, access to and participation in higher-margin value chains is a question of production and how smallholders can access such value chains.

As part of the HORTINLEA project, Otieno (2019) uses a mixed-methods approach to shed light on the role of value chain

actors involved, their activities, the coordination and governance structures that determine participation in AIV value chains in Kenya and influence outcomes. He compares the governance of traditional and modern "coordinated" value chains for rural and peri-urban smallholder farmers (Otieno, 2019). Traditional and coordinated value chains coexist in Kenya. However, small informal actors dominate them. This hinders vertical integration. Of the 269 farmers involved in the study, the majority (98%) participate in traditional value chains compared to only 2% who supply supermarkets in the context of 'coordinated' value chains. Although farmers' associations exist, they are too weak to organize collective production and marketing. Moreover, the use of productivity-enhancing technologies such as improved seeds, irrigation and fertilizers is too limited, so continuous supply to markets cannot be guaranteed.

Farmers often do not have direct transactional relationships with the more lucrative urban traders and supermarkets. Rural households consume about 40% of their total production and sell about 60%. On the other hand, 85% of production is marketed in peri-urban areas. Strong farmer marketing groups enable their members to sell wholesale and supply supermarkets in urban areas. About 41% of AIV producers in groups indicated that better prices are the essential benefit of a vegetable farmer group membership. Farmer groups play a vital role in providing production and market information, linking farmers to central input and output markets, and mobilizing savings and credit in rural areas where formal savings and credit institutions such as banks are lacking. Therefore, AIV producers organized in groups benefit related to commercial AIV producers who are not organized in groups (Otieno, 2019). About 70% of the group members are female, indicating that women are more likely to cooperate than men.

Food safety requirements and quality standards are generally flexible for AIVs (Homeister et al., 2016). However, participation in such value chains is associated with significant uncertainties for small farmers. The vertical linkages between value chain actors in both coordinated and traditional value chains are characterized mainly by "arms-length" market transactions (Otieno, 2019). While some studies point to the benefits of supply contracts with supermarket chains (Fischer and Qaim, 2012; Ogutu et al., 2020), our findings suggest that agreements in AIV value chains neither reduce uncertainty for small farmers nor incentivise farmers to invest in modernization.

Strategies to improve the emergent AIV-value chains should encourage collective action by smallholders and support investment in infrastructure development, including cold storage, and ensure better access to urban markets. Horizontal coordination is about cooperation at one level of the value chain; e.g., collaboration between producers, whose partnership enables farmers to reduce costs (use economies of scale), increase revenues (better prices, new markets) and reduce risks (Helmsing and Vellema, 2012; Vellema et al., 2013; McKaque, 2014; International Finance Corporation, 2018).

The participation of smallholders in profitable, market-oriented fresh vegetable production is—as the research has shown—associated with several difficulties. Nevertheless, research and practical examples show that collective action can support the integration of smallholders into profitable value chains. Bizikova et al. point out that access to markets through information, infrastructure and logistical support should be central to Farmer Organization (FO) design. However, natural resource management could also be more integrated into the services provided by FOs to mitigate the risks associated with environmental degradation and climate change (Bizikova et al., 2020). The potential role markets play in conserving agrobiodiversity through product diversification and increasing competitiveness in niche and novelty markets is receiving increasing attention. Several case studies explore market-based approaches for on-farm agrobiodiversity conservation and improved food security. These case studies highlight the need for improved trust, mutual understanding of stakeholder participation and an agreed process of collective action with a high level of community participation (Kruijssen et al., 2009). The support can be achieved in several ways (Fischer and Qaim, 2012):

- Collective action is key to the sustainable management of natural resources critical for agricultural production, especially in rural and remote communities.
- Collective action enables transaction costs to be reduced and economies of scale in procurement, production and marketing to be exploited.
- Collective action can increase the bargaining power of small producers vis-à-vis large traders.

In studying conventional and institutional markets for leafy vegetables, Mwema et al. found close networks of family members, friends, and neighbors as gatekeepers in accessing institutional markets. In addition to farmer groups, non-farmer and religious groups are also strategic networks that facilitate bulk purchases and link smallholder farmers to markets (Mwema et al., 2021).

To develop the potential of collective action for poverty reduction, certain conditions must be present inside and outside the group. The HORTINLEA project examined three existing forms of collective action in the form of case studies: (a) collective natural resource management by individual AIV producers (Kanyua, 2020); (b) AIV producer groups selling to supermarkets (Populus, 2015); (c) self-help groups of women AIV producers. The studies were conducted in Kiambu and Nakuru, two peri-urban counties in Kenya (Mwema and Crewett, 2019).

In the case of collective natural resource management, it has not been possible to increase AIV production during the dry season. The case shows how difficult it is to implement collective action from the top down. The problem was caused by a lack of common goals among the members, where not all of them saw sufficient benefit in participating, accompanied by a lack of enforcement of the measures (Kanyua, 2020).

In the supermarket study, collective action enabled information and connections to business partners in premium price value chains. In addition, pooling assets enabled them to cross a production threshold, making them potential business partners for supermarkets. However, our case study of AIV sales in supermarkets contradicts the assumption that collective action increases the bargaining power of small producers. Under

the supply arrangements, a large part of the transaction costs was shifted to farmers; they resulted in additional but uncertain income from sales to supermarkets (Populus, 2015).

Collective AIV production in the case of women's self-help groups increased income, food security and self-esteem of vulnerable women farmers. In these groups, collective action has crossed a threshold that has enabled the acquisition of agricultural inputs that would not be available to individual members. Respondents reported that they were empowered by financial independence. Collective action also provided a training ground for experimenting with new business models, leading to individual enterprises and further empowerment.

Conclusions 3.4 Improving Coordination

The results from the HORTINLEA project confirm the findings of many other studies. Due to diseconomies of scale, small farmers have difficulties obtaining their production and financial resources and have little access to up-to-date information and the necessary knowledge. They do not have the resources to access more distant markets and, due to their relatively weak position in the value chain, are in a poor negotiating position vis-à-vis local traders and supermarket buyers and do not have the means to enforce their claims against these actors. These restrictions lead to low yields, high post-harvest losses, low prices for their products, and low incomes.

Forms of coordination in value chains are being sought that can strengthen the position of small farmers vis-à-vis other actors in the value chain, avoid food losses, and promote adaptation to the changing demands of consumers. Vertical linkages between value chain actors are primarily characterized by informal market transactions in coordinated and traditional value chains. Our findings suggest that contracts in AIV value chains neither reduce insecurity for smallholders nor create incentives for investment in modernization. Policymakers are needed to minimize the disadvantages for farmers. They should ensure that smallholders assert their rights and enable access to inputs, land and water. In addition, it could help reduce functional deficits of small enterprises (joint purchase of means of production, coordinated logistics and distribution, collective contract negotiations with market partners) by creating suitable legal framework conditions and financial support for producer organizations or other forms of collective action. However, the initiative for collective action should usually come from private actors in the VAC who want to follow jointly formulated goals.

A CRITICAL REVIEW OF THE RESEARCH FRAMEWORK, THE RESULTS ACHIEVED, AND THE NEED FOR FURTHER RESEARCH

Local food systems around the world are diverse and, above all, site-specific. While they share some common characteristics, efforts to improve those systems need to consider their uniqueness. They result from the different areas' traditions, cultures, economic structures, and ecological conditions. This situation requires that different scientific disciplines are involved in the analyses and jointly contribute to the agreed objectives of such a project. Therefore, a regular exchange between the partners had to occur during the project. In this respect, the concept of value chains for Food and Nutrition security contributed significantly to a common understanding of the problems on the ground and the integration of the findings.

We propose that the connection between emerging social, demographic and ecological changes and the food system's resulting (local) adaption needs should be given greater attention in research (Kurgat et al., 2018a; Stöber et al., 2018; Chepkoech et al., 2020). Furthermore, given the increasing shocks from market development and climate change, the question arises of how to make local food systems and their actors more resilient (Ngenoh et al., 2018).

Even though the HORTINLEA project has produced a wealth of valued results, our studies have also made apparent that the existing knowledge and practical insights into production, quality maintenance, and processing are insufficient due to the low level of research interest. There are still considerable gaps in existing knowledge compared to the main crops that have been intensively researched worldwide. Due to the great importance of indigenous vegetable varieties for improving the food supply, there is a considerable need to catch up here. Irrespective of the significant gaps in knowledge on the subject, many publications provide partial results on specific aspects of production, quality management and processing of AIVs. Therefore, it is also an essential task of science to compile this knowledge by meta-analyses and reviews (see as examples: Nono-Womdim et al., 2009; Shackleton et al., 2009; Akinola et al., 2020).

Even if the state of knowledge on AIVs can be significantly improved in the foreseeable future, this does not yet ensure that this knowledge will be put into practice. Therefore, the multifaceted results HORTINLEA were compiled and made accessible to practitioners and extension workers (Henze et al., 2020) (https://edoc.hu-berlin.de/handle/18452/23783). PhD students and project partners from the study regions significantly contributed to this brochure. In addition, some farmers participated in the critical review and correction of the manuscript. In addition, policy briefs have been written aimed at practitioners and extension workers. Toward the end of the research, meetings were also held with farmers in different areas of Kenya, where the scientists involved presented their findings.

Nevertheless, the transfer of the results was not entirely satisfactory. This is partly due to the limited time frame in which such a project is funded. The question remains how the existing knowledge can be transferred into coherent practical actions given the complexity and the specific local situations in each case. On the one hand, this has to do with preparing this knowledge and making it available to the decision-makers in the value chain. More Collaboration with extension workers and other knowledge brokers is necessary, and professional training at various levels of the education system must be established. At the same time, however, the political framework conditions must be designed so that the actors involved in the value chain have sufficient incentives to participate in these systems. This framework conditions also include the necessary investments in infrastructure.

More knowledge is also needed to meet the specific challenges of social inclusion and environmental sustainability in food and nutrition security value chains. Therefore, case comparisons could even identify the causes of success and failure more precisely. In addition, the pooled experiences from the multitude of value chain projects could provide valuable suggestions in this

respect. Finally, to better use the experience gained from such projects, a systematic evaluation of such results would generally be needed.

The options for enhancing value chains identified in the HORTINLEA project require technological, social and/or organizational innovations (Barrett et al., 2020). Those innovations are emergent phenomenons (Kansiime et al., 2018). The process requires adaptive management while addressing local conditions and needs. In the agricultural innovation system concept, innovation emerges from complex interactions between researchers, input suppliers, extension workers, farmers, traders and processors who work together to identify problems, analyse them and research, design, test and implement strategies (Gevorgyan et al., 2015; Kuntosch and König, 2018; Sanya et al., 2018; Klerkx and Begemann, 2020).

Because of the necessary long-term development opportunities, the issue of capacity building is also of significant importance. The HORTINLEA project involved mainly African PhD students and produced many concrete results. In addition, linking problem-solving research and the training of young professionals at higher education institutions is of particular importance. Finally, we hope that the exchange among the participants in the international project and the hints on how research results can be actively and better prepared for practice could provide ideas for future activities in Kenya.

DATA AVAILABILITY STATEMENT

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

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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Role of Wild Food Environments for Cultural Identity, Food Security, and Dietary Quality in a Rural American State

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Wild foods are primary components of traditional and Indigenous food systems that are valued for food security while being vulnerable to global change. This case study examines practices, experiences, and perceptions associated with wild food environments through a household survey in the rural American state of Montana. Findings highlight that wild food environments contribute to cultural identity, sense of place, food security, and dietary quality of surveyed households while being vulnerable to loss of traditional ecological knowledge as well as climate and land-use change. Of the 182 informants, 80% hunt, 83% fish, and 68% forage wild botanicals. More than half of the informants agreed that wild food procurement is part of their cultural identity (66%). Collectively, informants procure more than 172 wild food species with the most prevalent being deer, waterfowl, elk, trout, bass, a range of berries, mushrooms, and botanicals used medicinally. Participants have a multidimensional value system where wild food procurement is valued for diets, recreation, family time, spirituality, and connection to the environment. The majority of participants agreed that the consumption of wild foods contributes to the nutritional quality (87%) and diversity (82%) of their diets while lowering food costs (59%). At least half of the informants reported observing changes in climate patterns over the past decade including increased temperature (50%) and more extreme and variable weather patterns (38%) that they perceive are impacting wild food environments including shifts in wild game, fish, and edible plant populations. Based on findings, we support that wild food environments and associated bio-cultural resources are a critical place to understand, conserve, and promote for nutrition. We thus advance the concept of "conservation for nutrition". Community engagement, education, and policy plans are called for to promote wild food environments toward supporting sustainable diets and planetary health.

Keywords: wild foods, food environments, food security, dietary quality, climate change

INTRODUCTION

The food system is critically dependent on healthy ecosystems while presenting greater environmental sustainability challenges compared to all other human activities (Foley et al., 2011; West et al., 2014). Concurrently, poor diets are a leading risk factor of the global burden of disease (Development Initiatives., 2018; IHME, 2018; Murray et al., 2020). These food system challenges are exacerbated by global environmental change including climate change and land-use change (IPCC., 2013; McConnell and Viña, 2018; Dury et al., 2019; Swinburn et al., 2019). Previous studies highlight that traditional and indigenous food systems of communities that have a deep understanding and connection to their surroundings can provide sustainability solutions for reconciling food production with human and planetary health (Bharucha and Pretty, 2010; Smith et al., 2019).

Traditional and indigenous food systems have been variously defined, including those that are place-based where communities procure wild and cultivated foods from their surroundings, or natural food environments (Downs et al., 2020), and prepare these foods in ways that are culturally acceptable and reflect cultural heritage (Kuhnlein and Receveur, 1996). Food environments are the consumer interface of the food system that influence the availability, affordability, convenience, desirability, and sustainability of food (Herforth and Ahmed, 2015; Downs et al., 2020). More specifically, natural food environments include wild and cultivated food environments such as forests, fields, and gardens (Ahmed and Herforth, 2017; Downs et al., 2020). Historically, wild foods procured through hunting, fishing, and foraging in wild food environments were primary components of food systems and continue to be valued globally for their contribution to multiple dimensions of sustainability (Kuhnlein and Receveur, 1996; Powell et al., 2009; Ahmed et al., 2010; Bharucha and Pretty, 2010; Turner et al., 2018; Reyes-García et al., 2019).

On an environmental basis, sustainable wild food procurement encourages stewardship and valuation of biodiversity, natural resources, and ecosystems (Kuhnlein and Receveur, 1996). Based on human health, wild food consumption contributes to food security, dietary diversity of nutrient-dense foods, and dietary quality by combatting micronutrient deficiencies and chronic disease through their rich nutrient and phytochemical profiles (Vinceti et al., 2012). Wild foods are further part of cultural heritage and contribute to a sense of place where food is entwined with the identity of communities and their surroundings. Economically, the procurement of wild foods contributes to affordable diets by providing a non-market source of diverse foods without a direct monetary cost to support food security (Ford, 2009), though not accounting for costs associated with acquisition.

Despite the role of wild foods for advancing sustainability, global environmental change is threatening wild food environments and associated food systems (Reyes-García et al., 2019; Smith et al., 2019). Drivers of global environmental change including economic growth, climate change, land-use change, globalization, urbanization, industrialization, and technological changes are associated with food environment transitions (Downs et al., 2020) and nutrition transitions (Popkin et al., 2001) away from traditional and indigenous diets toward more processed foods from built food environments (Popkin, 2004; Hawkes, 2006; HLPE, 2017; Reyes-García et al., 2019). The global trend of increasingly purchasing foods from built food environments is associated with diets high in saturated fat and sugar as well as ultra-processed foods while being simultaneously low in fiber, fruits, and vegetables that are associated with obesity and diet-related chronic disease (Popkin et al., 2001; Popkin, 2002; Boutayeb and Boutayeb, 2005), with disproportionate health impacts on indigenous and rural populations (Damman et al., 2008; Ploeg et al., 2009). Wild food environments are thus a critical place to understand to support nutritional outcomes globally.

This paper seeks to contribute to the need to understand wild food environments and associated practices, experiences, and perceptions in the context of environmental change through a case study in the rural American state of Montana. The locality of Montana serves as a compelling case study for assessing wild food environments because of its long history of hunting, fishing, and foraging coupled with its diverse socio-ecological context (Mehn, 1989; Josephy, 2002; Groessler, 2008; Smith et al., 2019; Byker Shanks et al., 2020). Our study team designed and administered a structured survey to address the following overall research question: What are practices, perceptions, experiences, and knowledge associated with wild food environments in the context of global environmental change? Findings have the potential to inform local programs and policies that promote the conservation of biocultural resources associated with wild food environments toward supporting sustainable diets and planetary health.

METHODS

Study Area

Montana is a rural, land-locked, montane state in the Rocky Mountains of the north-west United States with an economy that is primarily based on agriculture, including cereal grain farming and ranching, along with energy (oil, gas, and coal), lumber, and tourism. Historically, Montana is home to multiple indigenous tribes whose food systems relied on the wild food environment (Groessler, 2008; Grinnell, 2012); currently, the state is home to seven Native American reservations where households hunt, fish, and forage (Smith et al., 2019). The state has a population of 1,084,225 that is primarily Caucasian (88.9%) with the remaining being primarily Native American (6.7%) (U.S. Census Bureau., 2020). Additionally, the state has a relatively low population per square mile of 6.8 (U.S. Census Bureau., 2020).

In 2019, the number of people that were food insecure in Montana was 111,080 (Feeding America., 2019). Of those food insecure, an estimated 39% were above the Supplemental Nutrition Assistance Program (and other nutrition programs) threshold, and 61% were below. Of the 56 Montana counties, several counties were identified with higher rates of food insecurity and include Lincoln, Glacier (which share boundaries with the Blackfeet Reservation), Blaine (share boundaries with Fort Belknap Reservation), Mineral, Roosevelt (Fort Peck

Reservation), and Big Horn (Crow Reservation and Northern Cheyenne Reservation). The majority of Montana is defined as "rural" with approximately 44% of the population living in rural areas of the state (Montana State Legislature., 2020).

Montana's diverse topography and climate, ranging from mountains and forests in the west to prairies and badlands in the east, supports rich biodiversity including approximately 115 mammal species, 450 bird species, over 100 fish species, and over 4,600 plant species (Montana National Heritage Program., 2019). These species include a range of high-quality nutrient-dense wild foods such as deer, elk, bison, trout, and various berries (Jonkel and Greer, 1963; Groessler, 2008; Shores et al., 2019; Smith et al., 2019). Overall, Montana is a cold temperate state that is increasingly experiencing climate change (Whitlock et al., 2017). Previous studies in Montana indicate that tribal households perceive impacts of climate change on wild food environments (Smith et al., 2019) while farmers and ranchers perceive impacts of climate change on their agricultural systems (Grimberg et al., 2018). These perceptions are in line with climate data that demonstrates that temperatures in Montana increased during the 20th century (Pederson et al., 2010; Whitlock et al., 2017), and are expected to further rise between 2.5–3.3°C, along with a decrease in precipitation during the summer months (Whitlock et al., 2017).

Numerous federal and state agencies oversee the protection of conservation lands in Montana and associated biodiversity including the U.S. Department of Agriculture Forest Service, Montana Department of Fish, Wildlife and Parks, Montana Department of Natural Resources and Conservation, and Tribal Councils. Specifically, the U.S. Department of Agriculture Forest Service administers 16,800,000 acres of forest land across 10 National Forests across Montana that includes 3,300,000 acres in 12 wilderness areas as part of the National Wilderness Preservation System (Montana Interagency Council., 2018). The Montana Department of Fish, Wildlife, and Parks (MT FWP) operates approximately 275,265 acres of state parks and access points on the state's rivers and lakes while the Montana Department of Natural Resources and Conservation manages 5,200,000 acres of School Trust Land for the benefit of public schools and institutions in the state, and the Bureau of Land Management (BLM) administers about 8.1 million acres of federal lands (Montana Interagency Council., 2018). Tribal lands account for 8.3 million acres across Montana (Montana Legislative Services Division Margery Hunter Brown Indian Law Clinic., 2016). In partnership with Montana Fish Wildlife and Parks, the BLM manages more wildlife habitat than any other federal agency to ensure abundant, self-sustaining, and diverse wildlife populations on public lands (BLM, 2022a). Specific to Montana, FWP manages and conserves over 600 species of birds, mammals, reptiles, and amphibians throughout the state, including deer, elk, and antelope, prevalently harvested in the study area, as well as numerous fish and game bird populations (MT FWP, n.d.). While the state of Montana and native plant species therein are not included in the BLM Rare and Cultural Plant Conservation program, the BLM conserves, maintains, and restores native plant communities under its "multiple-use" and "sustained yield" mandate to support multiple uses including recreation, wildlife habitat provision, and grazing (BLM, 2022b).

Structured Survey

A structured survey was designed based on previous research on food environments and interview tools implemented by members of the study team regarding perceptions and observations on the impact of environmental change on food systems (Ahmed et al., 2014; Grimberg et al., 2018; Smith et al., 2019) along with literature on climate vulnerability and adaptation strategies (Mertz et al., 2011). The survey on wild food environments was reviewed for face validity based on a panel of five experts in the fields of agriculture, cultural anthropology, ethnobotany, nutrition, and climate science. Revisions were made upon receiving feedback from the field experts. The survey instrument was pilot tested with an independent group of key informants ($n = 13$) for further validity through interviews with who have a history of hunting, fishing, and foraging, revisions were then made upon receiving feedback. Key informants were not targeted in the recruiting efforts for the final survey tool distribution.

The final survey on wild food environments (Supplementary material: survey tool) consisted of 55 questions divided into the following five sections: (1) Background (eight questions); (2) Practices and Valuation on Hunting (11 questions), Fishing (11 questions), and Foraging (11 questions); (3) Wild Food Perceptions (six questions); (4) Observations and Perceptions of Environmental Change (13 questions); and (5) Protecting Community Resources (1 question).

Section Background of the survey included questions focused on demographic information (length of time living in Montana, age, gender; racial/ethnic and/or tribal affiliation including enrolled membership and/or descendancy was not collected); length of time harvesting wild foods; and brief screen for food insecurity. Section Practices and Valuation on Hunting, Fishing, and Foraging of the survey included questions regarding: (1) whether participants and/or family members engage in a specific wild foods activity; (2) what they value about the wild foods activity; (3) who they learnt the wild foods activity from; (4) types of animals, fish, and foraged wild edible species of plants and mushrooms they procure (herein: foraged edibles / foraged foods); (5) how often they procure wild foods; (6) types of habitats where they procure wild foods; (7) how often they consume wild foods and; (8) rituals and stories associated with wild foods. Section Wild Food Perceptions included questions on perceptions regarding the role of wild foods to diets, cultural identity, and traditional ecological knowledge and transmission. Section Observations and Perceptions of Environmental Change elicited informant observations and perceptions regarding changes in environmental variables over the past decade including changes in the timing of seasons and species populations as well as concerns regarding land-use changes, the availability of wild foods, water quality, and weather patterns. The final section, Section Protecting Community Resource included a question that elicited suggestions for protecting the community's food, water, land, and cultural resources.

Prior to administering surveys, the approval of human subjects to participate in this study was obtained by the Institutional Review Board (IRB) at Montana State University. Informed consent was retrieved from all of the study participants following IRB guidelines prior to taking the survey. The survey was administered online using the Survey Monkey platform. Participants were recruited by sending the survey to various organizations that have listservs of at least 1,500 community members who hunt, fish, and forage including: (1) Montana State University Extension, (2) Montana Organic Association, (3) One Montana, (4) Montana Food Bank Network, (5) Montana Co-op, (6) Montana Rural Education Association, (7) Montana Bowhunters Association, (8) Backcountry Hunters & Anglers, (9) Montana Wildlife Federation, (10) Montana Hunters Against Hunger, (11) Trout Unlimited and, (12) Montana Hook & Bullet News. The goal of the survey was to reach 1,500 people. Inclusion criteria for the study included that participants must have hunted, fished, or foraged wild foods, lived in Montana, and answered 75% or more survey questions. Since not all participants responded to every question, sample size varied based on survey question.

Qualitative Coding of Survey Responses

Responses from open-ended survey questions were transcribed by two members of the study team (TW and AS) and were coded to identify themes (Saldana, 2008) using a grounded theory approach (Glaser and Strauss, 1999). Following the process of transcribing interviews, a thematic qualitative codebook was created using strategies from Saldana (2008) by identifying approximately four to five common coded responses to each survey question. Two members of the study team trained in qualitative research methods applied the codebook to code the open-ended survey questions to identify prevalent themes. Each survey response was coded by two separate coders for inter-rater reliability and discrepancies were resolved. Coded responses to each survey question were then tabulated to determine frequencies of prevalent themes.

Foraged edible foods in particular, often have multiple uses. For example, dandelion can be used as greens in a salad, or in tinctures and teas. As such, the themes of foraged wild edible foods were classed into themes at the discretion of the two-code research team and reported in the results section (for further detail see **Table 2**).

Quantitative Analysis

Food Insecurity Screen

Food insecurity was measured using a validated two-question adaptation (Young et al., 2009) of the U.S. Adult Food Security Survey Module: Six-Item Short Form (USDA, 2012). The two-item measure included: (1) *'(I/we) couldn't afford to eat balanced meals.' Was that often, sometimes, or never true for (you/your household) in the last 12 months?"*, and (2) *In the last 12 months, did you ever eat less than you felt you should because there wasn't enough money for food?".* An affirmative response ("often true", "sometimes true", and "yes") to one or both questions indicates food insecurity. Based on this screening, when reporting food insecurity, respondents are either food insecure (yes), or not food insecure (no).

Wild Food Procurement Score

Following methods outlined in Smith et al. (2019), a Wild Food Procurement score (WFPSc) was tabulated based on a scale of either zero or one with a code of zero indicating that the participant did not engage in a particular wild food procurement activity (hunting, fishing, or foraging). Total WFPSc was based on a scale of one to three and calculated by totaling the WFPSc from each of the three wild food procurement activities (hunting, fishing, or foraging); a code of one or two indicated the participant engaged in at least one or combination of two wild food procurement activities respectively, and a code of three indicated that the participant engaged in all three wild food procurement activities.

Wild Food Dietary Diversity Score

In line with methods outlined in Smith et al. (2019), Wild Food Dietary Diversity score (WFDDSc) was calculated by tallying the number of food species or types consumed in each food category (game, fish, and foraged edibles). Similarly, Total WFDDSc was calculated by summing all three wild food categories to find the total number of wild food types consumed by each participant.

Frequency of Survey Responses and Statistical Analysis

The survey was tabulated for frequency of responses to all survey questions. JMP statistical software (version 12.0 SAS Institute Inc., Cary, NC) was used to carry out Analysis of Variance and Contingency Analysis to understand relationships between generation, gender, or food insecurity among survey responses to select questions. A Oneway Analysis of Variance (ANOVA) was completed to examine relationships in mean Wild Food Procurement Scores and Wild Food Dietary Diversity Scores based on (1) generation (Millennial (born between 1981 and 1996), Generation X (born between 1965 and 1980), and Baby Boomer+ (born between 1928 and 1964), (2) gender (male/female), (3) food insecurity indicator (yes/no), and (4) location (rural (county participant reported living in with population $\leq$49,999 people) or urban (county with population $\geq$50,000 people) (U.S. Census Bureau., 2017). The probability F-statistic p-value is reported at a significance level $p < 0.05$. Further statistical tests were completed to find directional differences when appropriate, including a Fisher's Exact Test was completed or a test probability with Pearson p-values reported, at a significance level $p < 0.05$. Further, a Contingency Analysis was completed to understand differences in responses to specific questions among generation, gender, food insecurity, and location.

RESULTS

Informant Demographic Background and Food Security Status

A total of 182 informants completed the majority (75% or more) of the survey, with most being male (68%). Informants

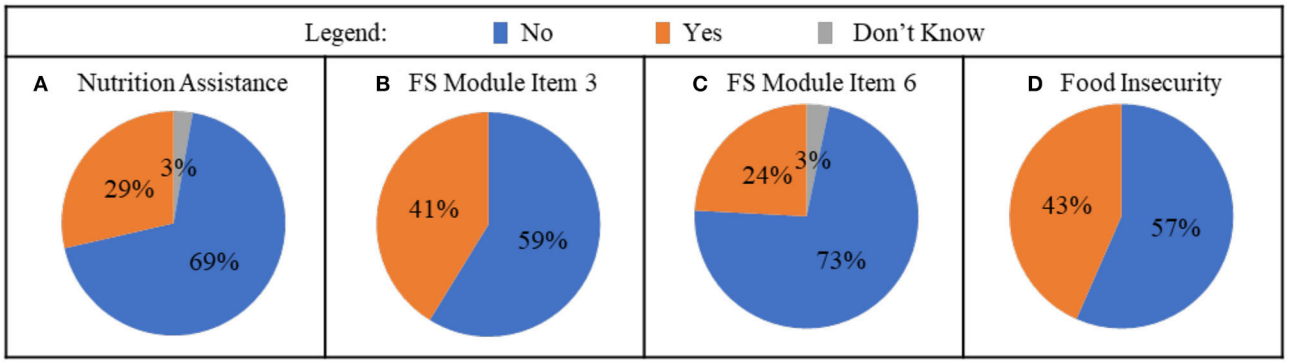


FIGURE 1 | Frequency of informants that reported **(A)** they receive nutritional assistance, **(B)** an affirmative response to USDA Food Security Module Item 3, **(C)** an affirmative response to USDA Food Security Module Item 6, and **(D)** composite food insecurity measurement.

were between 21 and 71 years, with a mean age of 42 years. Almost half of the informants are Generation X (47%), followed by Millennials (35%), and Baby Boomer+ (18%). Informants reported they lived in either rural (51%) or urban (49%) counties. Informants reported procuring wild foods between about 2–73 years or more, with the average experience of wild food procurement being 24 years. Around a quarter of informants reported that their household receives nutrition assistance to supplement the food they purchase including from the Supplemental Nutrition Assistance Program, food banks, and community kitchens (29%) (**Figure 1A**). Just under half of the informants were food insecure (43%) (**Figures 1B–D**) on the basis of their responses to the two-item food security screen (Young et al., 2009), and as a composite. Significant differences were found in food security status based on gender ($p = 0.0475$), generation ($p = 0.0047$), and location ($p = 0.0040$). Males were more likely to be food insecure than females ($p = 0.0335$), the Baby Boomer+ generation was the least food insecure ($p = 0.0004$), and rural participants ($p = 0.0031$) were more food insecure than urban.

Practices and Valuation on Hunting, Fishing, and Foraging

Hunting

The majority of survey informants reported they hunt (80%) and have members in their household that hunt (76%), including household members reported as partners (58%), friends (56%), extended family (33%), parents (33%), siblings (26%), and grandparents (9%). Significant differences were found for those that reported they hunt based on generation ($p = 0.0348$), gender ($p < 0.0001$), and food insecurity ($p = 0.0119$). Specifically, informants that reported they hunt included a higher proportion of Millennials (87%), compared to Generation X (80%), and Baby Boomer+ (65%). Informants that reported they hunt had a higher probability of being male ($p < 0.0001$), with the proportion of those that hunt higher for males (93%) compared to females (53%). In addition, informants that reported they hunt had a higher probability of being food insecure ($p = 0.0090$), with the proportion of those that hunt higher for those food insecure (89%) compared to the proportion of those not food insecure (73%). Differences were not significant among rural and urban participants that reported they hunt. Most informants learned to hunt from parents (59%) particularly their fathers. Informants shared multiple reasons they value hunting with the most prevalent themes reported being: (1) for food and/or health (78%); (2) recreation and/or self-fulfillment (72%); and (3) companionship (50%) (**Table 1**).

Informants reported they and/or their families hunt over 42 types of wildlife with the most prevalent animals being: deer (88%), birds and waterfowl (69%), and elk (65%) (**Table 2**). The types of wildlife participants reported hunting most often include deer (59%), birds and waterfowl (29%), and elk (29%) (**Figure 2**). Informants notably varied in how often they go hunting ranging from once to over 100 times per year, with a mean of 16 times per year ($n = 91$; SD = 15.68). Informants reported to primarily hunt on public (82%) and private (51%) lands while some informants also hunt in other areas (3%) such as tribal land. The majority of informants reported they consume the meat they hunt on a weekly basis (60%) while others reported they consume hunted meat one to three times per month (23%) or less than once per month (17%) (**Figure 3**). Informants shared a range of practices, rituals, and stories associated with hunting with the most prevalent being related to recipes and preservation techniques (70%). The most frequently reported preservation techniques for hunting included freezing, drying, canning, and smoking. Other practices shared included family traditions, connections, and stories (28%), harvesting practices (23%), and practices of a spiritual nature (19%) (**Table 3**).

For hunting, the majority of informants had a Wild Food Procurement score of 1 (91%) and an average Wild Food Dietary Diversity score of 3.19 ($n = 110$; SD = 1.61) that ranged from one to nine types of animals they harvest. Differences in mean WFPSc for hunting were not significant based on generation, gender, or location, and were significant based on food insecurity ($p = 0.0055$). Specifically, respondents that were food insecure had a higher mean WFPSc for hunting than those that were not food insecure. Differences in mean WFDDSc for hunting were not significant based on generation, gender, or location, and were significant based on food

TABLE 1 | Values related to hunting, fishing, and foraging coded into the most prevalent themes: food and/or health, recreation and/or self-fulfillment, companionship, conservation and education, and economic.

Wild food valuation

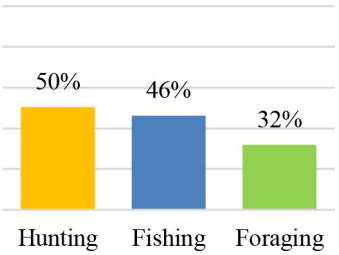
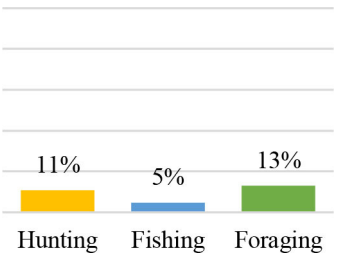
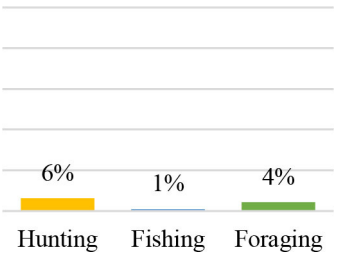
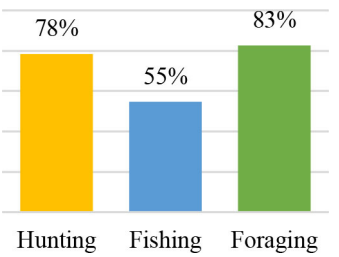
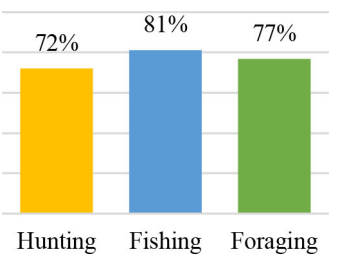
Research theme	Subthemes	Sample quotations	Frequency of theme
Theme 1: companionship	Subthemes: friendship, family, and social time.	*"Valuable time with friends and family."* *"My grandmother taught me about wild plants when I was a kid. We spent a lot of time together collecting wild plant foods.*	
Theme 2: conservation and education	Subthemes: teaching and learning from others, supporting conservation, and wildlife management.	*"Contributing to conservation through advocacy for wild animals and public lands."* *"I enjoy… teaching my young children about wild edibles."*	
Theme 3: economic	Subthemes: saving money and the inexpensive nature of wild food procurement.	*"I value… the money we get to save on groceries."* *"Free food."*	
Theme 4: food and/or health	Subthemes: healthy food, the quality and taste of wild foods, and knowing where their food comes from.	*"Knowing exactly how the animals I eat lived and died."* *"Cold water fish provides a good source of omega-3 fatty acids."*	
Theme 5: recreation and/or self-fulfillment	Subthemes: physical exercise, time spent outdoors, the connection to nature, and personal satisfaction.	*"I love just enjoying the nature and getting outdoors to have a good time."* *"Enjoying Montana's waterways, seeing new places, and spending a day outside."*	

TABLE 2 | Types of wild foods procured through hunting, fishing, and foraging.

Common name	Scientific name	Family	Food type
Hunting			
Black bear	Ursus americanus	Ursidae	Bear
Big Horn sheep	Ovis canadensis	Bovidae	Bighorn sheep
Canada geese	Branta canadensis	Anatidae	Birds/waterfowl
Coot	Fulica americana	Rallidae	Birds/waterfowl
Dusky grouse	Dendragapus obscurus	Phasianidae	Birds/waterfowl
Eurasian collared dove	Streptopelia decaocto	Columbidae	Birds/waterfowl
Gray/Hungarian partridge	Perdix perdix	Phasianidae	Birds/waterfowl
Mergansers	Mergus merganser	Anatidae	Birds/waterfowl
Mouring Dove	Zenaida macroura	Columbidae	Birds/waterfowl
Pigeons	Columba livia domestica	Columbidae	Birds/waterfowl
Quail	Callipepla californica	Odontophoridae	Birds/waterfowl
Ring-necked Pheasant / common pheasant	Phasianus colchicus	Phasianidae	Birds/waterfowl
Ruffed grouse	Bonasa umbellus	Phasianidae	Birds/waterfowl
Sage grouse	Centrocercus urophasianus	Phasianidae	Birds/waterfowl
Sandhill cranes	Antigone canadensis	Gruidae	Birds/waterfowl
Sharp-tailed grouse	Tympanuchus phasianellus	Phasianidae	Birds/waterfowl
Snow Geese	Anser caerulescens	Anatidae	Birds/waterfowl
Spruce grouse	Canachites canadensis	Phasianidae	Birds/waterfowl
Swans (this is trumpeter)	Cygnus buccinator	Anatidae	Birds/waterfowl
Tundra Swan	Cygnus columbianus	Anatidae	Birds/waterfowl
Turkey	Meleagris gallopavo	Phasianidae	Birds/waterfowl
Wood duck	Aix sponsa	Anatidae	Birds/waterfowl
Bison	Bison bison	Bovidae	Bison
Mule deer	Odocoileus hemionus	Cervidae	Deer
Whitetail deer	Odocoileus virginianus	Cervidae	Deer
Elk/Wapati	Cervus canadensis	Cervidae	Elk
Mountain goat	Oreamnos americanus	Bovidae	Goat
Moose	Alces alces	Cervidae	Moose
Bobcat	Lynx rufus	Felidae	Mountain lion or bobcat
Mountain lion	Puma concolor	Felidae	Mountain lion or bobcat
Badger	Taxidea taxus	Mustelidae	Other
Pronghorn/Antelope	Antilocapra americana	Antilocapridae	Pronghorn
Cotton-tail	Sylvilagus floridanus	Leporidae	Rabbit, squirrel, other rodent
Jack rabbit	Lepus townsendii	Leporidae	Rabbit, squirrel, other rodent
Red squirrel	Tamiasciurus hudsonicus	Sciuridae	Rabbit, squirrel, other rodent
Richardson ground squirrel	Urocitellus richardsonii	Sciuridae	Rabbit, squirrel, other rodent
Coyote	Canis latrans	Canidae	Wolf/fox/coyote
Fox	Vulpes vulpes	Canidae	Wolf/fox/coyote
Wolf (gray)	Canis lupus	Canidae	Wolf/fox/coyote
Porcupine	Erethizon dorsatum	Erethizontidae	Other
Racoon	Procyon lotor	Procyonidae	Other
Turtle (this is Western painted)	Chrysemys picta	Emydidae	Other
Fishing			
Bigmouth / Largemouth bass	Micropterus salmoides	Centrarchidae	Bass
Smallmouth bass	Micropterus dolomieu	Centrarchidae	Bass
Bluegill	Lepomis macrochirus	Centrarchidae	Bluegill
Large mouth / Bigmouth buffalo	ctiobus cyprinellus	Catostomidae	Buffalo
Small mouth buffalo	Ictiobus bubalus	Catostomidae	Buffalo
Burbot	Lota lota	Lotidae	Burbot

(Continued)

TABLE 2 | Continued

Common name	Scientific name	Family	Food type
Common Carp	Cyprinus carpio	Cyprinidae	Carp
Channel catfish	Ictalurus punctatus	Ictaluridae	Catfish
Mudcat / Flathead catfish	Pylodictis olivaris	Ictaluridae	Catfish
Crappie	Pomoxis nigromaculatus	Centrarchidae	Crappie
Freshwater drum	Aplodinotus grunniens	Sciaenidae	Drum
Redfish / red drum	Sciaenops ocellatus	Sciaenidae	Drum
Gar	Lepisosteus platostomus	Lepisosteidae	Gar
Goldeye	Hiodon alosoides	Hiodontidae	Goldeye
Mullet	Mugil cephalus	Mugilidae	Mullet
Musky	Esox masquinongy	Esocidae	Musky
Northern Pikeminnow	Ptychocheilus oregonensis	Leuciscidae	Northern pikeminnow
Paddlefish	Polyodon spathula	Paddlefish	Paddlefish
Perch	Perca flavescens	Percidae	Perch
Yellow perch	Perca flavescens	Percidae	Perch
Northern Pike	Esox lucius	Esocidae	Pike
Rock fish / Striped bass	Morone saxatilis	Moronidae	Rock fish
Steelhead	Oncorhynchus. m. irideus	Salmonidae	Salmon
Sauger	Sander canadensis	Percidae	Sauger
Shovelnose Sturgeon	Scaphirhynchus platorynchus	Acipenseridae	Sturgeon
Brook Trout	Salvelinus fontinalis	Salmonidae	Trout
Brown trout	Salmo trutta	Salmonidae	Trout
Bull trout	Salvelinus confluentus	Salmonidae	Trout
Cutthroat trout	Oncorhynchus clarkii	Salmonidae	Trout
Golden trout	Oncorhynchus aguabonita	Salmonidae	Trout
Kokanee Salmon	Oncorhynchus nerka	Salmonidae	Trout
Lake trout	Salvelinus namaycush	Salmonidae	Trout
Rainbow trout	Oncorhynchus mykiss	Salmonidae	Trout
Westslope cutthroat trout	Oncorhynchus clarkii lewisi	Salmonidae	Trout
Yellowstone cutthroat trout	Oncorhynchus clarkii bouvieri	Salmonidae	Trout
Walleye	Sander vitreus	Percidae	Walleye
Lake Whitefish	Coregonus clupeaformis	Salmonidae	Whitefish
Mountain Whitefish	Prosopium williamsoni	Salmonidae	Whitefish
Foraging			
Apples	Malus pumila	Rosaceae	Berries and fruits
Bearberries / Kinnikinnick	Arctostaphylos uva-ursi	Ericaceae	Berries and fruits
Blackberries	Rubus laciniatus	Rosaceae	Berries and fruits
Buffalo berries	Shepherdia argentea	Elaeagnaceae	Berries and fruits
Chokecherries	Prunus virginiana	Rosaceae	Berries and fruits
Crab apples	Malus sylvestris	Rosaceae	Berries and fruits
Currants	Ribes aureum	Grossulariaceae	Berries and fruits
Elderberries	Sambucus cerulea	Adoxaceae	Berries and fruits
Gooseberry	Solidago canadensis	Grossulariaceae	Berries and fruits
Hawthorne berries	Crataegus douglasii	Rosaceae	Berries and fruits
Huckleberries	Vaccinium membranaceum	Ericaceae	Berries and fruits
Juneberries / service berry / Saskatoon	Amelanchier alnifolia	Rosaceae	Berries and fruits
Oregon grape	Berberis repens	Berberidaceae	Berries and fruits
Raspberries	Rubus idaeus	Rosaceae	Berries and fruits
Red Elderberry	Sambucus racemosa	Caprifoliaceae	Berries and fruits
Rhubarb	Rheum rhabarbarum	Polygonaceae	Berries and fruits
Rose hips	Rosa rugosa	Rosaceae	Berries and fruits

(Continued)

TABLE 2 | Continued

Common name	Scientific name	Family	Food type
Strawberry	Fragaria vesca	Rosaceae	Berries and fruits
Thimbleberries	Rubus parviflorus	Rosaceae	Berries and fruits
Thorn apple	Datura stramonium	Solanaceae	Berries and fruits
Whortle berries	Vaccinium scoparium	Ericaceae	Berries and fruits
Wild Plums	Prunus americana	Rosaceae	Berries and fruits
Asparagus	Asparagus officinalis	Asparagaceae	Greens
Dandelion and dandelion greens	Taraxacum lyratum	Asteraceae	Greens
Goosefoot / Lamb's quarters	Chenopodium berlandieri	Amaranthaceae	Greens
Mustards	Sinapis arvensis	Brassicaceae	Greens
Watercress	Rorippa nasturtium-aquaticum	Brassicaceae	Greens
Yellow dock	Rumex crispus	Polygonaceae	Greens
Arnica	Arnica fulgens	Asteraceae	Herbs and medicinal plants
Aster	Aster alpinus	Asteraceae	Herbs and medicinal plants
Belladonna	Atropa belladonna	Solanaceae	Herbs and medicinal plants
Bistort	Polygonum bistortoides	Polygonaceae	Herbs and medicinal plants
Burdock	Arctium minus	Asteraceae	Herbs and medicinal plants
Calendula	Calendula arvensis	Asteraceae	Herbs and medicinal plants
Camas	Camassia quamash	Liliaceae	Herbs and medicinal plants
Chicory	Cichorium intybus	Asteraceae	Herbs and medicinal plants
Cleaver	Galium aparine	Rubiaceae	Herbs and medicinal plants
Devil's club	Oplopanax horridus	Araliaceae	Herbs and medicinal plants
Equistium / Horsetail	Equisetum telmateia	Equisetaceae	Herbs and medicinal plants
False Solomons Seal	Maianthemum racemosum	Asparagaceae	Herbs and medicinal plants
Feverfew	Tanacetum parthenium	Asteraceae	Herbs and medicinal plants
Fireweed	Chamerion angustifolium	Onagraceae	Herbs and medicinal plants
Gentian	Gentiana affinis	Gentianaceae	Herbs and medicinal plants
Gerenium	Geranium bicknellii	Geraniaceae	Herbs and medicinal plants
Glacier lily	Erythronium grandiflorum	Liliaceae	Herbs and medicinal plants
Goldon Rod	Solidago canadensis	Asteraceae	Herbs and medicinal plants
hanbene / hebenon	Hyoscyamus niger	Solanaceae	Herbs and medicinal plants
Hounds tongue	Cynoglossum officinale	Boraginaceae	Herbs and medicinal plants
knapweed	Centaurea jacea	Asteraceae	Herbs and medicinal plants
Lady fern	Athyrium filix-femina	Athyriaceae	Herbs and medicinal plants
Lomatium	Lomatium triternatum	Apiaceae	Herbs and medicinal plants
Mallow	Malva neglecta	Malvaceae	Herbs and medicinal plants
Mint	Mentha arvensis	Lamiaceae	Herbs and medicinal plants
Motherwort	Leonurus cardiaca	Lamiaceae	Herbs and medicinal plants
Mountain mint / Escoba de la sierra	Monardella odoratissima	Lamiaceae	Herbs and medicinal plants
Nettle	Urtica dioica	Urticaceae	Herbs and medicinal plants
Osha	Ligusticum porteri	Apiaceae	Herbs and medicinal plants
Oxeye daisy	Leucanthemum vulgare	Asteraceae	Herbs and medicinal plants
Pearly everlasting	Anaphalis margaritacea	Asteraceae	Herbs and medicinal plants
Pedicularis	Pedicularis canadensis	Orobanchaceae	Herbs and medicinal plants
Pepermint	Mentha balsamea	Lamiaceae	Herbs and medicinal plants
Rabbit brush	Ericameria nauseosa	Asteraceae	Herbs and medicinal plants
Rein orchid	Piperia unalascensis	Orchidaceae	Herbs and medicinal plants
Sage	Artemisia scopulorum	Asteraceae	Herbs and medicinal plants
Salsify	Tragopogon dubius	Asteraceae	Herbs and medicinal plants
Solomon Seal	Polygonatum multiflorum	Asparagaceae	Herbs and medicinal plants
Sorrel	Rumex paucifolius	Polygonaceae	Herbs and medicinal plants
Sweet cicely	Myrrhis odorata	Apiaceae	Herbs and medicinal plants

(Continued)

TABLE 2 | Continued

Common name	Scientific name	Family	Food type
toadflax	Comandra umbellata	Santalaceae	Herbs and medicinal plants
Valerian	Valeriana acutiloba	Valerianaceae	Herbs and medicinal plants
Vitex	Vitex agnus-castus	Lamiaceae	Herbs and medicinal plants
Western Pasque	Anemone occidentalis	Ranunculaceae	Herbs and medicinal plants
Yarrow	Achillea millefolium	Asteraceae	Herbs and medicinal plants
Chanterelle	Cantharellus cibarius	Cantharellaceae	Mushroom
Morels	Morchella esculenta	Morchellaceae	Mushroom
Oyster mushroom	Pleurotus ostreatus	Pleurotaceae	Mushroom
Porcini	Boletus edulis	Boletaceae	Mushroom
Puffballs	Calvatia booniana	Agaricaceae	Mushroom
Amaranth	Amaranthus retroflexus	Amaranthaceae	Nuts and seeds
Flax	Linum usitatissimum	Linaceae	Nuts and seeds
Pine nuts	Pinus edulis	Pinaceae	Nuts and seeds
Sunflower	Helianthus annuus	Asteraceae	Nuts and seeds
Chives	Allium schoenoprasum	Liliaceae	Wild chives, onions, leeks
Leeks	Allium tricoccum	Amaryllidaceae	Wild chives, onions, leeks
Wild onion	Allium textile	Liliaceae	Wild chives, onions, leeks
Cattail	Typha latifolia	Typhaceae	Other
Cocklebur root	Xanthium strumarium	Asteraceae	Other
Cottonwood buds	Populus deltoides	Salicaceae	Other
Fir cones	Pseudotsuga menziesii	Pinaceae	Other
Juniper	Juniperus communis	Cupressaceae	Other
Spruce tips	Picea glauca	Pinaceae	Other
Willow bark	Salix bebbiana	Salicaceae	Other

insecurity ($p = 0.0002$). In particular, respondents that were food insecure had a higher mean score than those that were not food insecure.

Fishing

The majority of informants (83%) reported they fish and have members in their household that fish (77%) including partners (65%), friends (54%), parents (33%), extended family (29%), siblings (28%), and grandparents (11%). Significant differences were found for those that reported they fish based on gender ($p < 0.0001$). Specifically, those that fish had a higher probability of being male than female ($p < 0.0001$), with the proportion of those that fish higher for males (91%) than females (67%). Most informants learned to fish from parents (57%), particularly their fathers. Informants shared multiple factors they value about fishing with the most prevalent themes reported being: recreation and/or self-fulfillment (81%), food and/or health (55%), and companionship (46%) (**Table 1**).

Informants and their families harvest approximately 38 types of fish with trout (77%) and bass (36%) most prevalently reported (**Table 2**). Further, informants reported the fish they catch the most include various species of trout (57%) (**Figure 2**). Informants varied in how often they go fishing ranging from once a year to over 100 times per year, with a mean of 19 times per year. Informants reported that they fish primarily on public land (87%) as well as private land (30%) with some informants fishing in other areas (1%) such as tribal land. Consumption of fish was variable, with about a third of informants that reported they consume fish on a weekly basis (38%), while others reported they consume fish less than once per month (35%) or one to three times per month (27%) (**Figure 3**). Informants shared a range of practices, rituals, and stories associated with fishing, with the majority focused on recipes and preservation techniques (55%). For example, multiple informants shared statements to indicate that they utilize cooking and/or processing techniques such as smoking and canning fish (**Table 3**). Other rituals and practices reported by informants included responses associated with tradition, connection, and stories (41%), harvesting practices (9%), and rituals being spiritual in nature (9%).

The majority of informants had a WFPSc of 1 for fishing (91%) and an average WFDDSc of 2.75 ($n = 104$; SD = 2.30) that ranged from one to 18 different species or types of fish. Differences in Wild Food Procurement Score for fishing were not significant based on gender, food insecurity, or location, and were significant based on generation. Specifically, in a means comparison using Student's t-test, the Millennial group had a higher mean WFPSc for fishing than the Baby Boomer+ group. Differences in mean WFDDSc for fishing were not significant based on generation, gender, food insecurity, or location.

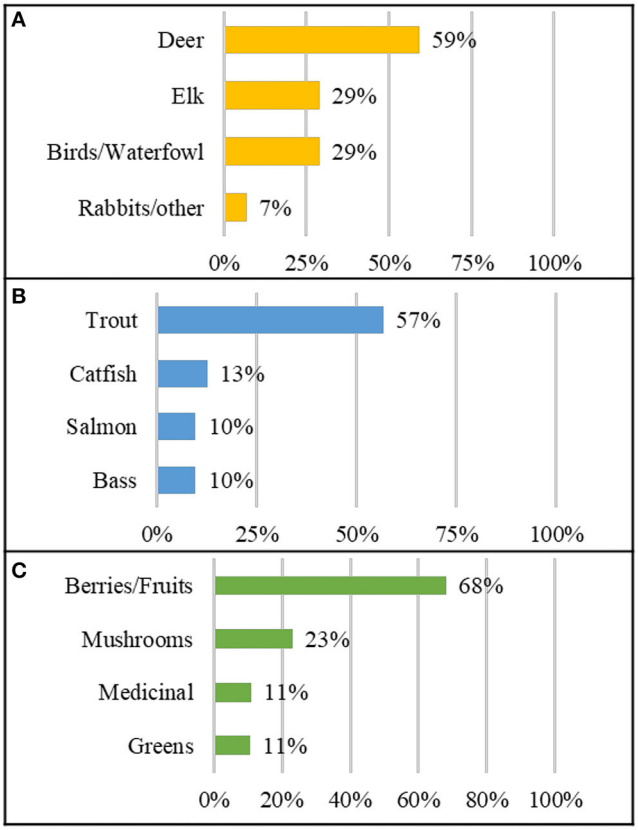


FIGURE 2 | Types of wild foods procured most often as reported for **(A)** hunting, **(B)** fishing, and **(C)** foraging.

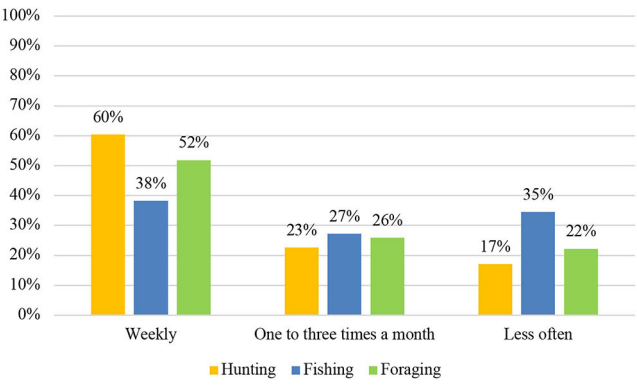


FIGURE 3 | Frequency of wild food consumption for hunting, fishing, and foraging.

Foraging

The majority of participants reported they forage (66%) and have members in their household that forage (59%) including partners (63%), friends (50%), parents (45%), extended family (28%), siblings (20%), and grandparents (11%). Significant differences were found for those that reported they forage based on generation ($p = 0.0035$) and gender ($p = 0.0040$). Specifically, those that reported they forage had a higher probability of being female ($p = 0.0028$), with the proportion of those that forage higher for females (81%) compared to males (59%). Most informants reported they learned to forage from parents (35%) and through a variety of sources (42%) other than their immediate family and friends including books, classes, and online learning. Informants shared multiple factors that they value about foraging (with the most prevalent themes reported being: food and/or health (83%), recreation and or self-fulfillment (77%), and companionship (32%) (**Table 1**).

Informants and their families forage over 92 wild edible plants (**Table 2**) with the most prevalent being: berries and fruits (87%), mushrooms (69%), and other botanicals used medicinally (25%). Further, informants reported the foods most foraged are fruits and berries (68%) (**Figure 2**). The majority of informants reported they primarily forage on public (64%) and private (36%) lands with few reporting they forage in other areas (2%) such as tribal land. Informants varied in how often they consume wild edible foods with just over half reporting their consumption is varies based on season (56%). Around half of the informants reported they consume wild edible foods weekly (52%), while other informants reported they consume wild edible foods about one to three times a month (26%) or less than once a month (22%) (**Figure 3**).

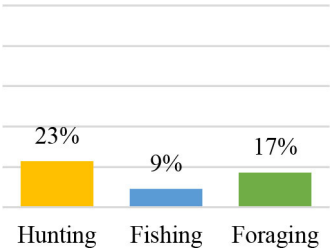
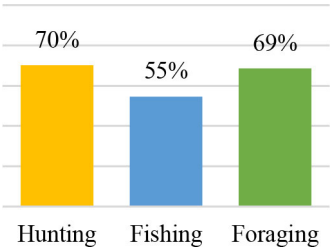
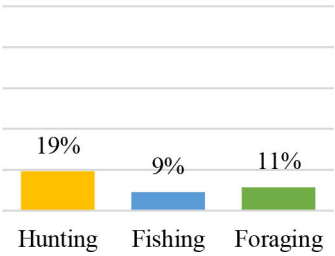
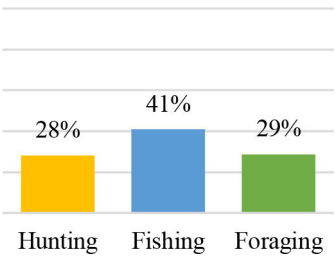
Informants reported numerous preservation techniques for foraged goods with the most frequent being freezing, drying, canning, and pickling. Informants also reported that they make a range of "home-made" food products using foraged wild edible plants including salads, soups, smoothies, and sides (73%); jams, jellies, and syrups (61%); desserts such as pies or baked goods (43%); and medicinal tonics including teas/tisane, salves, and tinctures (22%). Informants shared a range of practices, rituals, and stories associated with foraging, with the majority focused on recipes and preservation techniques (69%) (**Table 3**). Other rituals and practices reported by informants included responses associated with tradition, connection, and stories (29%), harvesting practices (17%), and rituals being spiritual in nature (11%).

The majority of informants had a WFPSc of 1 for foraging (68%) and an average WFDDSc of 2.70 ($n = 67$; SD = 1.47) that ranged from one to seven different types of foraged edible foods. Differences in Wild Food Procurement Score for foraging were not significant based on food insecurity or location and were significant based on generation ($p = 0.0132$) and gender (0.0078). Specifically, in a means comparison using Student's t-test, the Baby Boomer+ group had a higher mean WFPSc for foraging than both the Millennial ($p = 0.0033$) and the Generation X group ($p = 0.0369$), and females had a higher mean WFPSc than males. Differences in mean WFDDSc for foraging were not significant based on generation, gender, food insecurity, and location.

Wild Food Perceptions and Total Wild Food Procurement and Dietary Diversity Scores

The majority of informants agree that eating wild foods contributes to the overall nutritional quality (87%) and diversity

TABLE 3 | Prevalent themes associated with practices and rituals regarding the procurement of wild foods through hunting, fishing, and foraging.

Wild food harvesting practices			
Research theme	**Subthemes**	**Sample quotations**	**Frequency of theme**
Theme 1: harvesting practices	Subthemes: butchering the animal themselves and mindful harvest of a plant community	*"I process or butcher all of the game I take." "We try to dig roots when the plant is in seed, so we fill the hole with seeds. We intentionally spread seeds, and we caretake specific patches of all of our foods and medicines, keeping close eyes on how they are doing."*	
Theme 2: recipes and preservation techniques	Subthemes: specific family recipes and preservation techniques like freezing, drying, canning, pickling, and smoking	*"It's simple but it's hard to beat, cooking fish in a foil over open fire." "Morels fried in butter and used as a topping for pork loin sandwiches on ciabatta."*	
Theme 3: spiritual or rituals	Subthemes: harvest rituals, mindfulness, and saying a prayer when harvesting	*"When an animal is shot it is thanked and fresh branches are put in its mouth and on the wound." "When I harvest medicines, I consider it an activity that I need to pay special attention to and to be mindful."*	
Theme 4: tradition, connection, and stories	Subthemes: time spent with family, visiting traditional or special locations	*"My dad and I go out to a local burger place as a celebration of filling a tag." "My grandfather knows the best fishing spots. We make this a contest of who can catch "the biggest and the most.*	

(variety) of their diet (82%), as well as lowers the cost of their diet (59%). Furthermore, the majority of informants agreed (66%) that collecting and/or eating wild foods is part of their cultural identity, and they are concerned that younger generations in their community are losing both their desire to collect (73%) and traditional knowledge of collecting (73%) wild foods.

In parallel, the majority of informants had a WFPSc of 1, on a scale of 0–1, for hunting (91%), fishing (91%), and foraging (68%) (**Figure 4A**). More than half of informants had a WFPSc of 3 (58%), on a scale of 1–3, which indicates they procure wild foods from hunting, fishing, and foraging; while one-third of informants had a WFPSc of 2 (33%), which indicates they procure foods from a combination of two wild food activities. The remaining informants had a WFPSc of 1 (9%), indicating they procure wild foods from a single activity (**Figure 4B**). Differences in Total WFPSc were not significant based on generation, gender, food insecurity, and location.

The mean Total WFDDSc for informants was 6.34 ($n = 129$; SD = 4.26) with a range of one to 31 different types of total wild foods consumed from hunting, fishing, and foraging activities. Differences in mean Total WFDDSc were significant based on food insecurity status of participants ($p = 0.0181$), with a higher

mean score among informants that were not food insecure (6.9) compared to those that were food insecure (5.1). Total WFDDSc was not significantly different based on generation, gender, and location.

Environmental Change and Protecting Community Resources

Over half the informants reported they perceived some type of environmental change over the past decade (increase, decrease, or become more variable). Specifically, a notable percentage of informants reported they have observed an increase in drought (56%), temperature (50%), and intensity (42%) and frequency (40%) of wildfire (**Figure 5**). Over a third of informants further observed greater variability in overall snowfall (44%) and overall weather patterns (43%) as well as a decrease in snowpack (40%) and water availability (33%). Specific changes informants reported include "changes in rainfall and availability of animals", "higher temperatures with more frost-free days", "warmer weather with winter not lasting as long", "hotter summers fueling more wildfire" or "hotter with less precipitation", and "getting hotter and more rain".

Around two-thirds of participants noted some type of change (starting earlier, later, become more variable) for all four seasons

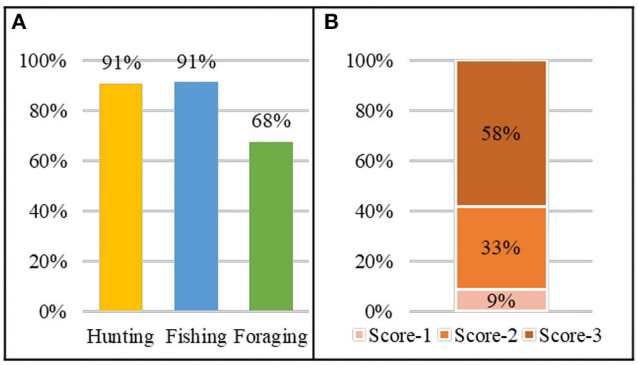


FIGURE 4 | Wild food procurement score. Wild food procurement score of 1 (on a scale of 0 to 1) for **(A)** hunting, fishing, and foraging, and **(B)** total wild food procurement score on a scale of 1 to 3.

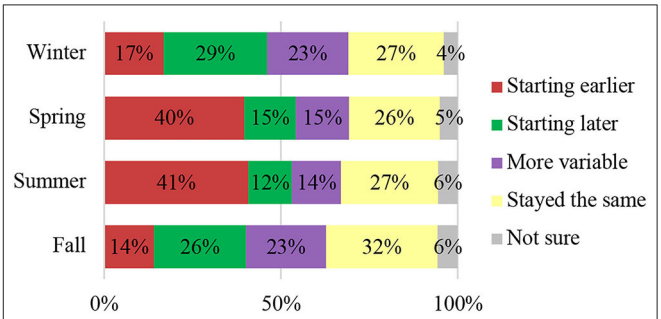


FIGURE 6 | Observations in seasonal variation. Percentage of informants that reported they perceived seasonal changes including seasons starting earlier, later, become more variable, no change, or were not sure of change.

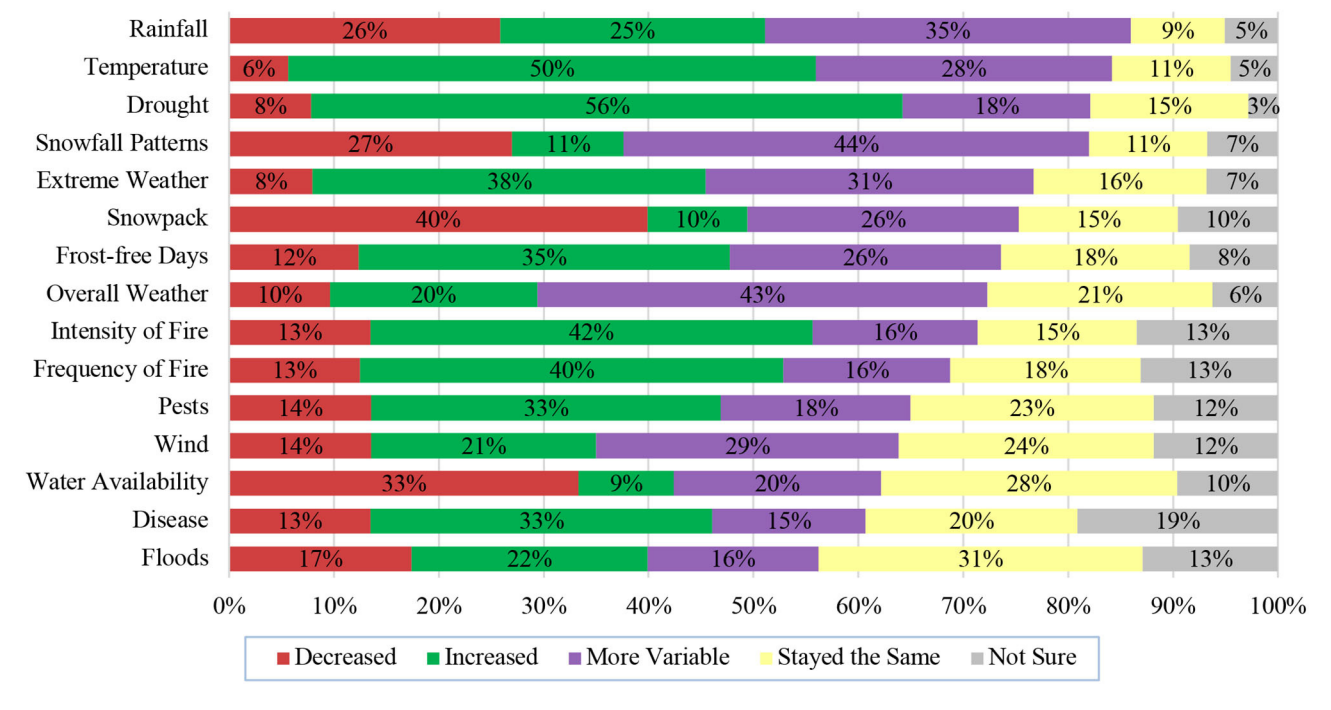


FIGURE 5 | Observations and perceptions on environmental change. Percentage of informants that reported they perceived a decrease, increase, variability, no change, or were not sure of change in environmental factors.

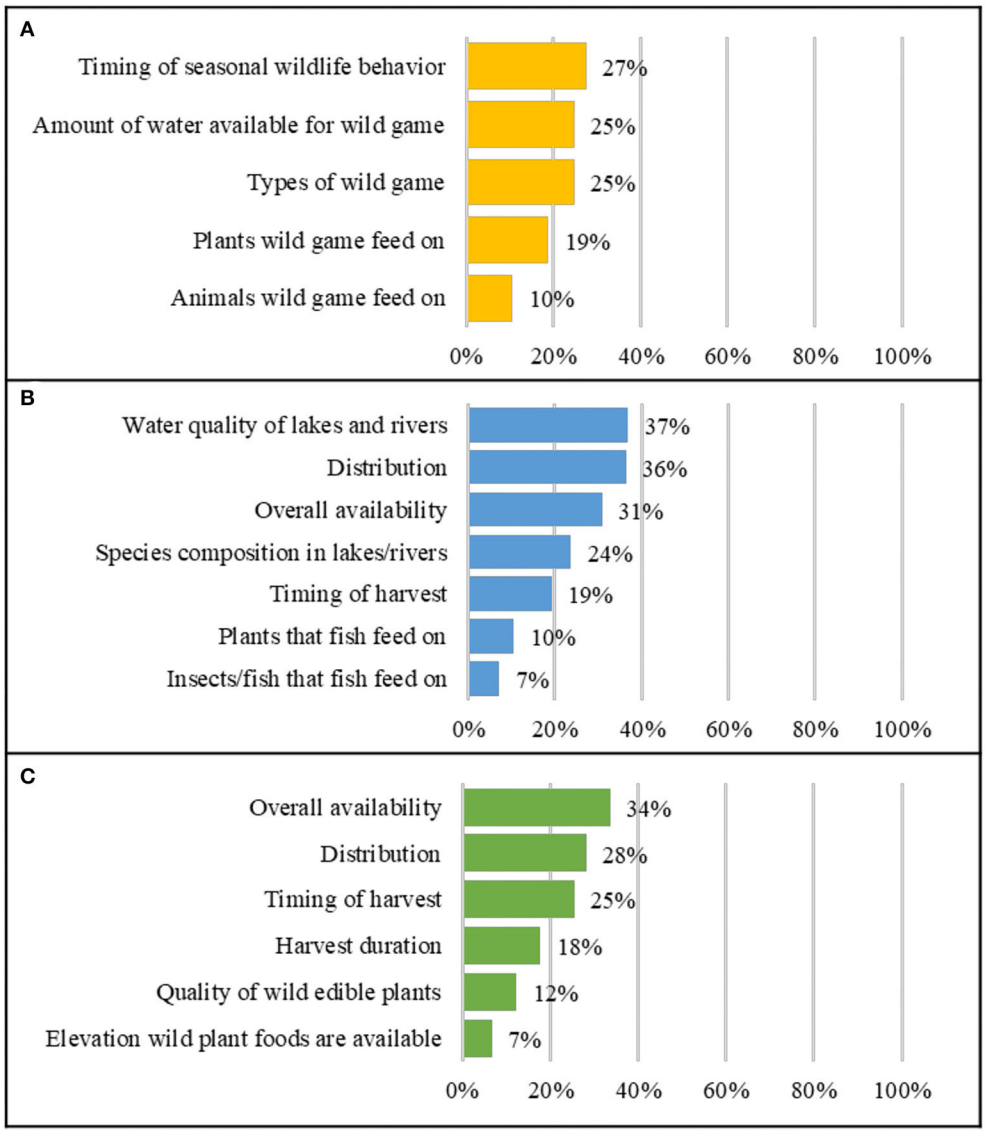


FIGURE 7 | Observed environmental changes. In the past decade observations that have resulted in changes in **(A)** wild game, **(B)** fish, and **(C)** edible plant populations.

(**Figure 6**). Specifically, over one-third of informants reported they have observed both summer (41%) and spring (40%) starting earlier. Approximately a quarter of the informants further reported they observed the winter (29%) and fall (26%) seasons starting later. For example, some changes informants reported include "growing season has increased", "extended growing season", "variable temperatures rather than stable cycles", "hotter spring and summer with winter and fall not as cold", and "higher winter temperatures and more pests in forests".

The majority of informants reported they have observed environmental changes in the past decade that have resulted in changes in wild game, fish, and edible plant populations (**Figure 7**). Some of the changes reported include: (1) changes in the timing of seasonal wildlife behavior (27%); (2) water quality of lakes and rivers (37%); and (3) overall availability or abundance of wild plant foods (34%). A few informants also noted changes in the types of wild animals that other wild game feed on (10%), aquatic organisms that fish feed on (7%), and the elevation wild plant foods are available (7%). Some of the specific observations reported by informants regarding changes in wildlife include "changes in big game winter distribution", "changes in timing or rut", "less elk", and "more deer". Changes reported for fish include "not as cold in the winter", "lake water level has decreased", and "less fish" and "lower abundance of fish". Changes reported for foraged edibles include "an increase in the amount of wild plant foods", "earlier harvest", "drier and less productive plants", and "longer season".

TABLE 4 | Protecting community food, water, land, and cultural resources.

Protecting community food, water, land, and cultural resources		
Research theme	**Subthemes**	**Sample quotations**
Theme 1: community engagement and education	Subthemes: education, participate in community activities, communication and relationship building	*"We need to talk about these issues more and education kids in school (let's start a sustainable agriculture and environmental science program in K-12!)."* *"Proactive and positive citizen participation in land use decisions."* *"Get more people interested in wildcrafting."*
Theme 2: Conservation and responsible resource use	Subthemes: protect open/green space, recycle, reduce waste and/or pollution, renewable energy, conservation practices	*"Promote sustainable land use practices, renewable energy, and promotes a lifestyle that reduces carbon emissions."* *"Support land conservation and opportunities for people to have access to nature and ways to connect with nature."* *"By wasting less and saving more."*
Theme 3: management, policy, and/or legislation	Subthemes: federal management, political leadership, public lands, laws/fines	*"Improving agricultural practices to reduce dewatering, pesticide & fertilizer reduction, public lands grazing allotment reduction, atmospheric carbon reduction"* *"Increase in funding to conservation efforts, protect open space (ranches and public land)"* *"Proper legislation to regulate game and fish populations. Putting funds toward fire prevention and resources needed to fight wildfires. Logging overgrown areas that lead to larger fires."*
Theme 4: planning and/or development	Subthemes: long-term management, smart development, environmental sustainability plans	*"Regulate sprawl, create more habitable cities, provide public transportation and services to allow people to live in cities and easily visit wild areas without building in them"* *"Place limits on building in wild lands, especially forested areas, while incentivizing urban infill."* *"Have a quality land use master plan for the county and all public lands."*

Themes, subthemes, and suggestions reported by informants to help protect their community's food, water, land, and cultural resources.

The majority of informants reported they agree they are concerned about land-use changes in and around their community (80%), water quality (77%), and future decrease in availability of wild foods (72%). Approximately two-thirds of informants reported they agree that changes in weather patterns were impacting the wellbeing of their community (65%). Informants shared a range of ideas for protecting food, water, land, and cultural resources in their community that focused on the following themes: (1) management, policy, and/or legislation (43%); conservation and responsible resource use (38%); community engagement and education (29%); and mindful planning and development (17%) (**Table 4**).

DISCUSSION

This case study highlights that wild food environments are an important biocultural resource that contributes to cultural identity, dietary quality, dietary diversity of nutrient-dense foods, and food security through lowered cost of diets. Informants, and members of their social networks, frequently engage with wild food environments to hunt, fish, and forage a diversity of species including 42 types of wildlife, 38 types of fish, and 92 types of edible and medicinal plants. The most prevalent types of wild foods procured among informants are deer, birds and waterfowl, elk, trout, bass, and a range of berries, mushrooms, and medicinal plants. Wild foods are frequently consumed by the informants; over half consume wild meat and plants on a weekly basis, while just over one-third consume fish weekly. The procurement of wild foods represents cultural heritage and traditional ecological knowledge with informants learning to hunt, fish, and forage from elder members of their families. The species that informants hunt, fish, and forage dually represent both local biodiversity and food sources that are rich in nutrient profiles (Dinstel et al., 2013; USDA, 2020). However, informants expressed concern that wild food environments are vulnerable to global change and have been impacted by climate change and land-use change. In addition, informants expressed concern that traditional ecological knowledge associated with wild food environments is at risk with the younger generation losing knowledge and motivation associated with wild foods. On the basis of findings, we support that wild food environments are a critical place to understand and conserve. Future research is called for to understand the social implications of wild food procurement and associated cultural heritage and traditional ecological knowledge within the context of their study region.

Coded responses regarding values associated with hunting, fishing, and foraging highlight the multidimensional value system among informants regarding wild foods procurement. The most prevalent value reported for procuring wild foods was for diets followed by recreation, family time, spirituality, and connection to the environment. Wild food procurement is associated with a range of practices and rituals ranging from food preparation and cooking activities to those spiritual in nature. Findings of the multidimensional valuation and practices associated with wild foods are in line with previous research (Groessler, 2008; Smith et al., 2019; Byker Shanks et al., 2020). For example, Groessler 2008 reported food preparation and storage techniques for berries such as huckleberry, serviceberry, and bitterroot, as well as preparation techniques for fish such as salmon as a prevalent wild food procurement practice.

The high valuation of wild foods for diets among participants is demonstrated in the relatively high frequency of consumption reported by informants. More than half of informants reported they consume wild meat and plants they procure on a weekly basis, while just over one-third reported they consume fish weekly. Findings on the frequency of consumption of wild meat and plants are higher than reported in a previous study in a tribal community in Montana, where approximately one-third of participants reported consuming wild meat and foraged plants at least once a week, while the frequency of consumption is the same.

Participants' valuation of wild foods for diets coupled with the frequency of consumption contributes to food security and dietary quality of informants. A majority of informants agreed that the consumption of wild foods contributes to the overall nutritional quality and diversity of their diet while lowering food costs. These findings are of importance to food security as a notable percentage of participants (43%) are food insecure and receive food and nutrition assistance (29%) through the Supplemental Nutrition Assistance Program, food banks, and community kitchens. The promotion of wild foods, and associated food environments and cultural resources, has the potential to contribute to enhancing food security and nutritional outcomes through non-market access to diverse and nutrient-dense foods. Previous research highlights that wild foods contribute to commonly consumed foods and food security as a non-monetary resource that can supplement diets through non-market sources (Ford et al., 2009; Smith et al., 2019; Byker Shanks et al., 2020). Given the role of wild foods for food security, it is essential for citizens to continue to have access to these resources. While access issues did not emerge as a key theme in this study for procuring wild foods, previous studies (including in the study area) have highlighted how access to natural resources can serve as a barrier for wild food consumption (Smith et al., 2019).

Wild foods are further recognized to contribute to dietary quality, nutrition, and health through enhancing dietary diversity of nutrient-dense foods with their rich nutrient and phytochemical profiles (Vinceti et al., 2012). For example, North American ruminants (elk, deer, and antelope) are a source of lean protein with a beneficial fatty acid composition that may help prevent chronic disease (Crawford, 1968; Cordain et al., 2002). Fowl, including pheasant and grouse, are lean sources of protein, with pheasant being relatively high in selenium and choline (USDA, 2020). Fish, including wild-caught trout and bass, offer unadulterated sources of protein high in potassium (USDA, 2020). Wild mushrooms such as morels and puffballs are high in vitamin D, with morels also substantially high in iron (USDA, 2020). Huckleberries and raspberries are high in both vitamin C and antioxidants (Dinstel et al., 2013; USDA, 2020).

While wild foods contribute to food security, dietary quality, and sustainable diets, these natural resources are vulnerable to global change including climate change, land-use change, and loss of biodiversity (Galloway et al., 2003; Tscharntke et al., 2012; Lowry et al., 2019; Willett et al., 2019; Prevéy et al., 2020). A notable percentage of informants have observed shifts in climate over the past decade including an increase in temperature, more variable rainfall, increased drought, more variable snowfall, decreased snowpack, increase in extreme weather, more variable weather patterns, increase in frequency and intensity of wildfires, greater variability of wind, decrease in water availability, and increase in frost free days. In addition, a notable percentage of informants further reported they observed seasonal variation in the past decade including spring and summer starting earlier and fall and winter starting later. Informants also observed an increase in the number of pests and diseases. Informant observations are in line with the Montana Climate Assessment (Whitlock et al., 2017) and have similarities to observations and perceptions reported by households in tribal communities in Montana (Smith et al., 2019) as well as farmers and ranchers in Montana (Grimberg et al., 2018). For example, the Montana Climate Assessment demonstrates that the area has experienced changes in precipitation patterns that are impacting snowpack, water availability, and increasing the severity of wildfires in the region (Whitlock et al., 2017).

Informants linked the observed changes in climate with impacts on wild food populations and associated biodiversity including: (1) overall abundance and distribution of fish and foraged wild edible plants; (2) changes in the types of wild game available; and (3) changes in the timing of seasonal behavior for game and fish, and timing of seasonal harvest of foraged edibles. In some cases, these observations include an increase in specific wildlife such as deer, while in other cases it includes a decrease in specific species such as a lower abundance of certain types of fish. Informants further noted shifts in the habitats of wild foods such as shifts in the water quality of lakes and rivers. Previous research highlights that wild foods are vulnerable to global change including climate change and land-use change (IPCC., 2007; Ford et al., 2009). For example, members of the Crow Nation in Montana observed reductions in freshwater fish populations due to warming waters (Doyle et al., 2013), while informants of the Flathead Reservation in Montana are concerned that changes in climate and land use coupled with overpopulation could decrease the availability of wild foods (Smith et al., 2019).

Informants shared a range of ideas to mitigate the impacts of environmental change on wild foods including enhancing education, research, and communication to community building efforts, policy, and conservation and management efforts. A third of informants shared ideas specifically targeted toward conservation and responsible resource use, perhaps due to feelings related to risk of restrictions on wild lands. Findings reinforce the need for research, education, evidence-based interventions, and policy to enhance wild food environments and associated cultural resources in the context of climate change (Cordalis and Suagee, 2008; Bharucha and Pretty, 2010; Lynn et al., 2013; Smith et al., 2019). For example, research is needed to better understand how climate change is impacting wild food populations, including quality, quantity, harvesting practices, and how this varies geographically.

Previous research provides evidence on the linkages between biodiversity and dietary diversity of nutrient-dense foods (Lachat et al., 2018; Gergel et al., 2020). Biodiversity is particularly critical to conserve given its role in ecosystem functioning

coupled with its' current status outside of environmental limits within which humanity can safely operate (Steffen et al., 2015). Dietary diversity of nutrient-dense foods is recognized to support dietary quality (Gómez et al., 2020). To foster linkages between biodiversity and dietary diversity of nutrient-dense foods, we support that wild food environments (Downs et al., 2020) and associated bio-cultural resources are a critical place to understand, conserve, and promote for nutrition. While the role of food environments for advancing nutrition is increasingly recognized, wild food environments remain under-recognized in the nutrition literature and practice (Downs et al., 2020), including in nutrition-sensitive interventions. Central to promoting wild food environments is systematic and comprehensive documentation of the composition of wild foods using metabolomics and other foodomics technology. Along with biochemical composition data, there is a need to document ethnographic and environmental information on the context of wild foods including perceptions of how food composition varies based on environmental factors (Ahmed and Stepp, 2016). Further, there is a need for clinical studies to document the impacts of wild food consumption on human health outcomes, including the gut microbiome.

Given the vulnerability of wild food environments to land-use change including development in the study area, conservation efforts are needed to preserve wild food environments that support biodiversity, ecosystem services, sustainable diets, and planetary health while giving communities access to these resources for sustainable harvests. In addition to natural resources, this study highlights the importance of ecological knowledge and value systems maintaining wild food resources including their safe and sustainable procurement. Numerous research documents the special cultural knowledge regarding the identification, harvesting, preparation, and processing required to utilized and consumer wild foods (Turner et al., 2011). In addition, multiple studies document the detriments to diets and wellbeing associated with a loss to traditional ecological knowledge (LaRochelle and Berkes, 2003; Turner et al., 2011). We thus support advancing the concept of "conservation for nutrition" which we define as, "the preservation and management of biocultural diversity associated with wild food environments including biodiversity, ecosystem services, ecological knowledge, values, and practices with the goal to support both human and planetary health".

Nutrition interventions in communities with a cultural practice of procuring wild foods should recognize these resources through supporting wild food environments as well as the ecological knowledge and values that foster their sustainable harvest and consumption. Previous studies have highlighted the role of forest conservation as a potential nutrition-sensitive intervention in low- and middle-income countries (Rasolofoson et al., 2020) as well as in rural communities globally (Hickey et al., 2016; Gergel et al., 2020) for supporting both ecosystem and human wellbeing. Forest conservation as a nutrition-sensitive intervention is recognized to provide a range of ecosystem services such as pollination that food crops are dependent on (Rasolofoson et al., 2020) along with providing nutrients for human diets through wild foods (Fungo et al., 2016). Gergel et al. (2020) highlight how forests are key sources of dietary diversity in rural settings. Fungo et al. (2015) found that foods harvested from forests in forest-dwelling communities in Cameroon contribute to 93% of daily vitamin A intake of women. The study presented here supports that ecological conservation efforts for nutrition are also important in high-income countries. In addition, this study supports that a range of wild food environments in addition to forests should be conserved including rivers, lakes, and grasslands.

Nutrition education that acknowledges wild food environments including ecological knowledge of sustainable and safe harvesting practices associated with wild foods could enhance the sustainability of wild food environments as well as their role for food security and dietary quality (Smith et al., 2019). Such initiatives should be place-based and culturally grounded for each context. For example, storytelling is a culturally-relevant way of transmitting ecological knowledge in many Indigenous cultures, "*Our past is preserved and explained through the telling of stories and the passing of information from one generation to the next*" (Inuit Tapiriit Kanatami) (Kuhnlein, 2013). Efforts should also be made to remove access barriers for wild food procurement in addition to knowledge. For example, previous research found that access to land and water, time, and costs for procuring wild foods were major barriers for the consumption of wild foods (Smith et al., 2019).

Some potential shortcomings and limitations of this study include the following with respect to survey distribution and the demographic background of participants that were reached through distribution efforts. The data is limited to what can be elicited to an online semi-structured survey where we cannot ask clarifying and follow-up questions to participants. Further, as this was an online survey it was not accessible to people who do not use the internet, or have internet access. The survey was distributed to various groups / listservs but is not representative of everyone who may procure wild foods in Montana that may not be part of those groups. Tribal affiliation was not collected given feedback from our Tribal Partners about cultural and sensitivity issues regarding the comparison between tribal communities, and with non-tribal populations.

CONCLUSION

Improving the nutritional quality of foods available in the food environment has been identified as a strategy to improve diets and health outcomes (Damman et al., 2008; Chodur et al., 2016). While the majority of food environment interventions have focused on the built or market food environment, this study highlights the importance of wild food environments where communities hunt, fish, and forage to support food security and dietary quality. Findings further highlight the vulnerability of wild food environments to environmental change and call for education, community building efforts, policy, and conservation plans to strengthen the sustainability of food systems to support both human and environmental wellbeing. On the basis of findings, we support that wild food environments

and associated cultural resources are a critical place to understand and conserve to overcome the global burden of disease and improve nutritional and planetary health outcomes. Specifically, we recommend the following for supporting healthy, safer, and sustainable food procurement from wild food environments. These recommendations call for multi-sector collaboration between natural resource managers, public health, communities, cultural anthropologists, botanists, zoologists, dieticians, food system scientists, and other stakeholders.

(1) **Conservation of Nutrition**. Communities with a cultural practice of procuring wild foods should recognize these resources and support conservation of wild food environments and associated cultural resources including ecological knowledge and values. We thus support advancing and operationalizing the concept of "conservation for nutrition" which we define as, "the preservation and management of biocultural diversity associated with wild food environments including biodiversity, ecosystem services, ecological knowledge, values, and practices with the goal to support both human and planetary health". Advancing conservation for nutrition should focus on equitable access to promote inclusivity of people from a range of cultural and socioeconomic backgrounds to access the wild food environment. For example, community provided transportation can help remove barriers to accessing wild foods. Our concept of conservation for nutrition acknowledges nutrition-sensitive landscapes that set nutrition, social, and environmental targets to benefit all three (Kennedy et al., 2017).

(2) **Research on Socio-Ecological Determinants on Wild Food Procurement**. In order for wild food procurement to continue in communities in a sustainable manner, research is needed to understand the socio-ecological determinants that enable this practice and how it contributes to community resilience. For example, what implication could wild food heritage have in terms of safeguarding the perception of "common goods"? Can wild foods represent a pillar of resilience or resurgence of a common goods-driven ethic?

(3) **Place-based Education on Wild Food Procurement**. Development and dissemination of a wide range of place-based educational offerings about safe food procurement in wild food environments including: plant identification, sustainable harvesting, harvesting from safe areas, and preparation of wild foods. Such education can be offered by community organizations and developed with the support of key informants who have expertise on wild foods such as community elders. These initiatives should also be place-based and culturally grounded for each context such as through storytelling. Several opportunities exist in the study area for those interested in procuring wild foods such as a certified hunter education course which includes education on conservation in addition to ethical and sustainable harvest of animals; wild plant identification courses and; community sponsored "field days".

(4) **Biochemical Profiling of Wild Foods and Dietary Interventions**. Future research is called for to characterize the impact of wild food consumption on dietary quality and human health outcomes. This requires comprehensive profiling of wild food composition using cutting edge metabolomics and other foodomics technology. Such interventions also require profiling of human health biomarkers including impacts on the gut microbiome as well as perceptions of wellbeing.

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 Institutional Review Board (IRB) at Montana State University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SA designed the survey tool with input from CB and VD. SA, CB, and VD contributed to administering data collection. TW and AS led the qualitative data analysis and TW led the quantitative data analysis with input from all authors. SA and TW wrote the manuscript with input from all authors. All authors contributed to data interpretation.

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Why and How to Strengthen Indigenous Peoples' Food Systems With Examples From Two Unique Indigenous Communities

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Indigenous Peoples' food systems contain extensive and sophisticated knowledge that is often undocumented and underutilized in contemporary society that has increasingly poor nutrition and loss of food biodiversity. Indigenous Peoples in all global regions are among the most vulnerable to marginalization, food insecurity and chronic disease and will benefit greatly from strengthening their resource-rich food systems to make them more resilient and sustainable. It is in this spirit that we contribute to the databases of Indigenous Peoples' food system knowledge with information on unique traditional foods from the Nuxalk Nation in British Columbia, Canada, and the Pwo Karen People of Sanephong Community, Thailand. Several publications from these case studies originated from interdisciplinary mixed-method research, in part through the United Nations Food and Agriculture Organization. We highlight selected foods with nutrient data and various qualitative and quantitative methods used to identify and promote their use within these unique communities. Our intent is to stimulate complementary strengthening efforts among other traditional and Indigenous Peoples that will contribute to global intercultural food system evidence and advances.

Keywords: Indigenous Peoples, Indigenous food systems, Nuxalk Nation, Karen, traditional food

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INTRODUCTION AND CONTEXT

The food systems of Indigenous Peoples are known to contain a vast tapestry of riches in food biodiversity, nourishment, and the potential to sustain biocultural knowledge, resilience, and sustainability. However, these internationally recognized and outstanding attributes, historically documented in part, are affected by many challenges of globalization that threaten their loss and eventual disappearance (Kuhnlein et al., 2009, 2013a; FAO, 2021; FAO and Alliance of Bioversity International and CIAT, 2021). With the contemporary advent of the 2021 United Nations Food Systems Summit and recent policies that encourage sustainability we highlight the need to address Indigenous Peoples' food system loss, and how communities can proceed to strengthen continuity and sustainability of their cultural food systems' continuity and sustainability and give impetus to improvement of nutrition and health in their communities, for all humanity, and for the planet.

The term "food system" is defined through several international agencies as the foods originating from forestry, fisheries, aquaculture, and crop and livestock production and the interlinked actors and activities for their processing, distribution, consumption, and disposal that shape

human dietary patterns, food security and nutritional status. Food systems are complex and dynamic interactions and synergies of social, economic, and environmental influences (FAO, 2020; USAID-RFS, 2021; von Braun et al., 2021).

In this contribution we refer to a "traditional food system" of an Indigenous People as all foods within the particular culture that are available from local natural resources and culturally accepted, including the sociocultural meanings, acquisition and processing techniques, use, biological composition and nutritional consequences for the people using the food (Kuhnlein and Receveur, 1996). The contribution of nature and culture to a food system form the complete health picture of the individual and the community—the aspects of physical, emotional, mental, and spiritual health, healing, and protection from disease (Kuhnlein, 2009). Since Indigenous Peoples' worldviews differ from mainstream science, their food systems differ from the above in that they are biocentric and intimately tied to nature and spirituality, rather than to linear value chains (FAO, 2021).

Situation

Recent attention to the world's food systems has highlighted the pressing need to address unsustainable food production and consumption (von Braun et al., 2021). Aimed at addressing the 17 Sustainable Development Goals in 2021, the United Nations Food Systems Summit included virtual presence of national leaders and all United Nations agencies to address global hunger, climate change and biodiversity loss. The Summit had mixed reviews with criticism for obvious private sector control of the agenda and results, and the lack of accountability (Globalagriculture, 2021; International Network of Mountain Indigenous People, 2021; SlowFood, 2021); ultimately a solution cluster and a coalition of Indigenous Peoples developed strategies for accountability (Food Systems Summit, 2021).

Indigenous Peoples are among the most severely in need of meeting the Sustainable Development Goals, especially those related to hunger, poverty, wellbeing, inequality, and justice, which are all affected by climate change and unsustainable global food supplies. The UNFAO published two sentinel documents that creatively describe the depth of needs and strengths of Indigenous cultures and food systems: "The White Whipala Paper" (FAO, 2021) and "Indigenous Peoples' Food Systems-insights on sustainability and resilience from the front line of climate change" (FAO Alliance of Bioversity International and CIAT, 2021).

Indigenous Peoples collectively make up about 5% of the global population with more than 476 million people. There are more than 4000 Indigenous languages over the 6700 globally spoken in 90 countries. The collective experience of Indigenous Peoples is from managing 22% of the world's ecosystems and land mass (Kuhnlein et al., 2019). Their vast traditional knowledge systems that include appreciation of this extensive global food biodiversity is linked to historical culture, way of life, identity, and spirituality (Cunningham, 2017). These rich natural treasures can sustain the planet if appropriately recognized, respected, and used. Many cultures of Indigenous Peoples realize four dimensions of health that include physical, social, mental, and spiritual health, all of which are interlinked in many ways with cultural food system practices that include the biodiversity that is foundational to food system resilience.

Over the past 250 years changes in global food production and distribution have driven large-scale dietary transformations. Communities have foods available from distant places, usually through commercial networks and increasingly through complex international food processing and distribution industries. Dietary change has been heightened by migrations to new areas and from rural to urban settings that present new culinary and dietary practices (Pelto and Pelto, 1983). At the same time, the imperative of colonization took precedence in many areas of the world to subjugate and dispossess Indigenous Peoples and disassociate them from their traditional land, culture, linguistic heritage, and identity to profoundly contribute to gaps in food security, health, and wellbeing (Cunningham, 2009; King et al., 2009; Egeland and Harrison, 2013).

Colonization, Dispossession, and Disparities

The impact of environmental dispossession cannot be underestimated. Indigenous Peoples are acutely aware of forced dietary change brought by environmental change creating overexploitation of fish and wildlife stocks, pollution and degradation of lands and waters, urbanization and loss of cultivatable lands, invasive species, and climate change (Turner et al., 2013a; Batal et al., 2021b). Further, disparities for Indigenous Peoples are also created from effects of several social determinants often created by colonization that led to a decline in dietary quality and nutritional health. Warne and Wescott (2019) describes these determinants for American Indians as forced relocation from ancestral lands to reservations that restricted access to traditional food, thereby creating dependence on federal food subsidies, and the forced attendance of children in distant boarding schools. Both promoted historical trauma contributing to poverty, alcohol and substance abuse, and rampant non-communicable disease (NCDs). For Indigenous Peoples the role of the physical environment is inseparable from issues of identity, balance, and life control (Richmond and Ross, 2009), food security and food sovereignty (Expert Panel on the State of Knowledge of Food Security in Northern Canada, 2014; Delormier and Marquis, 2018). Globally, Indigenous Peoples experience similar disparities in contrast to their national population averages that lead to increased obesity and NCDs) in high-income countries, and increased malnutrition and stunting in low and middle-income countries (LMICs; Anderson et al., 2016). The transition driving malnutrition and increasing NCDs can be reversed with more sustainable food systems that provide lifestyle balance in use of biodiverse food resources, increasing energy expenditure, and reducing exposure to high energy but poor nutrient foods and diets (Popkin, 2001; Batal et al., 2017; Swinburn et al., 2019; Popkin et al., 2020).

Effective Policies Are Needed

The World Health Organization is calling for all nations' policies to address their environments to create more healthy food systems and the populations they sustain; these are policies such as improving food security, reducing food marketing to children, and education to develop public consciousness of healthy foods and diets (World Health Organization, 2017). Barriers created by international trade and investment agreement stakeholders, especially in food and beverage markets in the public and private sectors, are described as accelerating the nutrition transition away from healthy food systems (Garton et al., 2021).

Knowledge systems of Indigenous Peoples embrace the use of food resources known and used in the culture, intergenerational wellbeing, traditional knowledge, and preferences to create food security and food sovereignty (Expert Panel on the State of Knowledge of Food Security in Northern Canada, 2014; FAO, 2021). Policies are needed to protect this knowledge and foster its use to promote wellbeing, which is based on the collective five interrelated human rights recognized in international law: the right to food, the right to health, cultural rights, the rights of the child, and the implied right to a healthy environment (summarized in Swinburn et al., 2019). All human rights are especially relevant for Indigenous Peoples as noted in the UN Declaration on the Rights of Indigenous Peoples (United Nations General Assembly, 2007), and protecting these rights is essential for strengthening Indigenous Peoples' food systems.

Strengthening Indigenous Peoples' Food Systems

This strengthening necessarily includes approaches that broadly stimulate intercultural research and education at several levels: international, regional, national, and within Indigenous communities. Research is needed to fully understand the availability and nutritional potential of biodiverse food resources in Indigenous territories (Kennedy et al., 2021). Intercultural education at all levels includes mutual careful listening and sharing knowledge of commercial food access, its quality and use, and learning the strengths, sustainability, and resilience of cultural resources and practices. Continuity of traditional practices is essential and includes encouraging new ideas and expressions of culture with food, including indigenous cuisines with biodiverse species and preparation techniques. These initiatives require legislation that enables and protects natural resources and their use, and ensures time, funds, and equipment for Indigenous Peoples to reinforce cultural food system access and identity (Kuhnlein and Burlingame, 2013; Delormier and Marquis, 2018; FAO Alliance of Bioversity International and CIAT, 2021).

The goal of strengthening Indigenous Peoples' food systems at the global level is to create the way forward for humanity to progress from our currently unsustainable food systems and ways of life (Argumedo et al., 2021; FAO, 2021). Collectively, Indigenous Peoples contain knowledge of a wealth of cultural diversity in the ingenuity of food systems that are adaptive to the world's diverse ecosystems and climate change. Realizing this goal begins with encouraging and enabling Indigenous communities to fully access and appreciate their local cultural heritage and identity.

In this contribution, we highlight two very different food systems and the partnerships that established essential data as a platform to create positive change. The Nuxalk Nation in the temperate coastal rain forest of British Columbia has a traditional food system based in wild fish and plant harvests that were assessed in 2009 to provide ∼30% of adult dietary energy. The Karen of Kanchanaburi Province, Sanepong Community, in the tropical watershed forest of Thailand have a food system traditionally based in shifting cultivation and wild food harvest that was similarly assessed to provide about 85% of adult daily energy (Kuhnlein et al., 2009; **Figures 1**, **2**). It is our intent to provide these two unique Indigenous Peoples' food system cases, and updates, as stimulation and inspiration for Indigenous communities everywhere to improve use of their traditional food systems, and for policy makers to realize the needs for urgent support of Indigenous communities' food systems at local, national, and international levels.

Both authors contributed substantially over several years to research with large teams in the case study communities. Both authors were involved in data collection to define the

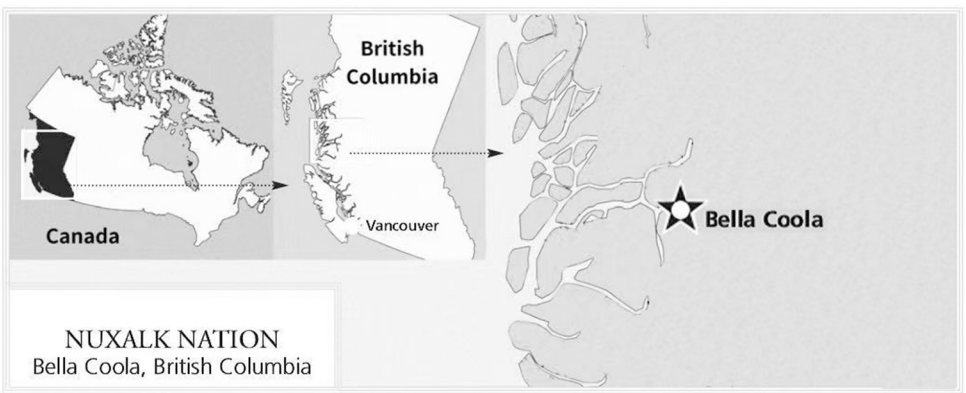

FIGURE 1 | Nuxalk Nation in Bella Coola, British Columbia, Canada.

FIGURE 2 | Karen Community in Sanepong, Kanchanburi Province, Thailand.

foods in the food systems (as reported separately in Kuhnlein et al., 2009), and then to stimulate community empowerment to improve wellbeing using traditional food and food system data. A diversity of research methods was employed using both qualitative and quantitative techniques which were summarized in separate chapters in Kuhnlein et al. (2013a). The data reported here include some from the former publications as well as new perspectives and research for policy considerations and actionable recommendations. Research and policy activities in both Indigenous communities are ongoing.

POLICY OPTIONS AND IMPLICATIONS

Nuxalk Nation of British Columbia, Canada

Setting and Context

The people of the Nuxalk Nation live in the community of Bella Coola and occupy lands on the central west coast of the Province of British Columbia. Their traditional territory extends more broadly in the temperate coastal rain forest of Canada. For tens of thousands of years, they occupied many villages in the region, but the population was decimated during the 1836-7 smallpox epidemic and resettlement of survivors took place in the remote Bella Coola Valley (McIlwraith, 1992). Today ∼1,200 Nuxalk People (*Nuxalkmc*) live in the Bella Coola Valley (about 50% of the valley population) or elsewhere in the province. The traditional Nuxalk language is Salish, and it supports rich cultural activities, although schools, health care, and commerce are conducted primarily in English. The once common extractive industries of logging and commercial fishing are in decline and unemployment and financial poverty are high. Gardening and subsistence traditional Nuxalk food harvesting and use is regularly practiced to supplement food purchased in the two grocery stores and several small outlets in the valley (Kuhnlein, 1992).

Health of Indigenous Peoples in British Columbia and Canada reflects the global circumstances noted earlier, with continuing colonization, poverty, and environmental dispossession. Food insecurity data on record for First Nations in Canada is 41% in contrast to the general population of 7% (Chan et al., 2011; Johnson, 2014), with 49% of 81 random Nuxalk First Nation households reporting food insecurity (FNFNES, 2011). Poor dietary habits result from increasing food insecurity and lead to increasing non-communicable diseases and decreasing quality of life (Thommasen and Zhang, 2006; Batal and Decelles, 2019). Batal et al. (2021a) reported that 73% of all British Columbia First Nations adults sampled in 2011 had overweight or obesity and 10% had diabetes, in contrast to 83 and 21% for First Nations over all regions in Canada; they suggest a protective effect of traditional food, especially fish, against diabetes in First Nations in British Columbia.

Nuxalk Food System Description

Until about 150 years ago Nuxalk families lived in varied environments, with seasonal location and food harvest depending on availability of a range of animal and plant foods from coastal rainforest and sea inlets of central coastal British Columbia to upland lakes and rugged mountains often capped with snow. The Bella Coola Valley, its river and tributaries provide many habitats and food diversity, including five species of Pacific salmon, sea foods, game (rarely found), tree foods, root foods, and a variety of wild fruits and greens (McIlwraith, 1992; Kuhnlein et al., 2013b) (**Table 1**). Harvested food was preserved by dehydration, smoking, fermentation, as jam, or caching. Today berry jam and fish drying and smoking are still common, as are preservation in jars or cans, and using household freezers.

The use of traditional food species by *Nuxalkmc* has been gradually declining. Interviews with three generations of Nuxalk

TABLE 1 | Summary of traditional wild food species harvested by Nuxalk Nation families.

Food type	Number of species
Fish (flesh, roe, oil)	16
Beach foods (shellfish, etc.)	7
Seaweed	3
Sea Mammals (seal)	1
Land mammals	7
Wild birds	5
Wild berries (including rose hips)	22
Roots	5
Greens	7
Tree foods (inner bark, crabapples)	3
Mushrooms	3
Total*	79

From Kuhnlein (1984) and Kuhnlein et al. (2013b).
**Number of species contributing primary foods. There are many food types within each species contributing various parts of the animals or plants to regular diets (Nuxalk Food and Nutrition Program Staff, 1984).*

FIGURE 3 | Harvested eulachon fish, Nuxalk Nation.

FIGURE 4 | Skimming eulachon grease from the surface of the cooking bin, Nuxalk Nation.

women about food use frequency by decade from 1920 to 1980 clearly shows gradually decreasing use of game, berries, greens, roots, and sea foods, with less impact on river fish (Kuhnlein, 1992). More recently, from 1980 to 2009 there has been even more dramatic decline in estimated use of traditional foods attributed to declining local availability and resource collapse of fish species that has increased food insecurity in the community despite families wanting to continue their food use traditions (Kuhnlein et al., 2013b; Batal et al., 2021b). Restoration efforts of salmon species, eulachon (see next section), and gardening have taken place, in particular the strengthening of efforts toward local management of eulachon (Sputc Project Team, 2017; Beveridge et al., 2020).

Here we emphasize the eulachon fish and the collective of berries because of their recognition as such in earlier interviews of Nuxalk women (Kuhnlein and Moody, 1989; Kuhnlein, 1992).

Eulachon Fish and Grease

The eulachon (*Thaleichthys pacificus* Richardson) is a cultural keystone species documented as important to wellbeing and Nuxalk identity (Sputc Project Team, 2017). This nutrient-rich fish is a popular flesh food harvested and prepared in several ways in spring by Indigenous cultures near rivers on the Northwest Coast. Eulachon grease is the fat rendered from the fish that has been a prominent food in itself, and a gift for feasts and many traditional ceremonies as a general sign of prosperity. It can be widely used as a frying medium, a condiment with several foods, or used as an ingredient in bread, salads, or stews; it can also be a preservative covering in containers of dried berries. It has been used as a versatile traditional lubricant for leather and wood, and as a locally important medicine for skin rashes and various ailments.

The preparation of the eulachon (ooligan) grease has specificity by family to yield the preferred flavor and storage capacity. Tradition in the Nuxalk Nation has been to net the anadromous fish from the river in early spring, March or April, and to pack the fish into cedar plank bins 2–3 m square lined with boughs of cedar (*Thuja plicata* Donn) built on the riverbank. The bins are covered, and the contents are left to ripen from 4 to 14 days until judged to be sufficiently decomposed. A second box is then constructed with a metal floor to enable heat from a fire below, and filled with water brought to a gentle simmer. The ripened fish is transferred by shovel into the box, and the rendered oil rises to the surface (see **Figures 3**, **4**). From 300–400 L of oil have been rendered from one box in the family process; the seasonal cooking in 1981 from five family preparations yielded about 2,000 L of grease. Grease was then shared with community households that at the time reported to use from 7 to 40 L/family per year (Kuhnlein, 1982).

The nutritional qualities of the fish and its grease are truly remarkable (**Table 2**). These were first documented in 1982 by Kuhnlein; a larger study was completed in 1996 that included sampling from five coastal First Nations. Analyses included retinol, calcium, iron, and zinc, and a suite of heavy metal and

TABLE 2 | Eulachon (*Thaleichthys pacificus*) fish and grease data summary.

	Fish, raw*	Rendered grease
Fat, mg/100 g ($n = 19$)	16.7	98.0
Retinol RE/100 g ($n = 19$)	3,196	2,400 ± 1,200
Tocopherol mg/100 g	nd**	22.0***
Vitamin K-1 mg/100 g	Nd	1.0***
Saturated fatty acids (g/100 g lipid)	23.5	19 ± 2.6****
Monounsaturated fatty acids (g/100 g lipid)	47.5	36 ± 5.8****
ω-6 Polyunsaturated fatty acids (g/100 g lipid)	2.0	1.1 ± 04****
ω-3 Polyunsaturated fatty acids (g/100 g lipid)	3.6	21 ± 6.8****
Calcium (mg/100 g)	273	nd
Iron (mg/100 g)	1.6	nd
Zinc (mg/100 g)	1.3	nd

Raw fish data from a composite of five fish samples from two British Columbia First Nation communities (Kuhnlein et al., 1996).
**Not detected.*
***Mean of samples from five separate preparations of Nuxalk grease. Tocopherol: (range 14.8–27.9); Vitamin K-1 (range 0.04–1.35) (Kuhnlein et al., 1982).*
****Determined from five separate Nuxalk family grease preparations, representing extract from a total of ∼11,000 kg fish (Kuhnlein et al., 1996).*

FIGURE 5 | Berries harvested in mid-July, Nuxalk Nation.

organochlorine contaminants (Chan et al., 1996; Kuhnlein et al., 1996). None of the contaminants exceeded regulation limits from Health Canada.

T. pacificus is rich in vitamin A expressed as retinol equivalents (RE/100 g). It appears that the ripening/rendering of the fish for grease, as well as smoking and dehydrating the fish creates some loss of this vitamin. Nevertheless, the fish grease is one of the best sources of retinol in British Columbia natural foods. It would fulfill nutrient needs of children and adults, even when consumed in small quantities. Available in spring, when traditional plant sources of carotene are limited to meet vitamin A needs, and because the grease was stored after preparation for annual use, this fat is an important nutrient in the annual traditional diet. Eulachon grease is also an excellent source of polyunsaturated omega-3 and omega-6 fatty acids, meeting human needs with a 20 g. portion. Calcium, iron, and zinc are also present in meaningful amounts in the fish and grease, especially considering that fish bones contributed some of this amount in edible dehydrated/smoked and ripened/rendered fish.

Unfortunately, and sadly for coastal First Nations Peoples, the eulachon has faced serious decline and extirpation, with the last large harvest for *Nuxalmc* in 1996 (Moody, 2008; Beveridge et al., 2020) because of commercial overfishing and shrimp trawl bycatch in the open ocean, and environmental effects such as flooding and silting of the river. Since then, there has been no eulachon fishing by the Nuxalk Nation. However, recognizing the importance of continued grease-making practices for cultural knowledge transmission, single batches of grease have been made in grease camps using fish from more Northern rivers since 2017 (Thompson, 2017). These camps fulfill important cultural and educational purposes, despite a lack of eulachon in the rivers. An annual community ceremony celebrates the time when *sputc* (eulachon) would have annually returned to the Bella Coola River (Moody and Beveridge, 2019). Serious efforts are being made to research and strengthen Indigenous management of this species based on extensive knowledge of the local environment and ecology, with the hope of returning and maintaining this nutrient-rich species into the diets of Nuxalk families (Sputc Project Team, 2017; Moody and Beveridge, 2019; Beveridge et al., 2020).

Wild Berries

The Bella Coola Valley and the coastal rain forest are famous for the diversity and quantity of wild berries available for consumption (Turner, 1995; Moody and Beveridge, 2019). More than 20 species of berries can be harvested at various elevations in the valley from April until frost in the autumn (**Figure 5**). In addition to being eaten fresh singly or in combination or incorporated into breads and salads, berries have traditionally been preserved by dehydration (by sun or smoke) and under a layer of eulachon grease. Recently, preservation is as jam and by freezing.

Use of traditional berries has been declining, as measured by interviews with three generations of Nuxalk women. From the 1920's until the 1980's both fresh and preserved use declined, although use scores of all berry species indicate that at least one fruit was used several times per week during the year (Kuhnlein, 1992). In 1985 family use of berries was roughly 46 kg/yr that was reduced to about 16 kg/yr in 2009. Although

all *Nuxalkcm* still greatly appreciate all their traditional foods, limited access and availability of the food system continue to decline (Kuhnlein et al., 2013b). Sweetened whipped soapberries (*Shepherdia canadensis*) continue to be one of the most popular berries in the Nuxalk Nation, but red huckleberries (*Vaccinium parvifolium*) and salmonberries (*Rubus spectabilis*) are more available than other species.

Nutrient data from species used by *Nuxalkmc* confirm that the array of Nuxalk traditional foods provided the full complement of nutrients essential for human nutrition (Turner et al., 2009; Centre for Indigenous Peoples' Nutrition and Environment, 2011). **Table 3** shows the diversity of berry species, the range of values for micronutrient adequacy, and the berry species with the highest analytical values on record (**Table 3**). Gooseberries and red elderberries had the highest nutrient values for multiple micronutrients: thiamin and niacin (gooseberries) and folate, iron, and phosphorus (red elderberries). Gooseberries and elderberries also had among the lowest taste popularity scores for women (not shown; Kuhnlein, 1989).

Nuxalk Food and Nutrition Program

The Nuxalk Food and Nutrition Program was initiated following identification of rich nutrient resources in traditional Nuxalk foods as detailed above. The program was funded from 1982 to 1986 by agencies within Health Canada, and others, as a demonstration project with objectives to establish the local knowledge of the Nuxalk food system and to then systematically encourage enhanced use of both traditional and nutrient-rich commercial foods to improve health status (Nuxalk Food and Nutrition Program Staff, 1984; Kuhnlein, 1987). With guidance of a committee of Elders, Chiefs and Council, community leaders in the Health Center, and program staff, ambitious and popular educational and assessment activities were conducted with substantial attendance by children and adults (Kuhnlein and Moody, 1989; Kuhnlein and Burgess, 1997). Importantly, the sampling and extensive food analysis provided the backbone of the knowledge platform upon which to base nutrition education activities (Kuhnlein et al., 1982; Kuhnlein, 1984, 1990; Kuhnlein et al., 1996; among others). Over the course of the program there was increased participation in program activities, a significant increase in traditional food use, and reduced commercial food expenditures per family; food use evaluations documented increased family consumption of fish, vegetables, and fruits. Improved retinol, carotene, ferritin and folate status in teens and adults were also documented, as was improved dental health (Kuhnlein and Moody, 1989; Kuhnlein and Burgess, 1997; Turner et al., 2013b). The Nuxalk Food and Nutrition Program emphasized food and nutrition education and development under the leadership described above. The Program was not specifically intended to prevent obesity and other non-communicable diseases, although healthy eating and fitness training and classes were given within the school system and in adult education through the Health Center (Nuxalk Food and Nutrition Program Staff, 1984).

The Nuxalk Food and Nutrition Program was the first community program for First Nations in Canada to document the traditional food system and build awareness and activities to improve overall dietary quality and health. It became a model for other Indigenous communities to promote use of local foods and holistic health and wellbeing (Kuhnlein et al., 2013b). The Nuxalk program was revisited in 2009 and 2013 to document its lasting impact in the Nuxalk Nation (Turner et al., 2009, 2013b; Kuhnlein et al., 2013b). While a greater percentage of Nuxalk families using traditional food increased from 1981 to 2009, the estimated weight of use per family had declined for reasons described above, especially decreased resource availability. Evidence from qualitative interviews and discussions with leaders in both 2009 and 2013 described several initiatives to share elder knowledge about local traditional foods and medicines with the intent to increase their use. The Nuxalk Nation has also been included in several provincial and federal research efforts to document continuing change in food use by First Nations (see following section).

Policies and Activities Affecting the Traditional Food System of the Nuxalk Nation

Global change in food distribution and availability since the mid-1700's, noted earlier, impacted all Indigenous Peoples. In addition, several factors in British Columbia's history have driven movement away from use of traditional food resources: Legislation restricted land and resource access of Indigenous Peoples including Legislative Acts to restrict access to Game, Fisheries, and Forests. Colonial policies beginning in the mid-1800's, such as residential schools, the reserve system, and ban of local cultural practices such as the potlatch had lasting impacts on knowledge transfer to younger generations (Fontaine and Craft, 2015). Environmental degradation and over-fishing because of extractive fisheries and forestry policy as well as widespread dispossession of lands and waters have reduced availability and accessibility of traditional foods (Moody, 2008; Hilland, 2013; Bennett et al., 2018; Beveridge et al., 2020). *Nuxalkmc* maintain that berries are in decline because of massive clear-cut logging blocks. Further, Nuxalk migration from home territory to urban areas and migration of settlers into the Bella Coola Valley brought increasing availability and use of less nutritious commercial foods. Education, social contact, and the media have fostered availability and appreciation of new foods and reduced native food harvesting, as has the impact of employment on time available for local food harvesting and funds generated to purchase mostly unhealthy energy-dense commercial foods. Employment also affected time available for women and men to create a transfer of food harvesting knowledge to younger generations. Few young Nuxalk women (<40 yr) have skills to cut and preserve fish or to harvest and prepare plant foods (summarized by Kuhnlein, 1992).

Since the mid-1990's international, national and local health agencies have embraced the concept of food security and ways to implement it. Attention to the Nuxalk Food and Nutrition Program has inspired traditional food evaluations and analyses, and education activities on benefits of traditional food that included honoring tradition in which food is recognized as

TABLE 3 | Micronutrient-rich Nuxalk wild traditional berries.

Nutrient, unit per 100 g fresh weight	EAR* for adult woman/day	Range of nutrient values**	Species with highest values: English	Scientific names
Thiamine, mg	0.9	nd–0.04	Salmonberry	*Rubus spectabilis*
			Black gooseberry	*Ribes divaricatum*
Riboflavin, mg	0.9	nd–100	Crowberry	*Empetrum nigrum*
			Wild strawberry	*Fragaria vesca*
Niacin, mg	11	nd–0.72	Black gooseberry	*Ribes divaricatum*
Vitamin C, mg	60	3.3–413.8	Rosehips	*Rosa nutkana*
Carotene, RE	Na	0.2–31.4	Salmonberry	*Rubus spectabilis*
Folate, DFE/ug	320	2.8–68.3	Red elderberry	*Sambucus racemosa*
Zinc, mg	6.8	0.1–0.8	Soapberry	*Shepherdia canadensis*
Iron, mg	8.1	0.2–1.1	Red elderberry	*Sambucus racemosa*
Phosphorus, mg	580	11–83	Red elderberry	*Sambucus racemosa*
Magnesium, mg	265	3.7–57.5	Wild strawberry	*Fragaria vesca*
Copper, ug	720	nd−1.3	Kinnickkinnick	*Arctostaphylos uva-ursi*
Manganese, mg	1.8 (AI)	0.01–4.4	Red huckleberry	*Vaccinium parvifolium*

**EAR and AI for adult women, IOM (2009).*

***Values from: Kuhnlein (1989), Canadian Nutrient File, Turner et al. (2009).*

Berry species analyzed included:

Blackcap–Rubus leucodermis; Black hawthorn–Crataegus douglasii; Bog blueberry–Vaccinium uliginosum; Bunchberry–Cornus canadensis; Crowberry–Empetrum nigrum; Gray blueberry–Vaccinium ovalifolium; Highbush cranberry–Virunum edule; Kinnickkinnick berry–Arctostapylos uva-ursi; Mountain bilberry–Vaccinium membranaceum; Red elderberry–Sambucus racemose; Red huckleberry–Vaccinium parvifolium; Rosehip (seedless)–Rosa nutkana; Salmonberry–Rubus spectabilis; Saskatoonberry–Amalanchier alnifolia; Soapberry–Shepherdia canadensis; Stink current–Ribes bracteosum; Swamp gooseberry–Ribes lacustr; Thimbleberry–Ribes parviflorus; Watery blueberry–Vaccinium alaskense; Wild blue currant–Ribes laxiflorum; Coastal black gooseberry–Ribes divaricatum; Wild raspberry–Rubus idaeus; Wild strawberry–Fragaria vesca.

contributing to social, mental, and spiritual dimensions of health as well as its contribution to nutrition and physical health.

Nuxalk Nation health promotion staff routinely use printed resources from the First Nations Health Authority (fnha.ca) and the Vancouver Coastal Health Authority including printed resources (Traditional Foods Fact Sheets) and dietitian consultations (Food Security Gateway, 2019). The Bella Coola Valley Sustainable Agricultural Society created a community garden, *Putliiux*, to teach and encourage gardening by Nuxalk families. The elementary *Acwsalcta* school has taken over caring for the local garden and a greenhouse, indoor garden, chicken coop and the outdoor garden as part of the school curriculum, as are harvesting and use of traditional foods that is supported by a local Food Security Coordinator. The Nuxalk Nation Health and Wellness Program has a *Nuxalkmc* Nutrition staff member, and the Pregnancy Outreach Program has a registered nutritionist on staff. A local Elder teaches fish-cutting and use of a smokehouse and other *Nuxalkmc* food processing techniques. Nuxalk College supports cultural resurgence activities like the grease-making described above and other traditional food harvesting practices.

Indigenous Services Canada (isc.ca), formerly the First Nations and Inuit Health Branch of Health Canada, funds and supports Indigenous communities and health organizations with food-related activities promoting healthy eating knowledge and food skills; improving access to healthy food, including commercial food and traditional food; improving food environments; and food security planning to support communities in defining ways to address local access to and availability of healthy food. All public health services in Canada now include programs in food security that foster building food knowledge for healthy diets while managing food budgets. Indigenous Peoples' programs include attention to maintaining healthy lands and waters. Many projects have themes and activities for First Nations in British Columbia to improve food security with traditional food, gardens, and community action (see for example Johnson, 2014; Blanchet et al., 2021). All these activities at provincial and federal levels, and their implementation in Indigenous communities, contribute to strengthening the food systems of First Nations in British Columbia.

As noted above, First Nations are supporting their own food security, wellness, and cultural connectedness, and are asserting their own management rights and authority. Parallel activities occur throughout British Columbia (see for example, Kuhnlein et al., 2013b; Jones et al., 2017; von der Porten et al., 2019; Beveridge et al., 2020; Blanchet et al., 2021; Steel et al., 2021).

There have been formidable historical and current challenges by many different constituents (government, resource extraction industries, education, health care, climate change, etc.) to the ability of the Nuxalk Nation to maintain their culture and way of life in their traditional homelands. However, committed Nuxalk leadership and staff together with partnerships with academia and local, provincial, and national resource agencies, have documented local empowerment to retain and use traditional biocultural knowledge for long-term nutrition and health benefits for *Nuxalkcm*.

THE PWO KAREN COMMUNITY OF KANCHANABURI PROVINCE, THAILAND

Setting and Context

Karen is the largest tribe among the Indigenous Peoples in Thailand with some communities located in Sangkhlaburi District, Kanchanaburi Province. Since settlement of the Pwo Karen occurred in Thailand more than 600 years ago, the relationship of the tribe with the Thai nation state has been positive, as the Karen have been seen as guardians of the nation's territory (Deepadung and Khammuang, 1997). The Sangkhlaburi Karen District is in a mountainous area 1,000 m high with the southwestern monsoon providing frequent rainfall throughout the year. The area hence functions as a watershed forest of rivers in both Thailand and Myanmar. The villages are embraced within a thick rainforest, and most of the woodland are mixed forest with flowing streams nurturing communities throughout the year.

A turning point for community life of the Karen People took place when the settlement, which serves as refuge for rare fauna and flora, became a target among frequent hunting groups. In 1964, the National Forest Protection Policy set a clear borderline around protected forest which engulfed the Indigenous community into the protected area (Sueb Nakhasathien Foundation, 2012). The government offered the people a relocation settlement with education services and modernization facilities, but the offer was not accepted. The community leaders strengthened the Indigenous tradition and promoted the uniqueness of the tribe successfully among the public until the present time (Grivijitr, 2019). Various development programs have inevitably influenced their lifestyle. Government and nongovernmental endeavors with different crops and livestock farming practices, modern health care and medical services (especially against malaria), and formal education have been promoted and conducted. Basic supportive education and healthcare services have been provided by the Thai government.

Some development missions had aims that alienated the people without considering their needs and ways of life. Examples are fixed land use indicated by official land marking, which is contradictory to crop rotation and shifting cultivation, the traditional practice accepted as sustainable for the Karen. The enforced radical shift eliminated the crop circle time span with highland plantation and wild product gathering. Further, monetary earning became mandatory as people must pay more for foods and additional expenses for shopping as well as for education, transportation, house-building materials, and health care. The working generation had to migrate to towns for work and income, and migration on to urban areas increased.

The original research for this case study with the Pwo Karen Indigenous Peoples in Sanephong, Thailand, was conducted in two phases: the description of the food system, followed by promoting local traditional food to address malnutrition. Basic principles of these phases are reported in Chotiboriboon et al. (2009) and Sirisai et al. (2013). This contribution elaborates the food system and presents several strategies used to promote and strengthen use of local Karen traditional food.

TABLE 4 | Summary of Karen traditional food species/varieties.

Food type	Number of species/varieties
Plant	321
Grain, Cereal, Seeds, Roots, and Tubers	51
Vegetables	208
Fruits	62
Animal	66
Fish, Shellfish, Shrimp, Snail, Amphibians	31
Land Animals	17
Reptiles	6
Fowl	10
Insects	2
Total	387

Karen Traditional Food System

Study of the Karen community food system was initiated in 2005 to explore information derived from both male and female Karen elders. It revealed knowledge and use of 387 food species: 321 plants (83%) and 66 animals (17%) (**Table 4**). The territory the community relies on is various in nature with hills, flat land, and creeks providing wild foods (187 species) and 183 additional species that were cultivated. Karen food management skills were effectively wise in providing family members with ample foods throughout the year that was sufficient for regularly sharing with Buddhist monks, relatives, and guests (Smitasiri, 2005, unpublished report).

Karen agricultural practices traditionally took place in a circuit of shifting cultivation with rice the most significant crop and staple food. Its value is addressed with local words of traditional wisdom: "The one who does not grow rice, the one who does not know how to grow rice, is not a Karen;" and "In the midst of a storm of might, hold tight to the ear of rice." These mottos reveal the Karen mindset for a strong faith in rice plantation, an essence they could rely on against the adversity of change. The sayings also suggest influences of worldly objects could harm or heal people's life, mind, and their natural resources (Premphund et al., 2016).

The Karen have considerable knowledge of edible vegetation in a large range of territory. There are more than 200 species of flora both in their agricultural fields and in the wild. Plants' roots, bulbs, shoots, stems, vines, young fruits, dry fruits, seeds, blooms, young leaves, and buds are known as parts of their meals, especially to match various chili paste types. Common Karen main dishes are known to contain rice, chili pastes, and fresh vegetables.

Crops of dry beans and sesame could be reserved for future consumption as special treasures reflecting Karen knowledge on crop planting, selection, utilization, and preservation. Karen cooks use beans and sesame as ingredients for curries, soups, and sweets and they are important agents in salt fermented paste, a major component of various dishes.

Diversity of the Karen Meal

With abundance of food types and accumulated knowledge, an array of cooked meals and home processed foods are available.

FIGURE 6 | Typical traditional Karen meal.

Soups, curries, salads, fried dishes, and stir-fried items can be prepared and varied to match family members' preferences, especially in the extended family typical in Karen lifestyle (**Figure 6**). A meal with various dishes holds the elderly, adults, and the young members as one. Chili paste is a core part of meals, as dried and/or wet paste. Karen rice is cooked with a portion of the boiled water saved for the preparation of liquified chili paste. For acidic taste sour cucumber is added–a supplementary crop in the rice field. Young mango, lime, and salacca fruit (palm fruit) are also applied for sharp acidic flavor. Side dishes of vegetables are various in tastes and types: cucumber is plain and refreshing; some flowers and young pods are preferred for their slightly bitter taste; and some sweet fruits [for example, *Myriooteron extensum* (Wight) K. Schum] are served for the same function as accompanying chili pastes. Vegetables are served fresh and boiled, roasted, and/or stir-fried (Sirisai et al., 2008, unpublished report).

Nutrient values assessed for 19 local indigenous foods showed that eight were good sources of vitamins and minerals (Chotiboriboon et al., 2009; **Table 5**). Other than snail, the food items shown are dark green leaves or leaves with shoots. Sanephong Karen use these as fresh, boiled and dipped in chili paste, added to curry, stir-fried with egg, added to fish soup, and added to dried fish curry. An example is the young shoots of fak-kao (*Momordica chochinchinensis* Spreng) that are blanched to create a favorite side dish. Snails are cooked in curry seasoned with roasted rice. Spicy soup is served with fresh leaf-like gawng-chu-na-du (*Erythropalm scandens* Blume) for a harmonious taste, texture, and nutritious dish.

Karen meals are also traditionally diversified with ingredients that may vary due to different ecosystems in various geographical areas. Wild harvests are fresh, toxin-free, and not contaminated with agrochemicals. Karen foods are considered much healthier than those of general Thais who consume commercialized products from monoculture farms that are suppressing consumption of local species and increasing detected contaminants (BIOTHAI, 2015, 2016). Besides the variety of fresh ingredients, the sourcing, gathering, harvesting, cooking, and arrangement of home-cooked foods are skills passed from generation to generation, providing nutritious meals for family and community cultural events (**Figure 7**). Karen food system knowledge of food variety, nutritional values, and traits of food access and use are part of ingenious local wisdom for nutrition and health care in the family, and are factors in environmental protection, knowledge vitalization, and Karen cultural heritage.

Identifying the Need to Improve Malnutrition in Sanephong

From the beginning of the century, Thailand experienced malnutrition in every region. Research included nutritional status assessment, root cause analysis, and cure programs to resolve the severe problems (Viravaidya and Damapong, 2002). Indigenous communities are vulnerable and live at risk with limited access to fundamental healthcare services. Beginning in 2005, a team of multidisciplinary experts from the Institute of Nutrition and the Language Research Institute for Development, Mahidol University, worked with partnership networks and the Karen community in research supported by the Micronutrient Global Leadership Program and the Thai Health Promotion Foundation (Smitasiri, 2005, unpublished report; Sirisai et al., 2008, unpublished report; Sirisai et al., 2013). Research guidelines were from the Centre for Indigenous Peoples' Nutrition and Environment (CINE), McGill University (Canada) for food system documentation and promotion of traditional food for health, wellbeing, and sustainability (Kuhnlein et al., 2006) The research direction emphasized the significance of clear comprehension and strength of the food knowledge of this unique Indigenous community. The study led to the promotion of healthy food and food stability, in particular for community students, and relied on the dialogue and collaboration among community members and researchers, and regular communication addressed the aims and expected results of the study consistently. This healthy cooperation-built trust within the village, creating clear understanding on the research process, and provided information for problem-solving.

Results of the first phase of the study illustrated the community's variety of traditional foods, but community members described a decrease in available and accessible quantities of many species reflecting ecosystem changes that negatively influenced regular consumption of many foods. The effects influenced local wisdom on planting, gathering, identifying of foods, processing, and cooking which were the common knowledge. Most energy-containing foods were traditional items, but half of the money spent on family food was on purchased products, especially snacks and sweetened drinks. Tooth decay and malnutrition problems were present among school-age children (Chotiboriboon et al., 2009).

A nutrition assessment was conducted for the local Karen children and adults by researchers from the Institute of Nutrition, Mahidol University, in collaboration with community members of Baan Sanephong (Baan literally means village), Sangkhlaburi District. It was found that among the children, newborn to

TABLE 5 | Nutrient data for Karen foods and potential dietary contributions for children 6 years and older.

English name	Karen name	Scientific name	Serving size*** (g)	Nutrients per serving (% Thai RDI)				
				Iron (mg)	Calcium (mg)	Vitamin A equivalent**** (μg)	Vitamin C (μg)	Folate (μg)
1. Shellfish	Khlu-mi	Unidentified	35	5.8 **(39)**	112 *(14)*	-	-	-
2. None	Pak-man-mu* or Le-khawng-du	*Gnetum gnemon* L. var. *tenerum* Markgr.	50	0.7 (5)	26 (3)	92 *(15)*	25 **(42)**	35.5 *(18)*
3. None	Kawng-thaing-du*	*Lemmaphyllum carnosum* (J.Sm. ex Hook.) C. Presl	50	1.35 (9)	46 (6)	61 *(10)*	2 (3)	18 (9)
4. None	Sa-ni-wa-du*	Unidentified	50	1.1 (7)	124 *(16)*	19 (3)	2.5 (4)	8 (4)
5. None	Yawd-fak-kao or Bai-khai-du**	*Momordica cochinchinensis* (Lour.) Spreng.	50	0.45 (3)	57 (7)	77 *(13)*	73.5 **(123)**	86.5 **(43)**
6. None	Ther-khu-mai-du**	Luffa cylindrical (L.) M.Roem.	50	1.1 (7)	65.5 (8)	62 *(10)*	2.5 (4)	32 *(16)*
7. Citron	Bai-ma-ngua or Baegu or Sa-zui-la*	*Citrus medica* L. var. medica	50	2.1 *(14)*	373.5 **(47)**	49 (8)	37.5 **(60)**	37 *(19)*
8. None	Gawng-chu-na-du*	Erythropalum scandens Blume	50	0.75 (5)	79 *(10)*	39 (7)	2 (3)	28 *(14)*

Adapted from research results (Chotiboriboon et al., 2009).
**Part of the plant for nutrition value analysis is green leaf.*
***Parts of the plant for nutrition value analysis are both green leaf and shoot.*
****Serving size derived from 24 h dietary recalls of Sanephong children.*
*****Beta-carotene 12 μg = 1 μg Vitamin A.*
⁻Not determined.
Thai Recommended Daily Intakes (Thai RDI) for children 6 or more years of age (Food and Drug Administration of Thailand, 1998).
Food item is considered a good source of a nutrient if one serving meets 10–19% of the Thai RDI and excellent source if one serving.
Meets ≥ 20% of the Thai RDI.
Italic: Good source of the nutrients (10-19 % of Thai RDI).
Bold: High in content of the nutrients (≥ 20% of the Thai RDI).

FIGURE 7 | Karen family cooking session.

12 years of age, there was chronic and acute malnutrition with 20% stunted, 14% underweight, 5% thin, and 1% were overweight (Chotiboriboon et al., 2009). The second phase began immediately with a project to promote traditional foods for healthy nutrition and food security.

Promoting Traditional Foods to Improve Nutrition and Food Security

Presentation of these findings to the villagers was followed by seeking ways to solve these problems. Dynamic conversations among children's caretakers and researchers facilitated community understanding and opportunities to have more traditional foods available for the children. This process was important to present and describe the value of local foods to the community. As a result, various activities were designed with the focus to make a difference in nutrition among the students in grades 4–6. A rationale for the selection of grades 4–6 was the finding of malnutrition among these children (as noted above) and the maturity of the students' thinking skills, decision-making, and their self-direction, all of which were anticipated to be beneficial.

Activities were integrated into community events and school projects, especially the school lunch program. Extra-curricular activities on wise local traditional cooking and informative learning about food and nutrition were also arranged. Resource people for these endeavors were women's groups, local researchers, and visiting researchers.

These activities embraced the exploration of students' perceptions about their community. The young generation realized the richness of natural resources and traditional cultures. They learned of changes because of the obvious decrease in the amount of some vegetables, such as the edible water fern (*Diplazium esculentum* Retz.) which was abundant earlier in village backyards. With promotion of backyard gardens, the number of families participating in the project and the variety of green vegetables consumed increased. Several events with cooking sessions to enrich popularity of local cuisine were held for both the development of traditional main dishes and healthy snacks and sweets. Mothers' groups used various local ingredients to make delicious and colorful dishes which were good for nutritional value and demonstration of practical preparation skills which would ensure the scaling-up process when the dishes were introduced to the community and schools in events such as Kids' Day Camp.

The effort to promote the values of local traditional foods, both knowledge-based sessions and developing and serving healthy dishes, were arranged for mothers' groups and students. This also encouraged the development of presentation skills among session facilitators who could inspire making local food gardens at home. These change agents were informants and speakers spreading information on local traditional food species for audiences within the community and in other venues, both in national and international settings.

It was a challenge sometimes to encourage consumption of local seasonal nutrition-rich foods and well-balanced food for malnutrition prevention because behavior change for a better diet requires changing strategies and suitable approaches in context over time. However, other more promising dimensions of project results included improving the potential of community members in thinking skills, learning ability, openness to conflicting opinions, perception shifts, and collaboration of local members with visiting researchers and other organizations to solve resource-related problems and availability of community assets (Sirisai et al., 2013).

The community mindset, learning capability, and potential were observed during the collaboration with the research visitors in the fieldwork when local researchers and visiting researchers completed assignments together. Karen villagers worked with researchers harmoniously; even though they led a unique lifestyle, believed in different matters, dined with different meals, and had different attitudes and traits, they adapted their way of life to blend in with their peers at work. Their knowledge, especially of the unique traditional food system management, skills, and self-adaptation, were significant human capital of the community.

The adjustment was not an easy flash phenomenon, because some episodes were obstructive. For example, a former research project was carried out in an untrustworthy manner. Researchers would arrive in the village without notice, gather information of their own interest, and then leave the community. The Karen villagers were not acknowledged on the findings and there was no contribution to the development of the local people. When our team of visiting researchers arrived, their intention and attention were questioned by the villagers and the early relationship was pushed away. In order to establish a healthy relationship with the community, the research team designed a transparency process sharing goals and working procedures to the community leaders and encouraged clear communication among villagers and researchers. As villagers assumed roles of local researchers in information gathering, information sharing, and resourceful informing of both the local residents and among public audiences (within the country and also internationally) throughout the 4-year research period, trust among community leaders and the villagers flourished. Regular authentic face-to-face communication among the local people and visiting researchers in nutrition and health status assessment required communal exploration, knowledge exchange, and active research sessions among all project participants. The process contributed and reinforced development of leaders and local researchers. They acquired research skills and confidence in sharing their wisdom with other researchers from other academic communities. Their experience also highlighted and signified the traditional livelihood, way of life, foods, and cuisine of the Karen (Sirisai et al., 2008, unpublished report).

Examples of reflections of community members:

"... why do the instructors from Mahidol University visit us and encourage local cooking and our homeland meals? It shows that there must be lots of good stuff in there. It is good to bring back our own local foods and pass it onto the young generations..." (a male community leader #01).

"…I saw them working on food and nutrition related to edible plants. I learned why the plants are good. The researchers studied child health; do they have anemia, are they underweight, and they record the data while I studied local food plants in the household and in the forest. We collaborated and understood each other better than before when we started the project…" (a male community leader #01).

A senior community interviewee described the project in an interview: As the local people adapted their unique ways of life to work with visiting researchers, they also applied innovative acts relevant to the local research findings. An example was the practice of backyard edible gardens. Certain greens were abundant in the wild setting; hence, they did not cultivate these varieties. Examples were the water fern [*Diplazium esculentum* (Retz.) Sw.] and pak liang (*Gnetum gnemor* L. var. tenerum Markr.). Some villagers believed that growing them at home may bring bad luck, but other villagers perceived this as a miscellaneous myth. Once the idea to grow this vegetable was suggested, some community members wanted to try the plants in their farm garden. Local researchers tried the idea, and the products from the experiment were gifted to neighbors, and the role model farm plot was scaled up among the villagers. The plantation brought the local species close to home, stabilized their availability and enriched this healthy food source sustainably. A traditional greens farm plot also included morning glory, Chinese cabbage, and kale, saving money spent at the market.

"…they are delicious, and good for health. We could grow them ourselves; no need to buy. They are better than the vegetables sold in the market on which they use chemicals. We do not use chemical fertilizer in our home-grown vegetables. Nowadays we bring in more vegetables from home than we did in the past..." (a female student #01).

Another interview story showed how local adaptation took place among the children. The project promoted the growing of local food species, traditional cooking, and healthy consumption of indigenous cuisine among students. Grade 4–6 students joined school/community-based activities which were designed to tackle health problems such as tooth decay, malnutrition, and anemia, for which unhealthy sweets and drinks were the cause. Local researchers cooked healthy snacks as alternatives providing more nutrients, cutting down unnecessary expenses, and revitalizing community food-related culture traits. Local popular greens, such as water fern, were introduced in school through collaborative cooking sessions among the students, mothers' groups, and community leaders. The cooking and dining of local vegetables enhanced the school lunch program and the students learned traditional processes resulting in nutritious meals.

Another part of the program was a school camp in which students presented what they learned and their opinion from their learning experience to their friends, teachers, family, and community leaders. The results were students' inspiration, health awareness, and esteem as they could take care of their own health, realized the value of local foods, protected natural resources, vitalized their unique culture and home community. Moreover, students gained better knowledge on food, nutrition, anemia prevention and appropriate treatment which made use of nutritious local foods. As they engaged in these activities, students' learning potential, ability to take care of their own health, and skills to pass on their knowledge to family and community members were observed. Appropriate learning activities could activate continual learning experience as mentioned by both the students themselves and their caretakers.

"....(I) want a happy village with good culture like it is now. The village should be well-developed. People should not be in pain and not sick. There are kids with anemia in many villages. The remedy is green vegetables which are available as baegu…" (a female student #02).

"…In the old days, we ate baegu. We ate it without any acknowledgment of its nutritional value; what kind of vitamin is in it. Once the researchers visited, we knew that the plant is rich in vitamins; it is good. Our wild stuff is good. If we could get it, we want our children to have a lot of it; this vitamin-rich food." (a parent #01).

The result of the programs to increase use of local species in local backyards was accepted among audiences within the community and outside. It enriched awareness on the significance of local foods to provide knowledge and direction for development of local cuisine, to provide healthy nutritional values among mother groups and students, and to strengthen essential skills of change agents.

Quantitatively, the variety of available food plants in the Sanephong community increased from 81 species to 137, with 119 of these being local species. The nutrition assessments for underweight, stunting, and thinness showed improvements in several percentage points among children aged 0–12 compared to the data of 2005 (Sirisai et al., 2013). Iron status based on hemoglobin also improved among children aged 8–12. There were more children in 2008 with normal levels of hemoglobin and fewer mild cases of low iron status. However, the number of overweight children increased from 0.5 in 2005 to 2.1% in 2008 (Sirisai et al., 2013).

Recognizing the Karen Community Capital

Both the process and the outcome of the research suggested the potential of the community capital which includes natural resource capital, human capital, and social capital. Natural resource capital provided villagers with many wild foods and natural harvest from fields, forests, and creeks. Human capital was the ability of learning from the Indigenous local heritage from hundreds of years in the territory. The intellectual property provided food and environmental protection of the forests and streams, embedded in local traditions and respect for sacred nature in the Karen context. These knowledges did not limit the ability to cope with changes in the community and from outside. The people learned and used their understanding to deal with problems effectively. Once they recognized natural resource degradation and cultural changes affecting students' health and the root causes of the problems, the villagers, community members, leaders, care takers, and the students could collaborate in the program with the community's essential social capital. They shared perspectives and collaborated with visiting researchers to design appropriate development activities based on their knowledge and unity to make a difference as shown in **Table 6**. Karen community strengths were in all three capitals, merging interactively as one (Hayami, 2008) which would work against internal and external negative forces. The collaboration and faith created a strong foundation of Karen self-actualization, and the capacity to strengthen the presence and sustain the development of the traditional food system into the future.

Community capital was an empowering factor enhancing community members' skills on researching, lifelong learning, and problem-solving. The capabilities supported the development of food security, community development, and problem-solving in times of internal conflicts and exogenous shocks. Community capital was a significant factor as it could be developed and transferred from generation to generation (Kirmayer et al., 2009; Green and Haines, 2015; Spring, 2018; Venning, 2021). Though this research was conducted several years ago the results of the systematic and continuity of effort are still applicable. The nature of community capital, the systematic and continual endeavor noted, can provide a clear perspective for policy makers and stakeholder agencies to realize community potential and opportunities of collaborative schemes for Indigenous communities and visiting scholars, both in the community and among external networks.

The continuing conflicting situation between Thai Indigenous communities and other actors concerning community rights to access natural resources for their subsistence is still active. It is important to emphasize that the accepted as sustainable way of life of the people, especially regarding the land conflict in shifting cultivation, is still not recognized as a constructive way of life through the lens of government (Thailand Science Research and Innovation, 2021). Urbanization and modern-day careers are known, as are other conditional factors causing

TABLE 6 | Summary of Karen natural resources capital, human capital, and social capital.

Community capital	Strength	Challenge	Intervention	Results	Community expression
Natural resource capital	- Food diversity on different landscapes	- State regulation - Increasing population - Commercial driven foods - Acceptance of home gardening	- Nutritional value assessment of traditional food and indigenous recipe - Promotion of home gardening	- More variety of home-grown vegetables	…Earlier, we did not grow ivy guard. Now we grow them in the backyard. It is good to have the plant nearby; we could rely on the yield…
Human capital	- Traditional local wisdom (food production and food use)	- Modernization and media influence on food choices and children's eating habits	- Formal/informal educational activities (landscape survey, gardening, cooking, and dinning) based on local wisdom	- Developed recipe with varieties of traditional ingredients	…The visiting researchers told us that our local vegetables hold lots of vitamins. Our wild foods are good. We want our children to eat much of these….
Social capital	- Community members have strong learning ability	- Child rearing tradition may obstruct the effectiveness of the project's intervention for behavioral changes	- Engagement of community leaders and community members in the process of design, education, and learning-by-doing activities	- Confidence of community leaders to educate children and community members	…Working together, we learned from each other (villagers and researchers); an exchange...
	- Plantation knowledge and skills	- In earlier times, people did not grow vegetables in home garden because wild harvest was abundant	- Knowledge provided by researchers on the decrease of some plant species and on nutritional value of Indigenous food	- Home gardening increase from 78 to 85.4%	…The Paco fern was not a farm plant as it is easy to find by any streams. We tried growing them in our farm plot so that it is easier to get, and it went well…
	- School children (older than 9-year-old) to help parents to take care of the young, farm work, and cooking	- Role of parents less influential today as children receive influence of school and time with TV/media			…We eat more vegetable as we realize it is good for our body. We are healthier. Before the research, we did not eat much vegetable for we did not know those essential nutrients in the greens.

changes in lifestyle and the food system, and which can be expressed as malnutrition including over-consumption, and other chronic diseases. In general, however, members of the Pwo Karen community of Sanephong are now more knowledgeable and capable to lead healthy lives by fully engaging with their traditional food system. They demonstrate promising potential to learn and adjust their way of life to collaborate with different agencies that aim to promote sustainable local food systems for health and wellbeing, and to protect against over-consumption and imbalanced diet.

Lessons Learned

The multidisciplinary team working in a relatively small case study in cooperation with a community consecutively for 4 years had multidimensional learning. Experiences reported here can be contributions for strengthening support for food systems of Indigenous Peoples throughout Thailand and in other countries.

The study of local traditional food diversity and nutritional values provided community members with knowledge of the significant health and cultural values of their Indigenous meals which inspired and strengthened community efforts to valorize and advance their food system for sustainable food security. The evidence-based active program over several years empowered the community to confidently cope with change. Improving nutrition with the local food system is complex with impacts from national and local policy, and societal changes in lifestyle and behavior. While improvements in nutrition measures of young children changed only modestly, the improvements were based on local community capital using local resources, and their human and social capital that is valued and trusted by the Karen as living heritage passed through the sacred forests and streams, thinking processes and wisdom, and respectful way of life.

The collaboration among Indigenous Peoples and researchers who valued the local culture was a significant element for trust and synergy and built confidence for the local leaders in their community capital. The outcome was a healthy dynamic cooperation throughout the process of work from data collection, goal setting, research design, problem-solving, and the communication to promote the significance of local food systems.

There is ample evidence from this research with the Pwo Karen in the Sanephong community that government policies to recognize, support, and enhance access to their traditional food resources will promote their health and wellbeing. It is hoped that strategies described here to strengthen the Pwo Karen food system can be usefully engaged by other Indigenous Peoples in similar settings.

ACTIONABLE RECOMMENDATIONS

Indigenous Peoples on all continents have clearly and unequivocally stated their purpose and imperative to assess and reclaim their traditional food systems for the many benefits they provide (Kuhnlein et al., 2009, 2013a; FAO, 2021; FAO Alliance of Bioversity International and CIAT, 2021); among many others). The United Nations Food Systems Summit (2021) affirms the potential of Indigenous Peoples to establish "effective landscape management, rights over land and resources, improved capacity for action, cooperation, and traditional knowledge at the center of sustainable food systems," and provides rationale and suggested solutions for this realization (Food Systems Summit, 2021). All member states of the United Nations are encouraged to affirm the Summit recommendations and develop national strategies for action. Of essential note is the need to address the management rights of Indigenous Peoples to their traditional territories as described in the examples of the Nuxalk eulachon crisis and the Pwo Karen need for access to their farming systems.

This welcomed United Nations development outlines ways to accomplish strengthening of all Indigenous Peoples' food systems along several lines of action for leadership by youth, women, and men and their scientific partners. Importantly, the imperative for documenting Indigenous knowledge with patterns of use of biodiverse traditional Indigenous foods and nutrient analyses is critical to broadly and interculturally share the traditional and scientific knowledge to accelerate change that will strengthen Indigenous Peoples' food systems. Guideline methods on how to do this documentation are widely available (Kuhnlein et al., 2006; McCune and Kuhnlein, 2011; Maundu et al., 2013; McCune et al., 2019). The FAO INFOODS network is a repository for food system information documentation that enables planning and activities in local communities and at national legislative levels.

With respect, recognition, and protection of this knowledge Indigenous Peoples' food systems can and should be actively used for intercultural education on the many health and cultural benefits of traditional foods of Indigenous Peoples. Indigenous and intercultural youth should be encouraged and empowered by understanding the knowledge and benefits of diverse Indigenous food systems and be given the resources to develop leadership for promoting this knowledge and related cultural activities in their communities and at national and broader levels. The school systems in both Nuxalk and Pwo Karen communities, explained above, are shown to encourage this learning in their local education settings to strengthen their food systems, and they have been active in sharing their experiences.

Building Indigenous community food pride, valorization, and stewardship is fundamental to maintaining the many benefits of Indigenous Peoples' food systems. These can be realized with recognition and utilization of the diverse social, natural, human and knowledge capital that develops and maintains culture and food systems in communities (Delormier et al., 2017; Argumedo et al., 2021; Cariño and Ferrari, 2021).

Indigenous community and national action should recognize and share the many benefits of Indigenous knowledge with free, prior, and informed consent. The contributions of Indigenous Peoples' food systems to global knowledge will support biodiversity protection, ensure the umbrella of human rights, and promote environmental sustainability and reduction of ecosystem threats, including climate change.

With this publication that includes detailed case examples of Indigenous People food systems, we hope that national and global support for strengthening Indigenous Peoples food systems will develop further with the recent imperatives of the United Nations Food Systems Summit. Sharing and strengthening the knowledge and values of an intercultural food system movement will develop evidence for effective policies to command overdue and well-deserved essential policy space to foster health and wellbeing of all humankind and the global common good.

Some examples of activities, among many, to strengthen Indigenous food systems suggested during the UN Food Systems Summit and World Food Day discussions are:

- Retain and share seeds of your crops within your community.
- Use your local food to decolonize your taste buds and your kitchen skills; seek and learn from Indigenous chefs to build your own cultural cuisine.
- Youth are encouraged to share and build the future together and pursue justice policies in their communities and with partners for food system sustainability.
- Put a tax on junk food in your communities; build local legislative power.
- Treat your Indigenous food and traditions with love, purpose, and care; teach these values at all levels in your schools and communities.
- Shift the paradigm of colonialism and materialism to build on local traditions and sharing.
- Activate your indigeneity and build food sovereignty and food and nutrition security with grassroots traditional knowledge and food practices of your knowledge keepers and food caretakers who are gifted with this ancestral knowledge.
- Build your education structures to create Indigenous food professionals.
- Bring your Indigenous voice to the table and take strength to avoid the temptations of junk food and other ultra-processed food.
- Reach out to learn and share with international networks for biocultural diversity and food sovereignty for Indigenous Peoples.

With the United Nations Food Systems Summit in the news and public consciousness, this is an exciting time for Indigenous

Peoples to activate their skills and knowledge to strengthen, protect, promote, and transform their food systems for better health and wellbeing.

AUTHOR CONTRIBUTIONS

HK and SC contributed to the overall outline and confirmed accuracy with their community collaborators and agreed on the final text. HK contributed the original section of the Nuxalk Nation text. SC contributed the original section of the Pwo Karen section. Both authors contributed to the article and approved the submitted version.

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Leveraging the Potential of Sorghum as a Healthy Food and Resilient Crop in the South African Food System

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An erosion of indigenous and traditional foods in the Global South has dramatically changed the global food system in the last 50 years. Reinvigorating these crops and the agro-biodiversity that they represent could provide benefits for healthier and more sustainable food systems. In South Africa, it has been proposed that studying indigenous plants more extensively and focussing on innovation to include them as mainstream foods on people's plates could improve food and nutrition security. With this background, this paper aims to contribute to addressing this challenge by researching sorghum (*Sorghum bicolor*) to identify the opportunities for innovating around sorghum as a healthy food and resilient crop. The paper traces sorghum through various encounters across the South African food system. The results point at clear areas where policy interventions could bolster the sorghum value chain. These include zero-rating VAT on sorghum products, investing more extensively in research and marketing across diverse stakeholders, raising awareness about the health benefits of sorghum and using public procurement as a way of instigating a market for novel sorghum products. The outcomes of a successful sorghum innovation programme could improve smallholder farmers' livelihoods, make a healthy food more accessible to South Africans and develop a local market for innovative products that utilize a crop that is resilient to projected climatic changes.

Keywords: food systems, sorghum, South Africa, indigenous food, healthy and sustainable diets

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INTRODUCTION

There have been widespread calls to align food systems more closely with nutrition and sustainability goals (Willett et al., 2019). Poor quality diets are a significant cause of ill health worldwide (Afshin et al., 2019). The diets of people living in poverty are typically monotonous and inadequately diverse, dominated by refined cereals; everywhere in the world, industrially produced foods low in nutrients and high in fats and sugars are associated with increasing levels of obesity and diet-related non-communicable diseases like diabetes (Hawkes, 2006; Popkin et al., 2012). The current food system also has an unsustainable level of environmental impact such as biodiversity loss from land use change processes like deforestation, overfishing, high levels of water extraction and greenhouse gas emissions (Gordon et al., 2017).

While food systems are currently not adequately supporting healthy diets and environmental sustainability, they also contain numerous opportunities for leverage points and agents of change (HLPE, 2017). As articulated by the HLPE, "food systems are sprawling networks of actors

responding to a wide array of incentives—all actors have a vital part to play in the pivoting of food systems toward, rather than away from, nutrition. These actions are different for each nation and for different areas within each country." (HLPE, 2017: p. 119). The same applies for sustainability, yet rarely are the two considered together in policy actions. There is a need for research to identify the actions needed from production to consumption to enhance both the nutritional and environmental aspects of the food system. Actions that can incentivise the production and consumption of healthy foods while also reducing environmental impact and remove perverse disincentives to change are critical to identify and promote.

A group of foods that are both nutritious and environmentally sustainable are indigenous and traditional food crops (ITFCs) (Akinola et al., 2020). While ITFCs were once widely consumed, over the past half century, the world has increased its reliance on three major cereals- wheat, maize, and rice- to the detriment of diverse diets (Frison et al., 2006). Although there are about a dozen cereal crops that are used for food, wheat, maize and rice account for 94% of all cereal consumption (Ranum et al., 2014). In contrast, many crops of regional importance, including cereals such as sorghum, millets and rye, have lost their status (Khoury et al., 2014). Prior to colonization in sub-Saharan Africa, ITFCs like *Sorghum*, *Amaranthus* species, Bambara groundnut (*Vigna subterranea*) and other crops were the main source of food for communities, but there has been a post-colonial displacement of these foods as they are replaced by foreign staples like wheat, and a concomitant stigmatization of these ITFCs as "poor man's food" (Demi, 2014; Chivenge et al., 2015; Mabhaudhi et al., 2018). As such, cultivation of ITFCs has become non-competitive and unattractive compared to the "major" crops that are promoted through formal seed systems and markets (Chivenge et al., 2015). The role of indigenous foods in diets continues to be eroded in line with global trends as Western diets and formalization of the food system continues apace (Drimie and Pereira, 2016; Mbhenyane, 2016).

However, the importance of ITFCs is being recognized. The African Model Law for the Protection of the Rights of Local Communities, Farmers and Breeders, and for the Regulation of Access To Biological Resources (OAU, 2001) emphasizes the contribution of indigenous farming systems in Africa to food sovereignty and security, and recognizes the need to maintain the genetic diversity, protected by Africa's smallholder farmers, as critical for the continent's economies, cultures, environment, food security and livelihoods (Munyi et al., 2012). In order to sustain these indigenous farming systems, there is a need to build markets and increase consumption: research suggests significant potential for innovation in indigenous plants to shift them onto people's plates (Dlamini and Siwela, 2015; Mbhenyane, 2016). Yet there is limited innovation in policy and investment around these species (Pereira, 2017). Increasing their consumption and production will require strategic policy interventions and innovation in order to overcome dominant trends in the food system. This study aims to identify entry points in the food system that could, if effectively incentivized (and disincentives removed), enable greater production and consumption of a specific ITFC—sorghum (*S. bicolor*) in South Africa. Learnings from this particular case study can be relevant for other settings where the inclusion of ITFCs are sought. Sorghum plays an important role in food security in some of the poorest places around the world, and a recent review provides evidence that its production is influenced by some key factors including agricultural inputs, population growth/economic development and climate change (Mundia et al., 2019). One of the key areas for research identified in the review is the need to go beyond these broad trends and to look into more local dynamics for planning purposes. This case study offers just such a contribution to the literature, focussing on sorghum in the South African food system, but understanding that it sits within broader, global dynamics. As a nutritious alternative to the cereal staples currently consumed in South Africa, sorghum offers a lot of potential as it is ecologically sustainable with potential for innovation to allow it to be consumed in a wider variety of ways (Hadebe et al., 2017). It is already used to make several food products in South Africa, including malted meal, beer, fermented or unfermented porridge, stews (with whole grains) and bread, and (as immature sorghum) a fresh vegetable (Bichard et al., 2005), but with a stagnating market, interventions are required for it to reach its full potential.

METHODS

Choice of Sorghum

Sorghum was selected for the study because it is one of the most important cereal grains for food consumption indigenous to the savannas of the African continent (de Wet, 1977).

There is archaeological evidence in the Sahara of the use of sorghum dating back 8,000 years (Wendorf et al., 1992) and that the domestication of sorghum likely took place in the Ethiopia-Sudan region in northeast Africa because the greatest plant diversity and variation in ecological habitats occurs there (OECD, 2016). Recent data from seed impressions on the Butana Group pottery from the fourth millennium BC in the southern Atbai region of the far eastern Sahelian Belt in Africa, show evidence for cultivation activities of sorghum (Winchell et al., 2018). It is clear that Sorghum formed an integral part of the caloric base of most Neolithic and Iron Age food-producing societies in sub-Saharan Africa (National Research Council, 1996) and following its domestication, humans moved cultivated sorghum across much of sub-Saharan Africa. However, sorghum is not restricted just to the African continent as many species are native to Australia and Southeast Asia (Lazarides et al., 1991). The cultivated sorghums have annual wild relatives native to Africa, Madagascar and the Mascarenes and introduced varieties as far afield as India, Australia and the Americas (OECD, 2016).

The species is highly variable with the division of cultivated sorghum into subspecies and races over the past century being somewhat archaic with many competing classifications, but there are officially 25 recognized species of sorghum, ranging from cultivated sorghum (*S. bicolor* subsp. *bicolor*) to its annual wild relatives (*S. bicolor* subsp. *verticilliflorum*) and annual weedy derivatives from hybridization between the two (*S. bicolor* subsp. *drummondii*) (OECD, 2016) (See the full nomenclature undertaken by Wiersema and Dahlberg, 2007). Sorghum has two

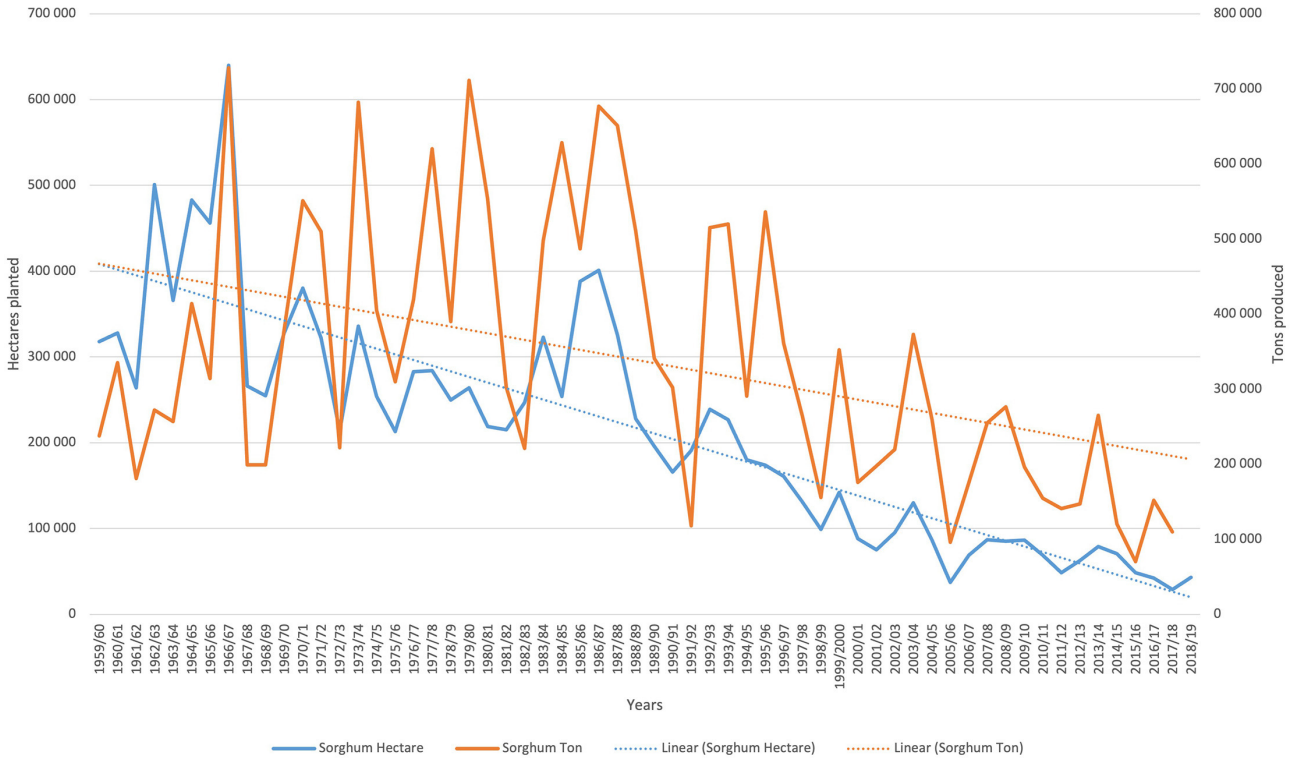

FIGURE 1 | Area of sorghum planted (Ha) and amount produced (tons) in South African from 1959/60 to 2018. (Source data: GRAIN SA).

main types- including a sweeter type (GM) and a more bitter type that contains more tannins (GH). It also comes in a range of colors- from white through to red. Sorghum's adaptability to a range of environmental conditions has led to it being cultivated in substantially varied climates with two main belts of cultivation in Africa: (1) the northern belt from the Ivory Coast north to the Sahara, and east toward Sudan and Ethiopia and (2) The second African sorghum belt includes the races *Kafir*, *Bicolor*, and *Caudatum*, running north to south from Ethiopia to South Africa (OECD, 2016). Sorghum's required annual rainfall ranges from 400 to 750 mm, which makes it an important crop for areas too dry for maize production and although it is primarily known for its drought resistance, cultivated sorghum can also withstand temporary water logging (OECD, 2016). Evidence from South Africa shows that different genotypes of sorghum have demonstrated adaptation to low water availability, emphasizing its drought tolerant capabilities (Hadebe et al., 2017). It is therefore ideal for production in water-scarce regions, especially under changing climate conditions such as those projected for South Africa, due to its high and stable water-use efficiency, drought and heat tolerance, and high germplasm variability (Hadebe et al., 2020a,b). Sorghum therefore holds much promise as a resilient option for farmers to plant under changing climatic conditions.

Africa is the world regional leader in total production of sorghum at 25.6 million tons, but it has the average lowest yield per hectare at 967 kg ha-1 (OECD, 2016). In South Africa commercial production of sorghum has declined in recent years (**Figure 1**) with only 28, 800 hectares planted in 2017, producing 109, 855 tons of sorghum. South Africa has therefore started to import sorghum, mainly from the United States, but also from Botswana, Brazil, Lesotho, Malawi, Ukraine and Zimbabwe, whilst exporting some sorghum regionally: to Botswana, Chad, Namibia, Swaziland, Tanzania, and Zambia (see **Figure 2**). Most of the commercially grown sorghum in South Africa comes from the Free State Province, followed by Mpumalanga (**Figure 3**).

Nutritionally, sorghum is mainly carbohydrate, followed by protein, fat and fiber; it contains 1 percent less fat and has a variable protein content that is generally 1–2 percent higher than that of maize (National Research Council, 1996). However, it is deficient in some essential amino acids, most importantly lysine- it contains about 45 percent of the recommended lysine requirement (National Research Council, 1996). Sorghum has low protein digestibility due to its tannins—the higher the tannin content, the lower the digestibility- and so it must be properly processed, which is perhaps why sorghum in Africa is generally fermented. Sorghum has high antioxidant and anti-inflammatory properties that are attributed to these tannins and so there is a trade-off between protein digestibility and other health benefits (Awika et al., 2003, 2009; Awika and Rooney, 2004; de Morais Cardoso et al., 2017).

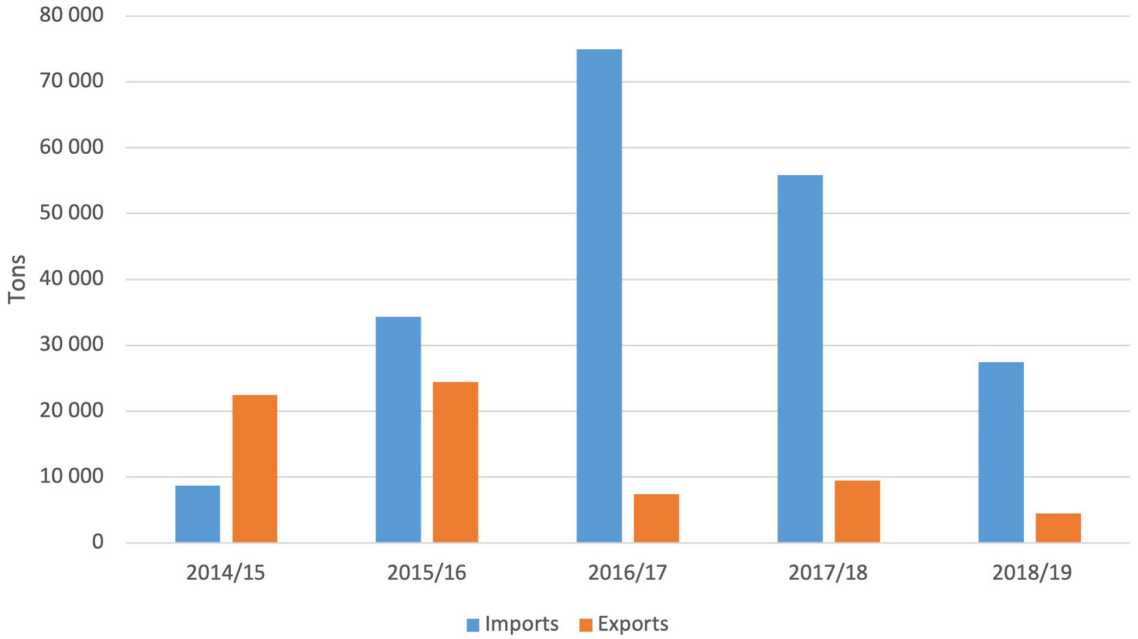

FIGURE 2 | South African sorghum imports and exports 2014–2018 (Source: SAGIS).

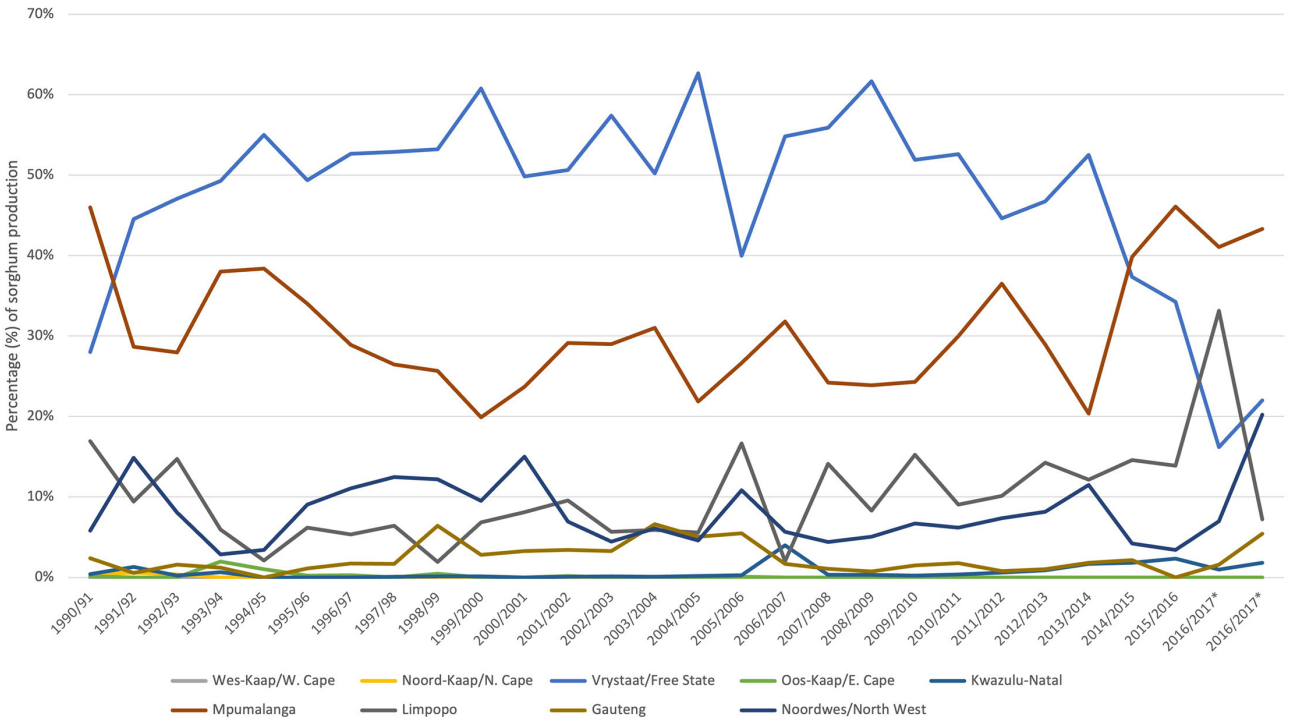

FIGURE 3 | Percentage of sorghum production (tons) by province 1990–2017 (Source data: GRAIN SA).

Study Methods

In order to draw on the richness of individual narratives and experiences, this paper employs an adapted "follow the thing" approach from the discipline of human geography (see Cook, 2004, 2017; Cook and Harrison, 2007; Pereira, 2010). The "follow the thing" method traces encounters with the material subject

TABLE 1 | List of key informants and the stakeholder group they represent.

Name/pseudonym	Stakeholder group
Malebogo Ngoepe	Urban Consumer
Sue*	Buyer and processor
Nemera Shargie	Research
Bob*	Industry and commercial farmers
Mark*	Industry and investment
John*	Industry
Kobus van der Merwe	Chef and innovator
Roelie van Heerden	Consumer and Innovator
Loubie Rusch	Indigenous food innovator
Mpho Tshukudu	Dietician
Riette de Kock	Research and innovation
Lawrence Makhapili	Civil society and smallholder farmer in Kwa-Zulu Natal Province
Temba Chauke	Smallholder farmer in Limpopo Province

**refers to a pseudonym.*

(sorghum) through different starting points in the value chain to unpack system complexities and potential interventions. The approach has similarities with other methods focused on tracing the product through the system (Hawkes and Ruel, 2020), such as value chain analysis or commodity chain approaches that focus on embedded power relations between production and consumption (Hartwick, 1998; Raikes et al., 2000; Gereffi et al., 2005).

Many research approaches tend to see food systems as linear. Yet food systems are complex adaptive social-ecological systems (Ericksen, 2008) making it important to employ a research methodology that can capture this complexity in a way that provides practical insights whilst not falling into a trap of assuming linear relationships. The "follow the thing" method enables an understanding of the connection to the more personal social-cultural drivers of change in the food system, such as cultural preference, aspirations and even the narratives that drive decision-making around food by tracing stories of particularly poignant individual encounters with the subject matter. This is necessary to provide a more grounded picture of reality as it plays out in the lived experiences of people, not just abstract value chains that move products from point a to point b (Pereira, 2021). This methodological approach allows the researcher to unpack the complexity of the food system through encounters with a specific subject and the personal stories associated with it. It uses an inductive approach to elucidate challenges and opportunities in the sorghum value chain based on people's actual experiences of the product (Cook, 2004). It does not aim to provide an in-depth analysis at each stage of the value chain, for which many more interviews would need to be undertaken at each point, and is therefore limited in the depth of information that it can provide. Rather, it attempts to provide a more holistic overview of a particular commodity in a system from a range of individual perspectives and through this perhaps to offer some novel insight that might be missed at a more granular level. There will be gaps due to the personal encounter aspect of the method that cannot encapsulate the full complexity of a food system, and it is likely that another person replicating the process would have different moments of encounter and therefore a different narrative to convey. However, this subjectivity, when acknowledged, should not limit the learnings that can be garnered from such an undertaking as it's often in the personal encounter that insights are revealed (Pereira, 2021).

The follow the thing method uses both standard qualitative interview techniques, as well as photography and experience as data. Qualitative information was primarily obtained through 13 semi-structured key informant interviews that took place between the last quarter of 2018 and the first quarter of 2019. The interviews started from the researcher's own networks who could talk to the different encounters of sorghum and then snowballed to ensure each core aspect of the value chain had been captured in at least one interview (see **Table 1** for a list of key informants).

Each interview had a core set of themes for discussion:

1. Constraints to production/ marketing/ consumption
2. Current market and future opportunities
3. Current government policies and programmes
4. Suggested government interventions to improve the production and consumption of sorghum
5. Other potential interventions for overcoming constraints and opening up opportunities

The interviews were recorded either on tape or in writing and then analyzed for responses based on answers to the five core themes. As emphasized above, the data are not meant to be representative of the entire sorghum value chain, but to present stories that are indicative of experiences across the food system that touch on different aspects of sorghum as a material that is produced and consumed across the country in different ways. From these stories and especially in their intersections, a picture of what interventions are deemed more appropriate from a range of perspectives emerged from the analysis. That said, throughout the paper, the information from the interviews is triangulated either through primary data from national databases (including GRAIN SA and the South African Grain Information Service- SAGIS) or through secondary sources, both in the peer-reviewed and gray literature, including Masters theses and publicly available government documents, like the minutes of Sorghum Forum meetings. The storylines of the encounters are more fully described in Pereira (2021), whereas in this paper, there is a greater reliance in the results on the gray literature and statistics to bolster the recommendations suggested for policy.

Ethical clearance was granted by City University of London, reference number Soc-REC / 80025567 / 22-04-18 and all whose names are used gave their permission otherwise where there is an asterisk next to a name in the paper, this is a pseudonym.

RESULTS AND DISCUSSION

The process of encountering and talking with people intimately involved in South Africa's sorghum system led to the identification of five key entry points where creating incentives and removing disincentives have potential to enable greater

production of sorghum in South Africa and thus contribute to improved nutrition and environmental sustainability in the country. Following the typology by Downs et al. (2020), these largely map on the availability, affordability and appeal of sorghum as a healthier and more sustainable food product. Whilst the richer narrative encounters are presented in Pereira (2021), the results are presented here with data from secondary sources to back up the claims made by interviewees and then directly discussed with reference to the literature.

Availability: Agricultural Research

The South African Agricultural Research Council (ARC)'s hub for sorghum is at the Grain Crops Institute in Potchefstroom. Sorghum is one of the ARC's mandate summer grain crops and although it has been researched since the 1980s, research capacity and funding has been very small compared to other cereal crops like maize and wheat. Historically, the ARC-Grain Crops breeding priority was improvement for bitter sorghum varieties, grown and malted for use in beer, but as people's preferences have changed toward clear beer (not made from sorghum) and increased awareness of the health benefits of sorghum, emphasis has moved to sweet sorghum (no or low tannin types) that can be milled for consumption as food and can also be used for ethanol production (Nemera). According to Nemera, the ARC's chief sorghum researcher, over the years the ARC has made sorghum germplasm collections sourced both locally and abroad, and at present maintains over 3, 800 accessions. Most of the accessions were assessed in batches for genetic diversity using morphological and nutritional traits. So far, sorghum has received little resource allocation for research and development compared to maize, but efforts have started to make the research approach more interdisciplinary, involving breeders, molecular biologists, agronomists, crop protection scientists and food technologists/nutritionists.

There is great potential for isolating potentially useful genes in South Africa because sorghum is an indigenous crop and there are races that have diversified there (Nemera). Smallholders still grow traditional varieties, but research support has been very low (Lawrence). The Limpopo province, where sorghum is mainly produced by smallholder farmers in intercropping systems, faces a major challenge in improving production and productivity (Temba). According to Nemera, in addition to varietal improvement and enhanced crop management, the use of quality seed significantly contributes to improved productivity of sorghum- one of the main challenges to its production. Open-pollinated varieties (OPVs), rather than hybrids, are the main varieties used in Limpopo and by other smallholder farmers. In 2010, the ARC-Grain Crops Institute started a sorghum seed production project with a group of smallholder farmers in Limpopo province with funding obtained from the then Department of Agriculture, Forestry and Fisheries (DAFF). Twelve farmers from the Difahlane project, in Makhuduthamaga municipality, and four farmers from the Ka-Dikweneng project in Lepelle-Nkumpi municipality, produced certified sorghum seed with assistance by the ARC and local extension officers. The standards for seed production have been met and enforced by the South African National Seed Organization (SANSOR), which controls the seed certification scheme. This success story of how research with farmers can translate into real change for small-scale farmers indicates what the potential is for more such projects to be undertaken. According to the Agricultural Research Council, training farmers in community-based seed production can have an impact on farmers' access to seed, provided that seed production costs can be kept lower than those of the formal seed sector and that the quality of the seed produced meets the farmers' expectations.

In the private sector, Pannar is the main seed company that worked on hybrid sorghum seeds, but since it was bought by Pioneer, most of its breeding work on sorghum has stopped and farmers are having to rely on imported seeds (Mark*). Pannar no longer maintains a specific breeder in South Africa and instead focuses on research overseas, mainly in the USA. Locally, there is a demand for hybrid seeds that are adapted to local conditions and some small seed companies are wanting to work with the ARC to get more capacity (staff, facilities, collaborators, testing sites). One of the main drivers of this work is climate change because sorghum is highly adaptive to heat and drought stress (Rosenow et al., 1983; Hadebe et al., 2017); conditions that are likely to become more prevalent across the African continent (James and Washington, 2013). Commercial farmers also want hybrids as they believe that these have a higher yield (Nemera). According to the interviews, most farmers would be keen to work with researchers on testing improved varieties as they are keen to plant sorghum as part of a crop rotation system. "*Getting improved, higher-yielding varieties of sweet sorghum, and focussing on local varieties not imported ones, will encourage farmers to grow more*" (Nemera). Furthermore, sweet sorghum types can not only be used for food, but also for bioethanol as they are more digestible and have a higher starch content. The strong international research on maize following the Green Revolution (GMOs, hybrid varieties etc.) has resulted in maize yields increasing to 3–5 tons per hectare in South Africa, although many of the characteristics that are bred are not those most desired by smallholder farmers (Fischer, 2022). However, sorghum yields have remained stagnant, so that now it makes up only about 2% of total grain production in South Africa. A strong focus on investing in appropriate sorghum research is needed to make it competitive with maize, and even if yields are never equal, other benefits such as drought-tolerance could be promoted.

Allocating such funds could allow farmers to be more competitive when growing sorghum. The relatively low yields need to be addressed through increased research on hybrids and OPVs that are developed in conjunction with commercial and small-scale farmers. More money therefore needs to be invested in research to improve varieties. According to Mark*, despite a renewed emphasis on indigenous crop research in the rest of Africa, South Africa does not seem to attract partnerships with research institutions to pursue breeding programmes. A concerted move to attract international funding needs to happen in conjunction with improved national coordination of funds.

Under the apartheid regime, the agricultural research system focused on commercial production, but this focus reoriented after 1994 when the smallholder community of mainly black farmers became a core focus of attention. Despite the political

reorientation, South Africa's agricultural system remains dualistic with around 35, 000 (largely white) commercial farmers producing almost all of South Africa's agricultural output with about 4 million (mainly black) small-scale farmers contributing very little (Aliber and Hart, 2009; Pereira and Drimie, 2016). Addressing these very different concerns is a difficult, yet not impossible task for agricultural research. The ARC gets their funding through Department of Agriculture Forestry and Fisheries (now the Department of Agriculture, Land Reform and Rural Development), but this is usually only sufficient to pay for salaries, infrastructure etc. and not for new research projects. However, at the provincial level, there is money allocated to agriculture from the Treasury, but they do not necessarily have the capacity (human and infrastructural) to undertake this research (Nemera). Combining the different funds, by making use of the resource capacity of the ARC and combining it with the money at provincial level for research done in conjunction with extension officers and farmers, could have a real impact. Meaningful co-produced research, especially with smallholder farmers is critical and could make these farmers more competitive. Research has shown that farmer-led seed systems have the capacity to supply seeds of good quality and it is important to recognize such systems and promote them as a means to meet the ever-evolving needs of smallholder farmers across the continent (Kusena et al., 2017). However, the research problems that need to be addressed extend beyond the agronomic to include grain marketing and processing as well as food product development, marketing and consumption. This is where clear partnering with universities and other research institutes, and funding these collaborations, is critical.

Affordability: Markets

Internationally, the sorghum trade has been declining since the 1980s, with the top five exporting countries (USA, Australia, Ukraine and France) selling primarily to meet demand for livestock feed (Pingali et al., 2021). Sorghum has to compete with maize as a preferred grain for feed and is only really competitive when its price is below that of maize (Pingali et al., 2021). This is a problem sorghum faces in South Africa too, but as a food crop rather than as feed. The local South African market for sorghum is ∼260 000 tons, of which in normal years half is produced locally and the rest is imported. Of what is produced locally, some goes toward industry, for wet beer brewing (∼6% of total production) and commercial use. Feed is a small component now (∼5,000 tons per year- 2% of the total) as it cannot be used in the formal feed sector due to the high tannin content of the bitter variety and erratic supply (*Bob). According to *Bob, feed suppliers have a set recipe for their feed that they cannot change just because there is an excess production of sorghum 1 year and not the next. He argues that there could be a good market for feed if sweet varieties were grown and sold at 80% price of maize, but currently no producer can meet these requirements. Bioethanol has been explored as a potential market for sorghum, but many of the projects in the Eastern Cape have not come to fruition although this could be an important component of the market in the future (Makanda et al., 2011). The main consumption of sorghum in South Africa is therefore for human consumption.

South Africa's has a series of "Grain Trusts" (Maize Trust, Sorghum Trust, Winter Grain Trust, Oil & Protein seeds Development Trust), which were formed following the closure of the agricultural marketing boards in the early 1990s. The main purpose of the Trusts is to support their respective industry, especially with regards to information and in particular to undertake and/or financially support scientific, technical or industrial research. This contrasts with the agricultural marketing boards that directly intervened in the marketing of produce. Under the previous board system, farmers could produce sorghum profitably as the boards would ensure that all sorghum was purchased. "The dismantling of the control boards with the enormous development capability they had exercised in establishing white agriculture, and the suspension of their protective and beneficial schemes; left the South African agricultural industry in general and the emerging sector in particular more exposed to the ravages of the market than in any comparable economy in the world" (Government of South Africa, 2020). Now, while the Trusts inherited the remaining assets of their respective boards, they no longer enable secure markets. The only remaining protection for sorghum is a 3% tariff on sorghum imports from all regions except the EU and SADC (SAGIS, 2020).

Maize is sorghum's direct competitor and it not only has higher yields, but maizemeal (the main food product of maize in South Africa) is also a zero-rated foodstuff, i.e., it is exempt from value-added tax (VAT). As maize yields have improved relative to sorghum over the past few decades, due to a much high investment in research and development globally, with prices being equal, farmers get more per acre for planting maize than for sorghum. The lower investment is also directly related to research capacity, as pointed out in the previous section, that is correlated with the higher financial capacity of the Maize Trust relative to the Sorghum Trust to invest in research and innovation. As the trusts rely on industry money, with the maize industry maintaining its hold and the sorghum industry becoming less competitive, this has also meant less funds available to the Sorghum Trust and therefore less funds to go into research for improved productivity resulting in a positive feedback loop. With a decline in production over the past few decades, sorghum is now seen as a niche crop, not a staple commodity. Mark* informed me that up until a few years ago, one of the biggest corporate buyers and processors of sorghum in South would actively target a specific group of farmers and offer them contracts at a premium price in order to keep them growing. However, as it became increasingly too expensive to compete with maize at this high price without a VAT exemption for their sorghum products, this contract is no longer offered and so these farmers are no longer planting. The decline in sorghum production has meant that, for buyers, domestic sorghum has traded at a high price for the past 10 years or so, but this has still not been a sufficient incentive for farmers to grow sorghum instead of maize, due to productivity differences. This has made it difficult to source high quality sweet sorghum for food products in the country. It has also made it next to impossible to offer a premium price to small-holder farmers as an incentive for them to enter the market.

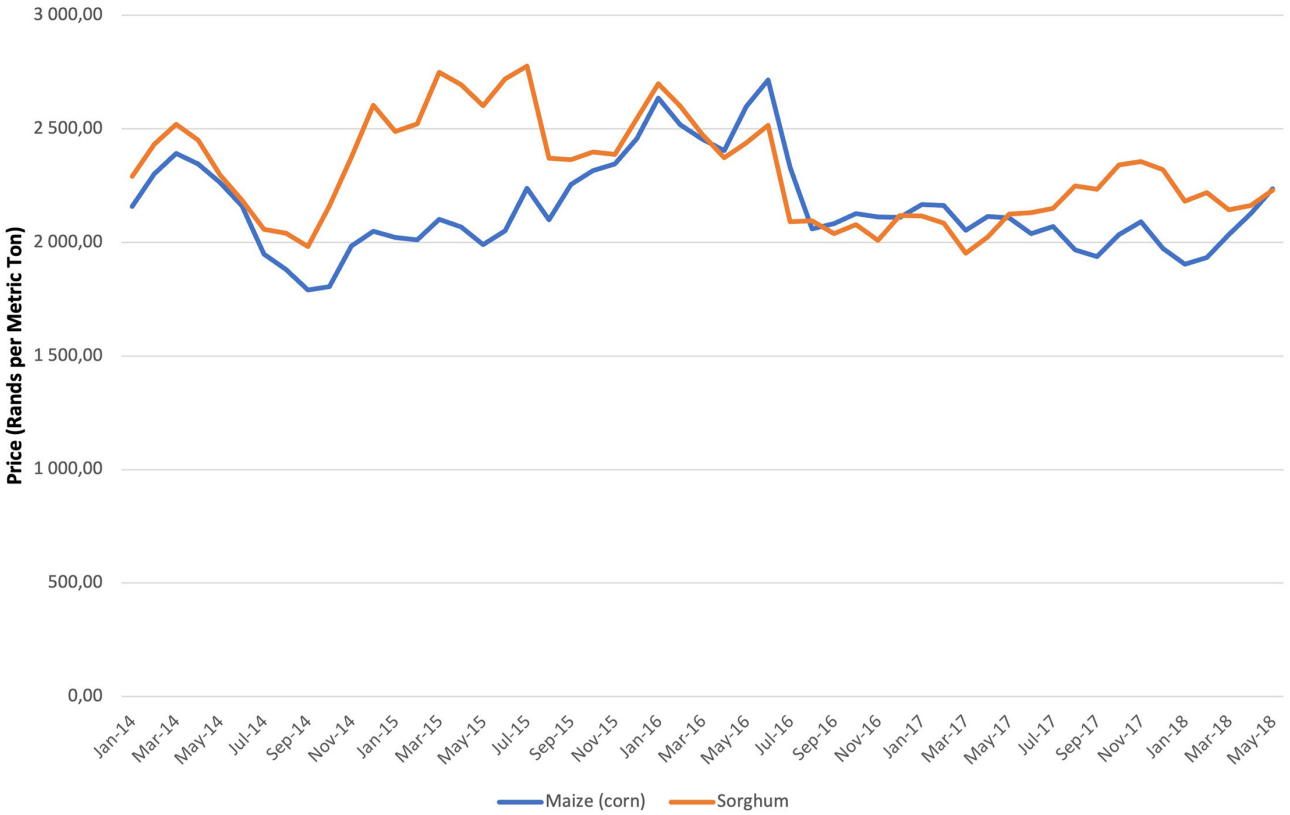

FIGURE 4 | Price of maize and sorghum January 2014 to May 2018 in ZAR per ton. Source: https://www.indexmundi.com.

Due to this decrease in production, South Africa has had to import sorghum in order to meet demand. Even though these days South Africa's processors rely on imported sorghum, some "*would love to buy locally… as we're a pip in the world supply*" and "*it's painful to buy internationally and try to get it here*" (*Sue). Most sorghum produced internationally is used for feed, but for food products in South Africa, companies require a certain quality and specific grade. Once the correct product has been sourced, it can still be difficult to divert the relatively small amount of sorghum that South Africa requires away from much larger international shipments; "*if you're not there, and it's not a waxed system, getting it here is really difficult*" (Sue*). South Africa imports much of its sweet sorghum from the Americas rather than the Ukraine and India, relying principally on the USA because the logistics from Brazil and Argentina can be difficult (*Sue).

As South Africa relies on the international market for its sorghum, and since import parity drives price, sorghum is generally either comparable to or slightly more expensive than maize on the international market (**Figure 4**). However, when it comes to the price that consumers pay, given the reduced cost of maize due to the VAT exemption, sorghum becomes uncompetitive. This makes maizemeal a much more price competitive product than sorghum and in the shops, "*whilst it is possible to pay in excess of 10.00 ZAR per kilo for sorghum, it is possible to get maizemeal at around 5.00 ZAR per kilogram*"[1] (*Mark).

Internationally, sorghum like other coarse cereals other than maize, has been neglected with support policies favoring the production and consumption rice, wheat and maize (Pingali et al., 2021). Similar to the VAT exemption that encourages maize consumption in South Africa, favorable procurement prices and subsidies to rice and wheat in Asia have led to a decrease in the consumption of sorghum. In India changing food preferences due to rising income and growing urbanization are further leading to a substitution away from coarse grains like sorghum toward fine cereals (Gali and Rao, 2012). Without a concerted effort to reinvigorate these resilient grains through innovation and policy support, these declining trends will continue. Unlike in many other developing countries and especially in Africa where it is usually grown for domestic consumption and stored in small quantities, with only small surpluses make its way to the markets (Pingali et al., 2021), there is commercial production of sorghum in South Africa meaning that that there is potential for the domestic market to overcome the traditional challenge of low and variable volumes, high transaction costs and long distances

[1] As an indication of this rough comparison, the cheapest Own Brand mabele meal product in the retailer Pick 'n Pay's online store is ZAR26.99 for 2kg whereas White Star super maizemeal is ZAR22.49 for 2.5kg.

to larger markets. However, affordability is a critical component of developing a thriving sorghum market in South Africa.

Affordability: Trade and Taxes

Sorghum prices are now directly linked to SAFEX (South African Futures Exchange) and pre-planting contracts are still afforded, but according to an international price. The sorghum contract on SAFEX can play a valuable role to ensure market and price transparency, but is not used to its full potential by market players. One of the possible reasons is because the previous size of the contract (100 tons) exceeded the entire production of a small sorghum producer. A smaller contract size on SAFEX may increase the use of the exchange for trading in sorghum as is the case for soybean, where the contract size on SAFEX is 50 tons and it is far better supported than the sorghum contract (Bob*). Therefore, on 2 November 2018, the Sorghum Forum resolved that a formal request will be made to the Johannesburg Stock Exchange Commodities Exchange to consider reducing the size of the SAFEX sorghum contract to 30 tons. As of 2020, this has been accepted (JSE, 2020) and over time might play an important role in incentivising smaller producers to enter the market by getting a guaranteed price through this mechanism.

If South Africa were to significantly increase local sorghum production, developing an export market for sorghum shows potential to be lucrative because it means that if there is over-production in 1 year, there is a mechanism to get rid of the surplus if it cannot be used for feed. South Africa used to export sorghum to Botswana, but they have now become almost self-sufficient, allegedly because farmers there are getting a premium price for their product (Bob*). China is a big export market for Australia where they brew a sorghum-based alcohol, Kaoliang, that is apparently the most popular in the world.[2] Accessing international markets could be beneficial for South Africa, but it would require a lot of research and most likely the establishment of bilateral trade agreements at a national level.

According to the Sorghum Forum, one of the major constraints facing the industry is the fact that sorghum is subject to Value Added Tax (VAT), which is not the case with maize and most wheat products[3]. Sorghum therefore has a 15% disadvantage to its competitor grains, which can historically be linked to its utilization in beer. Applications have been made to Government to exempt sorghum from VAT, but this has not been successful thus far. The opportunity of zero rating the VAT on sorghum was a strong incentive that emerged from many of the discussions. The argument is that if sorghum can be bought at the same price as maize, then people will start to shift their consumption because of its health benefits and because its indigenous heritage has marketing potential. However, there is some doubt as to whether lowering the cost would really be an influencer to get people to eat it more. Some think that there rather needs to be a concerted effort made in shifting perceptions about certain foods that are not seen as aspirational for historical reasons. It seems that any financial intervention to lower the price of sorghum would need to go hand in hand with a strong awareness raising campaign.

FIGURE 5 | Image of So Yhum! Sorghum biscuit products produced by researchers at the University of Pretoria.

Appeal: Innovating Novel Products

According to Riette, sorghum has an interesting taste profile. As opposed to maize, which is bland and therefore allows the consumer to eat lot of it without getting tired of the flavor, sorghum has a stronger taste. Riette says she likes to follow rye research and product development because it is a grain that also has a strong flavor, but many people appreciate this complexity and actively seek it out. She argues that consumers should be pushing themselves to appreciate more complex flavors. "*It is also necessary to describe and profile sorghum's taste profile as 'bitter' and 'sweet' doesn't really say much*" (Riette). Together with colleagues at the University of Pretoria, she has been developing processed sorghum products for the growing numbers of consumers in urban areas looking for affordable, convenient food. One such product is So Yhum! biscuits (see **Figure 5**). Similar interventions are underway in countries like India where the research councils and institutes are working on processing sorghum into a variety of products, and marketing them through Heritage Fresh retail outlets and Choupal Fresh (ITC) and other unorganized retail stores in Hyderabad (Pingali et al., 2021). Sharing across these developing country contexts could prove extremely fruitful as lessons are learnt- like the failure of cassava bread to take off in Nigeria despite decades of innovation and government support- and challenges are overcome. In the case of cassava in Nigeria, whilst decades of investment had gone into enabling the production of cassava bread in order to create markets for cassava farmers and reduce

[2]https://www.theatlantic.com/health/archive/2009/04/is-this-the-best-selling-liquor-in-the-world/13060/

[3]According to Kobus, there is a precedent for subsidizing local foods. The all-but-forgotten indigenous bean heerenbone (no English translation) were subsidized in the 1930s and the 40s.

billions of Naira spent on wheat imports, once the products hit the shelves thanks to government incentive schemes, they were not taken up by the public as insufficient market research had been done as to why people might prefer wheat bread or the stigmas associated with cassava that limits its potential to be an aspirational food (Pereira, 2018). One of these challenges for the South African market has been the strong flavor of sorghum compared to maize, but also a potential for lauding its health benefits.

Phenolic compounds in sorghum are responsible for its stronger flavors. Sorghum has some unique compounds not found in other cereals and these could have potential health promoting, anti-cancer, and anti-diabetic properties (Awika and Rooney, 2004; Awika et al., 2009; Park et al., 2012; de Morais Cardoso et al., 2017). Sorghum's bitterness comes from its tannins. For food purposes, the bitter (GH) type is usually not used, but, these varieties are more bird resistant. "*It's not that people cannot get used to more bitter flavors- some foods like tea and beer are bitter and that's what makes them attractive*" (Riette). However, there are other, more negative health implications associated with tannin-containing varieties. The compounds that cause bitterness also bind to proteins and divalent metal ions and when they bind the nutrients, they cannot be absorbed. This means that the food has low protein digestibility and poor mineral absorption, which is a negative in South Africa where there is a problem of anemia in the population.[4] On the other hand, the bitter types have other health promoting properties through anti-oxidants, with high potential for being health-promoting ingredients (Awika et al., 2009). Innovation to add other compounds like cowpea, roasted coffee, wheat flour and barley to sorghum products have all shown consistent results in improving the nutritive value, antioxidant properties and phenolic compounds (Salazar-López et al., 2018). Different ways of preparing sorghum can have different impacts on its nutritional properties, for example fermentation and extrusion cooking can have various benefits (Duodu et al., 1999; Cardoso et al., 2014; Salazar-López et al., 2018). Studies on chickpeas, sorghum, green gram and wheat showed that in general, sprouting and roasting provided more bio-accessible polyphenols and that there is an increase in tannin content of both the cereals on sprouting as well as roasting (Hithamani and Srinivasan, 2014). Furthermore, pre-cooking sorghum can be more convenient for consumers and can also give it interesting textures. "*I think it's open to much more investigation in the culinary sense*" (Loubie).

Yet as a food, sorghum also faces marginalization since maize became the main staple of the country. "*People think that maize 'pap' is traditional, but it isn't and we're also not eating it the right way by not nixtimilising it as maize was originally prepared in Americas* (See Moreno-Rivas et al., 2014). *We have the solution, but we don't use it. Apartheid government promoted maize for politics- it was seen as a waste food, but the new government hasn't changed this at all… Changing mindsets is difficult… (we need to) promote it (sorghum) as a healthy, indigenous grain"* (Mpho). Unfortunately, we now have a narrow idea of how to use sorghum and have been accustomed to maize, using sorghum only for ancestral offerings… "*you can't communicate with the ancestors with maize because they don't understand what it is and they get confused*" (Mpho).

TABLE 2 | Table of commercial sorghum products for human consumption in the mainstream market (based on data from SAGIS and Grain SA).

Type of sorghum product	Percentage of total production used	Main companies
Malted sorghum (e.g., Maltabella porridge, King Korn malted sorghum, Quick brew original beer powder)	∼36%	Tiger Brands, Nkosi Foods, Danhauser Malt
Meal/cereal (Mabele cereal, Morvite, sorghum flour to use in biscuits etc.)	∼54%	Tiger Brands, Nola (owned by Rainbow), Afgri, Brenner Mills, Botshelo Milling, Progress Milling, Pioneer Foods
Non-human consumption (animal feed, ethanol etc.)	∼10%	

Table 2 lists some of the main sorghum products and brands associated with the mainstream commercial market (i.e., not health stores or specialty food shops). As sorghum products are not the main brand for many of these food processing companies, they are often starved of marketing and attention, with more focus going onto other, more lucrative products (Sue*).

Interestingly, even when being served in the best of high-end restaurants, Wolfgat in Paternoster, sorghum porridge still comes with a stigma.

Roelie: "*One guest complained that it was famine food: How dare you feed me porridge in a high-end restaurant? And she sent it back…*"

Kobus: "*… that was the reaction she had- how dare you serve me poor man's African food? It's supposed to be a high-end experience… no, it's funny, some people just (have that reaction)…*

There has been a recent resurgence in popularity of "indigenous ways of cooking" like fermentation. If you go to supermarkets, mageu[5] has increased in consumption even in mainstream, and more upmarket areas. It seems that there is a trend to add some indigenous foods to products, like moringa (**Figure 6**). "*There appears to be a shift in local consumers mind that we're more interested in indigenous. I think there is a big market space and gap for proudly South African, proudly African, but you need interesting products and products that people can associate with. So mageu and some of those products that are linked to yogurt and similar packaging that makes them more marketable… "Super food" and "Ancient grain" branding* (can also be helpful)" (Riette).

[4]Overall in South Africa, the prevalence of anemia in people older than 15 years of age is 17.5% with female participants having almost double the prevalence (22.0%) when compared with males (12.2%) (Shisana et al., 2014).

[5]Mageu is a traditional fermented drink made from grains. It is also known as amarewu, mageu, mabhundu, and mapotho (See https://www.indemandmarketing.co.za/instant-sorghum-mageu-drink).

FIGURE 6 | Images of Mageu in a variety of flavors.

It seems that a focus on both sorghum's health benefits as well as its status as an indigenous food could be leveraged to encourage an increase in consumption if there is sufficient availability and development of innovative products. This means not just focussing on high-end consumers, but also to look at how taste palettes can become as accustomed to sorghum as they are now to maize products.

Appeal: Incentivizing Demand

Raising awareness about the benefits of sorghum as a viable alternative grain was perceived by all interviewees as really important. Sorghum is an extremely versatile grain- you can make sourdough bread, flapjacks, baked goods and many more things from it if you are willing to experiment. Mpho reminisced about Mosoko buns that were part of school feeding programmes under apartheid. She says that sorghum flapjacks remind her of those and recommends current school feeding programmes to give kids sorghum flapjacks. "*You can't feed kids the same thing every day, sorghum is versatile enough to offer something new all the time*" (Mpho). Incorporating sorghum and other indigenous grains at school level could be an important intervention not just in terms of nutrition, but also as a way to incorporate knowledge of these foods from an early age. For example, a study incorporating African indigenous leafy vegetables among school-going children in Kenya showed these to be an important intervention against malnutrition (Wakhanu et al., 2020).

The potential of introducing sorghum in schools as part of a school feeding process could have multiple benefits- both as a steady market for small-scale farmers and as a healthy meal for children. As suggested by Malebogo, incentivizing the planting of sorghum in school gardens could also go a long way in raising awareness about the benefits of the crop and in incorporating it into diets. Finally, an active campaign to communicate the health benefits of sorghum as part of a nutritional diet through healthcare workers and in school communities could be beneficial in raising people's understanding about the crop and countering existing stigmas.

All of the food innovators interviewed are experimenting with different ways to cook sorghum to make it more nutritious, delicious and convenient. For example, Kobus van der Merwe of Wolfgat is using sorghum as an alternative grain for gluten-free bread and also as a porridge to be served as dessert (Pereira, 2021). There are also nutritional benefits of certain cooking techniques; by letting it soak and sprout, the protein content of sorghum goes up (this is also the beginning of the malting process). The digestibility of chickpeas changes once they've sprouted, and this is often used by people on a raw food diet to get increased protein. The work by the University of Pretoria and their new impetus to market the products that they have developed could further help to share the benefits of sorghum and to push research further in understanding how to maximize the nutritional benefits of this grain. Having it on menus in restaurants, thereby making it accessible to ordinary South Africans, is also important- and not only in high-end establishments, but in ordinary cafés too (Pereira, 2021).

Some believe that there are definitely opportunities to expand the human food market, of sorghum but that it will always remain a niche product and so this expansion is relatively limited. They acknowledge that sorghum's excellent health properties have driven a small increase in demand for sorghum by health-conscious consumers. Others think that there is a much larger potential market if there is increased awareness about sorghum and its benefits. Malebogo suggested that a public health drive aimed at combating non-communicable diseases could highlight sorghum as an affordable African superfood that is an important part of a healthy diet. "*If sorghum were marketed as an indigenous wholegrain, I imagine it could gain popularity given its relatively low cost and health benefits*" (Malebogo). A greater awareness of the diets of different ethnic groupings within South Africa could also improve visibility and uptake.

CONCLUSION

The South African government has identified sorghum as crop of interest and in 2019 the Department of Science and Technology planned to conduct an impact study on sorghum, the outcome of this study should highlight the major issues that hamper the sorghum market. Hopefully the outcomes of this study will lead to better government understanding and support of the industry. What is clear from following sorghum in the South African food system is that it is an indigenous food with a rich and complex history. It has a comparable nutrient value to maize whilst also having high antioxidant and anti-inflammatory properties and when consumed as a whole grain helps meet requirements for dietary fiber. At the same time, it is more adaptive to climate variability, showing tolerance to drought conditions. It thus has the potential to help build resilience in the South African food system. However, there is a clear need to align the recent innovations around sorghum that has been happening amongst private individuals like chefs with the broader sorghum value chain that is floundering. Coordination between stakeholders is

key and the current mechanisms do not seem to be functioning adequately to hold the relevant knowledge exchange. There is also a fundamental need to learn from what is happening within other country contexts, like India, where there is also a drive to support increased production and consumption of these more resilient and nutritious grains. (Pingali et al., 2021), set out a variety of policies in sorghum producing countries that could be considered in the South African context. For example, the Nigerian government's attempt to set a guaranteed minimum price failed due to lack of funding and logistic constraints, but mechanisms like SAFEX or guarantees from large processing companies like Tiger Brands could overcome such constraints. In the longer-term, the potential for a sorghum food market to have to compete with livestock feed and ethanol production is a concern that needs to be considered in current policies.

A clear message from this research is that this may be a very opportune time for stakeholders interested in more diversified, healthier food systems to get government policy changes and significant private and public sector investments into sorghum research and value chain development. South Africa's industrial sector has sufficient technical capacity to produce a diverse range of sorghum-based products, but ensuring that these are affordable and that there is sufficient production is not an easy challenge to address. However, there are clear areas where policy interventions could bolster the sorghum value chain. These include zero-rating VAT on sorghum products, investing more extensively in research and marketing and coordinating better across diverse stakeholders, raising awareness about the health benefits of sorghum and using public procurement as a way of instigating a market for novel sorghum products.

These are clear policy interventions that could bolster the sorghum value chain in South Africa whilst improving smallholder farmers' livelihoods, making a nutritional food more accessible to South Africans and developing a local market for a crop that is resilient to projected climatic changes. Compared to maize, which is a staple food in South Africa, sorghum is relatively apolitical and is not as threatening to vested interests (Bernstein, 1996). It could therefore be used as a mechanism to engage multiple stakeholders (small and large-scale producers, millers, large and small industry players, government, civil society) about what a more sustainable and healthy food system in South Africa could look like, and what interventions are needed to get there.

If South Africa were to get it right in terms of developing a legitimate local and potentially even export market for sorghum, it could be a critical case study from which other countries facing similar concerns, like Nigeria, Ethiopia and India, could learn. How to engage an innovation system around indigenous crops that acknowledges indigenous knowledge systems and then to link it to address existing challenges and opportunities within the broader food system is a globally recognized problem (IPES-Food, 2016). Understanding the case of sorghum in South Africa could be a first step toward wider appreciation of and investment in this area of study for the innovation and policy communities.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by City University of London Social Science Ethics Committee, reference number Soc-REC / 80025567 / 22-04-18. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

LP led and undertook the research and first draft. CH was the PI and edited drafts. Both authors contributed to the article and approved the submitted version.

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Access to and Utilization of Wild Species for Food and Nutrition Security in Teso and Acholi Sub-regions of Uganda

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Wild foods significantly contribute to the global food basket, and food and nutrition security. Worldwide, wild food species form an integral part of local diets and their widespread assimilation into local food culture suggests an untapped potential to ensure easy availability and access to micronutrients for sustainable food systems. However, wild species are often overlooked within nutrition-related policies, and their levels of availability remain unknown. This paper, therefore, focuses on understanding the changes in availability, access and utilization of wild animal and plant species in Teso and Acholi sub-regions of Uganda. A four-cell agrobiodiversity mapping protocol was applied through focus group discussions to establish the different wild animal and plant species that have played and still play a role within local communities' livelihoods in the two sub-regions. Findings showed that at the time of the study (2017), wild foods were considered to be important contributors to food and nutrition security, although the number of species reported to be available was slightly lower [91 (Acholi) and 103 (Teso)], compared to 20 years ago, where around 109 edible wild species were reportedly available in both the Acholi and Teso sub-regions. Reasons for the decline included (i) increased cultivations, and (ii) natural habitat destruction due to settlements and changes in land ownership. In the latter case, individual owners have further fragmented their land and do not allow villagers to freely participate in hunting and gathering. Lastly, rebel unrest increased feelings of insecurity, and thus prompted a decline in hunting and gathering. The noted presence and contribution of wild foods in Teso and Acholi calls for collective efforts to increase access to knowledge on the value of these wild foods for not only food and nutrition but also for their potential contribution to the social and cultural lives of the people.

Keywords: wild species, utilization, food and nutrition security, changes over time, Uganda, wild plant species for food, wild animal species for food

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INTRODUCTION

Hunger and food insecurity remain major global challenges with approximately 768 million people reportedly undernourished and one in three people having inadequate access to food in 2020 (FAO et al., 2021). Although agroecosystems have been modified to ensure plants and animals can be used as food, fiber, fodder, medicines, traps, and weapons, the global food system is currently

dominated by only three food crops (wheat, rice and maize), while 5,000 food crops are estimated to exist (Bharucha and Pretty, 2010; FAO, 2021; Padulosi et al., 2021). According to FAO (2019), the drivers of this trend toward such predominance have mainly been: population growth and urbanization; climate change; natural disasters; infestations of pests, diseases and invasive alien species; emerging advanced technologies and innovations; changes in management and use of land and water; overexploitation of available resources; and implementing policies that do not favor conservation. Nevertheless, there still exists substantial evidence that wild foods which are part of neglected and underutilized species (NUS) remain an important component of the global food basket (Bharucha and Pretty, 2010), are playing a significant role in traditional food systems and are still often known to Indigenous and traditional communities (Padulosi et al., 2021). The term wild in this regard implies spontaneous growth outside of cultivated areas (Heywood, 1999). Overall, wild foods can play a vital role in providing food and nutrition security, either by income generation or consumption (FAO, 2019). It is estimated that globally, over one billion people use and incorporate wild foods into their diets (Burlingame, 2000). As such they are integral to traditional food systems, especially when availability is scarce, the household budget is insufficient or market access is difficult (Borelli et al., 2020). Often these wild foods have the same or even superior nutritional profiles compared to their cultivated counterparts (FAO, 2019). Across Asia and Africa, wild foods obtained from non-domesticated species are still an important resource, as a recent review corroborated, reporting agricultural and forager communities using 90–100 different wild species (Bharucha and Pretty, 2010). Ray et al. (2020) report the whole of India has more than 1,000 reported wild edible plant species, yet aggregate three-country national use has been estimated to be between 300 and 800 species for India, Ethiopia and Kenya. In Tanzania, it was established that the Tanzanian Batemi agro-pastoralists use 31 wild species as food, six wild species as thirst quenchers, seven for chewing, two as flavoring, one for honey beer and a further 35 wild, edible plant species have been incorporated into their cultivated systems (Bharucha and Pretty, 2010). However, at the regional and national level, the available food balances that guide policies on trade, aid and the declaration of food crises, notably do not include the contribution made by wild edible species (Bharucha and Pretty, 2010; FAO, 2019). Wild foods are often missing within food composition data and the information on use, conservation and state are limited, as well as financial support and lack of prioritization (Bharucha and Pretty, 2010; FAO, 2019; Borelli et al., 2020). Further, wild foods or NUS, in general, are perceived to be "food for the poor," or "women's food" (Powell et al., 2014; Hunter et al., 2019; Borelli et al., 2020). This, therefore, enhances the probability of neglecting the provisioning ecosystems and supportive local knowledge systems that sustain food chains around wild foods.

In Uganda, the situation is not different. Uganda ranks among the countries with the greatest diversity of animal and plant species with almost 19,000 recorded species of fauna and flora, even though the country only occupies ∼2% of the world's area (land and water) (NEMA, 2016). Still, malnutrition persists in Uganda and 70% of the population experienced moderate to severe food insecurity in 2018–2020 (FAO, 2021). According to NEMA (2016), the National Environment Management Authority, Uganda hosts around 11% (1,063 species) of the world's recorded bird species, which represents half of Africa's bird species It also hosts 7.8 % (345 species) of global mammalian diversity, or 39% of Africa's mammal diversity (NEMA, 2016). In addition, Uganda hosts 19% of Africa's amphibian species, 14% of Africa's reptile species, and 600 different species of fish. A study of indigenous woody species in Agoro-Agu Central Forest Reserve in Northern Uganda identified 86 different woody plant species where 16% are used for consumption within the area (Olanya, 2020). In the Teso-Karamoja region, a total of 100 edible plant species were identified within the forest reserves (Ojelel et al., 2019), while 73 edible plants from 39 families were identified in the Acholi sub-region (Nyero et al., 2021).

In another study carried out in Bulamogi, Uganda, edible wild plants embraced 105 mostly-herbaceous (70.7%) species (Tabuti et al., 2004). Most of the edible plants were found to yield fruits mainly consumed as snacks (41.4%) (Tabuti et al., 2004). However, the wild foods were noted to be infrequently eaten and their consumption was limited to casual encounters, periods of food shortages and as supplements to major food crops (Tabuti et al., 2004). The main reasons reported by Tabuti et al. (2004) for reduced use and neglect of wild foods were (i) the wide variety of introduced cultivated foods and (ii) erosion of traditional knowledge about wild foods (Tabuti et al., 2004). In addition, according to Plumptre et al. (2016), other major threats to biodiversity in Uganda include (i) the increasing human population that fuels a high demand for land in addition to overutilization of the species, and (ii) consequences of climate change that reduce their natural habitats leading to a decline in species or their extinction (Plumptre et al., 2016).

This paper focuses on mapping out the different animal and plant wild food species used within two sub-regions of Uganda, assessing the changes over two distinct time periods in their availability, access to and consumption by smallholder households. The paper aims to understand the changes and factors that influence, the availability, access to and utilization of wild foods for food and nutrition security comparing the two time periods. The past period (1997) was purposively selected, based on the time when the target communities of the Teso sub-region in the East, and Acholi sub-region in Northern Uganda had to leave their homes to live in camps due to the heightened Lord's Resistance Army (LRA) rebellion. The insurgency due to the civil unrest lasted for 20 years (1985–2005), leading to internal displacement and community raids which disrupted the communities' practices related to food production, food acquisition, food handling, food consumption, and other community practices that influence species' conservation. The current period (2017) was selected based on when the communities were back on their farms.

METHODOLOGY

Description of the Study Area

The study was conducted in two sub-regions of Uganda, located in the Northern and Eastern regions of the country, named Acholi and Teso, respectively (see **Figure 1**). Both sub-regions suffered the brunt of insurgency from 1985 to 2005 and in addition, Teso experienced intermittent insecurity between 1990 and 2003. The Acholi region is predominantly occupied by the Acholi ethnic group and is composed of seven districts (Agago, Amuru, Gulu, Kitgum, Lamwo, Nyoya, and Pader). The sub-region occupies a total land area of 29,174 km^2, which accounts for 12% of Uganda's total land area (Kasusse et al., 2015; Uganda Bureau of Statistics, 2018). This region is situated at a mean altitude of 1,050 m above sea level and experiences on average an annual rainfall of 1,434 mm with the temperature ranging between 16.8 and 30.5°C while the soil types are mainly petric plinthosols (Acric) and leptosols (Uganda Bureau of Statistics, 2015; Akongo et al., 2016). On the other hand, the Teso sub-region covers a land area of approximately 13,031 square kilometers comprising the districts of Amuria, Bukedea, Kaberamaido, Kapelebyong, Katakwi, Kumi, Ngora, Serere, and Soroti (Dbedia, 2022). The region experiences a humid and hot climate modified by its large swamp area, which mediates the rains over the great plain of Central Karamoja, and the Western slopes of the volcanic mountains of Napak (Kamalinga), Kadam (Debasien), and the Northern side of Elgon (Masaba). In general, the area receives bimodal rainfall averaging between 1,000 and 1,350 mm per annum supporting a predominant grassland savannah vegetation (Egeru, 2012; Okoboi, 2016; Uganda Investment Authority, 2016). Teso sub-region is predominantly inhabited by the Itesot ethnic group, which is the fourth largest ethnic group in the country (Uganda Bureau of Statistics and ICF, 2018).

Due to insurgency occasioned by the LRA rebellion and People's Redemption Army (PRA) in Teso, and the Karamojong cattle raiders, both Acholi and Teso suffered disruption in the social and agrobiodiversity systems which may predicate changes in the current culture. The changes between the past and current traditional systems can affect the way land is governed and household food security status. It is for this reason that the study was conducted in Acholi and Teso.

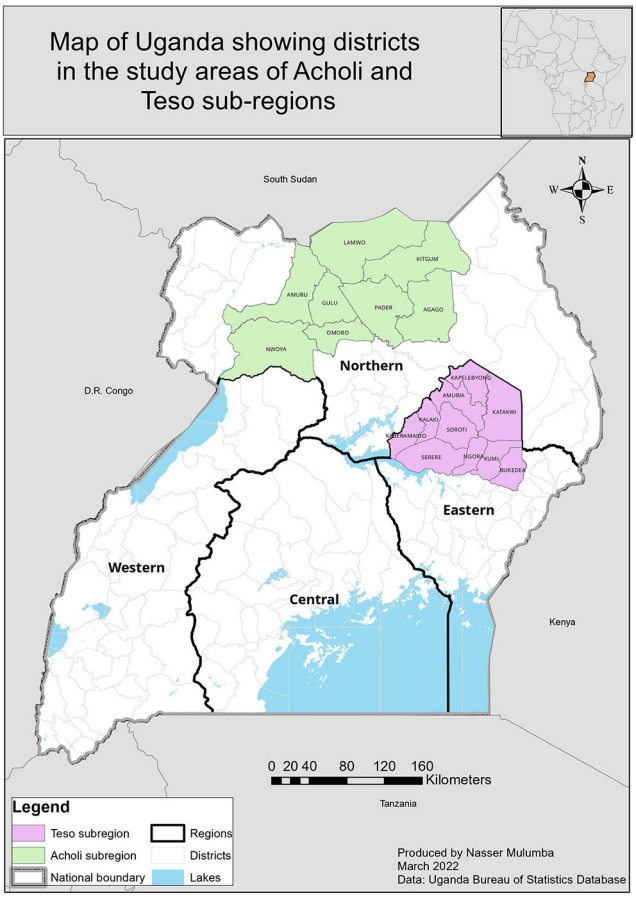

FIGURE 1 | Map of Uganda highlighting Teso (purple) and Acholi (green) sub-region and districts.

Selection of Study Sites and Sampling Procedure

The data used to develop this article was part of data collected during a baseline study for the project on "*Influences of land impermanence syndrome on conservation and utilization of agrobiodiversity and the subsequent effect on food attitudes and consumption patterns.*" The study regions, districts, sub-counties and specific project sites were selected in 2017 following a mixed-method (subjective and objective), multi-stage approach as shown in **Figure 2**.

Districts were selected based on the opinions of local leaders in both sub-regions. Four districts were purposively selected subjectively considering land security perceptions, selecting one district per region representing an area perceived to be land insecure (regarding land ownership), and one district which is considered to be land secure. After articulation and description of the study objectives by the core project team and through consensus, local leaders in the Acholi sub-region selected Nwoya and Lamwo, while those in the Teso sub-region selected Amuria and Bukedea. In the second sampling stage, four sub-counties per district and in each sub-county, one village (16 villages) were selected following simple random sampling.

Participants and Data Collection

The study employed a qualitative method approach that involved the use of focus group discussions (FGDs), which have the advantage of enabling in-depth information gathering within a considerably shorter period (Gundumogula, 2020). A total of 32 FGDs were targeted between November and December 2017. Group size ranged from 10 to 15 participants and the discussion lasted between 5 and 8 h. Each group was homogenous representing one gender to allow free participation basing on social and gender dynamics of the target communities. Thus, in each village two FGDs (one female and one male) were targeted. Additionally, FGDs comprised a mix of participants of all age groups with minimum age of 18 years and participants older

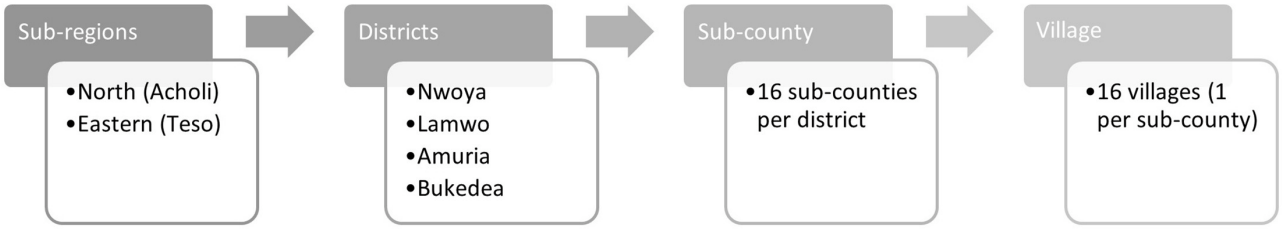

FIGURE 2 | Multi-stage sampling process to select the focus group discussions.

than 35 years old specifically encouraged to participate. Based on an existing *FGD methods guide for facilitators and note-takers*, developed by the PAR (2018), each session began with a brief introduction of the project, and each participant, and continued after verbal consent was obtained from each person (PAR, 2018). Every FGD was guided by two well-trained research assistants in the local language and was recorded using both notebooks and voice recorders. During the participatory FGDs, the trainers constantly reminded the participants that all their views were important, assured them of high level of confidentiality in data collected and created an open atmosphere for the participants to speak freely by avoiding the dominance of one individual or group of individuals during the discussion directly asking for the opinions of individual or group of individuals whose views seemed not to be coming out during the discussion. As the interest of the current paper is on the wild foods' availability, access and utilization, only FGDs that captured the respective information were considered within the analysis.

Collection of Qualitative Data

Qualitative data on wild foods was collected following the agrobiodiversity mapping protocol, also called four-cell analysis (FCA), developed by Bioversity International in 2006 (Lochetti et al., 2020). In general, the four-cells were established to document the role of agrobiodiversity in the local food system. The tool is created according to two axes, labeled for a relative number of households (many vs. few) and area of cultivation (large vs. small) (see **Figure 3**), to measure richness (abundance) and evenness (distribution) of local crop diversity, common, unique and rare/endangered varieties or species. The participatory method identifies the most important biological assets that play any role within local-community livelihoods. It also examines the species' utilization across four components: availability/production, consumption, purchase, and sale of various food species (including wild plant and animal species) (Lochetti et al., 2020). Additionally, the element of access to the species and the ease or difficulty with which households in the community find the species are considered, to help indicate the availability or scarcity of a food species. This study examined the current (2017) and past (before 1997) availabilities (access), consumption, sales, and purchases of wild foods. As illustrated in **Figure 3**, species that are available to many households and easily found (common) would be placed in cell 4, while a species that is available to many households but is difficult to find (unique and vulnerable) would be placed in cell 3. Furthermore, a species that is available to a few households and easily found would be placed in cell 2 (unique and vulnerable), while a species that is available to a few households and difficult to find (rare and under threat) would be placed in cell 1. The same method is applied to consumed, sold and purchased wild food species.

In addition, to help place the species within the 4-cell categories reasons and examples for the different categories were provided which can be seen in **Figure 4**.

Limitations of the Data

We acknowledge limitations that may have arisen from a possible lack of precision in the language used in the transcripts. The audio recordings were transcribed from Acholi and Itesot to English. Thus, some nuance could have been lost in the translation, although most of this was addressed during the review which involved transcribers exchanging the transcripts and checking to see whether the audio recordings were transcribed as accurately as possible. Also, the list of wild species provided is a mix of the local language and English. The communities were encouraged to name any type of edible species and often members did not know the name in English. Where possible the local names were validated *via* discussion with colleagues, the local community and available literature (Kimani et al., 2020). However, we acknowledge, that within this research it was a challenge to validate all named species and thus, we list the folk taxonomies, e.g., using the names and explanations provided by the participants instead of the specific scientific taxonomies and traits. Therefore, the number of named species might differ if species could be also identified through scientific taxonomy. Future studies should ensure data backup with scientific names and if possible, obtain pictures of any named food species for further verification. Due to the nature of FGD to let the community speak freely and with the exercise focusing on nine food groups, the information collected at this level focused on species, further studies could be done to move forward and look into varieties within species. In addition, this study presents information gathered only through FGDs it doesn't include details on quantities consumed and level of nutrients.

Data Analysis

In the first analysis step, data on the wild plant and animal species were of interest and the perceived levels of availability, purchase,

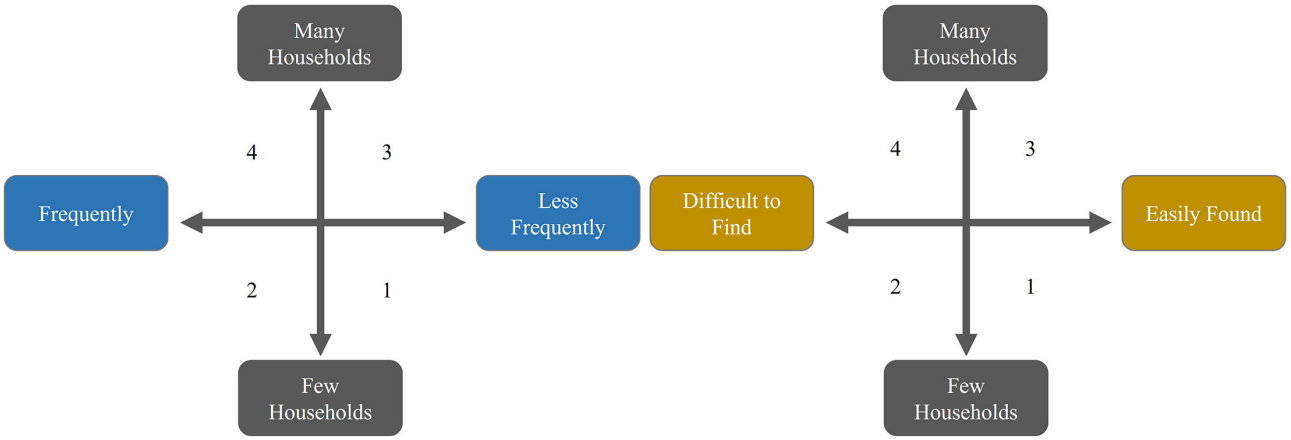

FIGURE 3 | Four-cell agrobiodiversity data collection tool.

selling and utilization in diets of each species considering dimensions such as (i) large and small areas; (ii) many and few households; and (iii) more and less frequently following the definitions and specifications of the community in both sub-regions. An example of how the maps looked can be found in **Figure 5**. The analysis included sorting and looking at the recordings to map the qualitative responses of the participants. In general, the village was considered as the target unit of the analysis. In the second step, the results of four-cell agro-biodiversity data collection were used to compare species' diversity for both the current (2017) and past (1997) periods to ascertain whether there were changes in wild species' diversity and levels of utilization over time, according to folk taxonomy. As reported by Harris and Mohammed (2003) and Ojelel et al. (2019) who classified plant based wild foods according to use category, this study adopted the same approach. The wild foods were later categorized as per what was obtained from the wild and the actual use category especially for plant-based foods. The categories included animal, bird, fish, fruit, insect, leafy vegetable, and stem/root/tuber.

RESULTS

In total, FGDs from 16 villages within the four sub-counties were considered within the analysis of wild foods. Fourteen FGDs (eight female and six male) adequately listed information on wild foods in Teso, while nine FGDs were considered for Acholi (three female and six male). Since data collection was not solemnly on wild foods but incorporated 8 other food categories (starchy staples, domesticated animals, fruits, vegetables, legumes, milk and milk products, eggs, oils/fats) in some villages not all data gathered from both male and female groups was complete enough to enable the desired analysis. For instance in one of the districts, Nwoya district, all the complete data came from male FGDs (see **Table 1**). In the following, we present the results separately according to Teso and Acholi sub-regions.

Wild Species in Teso

The participants within the Teso FGD named a total of 109 different wild species. Of those, 108 were available in the past compared to 103 species in the current period. The prevalence of the foraged wild foods according to species type comparing the past and current periods is summarized in **Table 2**. A complete list of the local names or folk taxonomy mentioned by the participants can be found in **Supplementary Table 1**. For both periods, the most listed species types were animals (32%), followed by birds (19%), fruits (18%), and stem/root/tuber (13%). In the past, more animals and uncategorized species were found compared to the current period, but the differences are small.

Four-Cell Dimension on Village Level

In total, at the sub-regional level, 490 different species were identified as available and accessible during the focus group discussions, which are grouped into six different wild species. Thirty species more were named to be accessible in the past compared to the current period. The difference between current and past periods according to the four dimensions displayed in **Figure 6** displays how often different wild food species were named by the participants (count). The greatest decline can be seen within the wild animal species. As for the dimension of consumption only three species are named to be consumed today compared to the past, although this does not consider the perception if found by a few or many.

Disaggregated per village, almost all of the wild species were available to many households and easy to find during the past period, but this changed over time and the availability in the current period is more diverse and different. **Table 3** displays the different species mentioned as being available per village in the Teso sub-region according to the locations and perceptions of the participants. A list of wild species according to folk taxonomy per level of availability can be found in **Supplementary Table 4**. The results generally revealed a decline in the level of availability of the different wild animal species in Teso over time. For instance, in Atarukot village, 4 animal species were easily available to many households during the

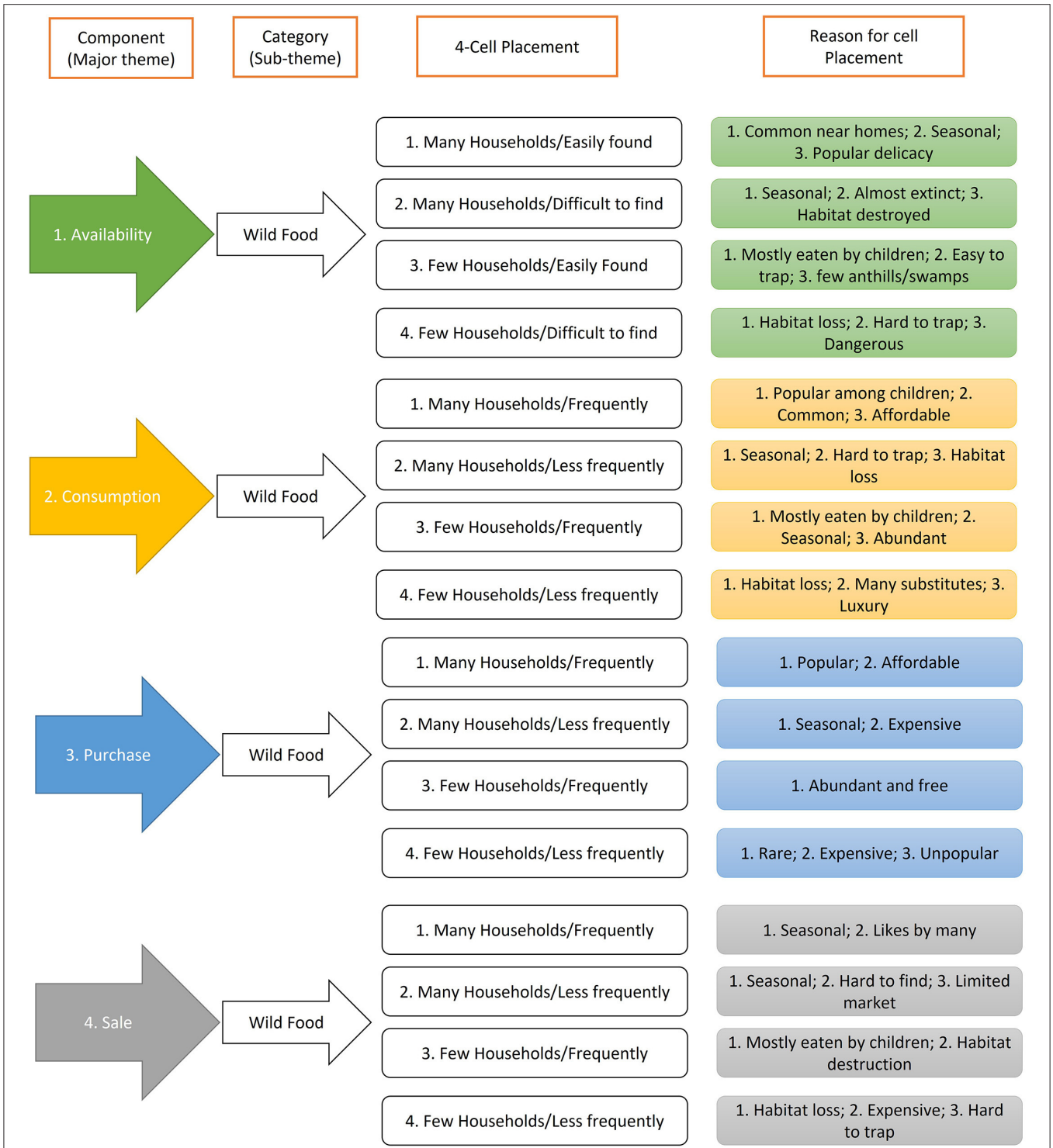

FIGURE 4 | Example reasons for the placement within the four different cells of the tool.

current period compared to fifteen species that were easily found by many households during the past period. Similar declining trends were also observed in the other villages in the Teso sub-region.

Most of the participants across the FGD mentioned that the wild species were difficult to find during the current period and only available for a few households, displaying that most of the common wild species in the past are rare and under threat

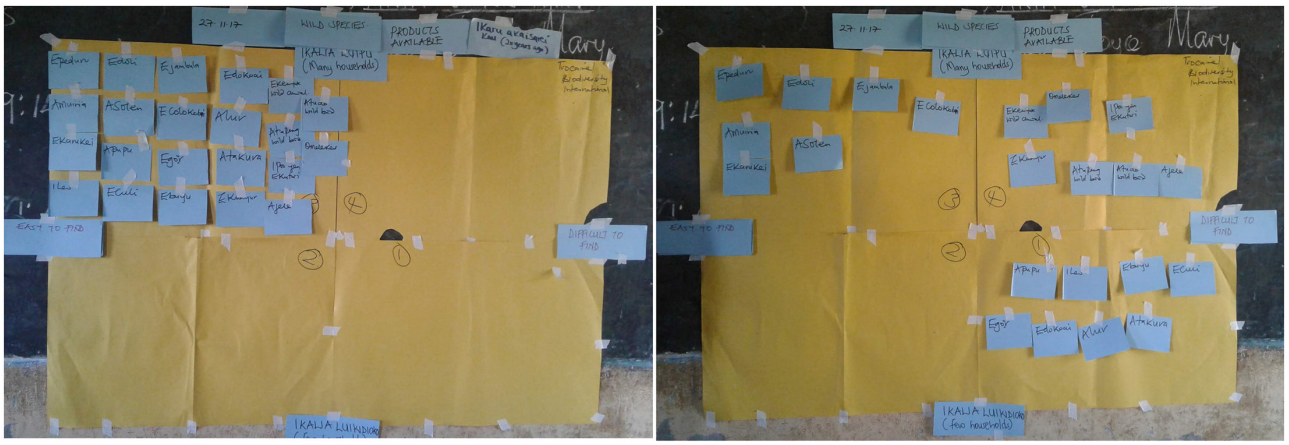

FIGURE 5 | Example of a 4-cell mapping tool for wild species for the past **(left)** and current **(right)** period.

TABLE 1 | FGD distribution across the two sub-regions.

Sub-region	District	Sub-county	Village	Gender
Teso	Bukedea	Koena	Katekwan	Female & Male
		Bukedde	Adodoi	Female & Male
		Kocheka	Kocheka	Female & Male
		Kidongole	Kidongole	Female & Male
	Amuria	Morungatuny	Acele A	Female
		Obalanga	Akileng	Female & Male
		Okungur	Atarukot	Female & Male
		Kapelbyong	Omokoti	Female
Acholi	Lamwo	Parabek ogili	Mudu West	Female & Male
		Agoro	Iromo	Female
		Lokung	Ngomoromo	Male
		Padibe east	Alenyo south	Female
	Nwoya	Purongo	Pabit east	Male
		Alerro	Bwobonam B	Male
		Anaka	Lamoki	Male
		Koch lii	Korobar	Male

today. This was mostly attributed to the reduction in the size of the communal land from which most of the wild species were gathered/ hunted. One respondent explained that in the past the villages had high vegetation and the number of villagers was smaller, hence the wild animals had more space and were also easier to find (see Quote in **Figure 7**).

Most of the animal species which were hunted for their meat were reported to be easily available during the past period often by many households but only in a few communities, while mostly in the Bukedea district male participants indicated that certain types of animal species are difficult to access.

Similarly, the level of consumption of wild species was high in the past with most of the species being consumed by many households frequently since they were abundant and easy to find (see also **Supplementary Table 3**). While within the current period (2017), participants across the Teso FGD reported a decline in the level of consumption of wild species, which was attributed to the reduction in their natural habitats making them hard to find in most of the communities. In 2017, the female and male participants across the Teso sub-region reported that around 15 different animal species were consumed frequently, while 18 species were identified as having been frequently consumed in the past period. A complete list displaying the frequencies of wild species according to the village, 4-cell placement and gender is displayed in **Supplementary Table 5**.

A list of wild species according to folk taxonomy per level of purchase and sale for the Teso sub-region according to the village can be found in **Supplementary Tables 6**, **7**, while on species level it can be found in **Supplementary Table 3**. Generally, the level of trade, meaning sales or purchase of wild species was low during the past period and higher in the current periods for different reasons. In the past, almost all households had easy access to the wild species as sufficient numbers existed. Thus, there was no market for them, but during the current period, almost all the wild species especially the animals and birds are proving difficult to find and are only available in small numbers, so they rarely come up for sale/ purchase. One participant told us if someone is lucky enough to hunt a wild animal it is used for own consumption (see quote **Figure 8**).

Wild Species in Acholi

A slightly smaller number of wild species was reported within the FGD in the Acholi sub-region. In total 97 different wild species were named by the different villages. In the past period, 97 compared to 91 species in the current period were available, which were categorized into six different species types (see also **Table 2**). A complete list of named wild species in the past and present including their categorization can be found in the **Supplementary Table 1**. In general (past and current), although as shown in **Table 2**, there were about 6 categories of wild species, the most mentioned wild foods were animals (35%), followed by fruits (24%), insects (14%), and birds (13%). Interestingly no fish

TABLE 2 | Collected wild food according to species in the past and current period in the Teso and Acholi sub-region.

	Teso sub-region				Acholi sub-region			
	Current period (2017)		Past period (1997)		Current period (2017)		Past period (1997)	
	n	%	*n*	%	*n*	%	*n*	%
Animal	30	29.13	35	32.41	34	37.36	34	35.05
Fish	5	4.85	5	4.63				
Bird	20	19.42	20	18.52	11	12.09	13	13.4
Fruit	20	19.42	20	18.52	22	24.18	23	23.71
Insect	5	4.85	5	4.63	14	15.38	14	14.43
Stem/root/tuber	14	13.59	14	12.96	7	7.69	9	9.28
Leafy vegetable	9	8.74	9	8.33	3	3.3	4	4.12
Total	103	100	108	100	91	100	97	100

Fish species only mentioned in Teso sub-region.

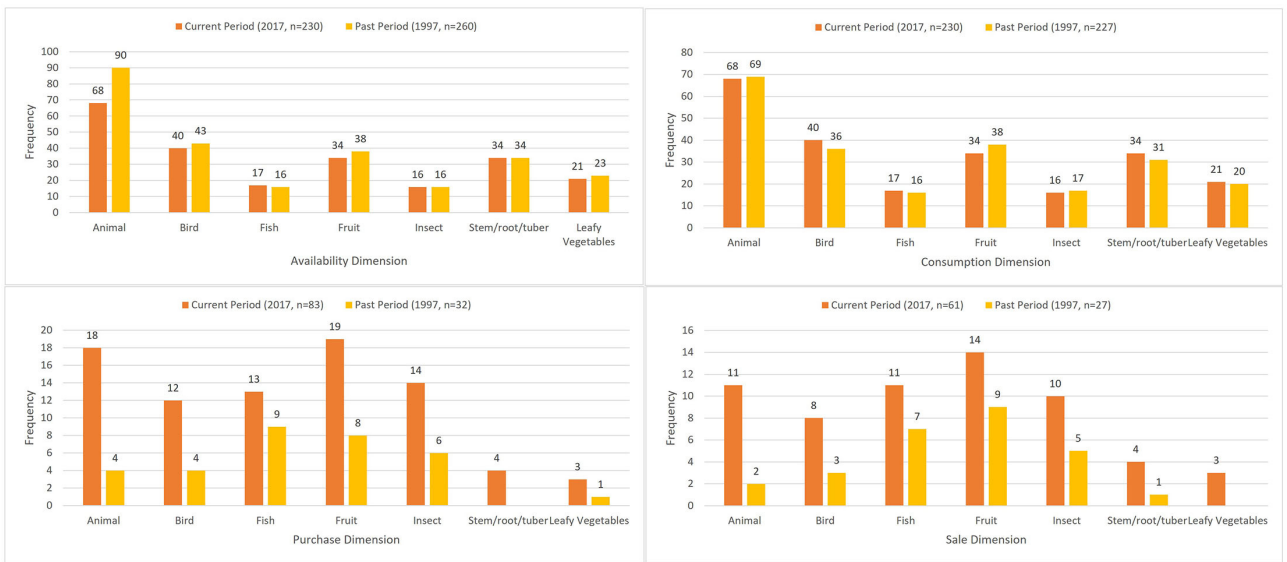

FIGURE 6 | Frequency of wild species according to the 4-dimension in Teso sub-region (availability, consumption, purchase, and sale) (**Supplementary Table 2**).

species were mentioned in any of the groups in Acholi, while in the Teso sub-region 5 different fish species were mentioned and compared to five different wild species in the Teso sub-region.

Four Cell Dimensions at the Village Level

In general, fewer species were easily found in Acholi compared to the Teso sub-region. Overall, disregarding the perception/categorization of the wild species 279 different wild species were accessible, as displayed in **Figure 9**. In the past, more species types were easily found by many households across the districts (**Table 4**). Although most of the wild species were found in only a few communities, their level of availability was high in those communities where they were found. In Mudu West, Iromo, and Ngomoromo villages, in Lamwo district, the number of wild animal species easily available to many households has not changed over time. On the contrary, Bwobonam B, Lamoki and Korobar villages in Nyowa districts all reported a decline in the number of animal species easily available to many households over time. However, Bwobonam B and Korobar villages in Nwoya and Alenyo south in Lamwo reported having more wild fruits being available to many households easily in the current period compared to the past.

A male participant in Nyowa district argued that the level of availability of most wild species has declined because most of their habitat has been destroyed for cultivation. Many wild species, especially animals were easily available in the past as the hunting restrictions were not enforced due to the level of political insecurity (see quote in **Figure 10**).

Similarly, the level of consumption of wild species had declined considerably over time due to restrictions on hunting wild animals. Consumption, purchase, and sale according to the 4-cell placement for the current and past period for Acholi sub-region according to the village and

TABLE 3 | Availability species according to the 4-cell placement for the current and past period for Teso sub-region according to village.

	Current period (2017)								Past period (1997)							
	FH_EF		FH_DF		MH_EF		MH_DF		FH_EF		FH_DF		MH_EF		MH_DF	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Katekwan (Bukedea)																
Animal	3	43	3	30	3	33					2	25	8	31		
Fish			2	20									2	8		
Bird			1	10	3	33	1	33			2	25	2	8		
Fruit	2	29	3	30							4	50	7	27		
Insect					1	11							1	4		
Stem/root/tuber	1	14			1	11	1	33					3	12		
Leafy vegetable	1	14	1	10	1	11	1	33					3	12		
Total	7	100	10	100	9	100	3	100	0		8	100	26	100	0	
Adodoi (Bukedea)																
Animal			8	47	1	10	2	25			6	50	7	35	3	33
Fish							3	38							3	33
Bird			5	29	3	30	2	25			2	17	4	20	2	22
Fruit			2	12							2	17	3	15		
Insect			2	12	1	10					2	17	1	5		
Stem/root/tuber					3	30	1	13					3	15	1	11
Leafy vegetable					2	20			1	100			2	10		
Total	0		17	100	10	100	8	100	1	100	12	100	20	100	9	100
Kocheka (Bukedea)																
Animal	1	33	2	29	3	25	3	50	1	100	2	25	8	38	1	100
Fish			1	15	0						1	13				
Bird					2	17	1	17					3	14		
Fruit	2	67	3	43	0		2	33			4	50	3	14		
Insect					1	8							1	5		
Stem/root/tuber					3	25							3	14		
Leafy vegetable			1	14	3	25					1	13	3	14		
Total	3	100	7	100	12	100	6	100	1	100	8	100	21	100	1	100
Kidongole (Bukedea)																
Animal			8	47	1	10	2	25			6	50	7	35	3	33
Fish							3	38							3	33
Bird			5	29			2	25			2	17	4	20	2	22
Fruit			2	12	3	30					2	17	3	15		
Insect			2	12	1	10					2	17	1	5		
Stem/root/tuber					3	30	1	13					3	15	1	11.
Leafy vegetable					2	20			1	100			2	10		
Total	0		17	100	10	100	8	100	1	100	12	100	20	100	9	100
Acele A (Amuria)																
Animal	1	100	4	40	1	10							5	23		
Fish			1	10									1	5		
Bird			3	30			1	50					4	18		
Fruit			1	10	7	70							8	36		
Insect					2	20	1	50					3	14		
Stem/root/tuber																
Leafy vegetable			1	10									1	5		
Total	1	100	10	100	10	100	2	100	0		0		22	100	0	
Akileng (Amuria)																
Animal			4	33	8	27	1	50			5	46	11	29		
Fish			3	25	1	3					3	28	1	3		
Bird			3	25	4	13					1	9	7	18		

(Continued)

TABLE 3 | Continued

	Current period (2017)								Past period (1997)							
	FH_EF		FH_DF		MH_EF		MH_DF		FH_EF		FH_DF		MH_EF		MH_DF	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Fruit					9	30							9	24		
Insect					1	3							1	3		
Stem/root/tuber			1	8	3	10	1	50			1	9	4	11		
Leafy vegetable			1	8	4	13					1	9	5	13		
Total	0		12	100	30	100	2	100	0		11	100	38	100	0	
Atarukot (Amuria)																
Animal			5	33	4	16	4	80					15	33		
Fish			2	13	1	4							3	7		
Bird			5	33			1	20					6	13		
Fruit			2	13	7	28					1	100	7	16		
Insect					2	8							2	4		
Stem/root/tuber			1	7	6	24							7	16		
Leafy vegetable					5	20							5	11		
Total	0		15	100	25	100	5	100	0		1	100	45	100	0	
Omokoti (Amuria)																
Animal			3	75	2	33	3	33					9	50		
Fish																
Bird							4	44					3	17		
Fruit																
Insect					2	33	1	11					3	17		
Stem/root/tuber			1	25			1	11					2	11		
Leafy vegetable					2	33							1	6		
Total	0		3	100	6	100	9	100	0		0		18	100	0	

FH_EF, Few Households/Easily found; FH_DF, Few Households/Difficult to find; MH_EF, Many Households/Easily found; MH_DF, Many Households/Difficult to find. For a complete list of available wild species see also ***Supplementary Table 5****.*

"It's because in the past, the village was very bushy, and the human population was very low, so animals had a very wide space to feed making them easy to find."

(Female participant in Omokori village (Amuria)).

"Many of them are common during harvest time when they are feeding on the ready crops especially cereals. However, it's difficult to find guinea fowls because they hide a lot. Most of these birds are hunted down by children in the bushes."

(Female participant in Adodoi village (Bukedea)).

FIGURE 7 | Quotes of female focus group discussion participants about availability in Teso sub-region.

aggregated form can be found in **Supplementary Table 8**. Today, around 12 different wild species were named as being consumed by many households frequently, while over 35 different types of wild species were consumed by many in the past (**Supplementary Table 10**). A complete list of wild species according to folk taxonomy for purchase and sale according to the village can be found in **Supplementary Tables 11**, **12**.

Trade was higher in the current period compared to the past, but less frequently and for a few households. As reasons, several participants across the Acholi sub-region groups indicated, additionally, that most of the communal land, where their natural habitat was located, has been converted into farmland and agricultural production. This has made it harder to access wild species, leading to less frequent consumption and a reduction in their sales/purchase levels. Similarly, some wild animals are

"No wild animal is sold around, when someone hunts it down, they normally eat them with their families."

(Female participant in Adodoi village (Bukedea)).

"No, we do not sell them, it is very difficult to hunt down these animals so whoever gets them does just consumes them in their households."

(Female participant in Omokori village (Amuria)).

FIGURE 8 | Quote of female focus group discussion participant about sales in Teso sub-region.

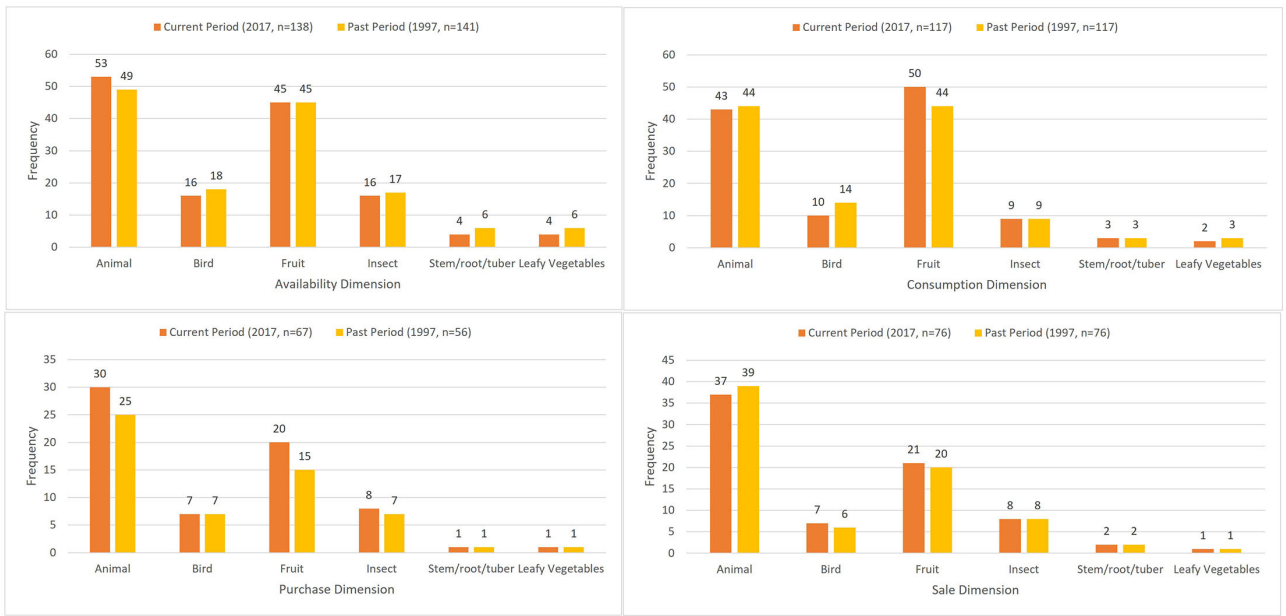

FIGURE 9 | Frequency of wild species according to the 4-dimension in Acholi sub-region (availability, consumption, purchase, and sale) (**Supplementary Table 2**).

difficult to hunt requiring rare, highly-specialized skills. Today these skills are almost lost within the community due to poor inter-generational knowledge transfer and sharing. In addition, the high level of insecurity due to rebel activities has limited people's access to the different wild species. Another participant in Pabit east noted that due to past poor security and surveillance, wild animals were easily available when park rangers were less rigorous than they are currently (see quotes in **Figure 11**).

DISCUSSION

Within this paper, we have considered the changes in the availability and utilization of wild food species over time within two sub-regions in Uganda. Our study mentions more than 100 different edible wild plant and animal species in both regions considering the two time periods (2017 and 1998). It further confirms that wild foods still play a major role in our food systems. However, the number reported here is significantly lower than what has been reported in a number of studies. In a study carried out in the Oraon tribal community in Jharkhand, India, more than 130 varieties of indigenous foods were identified, many of which were rich sources of micronutrients (Ghosh-Jerath et al., 2015). In another study that considered the whole of India, more than 1,000 wild edible plant species were reported (Ray et al., 2020). This high number could be because the study was carried out in a significantly larger geographical area considering the size of India than our study area of 8 sub-counties in 4 districts of Uganda. Nevertheless, all three studies acknowledge that wild food species form an integral part of local diets and their widespread assimilation into local food culture suggests an untapped potential to ensure easy availability and access to micronutrients for sustainable food systems (Ghosh-Jerath et al., 2015; Ray et al., 2020). In addition, in the India study, more categories of plant wild species were observed such as leafy shoots, seeds, and legumes while

TABLE 4 | Availability species according to the 4-cell placement for the current and past period for Acholi sub-region according to village.

	Current period (2017)								Past period (1997)							
	FH_EF		FH_DF		MH_EF		MH_DF		FH_EF		FH_DF		MH_EF		MH_DF	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Mudu West (Lamwo)																
Animal	2	67	7	37	5	42	2	33	2	50	6	26	5	29	2	29
Bird			2	11			2	33			3	13	1	6	3	43
Fruit			7	37			2	33			9	39	2	12	2	29
Insect	1	33	1	5	4	33			1	25	2	9	4	24		
Stem/root/tuber			1	5	2	17					2	9	3	18		
Leafy vegetable			1	5	1	8			1	25	1	4	2	12		
Total	3	100	19	100	12	100	6	100	4	100	23	100	17	100	7	100
Iromo (Lamwo)																
Animal			4	40	1	25					4	40	1	25		
Bird			3	30							3	30				
Fruit			2	20	2	50					2	20	2	50		
Insect			1	10							1	10				
Stem/root/tuber					1	25							1	25		
Leafy vegetable																
Total	0		10	100	4	100	0		0		10	100	4	100	0	
Ngomoromo (Lamwo)																
Animal			10	38	5	38					8	38	5	38		
Bird			3	12							1	5				
Fruit			8	31	4	31					7	33	4	31		
Insect			4	15	3	23					4	19	3	23		
Stem/root/tuber			1	4							1	5				
Leafy vegetable			0		1	8							1	8		
Total	0		26	100	13	100	0		0		21	100	13	100	0	
Alenyo south (Lamwo)																
Animal			7	41							7	35				
Bird			4	24							4	20				
Fruit			4	24	3	100					7	35				
Insect			1	6			1	100			1	5			1	100
Stem/root/tuber			1	6							1	5				
Leafy vegetable																
Total	0		17	100	3	100	1	100	0		20	100	0		1	100
Pabit East (Nwoya)																
Animal			5	38	1	25					1	17	5	45		
Bird																
Fruit			6	46	3	75					3	50	6	55		
Insect																
Stem/root/tuber			2	15							2	33				
Leafy vegetable																
Total	0		13	100	4	100	0		0		6	100	11	100	0	
Bwobonam B (Nwoya)																
Animal	1	25	4	40	2	20							5	31		
Bird	2	50	3	30	0						1	33	4	25		
Fruit	1	25	2	20	7	70					2	67	5	31		
Insect																
Stem/root/tuber			1	10									1	6		
Leafy vegetable					1	10							1	6		
Total	4	100	10	100	10	100	0		0		3	100	16	100	0	

(Continued)

TABLE 4 | Continued

	Current period (2017)								Past period (1997)							
	FH_EF		FH_DF		MH_EF		MH_DF		FH_EF		FH_DF		MH_EF		MH_DF	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Lamoki (Nwoya)																
Animal			7	78	1	33	4	80			7	78	1	33	4	80
Bird					1	33	1	20					1	33	1	20
Fruit			2	22	1	33					2	22	1	33		
Insect																
Stem/root/tuber																
Leafy vegetable																
Total	0		9	100	3	100	5	100	0		9	100	3	100	5	100
Korobar (Nwoya)																
Animal			6	86	5	71	3	100					14	82		
Bird													2	12		
Fruit			1	14	2	29							1	6		
Insect																
Stem/root/tuber																
Leafy vegetable																
Total	0		7	100	7	100	3	100	0		0		17	100	0	

FH_EF, Few Households/Easily found; FH_DF, Few Households/Difficult to find; MH_EF, Many Households/Easily found; MH_DF, Many Households/Difficult to find. Plant, species where stem/root/tuber is used as food. A complete list of available wild species see also ***Supplementary Table 9****.*

"20 years ago, most of these things (wild animals) used to be got any time since they also feared the rebels and lakwena so they would come around the neighborhood, and so people would eat them any time."

(Male participant in Pabit East village (Nyowa)).

"All the animals were in many numbers and many households could get because political insecurity that even rangers feared guarding the park. People were in camps."

(Male participant in Pabit East village (Nyowa)).

"They (monkeys) are easy to get, and they are many in this area when you try to go to the bush or jungle around you will see that they are so many."

(Male participant in Korobar village (Nyowa)).

FIGURE 10 | Quote of a male focus group discussion participant about availability in Acholi sub-region.

in this study the plant-based wild foods were fruits, other plant materials (stem, root, tubers) and leafy vegetables. This difference could be because Indian diets are more leafy vegetable/plant-based thus increased focus and utilization also contributes to an increase in conservation and availability. In another study carried out in Tanzania, a total of 92 species of wild (or spontaneous growing/uncultivated) foods were reported in the dietary surveys conducted between March and May and September and October 2009 (Powell et al., 2013).

The availability and use of wild foods can be influenced by several factors, some of which boost or reduce the use of wild foods, while the impact of others is very ambiguous and based on a particular context (Bharucha and Pretty, 2010). This study aimed to understand the level of availability and utilization of wild foods considering the two time periods. Participants were able to mention their perceived factors that either negatively or positively influenced availability and utilization. The availabilities and numbers of wild foods were

"Getting them (rabbits) is hard. You need to be a good hunter to be able to capture one. You can get them very early in the morning."

(Male participant in Korobar village (Nyowa)).

"People simply eat them in the wilderness, some people don't like them."

(Male participant in Pabit East village (Nyowa)).

"All these things (wild species) were many and many people could get them and sell them in many numbers more for example, bufalo, kob, warthog and edible rats… now you only find them occasionally."

(Male participant in Korobar village (Nyowa)).

FIGURE 11 | Quotes from male focus group discussion participants about sales in Acholi sub-region.

indicated to be negatively influenced by increased clearing of natural habitats to pave the way for cultivation and establishing new settlements to accommodate population increases. In addition, the rearing of newly introduced and exotic species has reduced interest in natural habitats and foraging for wild foods. Access to knowledge has been reported as a major factor influencing access to and use of wild foods. Studies have shown that foraging, hunting and trapping knowledge and skills have dwindled due to trans-generational information erosion (Tabuti et al., 2004; Ali-Shtayeh et al., 2008; Bharucha and Pretty, 2010). Our study corroborates these findings, whereby participants clearly indicated a lack of knowledge on how to sustainably and successfully trap, and hunt wild animals, ["you have to have good hunting skills which most of the current generation do not have"]. Bharucha and Pretty (2010) further indicate that the quantity and quality of indigenous knowledge on wild foods especially edible plants are closely related to the traditions, environment and cultural heritage of each country. Ali-Shtayeh et al. (2008) state that the observed decline in wild foods gathering is due to socioeconomic conditions that lead to lifestyle changes and road networks needing space.

The expansion of intensive agriculture limits the capacity of ecosystems to sustain food production and at the same time maintain wild-food species' habitats, which has restricted the availability of wild foods (Bharucha and Pretty, 2010). In addition, the commercialization of agriculture, an important driver of land-use change, has decreased reliance on wild foods, thus eroding the knowledge and skills associated with wild food species conservation, sustainable trapping/hunting/gathering and sustainable utilization (Bharucha and Pretty, 2010), which was also confirmed during the focus group discussions.

In addition, the relatively rapid turnaround of intensive agriculture leads to easier access to and higher availability of commercialized agricultural products, in addition to negative perceptions toward consumption of wild edible foods. Wild foods are perceived to be for the poor and thus are associated with poverty and backwardness (Meldrum and Padulosi, 2017; Padulosi et al., 2022). Other drivers documented include agricultural and land use policy, infrastructure development, and widened access to markets that have been implicated in the declines of wild species in Thailand and China (Bharucha and Pretty, 2010). Although land and agriculture were identified as drivers in this study it was not in relation to policies. Infrastructure, market access and association with poverty did emerge as drivers of wild species' loss during the discussions.

The continued reporting of high levels of food insecurity and malnutrition among communities dependent on forestry, natural habitats and agriculture for food and nutrition makes it important to understand current trends for wild foods. As wild food species offer a potentially critical role as a buffer against stress, especially during lean seasons or calamities such as famine, and natural disasters (floods, fires, insect infestation on farms). This also applies when caught up in pandemics such as COVID-19 which results in restrictions that influence livelihoods activities such as farming and marketing. In addition, the innate resilience of wild species to rapid climate change, and other harsh conditions which are often lacking in exotic species', means that they could play an increasingly important role in sustaining the diet and food systems of communities reliant on forests, natural habitats and production for their food and nutrition (Bharucha and Pretty, 2010).

Greater access to and availability of wild food species are often linked to more diverse diets, thus contributing to food and nutrition security and the livelihoods of rural communities (Powell et al., 2015). The noted presence of wild foods and their potential to contribute to food and nutrition security in the Teso and Acholi sub-region necessitated the reinforcement of strategies that support the preservation and conservation of wild foods and related agrobiodiversity. This study supports a call for collective efforts and actions for more capacity building and reinforcement of policies that enhance agrobiodiversity, forest conservation and functional ecosystem services. Synergies and linkages between wildlife and forestry should be developed and sustainably harnessed. Policies and laws directed toward characterizing documenting and managing the

available biodiversity should be prioritized and enforced. This is especially true for wild foods, with an emphasis on their multi-faceted value, sustainable utilization and conservation. Additionally, the communities' access to user-friendly, timely information should be ensured, through motivated and well-equipped extension service providers. and functioning extension service providers. To add value to the folk taxonomic data, the authors have proposed a follow-up MSc study to identify the scientific names of all species listed, for subsequent analysis.

CONCLUSION

This study has highlighted the importance of wild animal and plant species in Ugandan food and nutrition security. Aligning with other studies, our research acknowledges that wild food species form an integral part of the diet and their widespread assimilation into local food culture suggests an untapped potential to ensure easy availability and access to micronutrients for sustainable food systems (Ghosh-Jerath et al., 2015; Ray et al., 2020).

Our study findings indicate that over the last two decades there have been significant declines in wild food availability, access, consumption, and sales. It has been revealed that the reasons for the decline include increased cultivations and natural habitat destruction due to settlements and changes in land ownership. In the latter case, individual owners have further fragmented their land and do not allow villagers to freely participate in hunting and gathering. Lastly, rebel unrest increased feelings of insecurity, and thus prompted a decline in hunting and gathering. The noted presence and contribution of wild foods in Teso and Acholi calls for collective efforts to increase access to knowledge on the value of these wild foods for not only food and nutrition but also for their potential contribution to the social and cultural lives of the people.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study during group discussions. The necessary permissions were also obtained from administrative leaders.

AUTHOR CONTRIBUTIONS

BE designed the study, initiated the publication, coordinated, and led the improvement of the manuscript throughout the writing process. AF mainly worked on the review of related literature, organizing the findings, putting together the discussion area, and ensuring the citation and reference section is accurately put. MN carried out the transcription of the FGD data and carried out data analysis put together the tables and summaries and engaged in the review of the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Nutritional Challenges and Dietary Practices of Ethnic Minority (Indigenous) Groups in China: A Critical Appraisal

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Indigenous food systems can affect multiple aspects of Indigenous people's health. In China, the government declared that there are no Indigenous people in China and used the term "ethnic minority groups" instead. However, to date, no attempt has been made to investigate the nutrition status and dietary practices of all 55 ethnic minority groups. To understand this pertinent issue, a systematic review is required. The main selection criteria were publications should be about nutrition status or dietary practices among ethnic minority groups in China, specify the name of the ethnic minority group, and be published within the past 10 years. For this literature review, 111 publications were selected through Wanfang Med Online for Chinese publications and Google Scholar for English publications. Linear regressions were applied to explore what factors can affect the total number of publications for an ethnic minority group. The main findings include that only 15 ethnic minority groups have dietary intake data representing the general people of the ethnic group; only seven ethnic minority groups have data for both nutrition status (anthropometric and nutrients intake/deficiency) and dietary practices (dietary intake and dietary habits); there are still 10 ethnic minority groups with a total number of population 845,420 that lack studies on both nutrition status and dietary practices; ethnic minority groups are suffering from double-burden malnutrition and consuming unbalanced diets; primary and middle school students are the most prevalent study population than any other age group due to easy access; and an ethnic minority group is likely to have more publications about nutrition status and dietary practices if they have a larger population or are unique to a region. The results indicate that more national-level programs and timely nutrition and dietary reports should be implemented to address double-burden malnutrition and unbalanced diets among ethnic minority groups in China. More studies involving maternal nutrition, targeting underrepresented ethnic minority groups and age groups, and exploring traditional food systems in China are also essential to better understand and address this issue.

Keywords: Indigenous nutrition, ethnic minority, China, dietary practices, nutrition status, double-burden malnutrition, traditional food systems

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INTRODUCTION

Indigenous peoples are ethnic groups who are native to traditional lands with unique cultures, and relationships with people and the environment (The United Nations, 2015). Although the Chinese government officially declared in the 1990s that there are no Indigenous people in China and used the term ethnic minorities instead, some authoritative organizations like the United Nations (UN) include these Chinese ethnic groups as Indigenous peoples (Hathaway, 2016). Indigenous peoples' food systems involve valuable knowledge of traditional cultures and local ecosystems (Kuhnlein et al., 2009, p. 3). An Indigenous food system is essential to Indigenous peoples' health, including physical, emotional, mental, and spiritual parts of health (Kuhnlein, 2009, p. 3). Therefore, the study on Indigenous nutrition and traditional food systems is particularly important to Indigenous peoples' health and general livelihoods.

According to the Bulletin of the Seventh National Census in China, China has 55 ethnic minority groups (Chen, 2021). The total number of ethnic minority people in China is 125,467,390, accounting for 8.89% of the total population (Chen, 2021). Although the Chinese government has implemented many strategies to support the livelihoods of ethnic minority groups (The State Council Information Office of the People's Republic of China, 1999), health inequality has still been reported between ethnic minority groups and the Han main group (Ouyang and Pinstrup-Andersen, 2012; Ouyang, 2013). For example, the infant and child mortality rates of the western part of China where most of the Indigenous people inhabit are significantly higher than other regions (Ma et al., 2010). In terms of Indigenous nutrition and traditional food systems in China, fishing-hunting, animal husbandry, and agricultural farming are identified as three different dietary structures among ethnic minority groups (Liu and Zhai, 2004). Dietary unbalance is common in different dietary structures (Zhai et al., 2007), and malnutrition is common in different ethnic minority groups (Ma et al., 2010). Multiple factors have been reported to affect the nutrition status and dietary practices, such as the loss of cultural knowledge and agricultural resources (Zheng et al., 2012), family size, education (Qu et al., 2013), income (Wang C. et al., 2013), the lack of nutritional knowledge (Zhang and Wang, 2012), genetic differences, dietary differences, physical activities (Guo et al., 2016), geographical differences, environment, religions (Zhai et al., 2007), and economic development (Zhai et al., 2007; Zhang et al., 2008).

Considering the malnutrition, unbalance in dietary intake, health inequality, and a large number of the ethnic minority population in China, it is essential to pay attention to the nutrition status and dietary intake of ethnic minority people. Although there are publications related to this topic in recent years, none of them aim to discuss all ethnic minorities and compare the differences and changes from a broad perspective. Only eight of them are published in English (Gao et al., 2011; Zhang C. X. et al., 2012; Jingya et al., 2013; Qu et al., 2013; Wang C. et al., 2013; Guo et al., 2016; Dong et al., 2018; Zhang et al., 2018). The current literature review summarizes both Chinese and English publications related to the nutrition status and dietary practices among ethnic minority groups and discusses the causes of and potential solutions to malnutrition and other concerns caused by current dietary practices. The result of the current review will contribute to international scholars' understanding of the nutrition and dietary status of Chinese ethnic minorities and help policymakers to improve nutrition status and dietary balance. Considering the fast growth of Chinese gross domestic products (GDP) (The World Bank, 2020), and the fact that economic status is a key factor in affecting nutrition status (Zhang et al., 2018), only publications in the past 10 years are included. The research questions of the current review are:

FIGURE 1 | The distribution of publications of nutrition status among ethnic minority groups in China from 1998 to 2021 (generated by Wanfang Med Online).

1. What is the nutrition status (anthropometric results and nutrient intake/deficiency) of ethnic minority groups in China in the past 10 years?
2. What are the dietary practices (dietary intake and habits) of ethnic minority groups in China in the past 10 years?

METHOD

Literature Selection Criteria

The current review is a literature review of Chinese and English publications related to the research questions. The search engine used to collect Chinese literature was Wanfang Med Online (万方医学网), which provided the most complete and important medical journal resources and other resources (Wanfang Med Online, 2013). The keywords for searching were Ethnic Minority and Nutrition (少数民族；营养), followed by Ethnic Minority and Diet (少数民族；膳食).

In total, in August 2021, 703 papers were identified when searching for Ethnic Minority and Nutrition. The first publication related to this topic was in 1998. The number of publications on this topic peaked in 2013 and then gradually decreased (**Figure 1**). When searching for Ethnic Minority and Diet, the total number of publications was 371 with a similar trend of numbers of annual publications (**Figure 2**). After the first search attempt, if there were no ethnic minorities identified, then the name of each specific ethnic minority group was

FIGURE 2 | The distribution of publications of dietary practices among ethnic minority groups in China from 1998 to 2021 (generated by Wanfang Med Online).

searched with Nutrition and Diet, respectively, to ensure that no publications about these topics were missed.

Among all publications, the first criterion was selecting publications only in the past 10 years from 2011 to 2021. This was due to the rapid growth of the Chinese GDP (The World Bank, 2020), and the nutrition status of each ethnic minority group significantly changing (Guo et al., 2016). However, if the publications targeted the general trend of nutrition status and dietary practices in a specific period, or if the publications could show a broad overview of the nutrition and diet of the Chinese ethnic minority groups, the publications were then included. Also, if an ethnic minority group did not have publications within the last 10 years, then the most recent publication was selected, even if the article had been published before 2011.

The second criterion was that only publications that specified the names of ethnic minority groups were included because different ethnic cultures have an influence on dietary practices (Liu and Zhai, 2004). If studies only specified an ethnic minority region without the names of ethnic minority groups, they were excluded.

The third criterion was that all selected studies should target people in good health. For example, if a study population included people with cardiovascular diseases, diabetes, or other diseases, they were excluded. This is because some medical treatments include dietary recommendations and restrictions (Heilberg, 2000).

Finally, some undernutrition data such as stunting, and wasting were derived from published physical exams. For such publications, only data related to nutrition were selected. Other results of physical exams, such as eyesight and blood pressure, were excluded.

Google Scholar was used to collected English publications. The same keywords translated into English plus Chinese were utilized for the search. After applying the same criteria to Chinese publications, only eight English publications were identified, and eight Chinese publications had English abstracts. There were also eight English publications that discussed the nutrition status and dietary intake of ethnic minority groups in China but did not specify the particular ethnic minority group.

The details for every step of the selection process are summarized in a PRISMA flow diagram as shown in **Figure 3**.

DATA ANALYSIS

After selecting the relevant publications, the total number and those for each theme, sub-theme, and age group were counted. Themes were generated from the research questions: nutrition status and dietary practices. Sub-themes and age groups were generated during the literature review. Finally, 11 sub-themes and 12 age groups were identified and are shown in the Results section.

Subsequently, the number of total publications, plus basic information (total population, major distribution, and the rank of total population) for each ethnic minority group, were recorded in **Table 1**. Linear regression was utilized to analyze the relationship between the rank of total populations for each ethnic minority group and the numbers of total publications, region-level, and country-level publications, respectively to identify significant outliers and analyze relevant factors that affect the numbers of publications. The country-level publication describes the targeted ethnic minority groups in a publication distributed around China; and the region-level publication describes the targeted ethnic minority groups in a publication as only one specific ethnic minority group or living in a region (such as a town, city, or province).

Thematic analysis was used to summarize results from the selected literature. If publications met the selection criteria, the information about key results, related to specific themes, was summarized according to each ethnic minority group. The details were recorded in Attachment 1.

RESULTS

After applying the selection criteria, 111 publications were selected for the final analysis. Each article targeted from one up to 26 ethnic minority groups. Among them, 98 publications reported results about nutrition status, and 46 publications discussed dietary practices. Xinjiang Province had the most publications (25 publications) related to these two themes, followed by Yunnan Province with 22 publications. There were also 12 publications (eight of them were from Yunnan Province) that discussed nutrition interventions among ethnic minority groups in China, but they were excluded from the analysis because they were irrelevant to the research questions. Also, although all of the selected publications specified the names of the ethnic minority groups, only one of the publications (Chan et al., 2019) identified the specific branch of each ethnic minority group (e.g., Kunge people in Blang ethnic minority group, Yunnan Province).

Eleven sub-themes were identified. The sub-themes included undernutrition (low weight, stunting, and wasting), overnutrition (overweight and obesity), double-burden malnutrition, nutrient intake/deficiency, dietary intake, breastfeeding, dietary habits, nutrition knowledge, comparison with the Han main ethnic group (the Han group must be selected as study population for comparison), trends of nutrition status, and whether risk factors were the focus of research questions (the study should discuss risk factors rather than only calculating some social-demographic factors such as ethnicity, age, and sex)

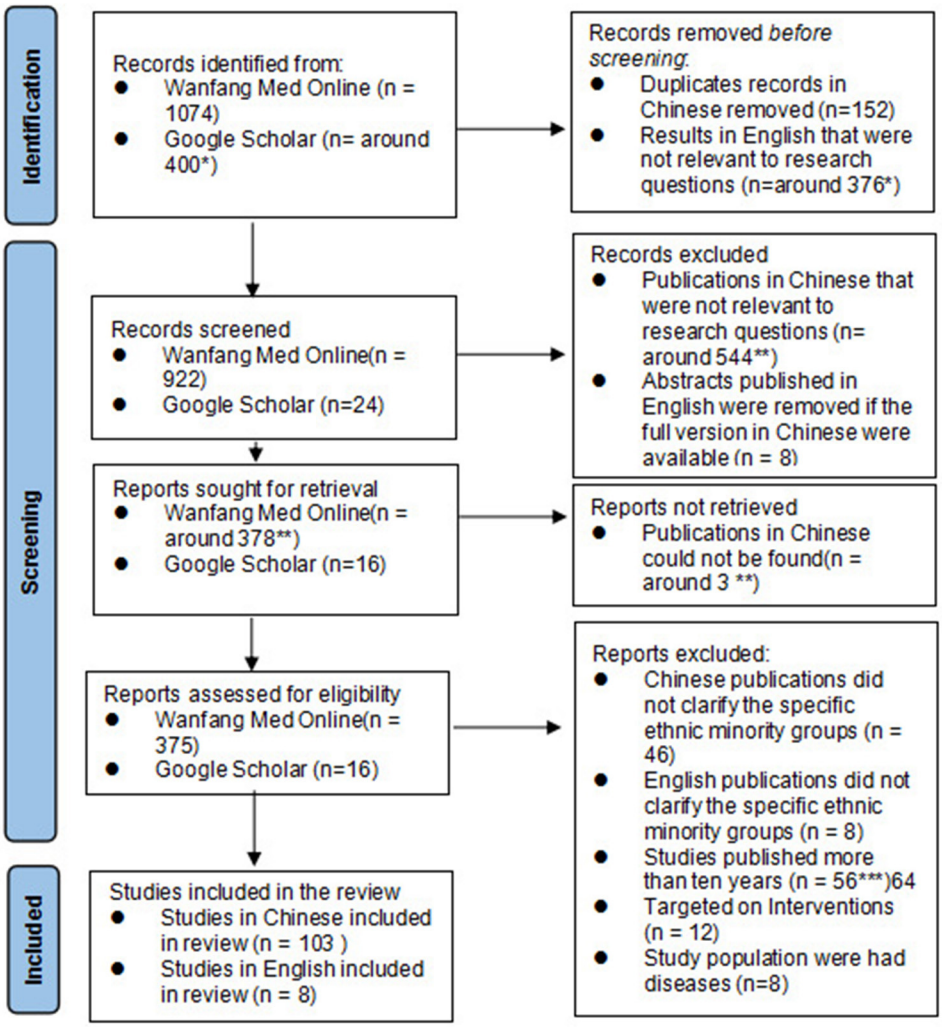

FIGURE 3 | The PRISMA flow diagram for the details of the literature selection process. *When using keywords searched in Google Scholar, there were more than 400,000 results in total. It was very difficult to identify them all. Because the following listed results were increasingly irrelevant to the beginning listed results, if there were continuously 100 results that were not relevant, the identification process will be terminated. Finally, around 400 results were identified by the first author. **The current review was edited based on a student course essay. The PRISMA flow diagram was provided during the submission review and formed based on research notes and memory. Thus, three numbers in the flow diagram were based on recall and may not be accurate, but it will not affect the literature review and the results. ***The total number of studies published more than 10 years was 64. However, eight of them were either related to the general trends of nutrition status and dietary practices in a specific period or the most recent publication for a specific ethnic minority group. Therefore, these eight publications were finally included.

(Shi, 2014). Undernutrition was the most frequent sub-theme; more than half of the total publications (60 out of 111) discussed undernutrition. Overnutrition was the second most popular sub-theme with 46 publications. Double-burden malnutrition was also widely reported by 40 publications. Dietary intake and nutrient intake/deficiency were also popular sub-themes and were reported in 36 and 34 of the publications, respectively. There were 29 publications comparing nutrition status and dietary practices with the Han main group. Only seven of them concluded that the Han main group had a better nutrition status or dietary practices than ethnic minority groups, while 15 publications showed that the Han main group only partially had better nutrition status or dietary practices in the studies; three publications concluded that the results of the Han main group and ethnic minorities were similar. Discussing risk factors related to nutrition status and dietary practices ($n = 20$) and the trends of nutrition status and dietary practices ($n = 17$), and dietary habits ($n = 16$) were also common. However, nutrition knowledge ($n = 6$) and breastfeeding ($n = 3$) were less frequent topics. **Table 1** provides a detailed analysis of the reviewed articles.

In terms of study populations, 12 age groups were identified; the details of different age categories were shown in **Table 1**. Because the ages for school in China can be different, the age

TABLE 1 | Information about publications, themes, sub-themes, and study populations.

Total publications reviewed	111
Themes	98
Nutrition status	
Dietary practices	46
Sub-themes	60
Undernutrition	
Overnutrition	46
Double-burden malnutrition	39
Dietary intake	36
Nutrients intake/deficiency	34
Comparison with the Han Main Group	29 (The Condition of the Han Main Group is better: 7; The Condition of the Han Main Group is worse: 4; The Condition of the Han Main Group is better in some areas: 15; The Condition of the Han Main Group is similar: 3)
Risk factors	20
Trends of nutrition status	17
Dietary habits	16
Nutrition knowledge	6
Breastfeeding	3
Study Populations	41
Primary school students (always 7–12 years old)	
Middle school students (always 13–18 years old)	41
Children (always 2–6 years old)	17
College students (always 18–22 years old)	12
Infants (always 0 to 2 years old)	10
Peripartum women	9
Adults	8
General ethnic population	6
The elders	4
Mother-infant breastfeeding dyads	4
Middle-age people	2
Women	2

range for primary school, middle school, and college students may overlap.

Primary and middle school students had a much larger number of publications than other study populations with each having 41. The number of publications discussing the nutrition status or dietary practices of children, college students, and infants was also considerable at 17, 12, and 10, respectively. Only nine publications focused on peripartum women, and six publications utilized general ethnic groups as the study population. The numbers of publications of other populations are shown in **Table 1**.

When discussing the publications related to research questions of each ethnic minority group, as shown in **Table 2**, 45 groups presented data about nutrition status or dietary practices available in the past 10 years. The Uygur group had the largest number of total publications at 29. There were 17 articles about the Miao group, 16 about the Tibetan group, and 15 about the Zhuang group. The Bai, Dai, Tujia, Hui, Kazak, Yi, and Naxi groups also had more than 10 publications related to the two research questions. Thirty-four ethnic minority groups had less than 10 total publications related to these issues. The remaining 10 ethnic minority groups (the Tajik, Xibo, Tatar, Hezhe, Uzbek, Gelao, Menba, Lhoba, Russian, and Gaoshan groups) did not report on these themes, and five of these groups lived in Xinjiang Province, which is the largest province in China. The total population of these 10 ethnic minority groups was 845,420. Gelao peoples comprised the largest ethnic minority group without any publications related to the research questions, followed by the Xibo and Tajik groups. **Table 2** provides greater detail about the total numbers of publications, total population sizes, the ranks of the total population, major areas of residency, and key publications related to the research questions for each ethnic minority group.

The linear regression was utilized to explore what factors affect the total number of publications for each ethnic minority group, as shown in **Figure 4**. The independent variable (the Rank of Total Populations) can explain 50.5% (R square = 0. 5051) of the movements of the dependent variable (numbers of publications for the ethnic minority group) in a negative linear regression model. However, significant outliers do exist. For example, the total population of the Uygur group ranked fourth, but the Uygur group had a much larger number of total publications than any other ethnic minority group. The Manchu group had the third-largest population, but only one publication was related to the research questions. The Dai, Naxi, Yugur, and Dulong groups also had more publications than the linear regression expectation, while the She, Gelao, and Xibo groups had fewer numbers of publications according to the equation.

To further understand what factors affect the total number of publications for each ethnic minority group, **Figures 5**, **6** show the relationship between the rank of the total number of publications and the number of country/region-level publications. Ethnic minority groups with greater populations are also more likely to be selected for analysis for country-level publications (R square = 0.64). The Manchu group, including 10,387,958 people (as shown in the distribution of **Figure 5**) is an exception with only one country-level publication (UNC University Libraries, 2021). The distribution of region-level (**Figure 6**) shows that even ethnic minority groups with small numbers of people could yield considerable numbers of region-level publications, such as the Yugur and Dulong groups. However, the Uygur group is still the ethnic minority group with the largest number of publications for both country-level and region-level publications.

The results of nutrition status and dietary practices of each ethnic minority group are summarized and shown in Attachment 1. Four categories (anthropometry, nutrients intake/deficiency, dietary intake, and dietary habits) were generated to show the key results from the 111 selected publications among 45 ethnic minority groups in China. Only seven ethnic minority groups (the Bai, Bouyei, Dongxiang,

TABLE 2 | Information about numbers of publications, total populations, and major areas of distribution for each ethnic minority group.

The ethnic minority groups	Numbers of total publications	Numbers of publications from region-level*	Numbers of publications from country-level**	Total population sizes	The ranks of total population	Major areas of residency	Key publications related to research questions
Uygur	29	20	9	10,069,346	4	Xinjiang	Zhai et al., 2007; Gu et al., 2013; He, 2013; Zhang, 2014; Zhang T. et al., 2014; Wu et al., 2015; Li T. et al., 2016; Liu et al., 2016; Zhong and Ma, 2017; and more
Miao	17	12	5	9,426,007	5	Guizhou, Hunan, Yunnan, Guangxi, Sichuan, Hainan, Hubei, Guangdong	Zhai et al., 2007; Li et al., 2011; Zhang F. et al., 2012; Fang et al., 2013; Ji and Yin, 2014b; Zhang and Zhang, 2014; Huang et al., 2020; and more
Tibetan	16	8	8	6,282,187	8	Tibet, Qinghai, Sichuan, Gansu, Yunnan	Zhai et al., 2007; Bai et al., 2018; Tao, 2019; Pubu et al., 2020; Wang and Shen, 2020; and more
Zhuang	15	7	8	16,926,381	1	Guangxi, Yunnan, Guangdong, Guizhou, Hunan	Zhai et al., 2007; Ma et al., 2009; Wei and Huang, 2011; Jiang et al., 2013; Wei and Wei, 2013 and more
Bai	14	10	4	1,933,510	7	Yunnan	Li et al., 2012; Yang et al., 2013; Li and Zhang, 2014; Zhang X. F. et al., 2014; and more
Dai	14	10	4	1,261,311	13	Yunnan	Zhou and Kang, 2016; Zhao et al., 2017; Lin et al., 2018; Lei et al., 2019; and more
Tujia	14	10	4	8,353,912	18	Hunnan, Hubei, Guizhou, Chongqing	Zhai et al., 2007; Zhang F. et al., 2011; Zhang et al., 2013; Zhou, 2016; Zhou Y. et al., 2016; Dai et al., 2019; and more
Hui	13	6	7	10,586,987	2	Concentrated in the Northwestern provinces such as Ningxia, Gansu, Qinghai, and Xinjiang; Communities of Hui are all over the country	Zhai et al., 2007; Wen and Zhang, 2010; Zhang and Wang, 2012; Li, 2015; Wang, 2018; and more
Kazak	12	8	4	1,462,588	17	Xinjing, Gansu, Qinghai	Zhai et al., 2007; Wen and Zhang, 2010; Gu et al., 2013, 2014; Li et al., 2015; Liu et al., 2019; and more
Yi	10	5	5	8,714,393	6	Sichuan, Yunnan, Guizhou, Guangxi	Wang, 2010; Li et al., 2012; Yang et al., 2013; and more
Naxi	10	6	4	326,295	26	Yunnan, Sichuan	Li and Hu, 2015; Shen et al., 2020; Fu et al., 2021; and more
Bouyei	9	4	5	2,870,034	9	Guizhou, Yunnnan, Sichuan	Zhai et al., 2007; Dong et al., 2018; Yu et al., 2018; and more
Mongol	9	2	7	5,981,849	11	Inner Mongolia, Liaoning, Jilin, Hebei, Xinjiang, Heilongjian, Qinghai, Henan	Zhai et al., 2007; Ma et al., 2009; Yang et al., 2012; Zhang and Wang, 2012; Wang et al., 2018; and more

(Continued)

TABLE 2 | Continued

The ethnic minority groups	Numbers of total publications	Numbers of publications from region-level*	Numbers of publications from country-level**	Total population sizes	The ranks of total population	Major areas of residency	Key publications related to research questions
Wa	9	6	3	429,709	12	Yunnan	Yang et al., 2012, 2015; Guo and Zhao, 2013; Li and Hu, 2015; Shen et al., 2020; and more
Yao	9	5	4	2,796,003	24	Guangxi, Hunan, Yunna, Guangdong, Guizhou	Zhai et al., 2007; Li T. et al., 2016; Zhou Y. et al., 2016; and more
Dongxiang	8	5	3	621,550	15	Gansu, Ningxia, Qinghai, Xinjiang	Zhou et al., 2011a, 2019; Wang C. et al., 2013; Li T. et al., 2016; and more
Hani	8	5	3	1,660,932	20	Yunnan	Guo and Zhao, 2013; Li and Hu, 2015; Shen et al., 2020; and more
Lisu	8	5	3	702,839	21	Yunnan, Sichuang	Li and Hu, 2015; Dai et al., 2018; Shen et al., 2020; and more
Korean	7	1	6	1,830,929	14	Jilin, Liaoning, Heilongjiang, Beijing Korean Town	Ma et al., 2009; Jin et al., 2012; Guo et al., 2016; and more
Blang	6	6	0	119,639	10	Yunnan	Luo et al., 2013; Chan et al., 2019; Shen et al., 2020; and more
Dong	6	2	4	2,879,974	16	Guizhou, Hunan, Guangxi	Ji and Zhang, 2014; Xie, 2015; Guo et al., 2016; and more
Li	6	2	4	1,463,064	25	Hainan	Shi et al., 2012; Zhang C. X. et al., 2012 Lei et al., 2019; and more
Shui	6	2	4	411,847	35	Guizhou, Guangxi	Ji and Yin, 2014a; Guo et al., 2016; Yu et al., 2018; Lei et al., 2019; and more
Yugur	6	6	0	14,378	47	Gansu	Zhang X. et al., 2011; Zhou et al., 2011a,b; Wang Y. et al., 2013; Bu, 2014; Zhou and Wang, 2018; and more
Dulong	5	5	0	6,930	28	Yunnan	Li and Hu, 2015; Dai et al., 2018; Shen et al., 2020; and more
Jino	5	5	0	23,143	31	Yunnan	Luo et al., 2013; Li and Hu, 2015; Yang et al., 2018; and more
Kirgiz	5	2	3	186,708	34	Xinjiang, Heilongjiang	Wen and Zhang, 2010; Guo et al., 2016; Yao et al., 2020; and more
Nu	5	5	0	37,523	40	Yunnan	Yang et al., 2012; Li and Hu, 2015; Zhao J. et al., 2019; Shen et al., 2020; and more
Salar	5	1	4	130,607	43	Qinghai, Gansu, Xinjiang	Wen and Zhang, 2010; Guo et al., 2016; Lei et al., 2019; and more

(Continued)

TABLE 2 | Continued

The ethnic minority groups	Numbers of total publications	Numbers of publications from region-level*	Numbers of publications from country-level**	Total population sizes	The ranks of total population	Major areas of residency	Key publications related to research questions
Tu	5	1	4	289,565	51	Qinghai, Gansu	Wen and Zhang, 2010; Guo et al., 2016; Lei et al., 2019; and more
Pumi	4	4	0	42,861	27	Yunnan	Li and Hu, 2015; Zhao Y. et al., 2019; Shen et al., 2020; and more
Qiang	4	1	3	309,576	38	Sichuan	Guo et al., 2016; Zuo et al., 2018; Lei et al., 2019; and more
Baoan	3	3	0	20,074	23	Gansu	Han et al., 2011; Yu et al., 2011; Zhou and Wang, 2019
Daur	3	3	0	131,992	29	Inner Mongolia, Heilongjian, Xinjiang	Hong et al., 2012; Ye, 2016
Lahu	3	3	0	485,966	33	Yunnan	Li and Hu, 2015; Shen et al., 2020
Maonan	3	3	0	101,192	36	Guangxi	Yu et al., 2014, 2018; Yang et al., 2016a,b,c
Mulao	3	3	0	216,257	45	Guangxi	Ju-qian, 2014; Yu et al., 2014; Zhang X. F. et al., 2014; Gong et al., 2017
Achang	2	2	0	39,555	32	Yunnan	Li and Hu, 2015; Shen et al., 2020
De'ang	2	2	0	20,556	39	Yunnan	Li and Hu, 2015; Shen et al., 2020
Ewenki	2	2	0	30,875	41	Inner Mongolia, Heilongjiang	Hong et al., 2012; Ye, 2016
Jingpo	2	2	0	147,828	44	Yunnan	Li and Hu, 2015; Shen et al., 2020
Orequn	2	2	0	8,659	50	Inner Mongolia, Heilongjiang	Hong et al., 2012; Ye, 2016
Manchu	1	0	1	10,387,958	3	Liaoning, Jilin, Heilongjiang, Hebei, Beijing, Inner Mongolia	Zhai et al., 2007
She	1	1	0	708,651	19	Fujian, Zhejiang, Jiangxi, Guangdong, Anhui	Chen et al., 2017
Jing	1	1	0	28,199	42	Guangxi	Jiang et al., 2013
Gelao	0	0	0	550,746	22	Guizhou, Guangxi, Yunnan, Sichuan	N/A
Xibo	0	0	0	190,481	30	Xinjiang, Liaoning, Jilin	N/A
Tajik	0	0	0	51,069	37	Xinjiang	N/A
Russian	0	0	0	15,393	46	Xinjiang, Inner Mongolia, Heilongjiang	N/A
Uzbek	0	0	0	10,569	48	Xinjiang	N/A
Menba	0	0	0	10,561	49	Tibet	N/A
Hezhen	0	0	0	5,354	52	Heilongjiang	N/A
Gaoshan	0	0	0	4,009	53	Taiwan (population not counted), Fujian	N/A
Lhoba	0	0	0	3,682	54	Tibet	N/A
Tatar	0	0	0	3,556	55	Xinjiang	N/A

*The information about population and major area of distribution are from UNC University Libraries (2021). *Publications from region-level: the publications target on one specific ethnic minority group or target on ethnic minority groups in a region (a county, city, or province). **Publications from country-level: the publications are for national-level analysis. Always, the targeted ethnic minority groups are distributed around China.*

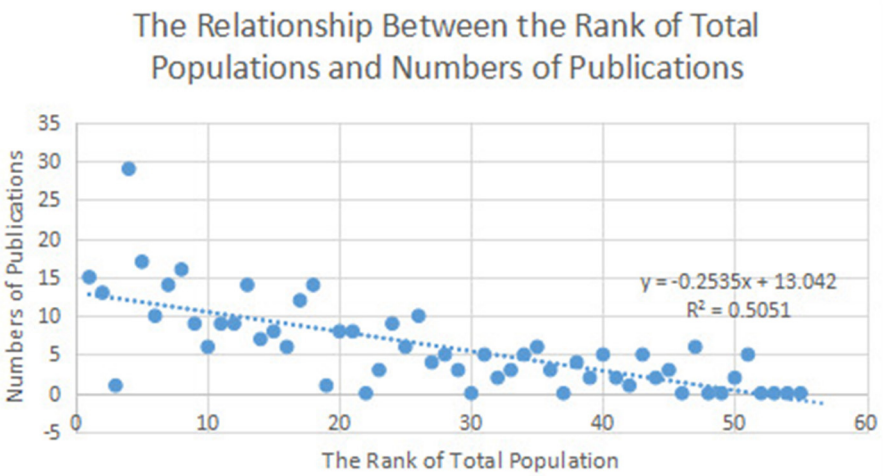

FIGURE 4 | The relationship between the rank of total populations and numbers of publications.

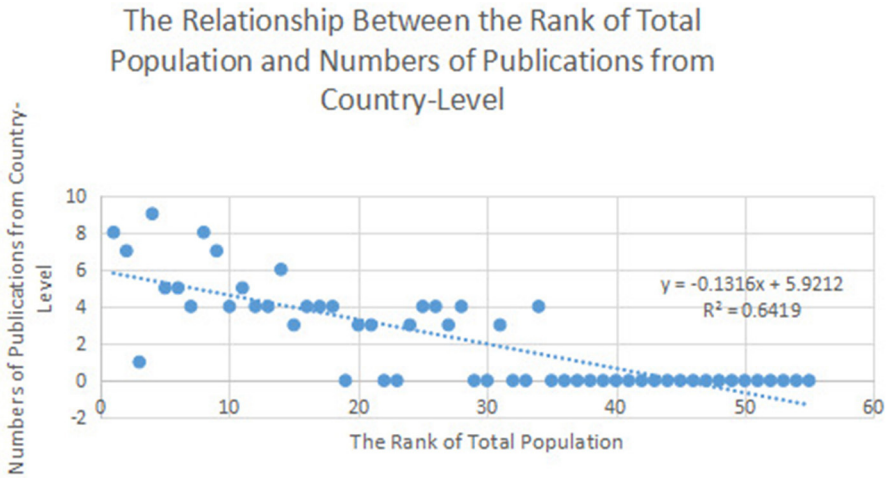

FIGURE 5 | The relationship between the rank of total population and numbers of publications from country-level.

Hazak, Miao, Nu, Uygur, and Zhuang groups) had results for all four categories.

Both region-level (see the references in Attachment 1) and country-level publications (Zhang et al., 2008; Guo et al., 2016; Dong et al., 2018; Lei et al., 2019) were identified that report anthropometric data (undernutrition and overnutrition). Thirty-two ethnic minority groups reported both the existence of undernutrition and overnutrition (double-burden malnutrition) and the changes in undernutrition/overnutrition rates in the selected literature. Twenty-seven of these 32 ethnic minority groups showed the trend that the undernutrition rate was decreasing while overnutrition was increasing during a time period (see the details and references in Attachment 1). Another five ethnic minority groups had different trends of undernutrition/overnutrition rates. More specifically, the Shui group showed an opposite trend. The undernutrition rate increased while the overnutrition decreased from 1991 to 2005 (Zhang et al., 2008). Both the undernutrition and overnutrition rates for the Tu group increased from 1995 to 2005 (Wen and Zhang, 2010). The existing literature only shows that the undernutrition rates of the Miao and Yao groups increased from 1991 to 2005, but lacks the data for the change in overnutrition rates that could represent the whole ethnic minority groups (Zhang et al., 2008). A study at Jinxiu Yao Autonomous County showed that the undernutrition rate of the Yao group increased while the overnutrition rate was stable from 2007 to 2012 (Li T. et al., 2016). For the rest 13 ethnic minority groups with existing literature on dietary practices or nutrition status, nine of the ethnic minority groups (the Baoan, Daur, Dongxiang, Ewenki, Madonna, Mule, Oreqen, Qiang, and Yi groups) reported both

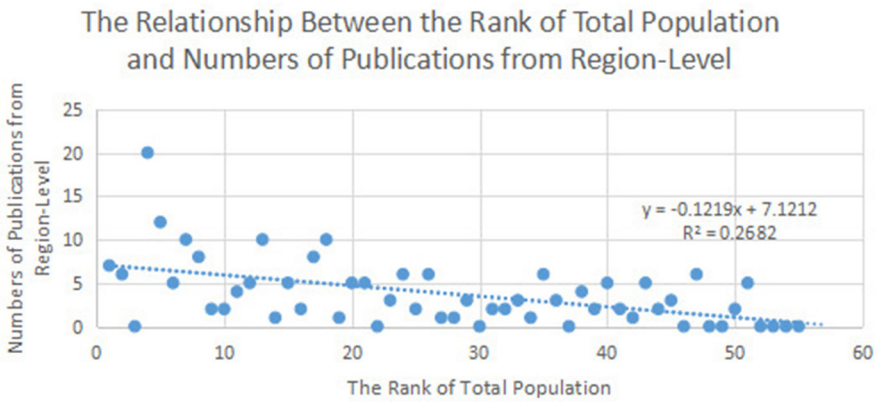

FIGURE 6 | The relationship between the rank of total population and numbers of publications from region-level.

undernutrition and overnutrition but did not report trends. Four ethnic minority groups (the Jing, Manchu, She, and Yugur groups) lack reports on undernutrition or overnutrition in the existing literature.

The results of nutrient intake/deficiency are available for 18 ethnic minority groups. The Uygur, Zhuang, and Miao groups provided more details about the results than the other 15 ethnic minority groups. Nutrients intake insufficiency, nutrient over-intake, and using blood testing to detect nutrient deficiency are three major topics for the results of nutrient intake/deficiency. Fourteen, six, and seven ethnic minority groups have results on these three topics, respectively. Iron was the most prevalent element reported among different ethnic minority groups in nutrients deficiency through blood samples (Yu et al., 2018; Huang et al., 2020), and sodium over-intake was reported most in nutrients over-intake (Jiang et al., 2013; Xie, 2015; Ka et al., 2018). The intake insufficiency of multiple nutrients was reported at least once among different ethnic minority groups. These nutrients included fat, protein, dietary fiber, energy, sodium, potassium, vitamin A (retinal), vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin C, vitamin D, vitamin E, calcium, niacin, zinc, iodine, folic acid, selenium, and magnesium (see details and references in Attachment 1). However, no publication was identified that summarized nutrient intake/deficiency among ethnic minority groups at the country level.

There were 19 publications that examined dietary intake including the intake of foods or food types and comparing with any dietary intake standards [such as dietary reference intake (DRI) and Reference Dietary Allowance (RDA)]. Only one country-level publication examined dietary intake for the general population of the ethnic minority groups and it has dietary intake information for 12 ethnic minority groups (the Mongol, Hui, Tibet, Uygur, Miao, Yi, Zhuang, Bouyei, Manchu, Yao, Tujia, and Kazak groups) (Zhai et al., 2007). The article was published in 2007, but is still the major source of results on dietary intake and thus was retained for analysis in the current review. The Uygur group remains the ethnic minority group with the most publications on this topic; the Tujia group and some Gansu Province-based ethnic minority groups such as the Yugur and Dongxiang groups also have considerable dietary intake information. Moreover, most publications about dietary intake only focused on one age group. Besides the 12 ethnic minority groups reported by Zhai et al. (2007) focused on the general ethnic minority group population, only the Jing, Nu, Naxi, and Zhuang groups have articles that discussed dietary intake conditions focusing on the general population of a specific ethnic minority group. At the level of the general population of a specific ethnic minority group, no ethnic minority group has a balanced diet.

Other diet-related behavior or practices are noted in the results of dietary habits, including exclusive breastfeeding, high-salt diet consumption, the consumption of pickled food, high-fat food, habits when buying foods, tea consumption, sweets consumption, breakfast consumption, meals per day, nutrition knowledge, causes for unbalanced diets, the influence of the Han main group or modernity, and more dietary habits. Exclusive breastfeeding is the most prevalent dietary habit and 18 ethnic minority groups have reported it. Fifteen of the 18 ethnic minority groups live in Yunnan Province and three of them are mainly distributed in the northeastern part of China. None of the ethnic minority groups practice 100% exclusive breastfeeding for 6 months after delivery. The Blang group had the lowest exclusive breastfeeding rate at only 9.8%, while the Nu, Ewenki, and Hani groups had exclusive breastfeeding rates more than 75% (77.1, 76.5, and 75%, respectively). However, although exclusive breastfeeding was the most prevalent dietary habit among different ethnic minority groups, only one article (Li and Hu, 2015) covered 15 ethnic minority groups in Yunnan Provinces.

In addition, the Uygur group has nine publications that focus on pregnant women and is the only ethnic group for which attention has focused on maternal nutrition. Both malnutrition (undernutrition and overnutrition) (Yuan, 2013) and unbalanced dietary structure (Maimaitiming et al., 2013) are reported. The intakes of seafood, vegetables, fruits, eggs, and milk are

insufficient, while the intakes of cereals and grains exceed the standard (Yan et al., 2019). Nutrients intake insufficiency is also reported, including potassium, iron, zinc, vitamin A, vitamin C, iodine, calcium, vitamin B1, vitamin B2, iodine, and folic acid (Sun et al., 2011; Maimaitiming et al., 2013; Yuan et al., 2013; Yang et al., 2016a,b,c; Ka et al., 2017, 2018). Two existing studies (Sun et al., 2011; Maimaitiming et al., 2013) proposed that more animal protein is needed to improve nutrition status and dietary balance.

DISCUSSION

The current study reviewed 111 selected publications about the nutrition status and dietary practices of ethnic minority groups in China. This study aimed to summarize the nutrition status and dietary practices of all 55 ethnic minority groups in China. However, it was limited due to a lack of data for 10 of the groups. The study shows that the Uygur, Miao, and Tibetan groups have the most publications related to nutrition status and dietary practices. Ethnic minority groups tend to have more total numbers of publications and country-level publications if they have a larger total population. Primary and middle school students are the two age groups with the most relevant publications. The results show that both double-burden malnutrition and diet unbalance are common among different age groups of Chinese ethnic minorities. The rate of undernutrition was generally decreasing while the rate of overnutrition was generally increasing in the past years. There is insufficient intake of multiple nutrients in many publications. Exclusive breastfeeding is the most prevalent reported dietary behavior and the rates are low among Chinese ethnic minority groups. Only the Uygur group has studies on pregnant women. When comparing with the Han main group, only 9 of 29 publications conclude that the Han main group has better nutrition status or dietary practices than ethnic minorities.

The current review summarizes nutrition status and dietary practice from a country-level perspective. Apart from the current review, the results of anthropometry were reported by five large-scale country-level publications. At least ten ethnic minority groups were included for each (Zhang et al., 2008; Ma et al., 2009; Guo et al., 2016; Dong et al., 2018; Lei et al., 2019). The five publications showed the prevalence of undernutrition, overnutrition, or double-burden malnutrition. Three existing studies (Zhang et al., 2008; Ma et al., 2009; Guo et al., 2016) showed the general trend that the undernutrition rate was decreasing while overnutrition was increasing in the past few years. The results aforementioned from existing literature are consistent with the results of the current review. Economic development of ethnic minority regions was proposed by Zhang et al. (2008) as the major cause of the prevalence of double-burden malnutrition and the trend of undernutrition and overnutrition rates. Development of tourism in ethnic minority regions, rapid urbanization, and cultural exchanges may also contribute to the increase in the overnutrition rate (Guo et al., 2016); high physical activity lifestyles may affect both undernutrition and overnutrition (Guo et al., 2016; Dong et al., 2018). The study by Guo et al. (2016) showed that the rates of undernutrition of the Han main group (4.2%) and ethnic minority groups (4.1%) were comparable in 2010, while the overnutrition rate of the Han main group was larger than in the ethnic minority groups (19.2 and 13.5%, respectively). This result is also consistent with the result of the current review that among 29 publications comparing the nutrition status or dietary practices of the Han main group and ethnic minority groups, only 7 publications conclude that the Han main group has better nutrition status or dietary practices than the ethnic minority groups. The remaining publications showed that the nutrition status or dietary practices of ethnic minority groups were comparable to or better than the Han main group. Genetic differences, different diets, more physical activities, and preferential policies and subsidies (Guo et al., 2016) among the ethnic minority groups could explain why the Han main group has a worse nutrition status than the ethnic minority groups in China.

Only one country-level article (Zhai et al., 2007) reported the dietary practices of multiple ethnic minority groups was found for the current review. Zhai et al. (2007) examined the dietary intake of the general population of 12 ethnic minority groups. Three region-level publications also showed the results of dietary intake of general ethnic minority people of the Nu (Zhao J. et al., 2019); Naxi (Fu et al., 2021), and Zhuang and Jing groups (Jiang et al., 2013). The results of these three publications are consistent with Zhai et al. study (Zhai et al., 2007) that the diets of ethnic minority groups are unbalanced.

The results of the linear regressions can be used to explore what factors may affect the studies and publications relevant to nutrition status and dietary practices among ethnic minority groups. Ethnic minority groups with large populations are more likely to have a country-level analysis. This may result from scholars' attention to the ethnic minority groups with larger populations, while ethnic minority groups with smaller populations lack publications, such as the Uzbek, Menba, Russian, Hezhen, Lhoba, and Tatar groups. The populations for these six ethnic minority groups are approximately or less than 15,000. However, ethnic minority groups, such as the Uygur, Dai, Naxi, Yugur, and Dulong groups, mainly live in only one province (UNC University Libraries, 2021). Even though some of them (such as the Dulong and Yugur groups) only have small numbers of the total population, they still have higher numbers of publications, especially in region-level publications. This may have occurred as an ethnic minority group is perceived as unique in a province; the local scholars may pay more attention to this ethnic minority group. For example, publications such as "Investigation on malnutrition and obesity of 0 ∼ 6-year-old children of 15 unique ethnic minorities in Yunnan" (Shen et al., 2020) and "Physical health status of college students from six unique ethnic minorities in Yunnan Province"(Bai et al., 2016) demonstrate this potential tendency in Yunnan Province through the titles using "unique". The Yi and Miao groups are larger ethnic minority groups than many others in Yunnan, but the Yi and Miao groups are not unique ethnic minority groups in Yunnan (People's Government of Yunnan Province, 2021). This may be the reason why no publications in Yunnan Province focus on the Yi and Miao groups, especially considering that

Yunnan is the province with the second most publications. The publications in Gansu Province and the northeastern part of China also present a similar tendency. In Gansu Province, the Yugur group only has 14,378 people but has six region-level publications. In the northeastern part of China, smaller but more unique ethnic minority groups such as the Oroqen, Ewenki, and Daur groups have more region-level publications than larger but non-unique ethnic minority groups such as the Mongol, Korean, and Manchu groups. The scholars also tend to work with the ethnic minority groups near their location. For example, Yu Wang is the corresponding author in most of the publications in Gansu Province among the Yugur, Baoan, and Dongxiang groups. The publications (such as Zhou et al., 2011a; Zhou and Wang, 2019) show that his team is at Lanzhou University, located in the capital city of Gansu Province.

The linear regression models also identified that the Manchu and Gelao groups are two significant outliers. Both of them have large populations (UNC University Libraries, 2021), but with only one and no publication, respectively. This may be attributed to the situation that neither of them is unique to any province (UNC University Libraries, 2021). The Manchu group may be seen as acculturation. The current scholars may overlook the Manchu people's dietary practices because they have been fused with the Han main group since the foundation of the Qing Dynasty (A.D. 1644- A.D. 1912) (Liu and Zhang, 2007). The Gelao group may be attributed to a lack of funding as well as few local scholars. Although the culinary culture of the Gelao people is still unique (Zhu, 2013), the major residency region of the Gelao people is Guizhou Province (UNC University Libraries, 2021), one of the most underdeveloped regions (Liu, 2016) with only one of the 211-project top university among all provinces in China (Ministry of Education of People's Republic of China, 2005). Lacking funding and few local scholars may result in the lack of studies related to research questions of the Gelao group.

The Gaoshan group is another ethnic minority group that lacks existing publications related to the current research questions. The condition of the Gaoshan group is unique as Taiwan is the major habitat of the Gaoshan group (UNC University Libraries, 2021). Currently, the People's Republic of China (PRC) is the sole representative of China in the United Nations and declares Taiwan as a province of China (Embassy of the People's Republic of China, 2021). PRC divides the Indigenous peoples in Taiwan as the Gaoshan ethnic minority group (UNC University Libraries, 2021). However, Taiwan has its independent government (Minister of Foreign Affairs, the Republic of China, 2021) and divides Indigenous peoples in Taiwan into different Indigenous tribes, including "Amis, Atayal, Paiwan, Bunun, Puyuma, Rukai, Tsou, Saisiyat, Yami, Tsao, Kavalan, Taroko, and any other tribes" (Council of Indigenous Peoples, 2021). Scholars from the Chinese mainland rarely go to Taiwan for research about nutrition and diet as they are required to have a Taiwan pass and endorsement (National Immigration Administration, 2019), whereas Taiwan scholars may not use the Gaoshan group for ethnic classification when conducting research. Several publications use the Taiwanese ethnic classification to document the nutrition status or dietary practices, such as the diet and nutrition study of Tsou Indigenous people in Taiwan (Huang, 2000). This may be the reason why no existing publications related to the nutrition status and dietary practices among the Gaoshan ethnic minority group. Therefore, when conducting a study related to Indigenous peoples in Taiwan, appropriate terms should be utilized when searching the literature. It is also important to evaluate why Taiwan categorizes Indigenous peoples in its way and consider whether it is valuable for the China mainland (PRC) to learn from this knowledge. According to the Center for World Indigenous Studies (Hinden, 2021), the lack of recognition of Indigenous peoples in China is because of tension between the construct of the Han group identity and western Indigeneity.

Only one publication specifies the branch of the ethnic minority group, Kunge people of the Blang group (Chan et al., 2019). It is essential to specify the location and branch of the study population as belonging to the same ethnic minority group can have different lifestyles and worldviews, which may affect nutrition status and dietary practices. For example, the Wa group in Yunnan Province has three branches with huge cultural differences, including the languages used in each branch (Gao, 2016).

The Chinese government has adopted multiple national policies to improve nutrition and health for the general Chinese population. This includes National Strategy for Healthy China, "Healthy China 2030" Planning Outline, National Nutrition Plan (2017–2030), China's Child Development Program (2011–2020), China's Rural Poverty Alleviation and Development Program (2011–2020), and Healthy China Action (2019–2030). Ethnic minority groups are included under these policies and even prioritized in several of them such as poverty alleviation programs (Zhang, 2013). Despite this, only a few studies consider factors of the traditional food systems of ethnic minority groups. This may be attributed to a lack of awareness and funding of traditional food systems of ethnic minority groups. As a result, several key studies easily influence the number of existing publications for each ethnic minority group. For example, Li and Hu (2015) study on exclusive breastfeeding rates leads exclusive breastfeeding to become the most widely distributed topic among ethnic minority groups for dietary habits; there are 15 ethnic minority groups who have exclusive breastfeeding data associated with this study. The studies on the Yugur group have six regional-level publications all led by the Lanzhou University (such as Zhou and Wang, 2018, 2019).

Therefore, more studies involving traditional food systems should be implemented in China because the diets of Chinese ethnic minority groups are affected by the influence of regions, environment, economic development, and religions (Zhai et al., 2007). Studies in other parts of the world have shown that many other factors in traditional food systems can affect the diet and nutrition of Indigenous peoples; the key factors include environment, cultural preference, affordability, health belief, education, and social media (Kuhnlein and Receveur, 1996). These factors may also affect the diet and nutrition of Chinese ethnic minority groups. Although existing publications have shown the utilization of traditional foods for either a specific ethnic minority group [such as the Blang group (Jiang et al., 2011) and the Tibetan group (Dickerson et al., 2008; Boesi,

2014)] or a specific region [such as Yunnan Province (Zhou et al., 2012)], no publication targets analysis of how traditional food systems affect nutrition and diet of ethnic minority groups from a broad perspective. Identifying traditional food systems can also help to improve nutrition status and dietary practices. For example, advocating local micronutrient-rich food to address micronutrient deficiency, introducing nutrition education based on local dietary habits to improve nutrition knowledge, and encouraging local plant cultivation to increase access to traditional foods (Caicedo and Chaparro, 2013).

Primary and middle school students are the main age groups for selected publications. This may be attributed to the convenience and cooperation of schools for research. Only studies on the Uygur group report maternal nutrition during pregnancy. Maternal nutrition will affect both the health of mothers and children (O'Toole et al., 2003; Schwarzenberg and Georgieff, 2018). Therefore, it is essential to implement more studies in maternal nutrition.

There are five limitations to this review. First, the current review does not include the analysis of risk factors or interventions concerning nutrition status or dietary practices of the ethnic minority groups in China as research questions, especially considering 20 and 12 publications are identified, respectively. Analyzing risk factors of malnutrition or dietary intake and nutrition interventions may inform the design and implementation of nutrition and dietary interventions. Thus, it is necessary to include the analysis of risk factors or interventions regarding nutrition status or dietary practices of ethnic minority groups in future studies. Second, there are multiple publications in Chinese related to ethnic minority food cultures (such as Ma, 1999; Kong, 2005; Fang, 2007; Zhao, 2007; Cai and Situ, 2008; and more). However, these publications focus more on anthropological and cultural issues without connecting to health, dietary intake, and/or nutrition in Indigenous cultures. Therefore, they were excluded but are worth examining for future interdisciplinary study designs. Third, contradictions exist in the results of nutrition status or dietary practices within an ethnic minority group. However, multiple factors, such as family size, education (Qu et al., 2013), income, and geographical factors (Wang C. et al., 2013), may contribute to the inconsistency of nutrition status and dietary practices because of the long time period. Fourth, Taiwan categorizes Indigenous peoples in a different manner than the China mainland. Therefore, when searching for literature on Indigenous peoples in Taiwan, it is imperative to use the appropriate terminology (i.e., tribal names) to find the most appropriate studies. Future research should evaluate why Taiwan categorizes Indigenous peoples in this way and consider whether it is valuable for China mainland (PRC) to also change their terminology and categorization. According to the Center for World Indigenous Studies (Hinden, 2021), the lack of recognition of Indigenous peoples in China is because of tension between the construct of traditional Han identity and western Indigeneity. Finally, the current review used undernutrition and overnutrition to represent the nutrition status of the ethnic minority groups. The definitions of undernutrition and overnutrition may not be the same and may not be the global criteria for under- and over-nutrition (Guo et al., 2016). Despite this, the current review reflects the nutrition status and dietary practices of the ethnic minority groups in China over the past 10 years.

CONCLUSION

This scoping review is the first study to target all 55 ethnic minority groups in China regarding their nutrition status and dietary practices. Through a review of 111 selected publications, the study shows that ethnic minority groups in China are suffering double-burden malnutrition and consuming an unbalanced diet but still have a better nutrition status than the Han main group in 2010. Multiple factors such as regional economic development, genetic differences, different diets, and physical activities may explain this phenomenon rather than just ethnicity inequality. Studies and publications are distributed unevenly among different regions and ethnic minority groups, and it may be attributed to funding availability, the convenience of studies, lack of awareness and policies, and the uniqueness of a specific ethnic minority group. More country-level programs and policies are necessary to address malnutrition and unbalanced diets at the country level. There is a dire need for more timely reports, research on traditional food systems and dietary intake, different age groups including maternal nutrition, the ethnic minority groups (Indigenous people in China), interdisciplinary perspectives and approaches, and specifying branches of the ethnic minority groups to better understand and address malnutrition and unbalanced diets among the ethnic minority groups (Indigenous peoples) in China.

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/s.

AUTHOR CONTRIBUTIONS

ZW contributed to the overall design, literature review, and writing about the current manuscript and was instructed and revised by AM-P. Both authors contributed to the article and approved the submitted version.

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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.2022.867848/full#supplementary-material

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The Kumiai traditional food system: Reconnecting nature, food and health through ancestral knowledge

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Traditional foods, once central to the diets of different cultures, are losing relevance as knowledge about food and its natural ecosystem deteriorates. This qualitative study describes the traditional food system of a Kumiai community in Baja California, and the ways in which the Kumiai have continually adapted their use and management of wild food resources to different food culture influences, demographic changes and contemporary food preferences. Present-day Kumiai recognize that their traditional diet was more nutritious and more connected with nature than their current diet, and express concern over transmitting existing knowledge about it to younger generations. We conclude that the characteristics of the Kumiai traditional food system not only strengthen their cultural identity and community economies, but also present potential solutions to the problem of food system sustainability by way of wild food resource management, as well as containing elements of a strategy for improving the health of community members.

KEYWORDS

traditional food systems, sustainable food systems, Kumiai ethnobotany, traditional foods and health, traditional food knowledge, wild foods, Kumiai native group

Introduction

Indigenous food systems are committed to ensuring a balance between communities and their environments, where diets are related to local ecosystems and to a culturally appropriate disposition of ingredients [Nabhan, 2006; Kuhnlein H. V. et al., 2009; Food and Agriculture Organization (FAO), 2020]. Traditional foods from native groups represent culturally significant ecological practices, and often provide significant nutritional value (Joseph and Turner, 2020). Indigenous peoples' original diets were generally well balanced and considered healthy in terms of their composition of proteins,

carbohydrates, fats, vitamins and fiber (Kuhnlein and Humphries, 2017; in Joseph and Turner, 2020, p. 3). It has also been shown that traditional food sources of carbohydrates are more slowly digested and absorbed, thereby protecting against diabetes (Brand and Cherikoff, 1985; Weiss, 1994).

The Food and Agriculture Organization of the United Nations (FAO) maintains the importance of recognizing the links between traditional food systems and indigenous peoples, who they see as knowledgeable guardians of biodiversity [Food and Agriculture Organization (FAO), 2021]. In contrast, most diets are no longer determined by what is produced locally and traditionally, instead reflecting the integration of industrialized foods, a situation that has resulted in several problematic conditions that affect both the environment and the health of the people who consume such food (Gálvez, 2013; Bertrán and Pasquier, 2021). In Mexico, malnutrition and obesity-related diseases affect more than 20% of the population, and constitute a major challenge facing the country's public agenda today (Consejo Nacional de la Política de Desarrollo Social (CONEVAL), 2021). These public health problems are linked to the type and quantity of foods that are present in urban as well as rural environments; this includes the accessibility and consumption of industrialized foods (Bertrán and Pasquier, 2021), which tend to be readily available due to their low cost, and are often seen as more practical (Contreras, 2005). Kuhnlein H. V. et al. (2009), maintain that traditional food systems articulate patterns of living in local ecosystems with food knowledge from the past and present, a situation that contributes to well-being and health, and can influence the implementation of more sustainable food processes that are functional for local environments.

Mexico exhibits a vast biocultural diversity of indigenous peoples who have inhabited and interacted within the territory, characterized by adaptation to different ecosystems as well as by the various ways in which the articulation between the complex field of food and food system knowledge is manifested (Toledo, 2013). We use the triadic relationship "nature-food-knowledge" to refer to this socio-ecosystemic perspective that conceives of human societies as having bidirectional interactions with their ecosystems, and where humans' food knowledge and decisions about food configure and support human nutrition as well as maintain a balance with nature (Galafassi, 2000). Indigenous food systems in Mexico represent ways of reproducing food-transformation practices that make use of resource underutilization strategies that ensure their conservation, such the milpa food system in Mesoamerica [(Comisión Nacional Para el Uso Del Conocimiento y la Biodiversidad (CONABIO), 2013), p. 4]. Recognition of a territory's food biodiversity, its food crops and its connection with traditional knowledge, is key to confronting the homogenization of diets found in industrialized food systems that are based on centralizing diets on a few intensive crops such as corn, wheat and rice (Guzmán-Flores, 2013; Galeana-Pizaña et al., 2018).

The present study was carried out among the Kumiai native group that has inhabited the extreme northwest segment of arid America for ∼5,000 years (Garduño, 2015). In the arid America region, unlike Mesoamerica, there is little recorded information regarding traditional foods of native groups (Cruz, 2015, p. 35). The Kumiai are not historically recognized for agricultural production, since they were traditionally seasonal hunters/fishermen and gatherers (Tapia-Landeros and Grijalva, 2012). The Kumiai in Baja California, Mexico link their existing food and medicinal knowledge to a vast experience in local ecosystems management (Wilken-Robertson, 2018). They developed a semi-nomadic lifestyle defined by season-based settlement in places where water was present and the vegetation contained edible flora and fauna. This case study was carried out among members of one particular Kumiai community, San José de la Zorra. This community is embedded in the wine-production region of the Guadalupe Valley near Ensenada, Baja California, a region that has become highly developed for tourism over the past three decades.

In this article, we outline the historical elements that are connected with current Kumiai knowledge about, and practice of, their traditional food system, much of which demonstrates continued viability in the observable customs and traditions of their present-day cuisine. Theoretically, this analysis provides information to predict future transitions in the Kumiai traditional food system. However, the Kumiai identify a crisis in their ability to maintain the cultural knowledge required to sustain the practices associated with the maintenance of this system. The crisis has to do with the fact that knowledge transmission has always depended on oral tradition, and Kumiai speakers who hold ancestral food knowledge are aging and passing away. We discuss this situation as part of the study results. This article also presents Kumiai perceptions of the value of their traditional food system in terms of its ecological and nutritional significance. Throughout the document we answer the following research questions: (1) How has the Kumiai traditional food system changed in response to historical and contemporary influences? (2) What are some of the attributes of the present-day Kumiai traditional food system that remain functional? (3) How can the value of the present-day Kumiai traditional food system be assessed?

Traditional food systems: Conceptual approach

Traditional food systems represent their broader cultural systems and reflect interactions with various environmental and social contexts (Johns et al., 2013). Kuhnlein and Receveur (1996) define food systems of indigenous peoples as being composed of items from the local, natural environment that are culturally acceptable" (p. 418), including socio-cultural meanings of food acquisition, processing techniques, use, and

nutritional values. Kuhnlein (2000) later added a historical dimension, by considering traditional foods to be those that were introduced in some communities long ago, including those of plant and animal origin, whether produced locally (domesticated or cultivated) or obtained from the wild. Johns et al. (2013) point out that the low productivity of traditional food systems makes the local environment more resilient, and in this sense functions as "a key link between biological and cultural diversity" (p. 3440). Traditional indigenous food systems stand in stark contrast to the prevalent hegemonic and inequitable global food system. The recognition of such systems can provide a path to, in some sense, decolonize the local food culture, thereby contributing to a cultural resurgence that includes the possibility of better health outcomes for its members (Grey and Patel, 2015, p. 719, in Grey and Newman, 2018).

The characterization of cultures according to historical process and meanings of food as traditional or non-traditional, together with their ecosystemic contexts, provides fertile ground for an analysis of the human construction of knowledge about foods that occur in their natural surroundings (Kuhnlein H. et al., 2006; Johns et al., 2013). Hence our use of the term nature-food-knowledge to refer to the way in which a traditional food system is created. Here, nature refers to the ways in which an ecosystem generates and sustains life through its resources and processes that benefit human beings; food corresponds to a vital biological need and the socio-cultural construction of its meaning (Fischler, 1995, p. 14–15); and knowledge results from reasoning regarding the lived experiences of interacting with nature in order to obtain food.

Traditional food system knowledge contains the customs that constitute historical cultural elements related to obtaining/producing, processing and consuming food, and that have been maintained in the present or have been adapted and reconfigured in the context of daily life (Batal et al., 2020). Traditions are non-static, since local cultures undergo constant reconfigurations due to interactions with the global society, and are better understood as dynamic cultural complexes that imply ethnic and ideological landscapes (Appadurai, 1991). We therefore consider traditional food in relation to current knowledge, with its culturally accumulated syncretism recognized by the community, and understanding its role in preserving historical values and renewing the sense of belonging to a group (Amilien and Hegnes, 2013).

So why is it necessary to maintain this knowledge in cultural memory? Such knowledge contains representations that contribute to providing meaning to habits or processes that, in some cases, are at risk of being forgotten and forever lost (Duque, 2020, p. 6). The recognition of traditional foods can serve as an identity response for remembering all that is implicit in knowledge about ingredients and techniques, as well as forms of thought and behaviors related to food practices (De Garine, 1998). Traditional food knowledge can thereby serve to maintain cultural identity and to revitalize the natural resources of local ecosystems [Food and Agriculture Organization (FAO), 2020].

What is considered traditional in Kumiai food culture? Amilien and Hegnes (2013) maintain that it is the collective knowledge and acceptance as typical within a given culture, that validates food as traditional. Therefore, foods introduced by other cultures, as well as foods that connect the population with external and contemporary food practices, may be considered as part of a traditional food system, as long as these foods correspond directly to the territory and cultural adaptation (Villegas, 2019). Such an exchange and assimilation of culinary cultural attributes defines the history of post-contact transitions in the traditional Kumiai food system, resulting in the current Kumiai food culture (Bonilla Cazarín, 2008).

The Kumiai traditional food system did not incorporate cultivation methods until the arrival of missionaries and ranchers, although some authors argue that their management of wild edible species, and of the local landscape, is related to the practice of agriculture (Parrish and Lightfoot, 2009). The first transitional period accompanied the arrival of Spanish missionaries, who recruited native people to live around the missions, incorporating practices such as cattle ranching and agriculture (Magaña and Leon, 2006). Nevertheless, for native people, hunting and gathering practices remained an important way of obtaining food, complementary to the activities of grazing and agriculture (Garduño, 2015). The Kumiai settled into valleys and mountains, gradually disconnecting their food procurement from the coast, and eventually eliminating dietary seafood. A later shift in the traditional Kumiai diet was the incorporation of the modern Mexican food system. Living memories of members of the Kumiai community of San José de la Zorra are vanishing as elders pass on and modernization encroaches. Nevertheless, traditional cultural activities such as collecting, growing and hunting, continue to be practiced, thereby keeping these aspects of the traditional food system alive.

The study community and its context

The Kumiai are an amerindian tribe of indigenous peoples belonging to the Yuman-Cochimi branch of the Hokan language (Garduño, 2014, p. 13), whose original territory spanned a broad area on both sides of what is now the northern border of Baja California in Mexico, and the southern border of California in the United States (Shipek, 1982). Lacking a written language, the communities that became part of the United States adopted the English spelling of "Kumeyaay," and the communities that remained in Mexico use the Spanish spelling of "Kumiai." The Kumeyaay and Kumiai, though originally the same cultural group, have developed differently since their geopolitical division (Wilken-Robertson, 2018). The Kumiai are currently distributed in four native communities in the municipalities of Ensenada and Tecate (Garduño, 2015). The

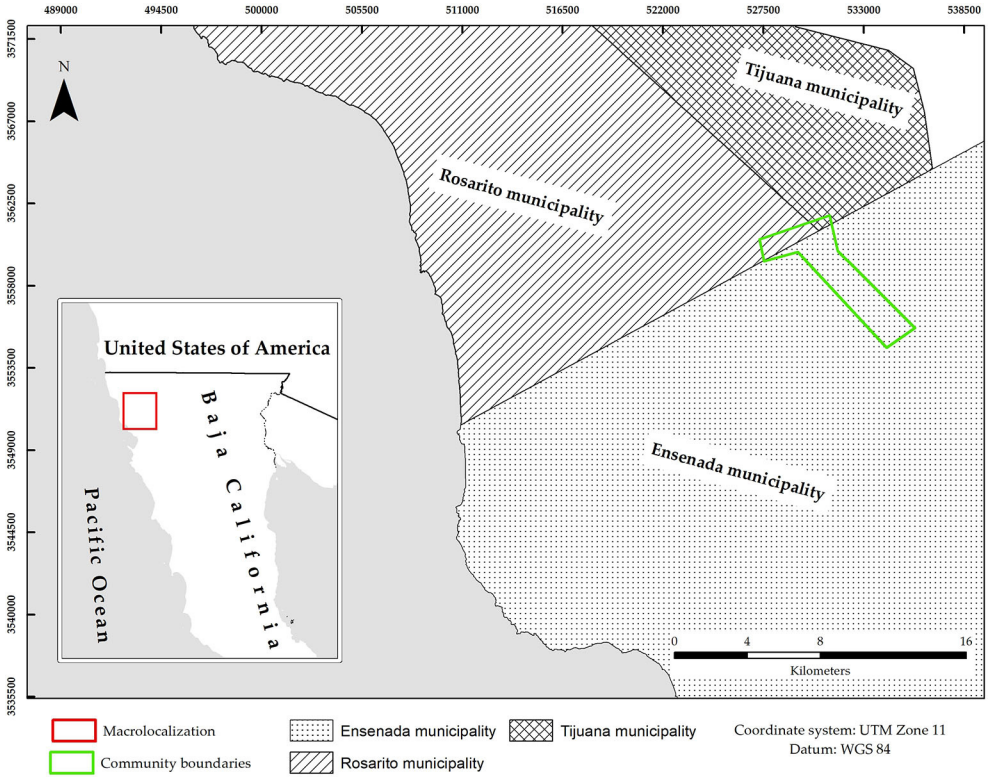

FIGURE 1
Map showing the polygonal territory of San José de la Zorra, one of four Kumiai native communities in Baja California. The inset shows the community's proximity to the United States of America and to the Pacific Ocean (retrieved from Andrade-Sánchez et al., 2021).

subject of this article refers exclusively to the Mexican Kumiai and in particular to the community of San José de la Zorra.

Although principally located in Ensenada, small parts of the northern fringe of this community are found in the southern sections of the municipalities of Rosarito and Tijuana (see Figure 1). The community is located in a rural area with a Mediterranean-style climate, 58 kms from the municipal seat of Ensenada and 18 kms northwest of the Guadalupe Valley (Leyva and Espejel, 2017). The development of the Guadalupe Valley has led to its designation as an international destination for viticultural and gastronomic excellence, attracting busloads of tourists (Zarate and Barragan, 2018, p.88)—and has radically changed the environment of the Kumiai people who settled into their small communities over a hundred years ago.

The original Kumiai semi-nomadic, clan-based organization was replaced by a community system of communal lands. San José de la Zorra was settled around the beginning of the XX century in accordance with changing national policies that were geared toward marginalizing the native groups (Morales, 2003, p. 91–92). According to the National Institute of Statistics and Geography [Instituto Nacional de Estadística y Geografía (INEGI), 2020] a total of 167 people constitute the community of San José de la Zorra. However, the community keeps a separate updated list showing more detailed information, that indicates a total of 99 people currently living there (Community list census information by interlocutor 6, 2020). Of this total population, 19 are indigenous language speakers capable of transmitting traditional food knowledge learned from their grandparents and parents reaching back to the first half of the past century (Community list census information by interlocutor 6, 2020). This dwindling number constitutes a cultural-heritage concern, since fluent speakers tend to be over forty years of age, and no children are learning the native language as their mother tongue (Leyva, 2014, p. 4).

The Kumiai adapted the cowboy culture as part of their identity related to cattle herding and grazing practices, an important activity for culinary diversification. San José de la Zorra depicts the characteristic housing patterns seen today, referred to as *rancherias*, consisting of a set of structures, or ranches, dispersed throughout the rural space that makes up the community (Magaña and Leon, 2006). Among their customs and traditions, is the elaboration of handicrafts from the leaves and seeds of wild plants (Garduño, 2014). Their economy is sustained by temporary employment, agriculture

(wine production and agricultural land lease), salaried work, handicrafts and remittances from the United States (Wilken-Robertson, 2018).

Methodology

Several factors contributed to our decision to work with the Kumiai of San José de la Zorra, apart from their basic characteristics of having thrived on semi-nomadic food procurement practices, their late inclusion of agricultural techniques, and a varied diet of different species of flora and fauna that represent Baja California biodiversity (Garduño, 2014). Of the four regional Kumiai communities, San José de la Zorra was chosen due to its location, its endemic wild foods and the openness of interlocutors. We believe the information they provide will contribute to the recognition of this regional food heritage under circumstances of scarce documentation and the rapid loss of members who carry living memories of changes to the traditional food system. The location is of special interest because of its juxtaposition to the Guadalupe Valley, where a robust gastronomical-viticultural development has taken place.

The overall methodological approach employed an array of qualitative techniques designed to characterize the extent to which community members consider the traditional food system as remaining functional, and to investigate the value they see in it and its maintenance. Ethnographic methods primarily employed participant observation and in-depth interviewing, but also utilized workshops and photographic tools (Berg, 2007; O'Reilly, 2011; Mikhailovich et al., 2015; Codesal et al., 2017).

In order to answer the research question regarding the persistence of the historical Kumiai traditional food system in the modern context, we compared our ethnographic findings with descriptions of the traditional Kumiai food system found in literature dating as far back as the first missionary contacts. The literature review also revealed the various cultural influences to which the Kumiai were exposed and forced to adapt throughout the different historical periods since first contact, thus providing information to compare with what is known from the primary sources (Snyder, 2019).

Fieldwork took the form of numerous day visits as well as stays of several days, over a period of 4 years. During these times information was gathered from informal conversations with key interlocutors and their family members, as well as the formal interviews and workshops. Fieldwork involved an initial period of rapport-building, and the gradual implementation of a snowball sampling (Etikan et al., 2016) designed to identify community members who possessed the highest degrees of knowledge about the traditional food system and maintained involvement with its techniques and practices. This method produced eight women and two men ranging in age from 25–60 years who became key interlocutors. More women were involved due to the nature of the research, involving food and food preparation, which is principally the domain of Kumiai females. Men tend to be more knowledgeable about hunting practices and techniques, and in the traditional ways of preparing game. We stopped the snowball sample at the point of data saturation. In-depth interviews were conducted with these ten interlocutors, comprising roughly half of the 19 Kumiai speakers of the community who acquired their traditional food knowledge in their mother tongue.

The guide for in-depth interviews was based on topics concerning the transmission of traditional food knowledge, food diversity in Kumiai traditional and contemporary diets, and how these relate to a healthy and sustainable diet. In-depth interviews provided information about present-day traditional food items and contemporary influences affecting their dietary practices and preferences. They also revealed members' knowledge and practices regarding the acquisition, preparation and storage of wild elements contained in the local ecosystem, as well as perceptions of their nutritional value and place in current dietary practices. Finally, the interviews contained members' thoughts about the loss of traditional food system knowledge and associated practices, and ideas for how to revalue and transmit these to younger generations.

Fieldwork also included ethnobotanical walks to identify and collect the traditional food items growing wild within a half-mile radius of the community, as well as participation in the food preparation process. These activities were recorded photographically in addition to field notes (Piñeiro and Diz, 2018). We also conducted two workshops with women from the community in 2019 and 2020. The first workshop was designed to identify the elements of the traditional food system and to discuss ways of improving their current diets. The second workshop developed plans for accomplishing these goals and discussed ways of integrating the community around them, with the vision of food as a uniting factor. This constitutes a topic of ongoing work with the community.

The study also included data collected in conjunction with our participation in the organization of a dinner event that showcased Baja California's native cultures and their foods, organized by the Institute of Native Cultures of Baja California. During this event, we collected questionnaires from an additional 15 members of three Kumiai communities, ranging in age from 18–60 years, regarding their knowledge about traditional foods, and the importance of keeping this knowledge alive. This allowed us to compare and corroborate with other Kumiai, some of the information retrieved from San José de la Zorra.

Data analysis

A grounded theory approach was utilized to develop themes surrounding the key elements of the Kumiai traditional food system, and to visualize relationships among these elements

within the context and processes of the food system. Interviews were processed using the software package Atlas.Ti (L-085-399) (Taylor and Bogdan, 1987; Restrepo-Ochoa, 2013). This analysis incorporates historical, cultural and ecological factors related to food disposition and preferences, thereby contributing to our integration of primary and secondary data.

We constructed tables to synthesize information obtained from in-depth interviews, in combination with other indirect data. For example, Figure 2 shows the different historical periods that influenced the Kumiai traditional food system, the nature of the culinary influences, and the ways in which those influences are seen in their current diet. Figure 3 shows three different foods that form part of the traditional Kumiai diet, as described during the interviews and identified on ethnobotanical treks; their botanical characteristics and nutritional values are added from the literature in order to lend credence to the perceptions expressed by interlocutors about the relatively healthier nature of traditional food items as compared with processed industrialized foods.

The research protocol was approved by the Institutional Review Board of the Autonomous University of Baja California. In addition a signed informed consent was obtained from the traditional authority of the Kumiai community of San Jose de la Zorra, and from all participants.

Results

The following results describe elements of the traditional diet in relation to the interpretation of what is known and perceived about the food traditions in a present-day context. Findings confirm that the present-day Kumiai daily diet maintains elements of their historical traditional food system that are collectively considered as traditional. They also show the ways in which the Kumiai reconfigured their traditional diet around enduring core practices of hunting and gathering animals and plants from within their local ecosystem, in response to various influences, and how they adapted and integrated these external culinary influences. Finally, results are presented concerning the value of the traditional food system to present-day Kumiai, not only as a cultural heritage, but also in terms of its relation to the local ecosystem, the nutritional value provided by Kumiai traditional foods and the problematic nature of transmitting knowledge about it to younger generations.

The Kumiai daily diet reflects significant diversification from their original traditional diet due to the incorporation of elements introduced by the migration of different cultural groups to the Baja California peninsula after the arrival of the Spanish missionaries, and especially since the 1970s, when modern Mexican culture began to expand into rural areas of Baja California. This gives rise to the first research question: How has the Kumiai traditional food system changed in response to historical and contemporary influences. Figure 2 shows a rough timeline of the cultures that established themselves in Kumiai territory, some of their contributions to the general food culture, and elements that are incorporated into the food dynamics of the Kumiai of San José de la Zorra. Ingredients, such as sugars, oils, cereals, spices and certain fruits appeared with the arrival of Spanish explorers to Mexico in 1519, giving rise to a process of "culinary miscegenation" (Bonilla Cazarín, 2008). While these items were incorporated into the diets of mesoamerican indigenous groups, they did not reach the Kumiai until 1834, when the final Dominican mission was built in the area where the San Jose de la Zorra reserve was later established in 1867 (Morales, 2003). Other foreign influences were inserted in subsequent periods, most notably the Mexican, Russian Molokan, Japanese and other Asian, and American (Meigs, 1994; Leyva and Espejel, 2017). These cultures exchanged culinary practices and ingredients with the Kumiai community, resulting in new ways of eating, preparing and producing foods for all of them. Although some members of the San Jose de la Zorra community have incorporated practices that reflect elements of the regional context, such as small-scale agriculture and the production of wine, cheese, and olive oil, community members consider only the older methods of gathering, hunting, and family farming as definitional of their traditional diet.

The establishment of settled communities brought with it the cultivation of other foods that were introduced to their original diet, such as "wheat, beans, and barley" (Interlocutor 2, Personal Communication, 2019), as well as the raising of farm animals, including cattle, as practiced by the missionaries and ranchers in the ninteenth and early twentieth centuries (Aschmann, 1952). The change to a sedentary lifestyle resulted in the Kumiai disconnection from their traditional fishing practices and consumption of seafood. This tendency was reinforced by the gradual settlement of migrant Mexican and international populations that progressively appropriated coastal areas, displacing the indigenous presence. In the contemporary era (XX–XXI) this disconnection is linked to urban growth and the privatization of beach areas in the municipality of Ensenada. Memories concerning knowledge about the use and consumption of marine resources in the Kumiai diet were documented in interviews carried out during the earlier stages of this research. As one interlocutor from San José de la Zorra mentioned: "*I have heard that the oldest people used to go to the coast to eat shells; I imagine they went down to Ensenada*" (Interlocutor 1, Personal communication, October 15, 2016). The oldest village elders indicate that perhaps during the early twentieth century, the Kumiai still maintained their nomadic relationship with coastal food procurement. However, a native Kumiai interlocutor from San José de la Zorra noted that "not much seafood is consumed" as part of their present-day traditional diet (Personal Communication, 2016[1]).

1 Personal communication with a person who now is deceased.

Cultures established in Kumiai territory (Ensenada Municipality)	Contributions to the local food culture	Elements incorporated into the Kumiai traditional food system
Spaniards-mestizos (Dominican missionary period XVII-XIX)	• **Agriculture>** grapes, figs, olives, citrus, apricots, wheat, corn. • **Mesoamerican crops>** corn, squash, chili, beans. • **Rancherias>** grazing animals (donkeys, goats, etc.)	• Olive tanning. • Planting in pattern of rancherias, and consumption of lemons, oranges, quince and figs.
Americans (XIX century)	• **Livestock>** cattle, sheep, pigs. • **Intensive crops>** wheat, barley.	• Potentiation of the cowboy culture and consumption of grazing animals.
Russian colony. Molokans (XX century)	• **Crafts>** cheese making, bread, sausages. • **Crops>** melon, cucumbers, apples, wheat. **Grazing>** Sheep.	• Cheese making and cheese consumption is incorporated and maintained in the diet.
Asian cultures (Japanese-Chinese) (XX century)	• **Grocery stores>** coffee, grains and household items. • **Intensive crops>** wheat and barley planted by outsiders within the study community.	• Wide acceptance of Chinese food for its flavor and abundant portions. • Extensive wheat and barley crops for livestock feed.
Migrant cultures from southern and northern Mexico (Mexico City, Oaxaca, Durango, Sinaloa) (XX century)	• **Crafts>** sauces; baked, fried & refried foods. • **Crops>** beans, tomatoes, tomatillos, onions, squash, chili, corn. • **Kitchen tools>** griddles, mortars, gas stove. • **Introduced products>** coffee, sugar.	• Incorporated into the food system> wheat flour, corn tortilla, hot sauces, and condiments. • Beans and coffee are important for traditional and contemporary diet. • Forms of cooking> fried, baked and pan cooked.
Modernity. Globalized food system (XX-XXI century)	• **Industrialized products** (pasta, flour, canned goods, chips, cookies, vegetable oil, soluble coffee, sugar).	• Welfare programs provided low-cost industrialized foods, including refined sugar to sweeten hot and cold drinks.

FIGURE 2
Cultures that arrived and settled in Kumiai territory. Showing the culinary elements adapted to the traditional and daily diet of the Kumiai. Author's creation based on information found in Meigs (1994), Piñón (2000), Williams (2004), Magaña and Leon (2006), Leyva and Espejel (2017), and field conversation information.

Contemporary version of the Kumiai traditional food system

Rural communities in Baja California enjoy an increasing access to, and consumption of, industrialized foods that, however, may have a negative effect on the health of native communities (Fleuriet, 2009). Such items include "junk food" (cookies, sodas and chips) and additional non-native foods incorporated from the government's list of elemental food items that are considered by the government as fulfilling the needs of the average household, including pasta, refined flour, bread, sugar, canned goods, rice, beans, eggs, dairy products, oils (Secretaría de Agricultura y Desarrollo Rural, 2020). Kumiai interlocutors say they incorporate such processed foods into their diet because they are readily accessible in local stores.

The Kumiai diet is under constant reconfiguration. Some of the ingredients that were used for traditional cooking have been replaced by what the modern market offers and although some everyday foods such as refined flour and sugar are not beneficial to their health (Weiss, 1994), they nevertheless have become incorporated into modern dietary practice (Fleuriet, 2003). Community members point out that, given the lack of refrigeration, it is more convenient to buy industrialized and canned foods. Nevertheless, there is awareness that these foods are not the same as food derived directly from the earth: *"most people consume products such as soups and canned food. Some of them used to harvest their own vegetables and grains, but many people no longer do so"* (Interlocutor 3, Personal communication, June 16, 2016).

Kumiai adoption and adaptation of outside foods is visible in the current preparations of their traditional foods. An example is the consumption of flour tortillas with nearly all meals and the incorporation of corn tortillas into their diet. As one community member stated: "In fact, we didn't eat corn tortillas until about 26 years ago. Before, there was no corn flour, [there were] no stores. Here wheat was sown and right here it was threshed and cleaned, brought home and ground" (Interlocutor 2, Personal communication, October 5, 2016). In general, present-day Kumiai prefer to accompany their meals with flour tortillas rather than corn tortillas, despite knowing that excessive consumption of refined wheat flour can contribute to negative health consequences. The Kumiai use of corn plays a smaller role in their daily diet than the ways corn is used in central and southern regions of the country, where it continues to be the main staple food and signifies great biological and cultural importance for the food systems of southern Mexico (Ordoñez, 2018).

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Traditional food name	Ethnobotanical information	Nutritional characterization		Culinary and nutritional knowledge
Spanish: Bellota amarga **English: Bitter Acorn**	Scientific name: *Quercus agrifolia* Vegetation: coastal chaparral Growth: arboreal Flowering: March-April Use: food-housing-toys Parts Used: Stem; fruit Manner used: atole Taste: bitter Collection season: Autumn Frequency of consumption: medium	**Per 100gr**. Humidity: 63.76% Minerals: 2.24% Crude fiber 63.62% Carbohydrates: 10.45% Lipids: 15.67% Proteins: 8.03% Calories: 214.95%		**CK:** In adapting different seeds for human consumption, the Kumiai use processing techniques such as drying, grinding, leaching, and cooking to eliminate concentrations of tannic acid from the acorn. **NK**: Acorns are known for their great nutritional value and healthy unsaturated fats.
Spanish: Berro **English: Watercress**	Scientific name: *Nasturtium officinale* Vegetation: transitional chaparral. Growth: aquatic Use: edible-medicinal Parts Used: Stem-leaf Manner used: Direct collection, stew Taste: salty Collection time: Winter-spring Frequency of consumption: low	Calories: 11 Lipids: 0.1g-2.59% Sodium: 41mg-1.06% Potasio: 330mg-0.85% Carbohydrates: 1.3g-33.76% Proteins: 2.3g-59.74% Vitamin C: 43mg-1.11% Calcium: 120mg-0.31% Magnesium: 21mg-0.54%		**CK:** It is consumed either raw or cooked as part of a stew. **NK:** People reported that watercress is good for kidney pain and for diabetes.
Spanish: Islaya **English: Holly-leaf Cherry**	Scientific name: *Prunus ilicifolia* Vegetation: coastal chaparral Growth: shrubby Use: Edible Parts Used: fruit-seed Manner used: Direct from collection, ground Taste: sweet Collection season: summer-autumn Frequency of consumption: low	Pulp Humidity: 63.19% Minerals: 4.10% Crude fiber 76.82% Carbohydrates: 11.99% Lipids: 1.95% Proteins: 5.14% Calories: 86.07%	Seed Humidity: 42.07% Minerals: 2.86% Crude fiber 75.48% Carbohydrates: 8.37% Lipids: 3.01% Proteins: 10.28% Calories: 101.69%	**CK:** To process the seed, the techniques (such as drying, grinding, leaching, and cooking for detoxification) are the same as those used for preparing acorn atole. **NK:** People reported that holly-leaf helps with headaches

FIGURE 3
Nutritional, cultural and botanical characteristics of traditional food resources. Author creation based on information found in Cortés (1994), Weiss (1994), Lucero (1995), Wilken-Robertson (2018), U.S. Department of Agriculture (USDA) (2020), and field conversation information.

Contemporary kitchen space exhibits a duality of the modern and the traditional, since the Kumiai still prefer cooking with a wood stove, even if there is access to a gas stove. They cite the main reason as the flavor it brings to food. Interestingly, this characteristic has become a hallmark of the new gastronomy that is being developed in the region. Present-day family traditional meals within the community may contain handmade, fire-roasted flour tortillas, roasted or fried game rabbit, porridge made from acorns (*Quercus agrifolia*) "acorn atole" (Gutierrez and Von Glascoe, 2019, p. 216), seasonal fruits (in this case peaches), fresh cheese made from cow's milk, and occasionally a homemade sauce made with tomatoes and grilled peppers. Many of the families also consider it essential to have rice and beans, which have become a staple meal accompaniment (Field Observation, 2019). The use of sugar has increased in daily preparations, although people from 40 to 50 years old remember that only honey was used to sweeten drinks or food. Honey was not easily obtained because it had to be found and harvested. Traditionally, honey was considered a medicine more than a food.

These Kumiai recognize certain ingredients, techniques and preparation methods related to traditional ancestral practices versus those of recent or contemporary incorporation. Principal ingredients from the traditional system that are still consumed include: acorns, deer, wheat, quiote (the stem and flowers of *Yucca whipple*), rattlesnake, honey, mustard, cactus leaf (nopal), rabbit, lard, beans, wild mushrooms. Contemporary foods that form part of their diet include: potatoes, barley, rice, chicken, beef, corn, onions, and milk. Traditional flavors they identify as traditional are bitter-sweet-smokey; contemporary flavors are sweet-salty-smokey. Traditional and contemporary food preparation techniques include drying, roasting, boiling/stewing, baking and grinding. They also make preparations with traditional and contemporary ingredients and methods. These include: tortilla dough, pinole (wheat ground with water or milk and sugar or honey), atole (flour made with washed and slightly fermented acorns), pozole (soup made with alkaline-processed corn kernels), beef broth, stew (traditionally made of wild leaves collected according to season), dehydrated figs, beans cooked with wheat and barbecue (both traditional and contemporary).

The foods that are consumed daily in the community tend to be basic pantry staples. Yet community members still consume elements of their traditional diet at different times and for different reasons, such as to mark significant occasions or simply to experience tastes that carry important cultural meanings and sentiments. They also continue to prepare traditional foods as a way to keep alive ancestral practices associated with certain festivals, such as the annual community celebration of their patron saint, and the annual "Nativa Festival" which brings together members of all the native tribes of Baja California (Field Observation, 2017–2019). For more common celebrations such as birthdays, they tend to barbecue a freshly slaughtered cow or sheep in the style of the cowboy culture they adopted after the missionary period and reinterpreted in terms of contemporary Mexican customs.

Kumiai traditional food in relation to the local ecosystem

As mentioned above, the contemporary version of the traditional Kumiai diet maintains the use and consumption of different wild plant and animal species, thereby continuing to benefit from the nutritional value provided by them (Andrade-Sánchez et al., 2021). The second research question has to do with which of the traditional food system's original elements have been preserved and are still in use. Field work resulted in the identification of many vegetable and animal species important to the traditional food system, One interlocutor recalled what the ancients ate: *"Uh well, what we ate was deer, wheat tortillas, mustard, quiote flowers, rabbit meat, quail, and for fresh water, manzanita. All of this was prepared by my grandmother and hence the poleo that was on the hill; poleo is very good*" (Interlocutor 2, Personal communication October 3, 2016). What they call *poleo* (*Ptelea aptera)* is actually a species of Ptelea, commonly known as hops or quinine tree, which shares some of the medicinal characteristics of *Mentha pulegium*, more generally known as *poleo,* in that they both have beneficial effects on the digestive system. It is characteristic of the Kumiai to apply the name of a commonly known plant to any particular native plant found in their habitat, according to the similarity of their uses and effects.

Different types of animals identified as part of the traditional diet are still found in the ecosystems of low-lying shrubs and grasslands (Leyva and Espejel, 2017, p. 138–141), and are sporadically consumed, among them: rattlesnake (*Crotalus ruber,* subject to Special Protection by the NOM-059-SEMARNAT-2010), mule deer (*Odocoileus hemionus*), hare (*Lepus californicus*), rabbit (*Sylvilagus audubonii and Sylvilagus bachmani*), and quail (*Callipepla californica*). Their limited consumption is due to factors that include the displacement of fauna in response to population, tourism and agricultural development of the rural area, legal restrictions, and a lack of interest in continuing the practice.

Some uses of plant species are transitioning from their original culinary, sacred or medicinal use, to a commercial use (Cortés-Rodríguez and Venegas-Cardoso, 2011). The Kumiai made baskets of insect-repelling leaves that protected the seeds they harvested for food. They used the reed (*Juncus* sp.) to weave their *Sawil*—"a plate for cleaning seeds" and *Jilu*—"small woven pot to store seeds", and the willow (*Salix* sp.) to weave their *Shkwin*—or "woven pot" (Personal Communication, 2021). These plates and pots were important for the handling of seeds and other foods, and for their cleaning and storage (Tapia-Landeros and Grijalva, 2012). As the need to use and store plants for food, or to make utensils or tools with them lessened, some community members began to apply the same techniques to making decorative items that could be sold. The elaboration of handicrafts with reed and willow continue to be some of the most important activities within San Jose de la Zorra, and an important element for community sustenance (Field Observation, 2019). Kumiai artisans sell their hand-made jewelry and elegant basketry in local shops, shows and craft events, and the increasing demand "has become a major force in the local economy, where a large percentage of the local residents now depend to some degree on the income generated by this traditional activity" (Andrade-Sánchez et al., 2021).

Certain vegetal species are considered sacred in Kumiai culture, such as the white sage (*Salvia apiana*) native to coastal scrub and chaparral in Baja California and California. Aside from its use in sacred cleansing rituals, white sage is known to benefit the respiratory system (Córdova et al., 2016). These characteristics have garnered interest among members of the general public, which has led to an ongoing illicit harvest that increased dramatically in response to the SARS-CoV-2 (COVID-19) pandemic, when white sage products were offered by international online markets such as Amazon and Walmart (Ramirez et al., 2022). The significant uptake in the illicit overharvesting of white sage was observed by local native groups and documented by the NGO Terra Peninsular. This situation is concerning because white sage serves the local ecosystem in many ways, providing refuge and food for mammals and pollinating insects. It also carries cultural meaning in the form of medicinal, culinary and ceremonial uses for native peoples. The small-scale harvesting of white sage, as well as other plants and seeds such as acorns, rush and willow, is vital for maintaining cultural practices and contributing to the Kumiai economy, underscoring the importance of maintaining their sustainable management (Galván et al., 2016).

Workshop results underscored the need to preserve traditional knowledge and to reinforce the connection with natural foods. Participants mentioned the importance of conserving certain species due to reductions in their habitat availability associated with climatic changes as well as human activities such as grazing practices. Oak, sage, yerba santa ("holy

herb") and prickly pear were specifically singled out for their edible, medicinal and culturally relevant qualities. Oak (*Quercus agrifolia*) is emblematic of the Kumiai culture, as it provides shelter from sun and rain, as well as the acorns that are central to their traditional food system. Yet, not all Kumiai houses are sheltered by oaks, hence the need to propagate this species. Sage (*Salvia apiana, discussed above) was mentioned* for the use of its leaves for incense and medicine). Yerba santa (*Eriodictyon sessilifolium*) is significant for its medicinal uses, while prickly pear (*Opuntia* spp.) is an important food that has been shown to control blood sugar levels.

Workshop results also revealed important barriers to maintaining a healthy diet. Participants identified the lack of fresh food availability in the community…"*In the community we only have three stores to stock our pantries, but nothing fresh, everything is packaged. If you want fresh things for the daily meal, you have to leave the community and you can't always go, because it's difficult to do so*" (Interlocutor 5, personal communication, march 2020). Because the collection of traditional wild foods can be difficult, sometimes involving a major effort, participants expressed an interest in growing their own native and non-native foods in family vegetable gardens. This also explains the fact that certain ingredients, such as pinto beans and wheat, that are readily available in stores, have been adapted for the preparation of dishes considered traditional. Despite these factors, members of the community still collect wild plants from the immediate environment for food and medicinal purposes. In the following section we discuss an emerging and relevant topic as a subquestion of the second research question, namely: what nutritional value is provided by Kumiai traditional foods?

Kumiai knowledge about the nutritional value of traditional foods

The Kumiai worldview understands everything as being related through the natural order, such that wild foods that are consumed also have curative properties (Cortés-Rodríguez and Venegas-Cardoso, 2011; Wilken-Robertson, 2018; De la Fuente Ruiz, 2019). Present-day Kumiai ethnobotanical knowledge is seen as a kind of "green health insurance" that is shared among people who live in the area where medicinal and edible plants grow (Wilken-Robertson, 2018). Weiss (1994) presented evidence "to support the theory that Kumiai ancestral menus and lifeways of the past protected genetically susceptible populations from developing diabetes" (p. xv), specifically by controlling blood sugar levels (p. 190).

Some studies have shown that the elimination of traditional foods from the daily diet can adversely affect people's health, and can be potentially associated with an increased incidence of adult onset obesity and diabetes, which in turn can be related to the quality of food consumed today (Villela and Palinkas, 2000; cited in Nabhan, 2006, p. 130). Kumiai community members perceive that the industrialized food that has come to prevail in their current dietary practices can exert a negative influence on their health, and that the foods that once formed the basis of their grandparents' and distant ancestors' diet, contained beneficial nutritional properties: "There have been many people my age who have been sick and diabetic; I think it is due to diet, that one used to eat pure [food] from the fields, but no longer. Now people eat very differently, from cans and so on; [but] that is not healthy, [all food] should be natural" (Interlocutor 4, personal communication 2016–2019). Figure 3 shows ethnobotanical and nutritional information for three of the most important wild-food elements of the Kumiai traditional food system, as well as Kumiai knowledge and preparation techniques. These three wild foods exemplify the importance and value of ingredients in the traditional food system in terms of taste, appearance, and nutritional profile, namely, seed (acorn), berry (cherry), and leaf (watercress).

In addition to having a legitimate reputation in the diet of the Native Americans of Baja California and California, it is known that acorns (*Quercus* spp.) have more nutritional value than industrially produced modern grains such as wheat and corn (Weiss, 1994). Our interlocutors perceive their traditional dish of acorn atole to be "very nutritious food" (Field observation, 2021). Acorns are rich in tannins and provide up to 8 g of protein per 100 g (Lucero, 1995). Watercress (*Nasturtium officinale*), while believed by community members to help with liver problems and diabetes, is difficult to find due to the arid characteristics of their ecosystem. The fruit of the holly-leaf cherry or wild cherry (*Prunus ilicifolia*), is eaten during the summer season, and the leaves are used in infusions for headaches (Personal Communication, 2021); it has also been documented that traditionally the Kumiai prepare atole with cherry seeds, but with a special process because it contains cyanuric acid/hydrocyanic acid (cyanide) (Wilken-Robertson, 2018, p. 181). Our interlocutors describe using certain wild foods as remedies for common ailments such as headaches, colics (colicos) and flu, including: Yerba santa (*Eriodictyon lanatum*), Salvia (*Salvia apiana*), Yucca lechuguilla (*Hasperoyucca whipplei*), Mugwort or Feverfew (*Artemisia tridentata*).

Other foods considered part of the cultural landscape include edible wild vegetable species whose dietary consumption has been recommended for their high nutritional value (Lucero, 1995). For the Kumiai of San José de la Zorra these include manzanita (*Arctostaphylos glauca*), mustard (*Brassica nigra*), nopal (*Opuntia* spp.) and purslane (*Portulacca olaracea*). Also on this list is a peculiar edible bulb that flowers after the rainy season, which some children still search out, called "*Jalpap*" (name given by one interlocutor), a Wild Hyacinth native to the Western United States and northwestern Mexico, commonly known as blue dicks (*Dichelostemma capitatum*)

(field observation and conversation, 2016–2019). Children like to eat the bulb raw for its sweet nut-like flavor, but complain of sleepiness if they eat too much of it.

Community elders of San Jose de la Zorra reflect on their current diet of industrialized foods with high caloric content, along with a more sedentary lifestyle, and remember their grandmothers' food as healthier, requiring greater energy expenditure to procure and prepare (Personal Communication, 2019). These findings underscore the importance of native peoples' traditional food knowledge and the need to defend their presence in the local ecosystem.

The cultural transmission of traditional food knowledge

In this section we address concerns expressed by the Kumiai regarding the transmission of traditional food knowledge and practices. This inquiry is related to the second research question as it considers how certain attributes of the traditional food system will be able to maintain permanency, but also to the third research question of how can the present-day Kumiai traditional food system be valued. It is clear that its continued permanence will require the training and interest of younger generations in ancestral knowledge and ways. The Kumiai language is not written, and transmission of their cultural knowledge has always relied on oral tradition (Wilken-Robertson, 2018, p. 235). It has been mostly females—mothers, aunts, grandmothers—who have transmitted knowledge about food, and now this knowledge is in danger of fading away due to the loss of indigenous-language speakers (Garduño, 2015). We observed that food is part of a language where people can transmit their culture and an important value to food traditions.

Just as the language of native peoples has been learned through oral tradition, so have their recipes and ways of collecting, hunting, identifying and preparing the foods found in the wild. Food is intertwined with their culture and transmission of knowledge (Wilken-Robertson, 2012). We have shown how this knowledge is a product of cultural and culinary adaptation or reconfiguration through post-contact interactions, including the influx of other emerging food systems. We witness the process of continual adaptation by way of interactions with the local tourist dynamic through activities related to traditional cuisine, plant knowledge or handicraft workshops.

The questionnaire administered to 15 adults from three Kumiai communities showed that over three-quarters of them believe they have a basic knowledge about the identity and modes of preparation of their traditional foods. They name the most salient traditional food items as being acorn, sage, venison, quelite, quelite flower, deer and pigeon; and true to form, they include some items that have been adapted from cultural influences that have come their way post-missionary contact, such as corn, grapevine, and squash flowers, ingredients found in the valley area (Garduño, 2015). However, even though most of these respondents can name traditional food items, and claim to know where to find them in the wild, only 60% say they know how to prepare or preserve traditional Kumiai foods. Importantly, all of them believe it is important to transmit information about the ancient traditional Kumiai diet, and nearly all believe it important to share community knowledge about it with the surrounding region.

Today the Kumiai tend to maintain cultural independence, even though their children attend government schools built in their communities and learn in Spanish as opposed to their native tongue (Leyva, 2014). Nevertheless, some young natives' traditional knowledge is learned in childhood by listening to the elders and through educational community programs, where elders have the opportunity to teach the children about their traditions. It is observed that kitchen, classroom and community landscape have an important role for the exchange of knowledge about traditional practices and for strengthening the recognition of food and natural heritage. However it is learned, knowledge transmission has always played an important role in cultural survival (Muller, 2018), and is fundamental for the sustainability of native culture and habitats as part of the identity of contemporary Baja California natives (Wilken-Robertson, 2018).

Discussion

This study investigated the culturally-accepted foods and practices of present-day descendants of hunter-gatherers located in a particular Kumiai community, where food is not seen as a measurable indicator, but rather as a cultural construct that incorporates traditional forms of production and consumption. We have presented how the Kumiai traditional food system changed in response to historical and sociocultural exchanges. The main effect of the territorial reduction that accompanied national political development and its concomitant national and international migration, was the settlement of native groups into sedentary communities, which in turn resulted in the gradual disappearance of the semi-nomadic lifestyle and a disconnection with the coastal ecosystem. We found attributes of the present-day Kumiai traditional food system that remain functional and can be used to evaluate it in relation to the use of local resources and certain challenges presented by the local gastronomy scenario. We show how Kumiai traditional food is inextricably linked with the local environment, knowledge preservation and health. Yet in the current Kumiai community scenario we found that food alone becomes more complex, whether in reference to the everyday or the traditional, the natural or the industrialized, the globalized or the localized.

Ibarrola-Rivas and Galicia (2017) maintain that "food systems need to be oriented toward the sustainability of

ecosystems and quality of life" (p. 107). This is important, based on the direct relationship of Kumiai traditional food with its natural habitat, which is altered and threatened by abuses such as the exhaustive extraction of natural resources, or the commercialization of certain specimens of flora or fauna in response to a folkloric interest in native traditions. Such variation in the use of resources can have a negative effect on the environment and the sustainability of the local resource (Loring and Whitely, 2018).

The Kumiai of San José de la Zorra continue to adapt to a changing food system environment by engaging in economically productive family projects that incorporate traditions and customs related to native and endemic natural resources, including collecting practices, the production of artisanal handicrafts, wine production and ecotourism. This community has only just begun to explore the possibilities of developing the economic potential inherent in linking cultural activities involving tourism to its traditional food resources, food cultivation and preparation. If the traditional diet and customary uses of natural resources are part of a community's cultural heritage and provide added value as a means of subsistence, then food culture requires reference to elements and practices related to conservation of local ecosystems (Baptiste et al., 2017; IPES-Food and ETC Group, 2021).

However, the practices of the Kumiai traditional food system that have been maintained in the current socio-gastronomic setting that has flourished over the past three decades, have garnered little visibility in terms of the regional rural development process (Andrade-Sánchez et al., 2021). This is concerning given that traditional foods from indigenous cultures have been considered as a resource for tourism development, as key elements in health promotion, and as necessary for the creation of more sustainable production systems (Bringas and González, 2004; Anderson, 2005; Contreras and Thomé, 2019; Bak-Geller and Pasquier, 2020; Prunier et al., 2020). We consider that the incorporation of Kumiai ancestral territorial knowledge and efforts to sustain traditions, could improve the practices within the established industry that involves agriculture, restaurants, and tourism. Grey and Newman (2018) maintain that the market can incentivize the incorporation of indigenous foods into a larger gastronomic scenario. Nevertheless, it will require a concentrated effort to make the native traditional food system visible to this ongoing development, and to link some part of the development not only to knowledge about the nutritive value of the wild foods found in the territory, but to the repository of knowledge and techniques represented by members of Kumiai culture (Kuhnlein et al., 2019).

Our work confirms the observations found in the literature that in the Kumiai food system, the traditional diet stands in sharp contrast to the diet of the last 30 years where the availability and consumption of, and preference for industrialized and refined foods has prevailed (Cortés, 1994; Weiss, 1994; Fleuriet, 2003, 2009). The recognized nutritional value of certain elements of the traditional food system affords them a role in general health and health maintenance (Nabhan, 2006). Although not the focus of this research, there is an inseparable relationship between health and the consumption of traditionally grown or harvested foods. Different studies have highlighted the role of dietary change from traditional to industrialized foods, as risk factors for the development of obesity and type 2 diabetes among native groups in the arid America region, including the Kumiai of Baja California (Weiss, 1994; Alvarado-Ozuna et al., 2001; Fleuriet, 2003, 2009; Nabhan, 2006; Longstreth and Wilken-Robertson, 2010). This situation constitutes a diet-related national health concern (Bertrán and Pasquier, 2021) that we deem worthy of future study.

Another topic for future study that we identify, involves the concept of food sovereignty, defined as "the right of peoples to control their own seeds, land, water and food production, through local, autonomous (participatory, community and shared) and culturally appropriate production, in harmony and complementation with mother earth" (Comité Internacional para la Soberanía Alimentaria-Coordinación Regional América Latina y el Caribe 2012, cited in Micarelli, 2018: 120). This concept implies the importance of sustaining communities together around a number of activities, including food production, appropriation, promotion of indigenous traditional knowledge and the ecologically responsible use of land for farming (Chappell et al., 2014; Grey and Newman, 2018; Prunier et al., 2020). The period of the SARS-CoV-2 (COVID-19) pandemic saw increased interest in home gardening among Kumiai community members. However, a serious attempt to address food sovereignty would require addressing community organization in terms of who performs collection or cultivation in the traditional food system and how they do it (Wittman, 2011), as well as addressing the opportunity to generate community initiatives that aim to revalue and integrate some traditional foods into local marketing circuits in support of their local economy.

We underscore the importance of examining and diffusing human knowledge about the natural habitats of foods, where local food cultures act as the axis that guides and maintains the local food system (Béné et al., 2019). Research among existing native groups in Baja California shows that such expertise is in danger of becoming lost since few people remain who can speak of traditional knowledge and transmit traditional practices (Leyva, 2014; Garduño, 2015; Galván et al., 2016; Wilken-Robertson, 2018). We propose that knowledge about the traditional food system be introduced to younger generations through participative workshops and memorialized in the form of written materials. Not only will this contribute to the cultural sustainability of the Kumiai tribe, it will offer the potential of fostering the development of future generations' own alternative means of endemic food production within the framework of the tangible and intangible values of their heritage (Joseph and Turner, 2020).

This study illustrates an approach to the traditional food system by way of what we term the axis of nature-food-knowledge, which emphasizes the health of food environments, and we offer it as a reference for other traditional food systems with similar contexts. One of the strengths of this research is the documentation of knowledge that is being lost as part of the cultural and natural heritage of the region. Our goal is to diffuse this knowledge so that those who visit this region and those who decide to live here, will develop an awareness and respect for the surrounding natural resources and their uses, and the native culture that developed a food system based on these resources that perdured for many thousands of years. A perceived weakness of this research is the small number of interlocutors interviewed who retain memories of the traditional food system as practiced by their ancestors–roughly half of those who continue to live in the community. This factor lent more urgency to the project, owing to the belief that this knowledge forms an important part of the cultural heritage of the region, and needs to be revalorized by the current generation.

Conclusions

The native community of San José de la Zorra provides an example of how a traditional food system can function as an elemental link between culture and environment. Their small-scale use of complementary agricultural practices corresponds to the same seasonal availability of undomesticated foods that gave rise to their original semi-nomadic lifestyle, providing cultural resistance to the modern hegemonic industrialized food system and bringing into the twenty-first century an ancient wisdom about a semi-arid ecosystem where scarcity is a part of the natural cycle. This connection of food knowledge with local ecosystems where indigenous populations are found, allows opportunities for the implementation of traditional knowledge in the form of conservation strategies, as well as the revaluation of traditional wild foods. We conclude that the characteristics of the Kumiai traditional food system not only strengthen their cultural identity and community economies, but also present potential solutions to the problem of food system sustainability by way of wild food resource management, that contains elements of a strategy for improving the health of community members.

Data availability statement

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

Ethics statement

The studies involving human participants were reviewed and approved by Institutional Review Board of the Autonomous University of Baja California. The participants provided their written informed consent to participate in this study.

Author contributions

MB, JL, MV-C, NC, and CGu contributed to design. CGu contributed to data analysis. CGu and CGl contributed in writing. CGl contributed to revision and translation. MB, JL, MV-C, and NC contributed in articulation and review process. All authors have made an intellectual contribution to the article, 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.

Publisher's note

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Food governance for better access to sustainable diets: A review

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'Governance', understood as organizational governance, is essential to more sustainable food provisioning systems ensuring sustainable health, heritage, and natural environments. Governance enables regional and local perspectives to be aligned with commitments from national and international organizations. Within the wealth of scholarship on food systems governance, agricultural governance and agency is a rarely interrogated dimension, despite the clear impacts of agricultural decisions on health and environmental outcomes. In this paper we discuss the findings of a scoping review that focuses on the question "How can food governance transform food systems to ensure better access to sustainable diets?", meaning diet that protect health, cultures, and the natural environment. Our results show that it is first needed to determine the governance level and the expected outcomes. From a national perspective, policy coherence is described as a way in which different public institutions can add to the sustainable diets access goal. From a local perspective, community supported activities and the incorporation of local knowledge are also described as ways that can help achieving an improvement on sustainable diets access. Either from a regional or local perspective, commitment from organizations must be ensured for common objectives being aligned. Also, it is necessary to request more from the agricultural sector role in delivering nutritionally and environmentally appropriate food. Thus, the idea of governing agriculture as a health and environmental activity is an approach that should be considered when designing, implementing, and assessing food systems.

KEYWORDS

culture, food governance, food systems, agriculture, scoping review, sustainable diets

Introduction

Global food production represents an important pressure over the Earth's natural systems and is related to problems associated to food and nutrition insecurity (Willett et al., 2019). It is estimated that between 720 and 811 million people faced hunger in 2020, 118 million more than in 2019, while one in three people did not have access to adequate food during the same period (FAO, 2021). On the other hand, in 2016, 1.9 billion adults were overweight, and 650 millions of these were obese, while in 2020 and 39

million children under the age of 5 were overweight or obese (WHO, 2021). In addition, the number of people suffering from "hidden hunger" (insufficient intake of essential minerals and vitamins required in small amounts by the body for proper growth and development) was likely to be between 1 and 2 billion in 2021 (WHO, 2021). When these three conditions coexist in the same individual and/or community, we speak of the "triple burden of malnutrition", which nowadays represents the most worrying issue related to food and nutrition security (Ingram, 2020).

Food security definitions have evolved over time. In 1996 the international community defined that "food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their daily energy needs and food preferences for an active and healthy life." Nowadays, however, we see how increasingly the environmental—e.g., "planetary health" and "one health" approaches—socio-cultural, acceptability and agency—or the power of citizens to the define and secure their rights, in particular to food security—dimensions have become more relevant (Calistri et al., 2013; Lerner and Berg, 2015; Chappell, 2018). For example, approaches such as the "agency" dimension proposed by Rocha and the concept of "food sovereignty" have been proposed, among other things, to enhance social inclusion and participation on food systems design and management (Chappell, 2018), considering cultural and acceptance values around food production and consumption.

Related to the above, the "sustainable diets" approach arises as a holistic paradigm that considers context specific ecological concerns together with health and nutrient adequacy, as well as the affordability and socio-cultural acceptability of diets at the global, regional, local, and individual level (Garnett et al., 2014; Johnston et al., 2014). To provide sustainable diets that help reducing both food insecurity and the incidence of non-communicable diseases while strengthening the sustainable management of natural resources, is necessary to transform food systems (van Bers et al., 2019; Dupouy and Gurinovic, 2020). To achieve the aforementioned, Swinburn et al. (2019) and WHO (2020) propose a focus on three complementary areas: (1) strengthening local levers and engaging civil society into food systems transformations (2) acknowledging the diversity and complexity of food systems, with a particular scope in a nutrition-sensitive agricultural production; and (3) the inclusion of local—indigenous/traditional—approaches to health and wellbeing. Actions in these areas require a multilevel coordination and a multi-sectorial approach that can only occur if proper conditions exist (Lee et al., 2020; Delabre et al., 2021). In this sense, the concept of governance appears both as a process and a value that allows the socio-cultural environment for a proper functioning of food systems (Berry, 2019).

Based on the presumed relationship of both concepts (food governance and sustainable diets) to socio-cultural dimensions of food and agriculture, most of the literature is extensive in exploring each of these concepts separately, paying less attention to elucidating whether and how they are related. Herein we review and discuss the evidence regarding what is known about the implications of food governance, its relation to sustainable diets, and recommendations for future research.

Methods

A scoping review was conducted from April 2021 to May 2021 to find evidence on our research question: "*How can food governance transform food systems to ensure better access to sustainable diets?*" The search included peer-review papers of both qualitative and quantitative research, and book chapters from any country between 1990 and 2021. We chose the timeframe 1990–2021 for this review was to find out whether the theoretical link between the two concepts (food governance and sustainable diets) corresponded to something widely studied or was relatively new.

The search strategy covered three databases: Ovid, ProQuest, and Web of Knowledge. Three groups of research terms were applied: governance, diets, and food systems. Key words relating to governance (e.g., governance, food governance, public policy, food policy, etc.), diets (e.g., local, healthy, indigenous, etc.), were combined with terms indicating transformation of the food system (food system transformations, inclusive food systems, resilient food systems, etc.). Terms were combined using Boolean AND/OR strategies (e.g., food policy OR food governance AND food system transformation OR resilient food system, etc.).

Initial search conducted by a single reviewer (MdV) using the aforementioned databases. Title and abstract screening were conducted independently by two reviewers (MdV) and (ASAVM) using the web-based software platform Covidence, an online review and data-extraction tool. Disagreements were resolved through further discussion between both researchers, analyzing case by case the reasons that led them to choose if each article would fit in the review according to the inclusion criteria. The final list of papers was discussed with a third reviewer (KS). In this case, and due to the expertise of KS in food governance, the set of studies selected was assessed according to its explicit focus on governance structures examples regardless its level (global, regional, local), and explicit mention of different sustainable diets dimensions, such as ecological concerns, health and nutrient adequacy, affordability, and cultural acceptability, among others.

Data extraction was conducted using an Excel matrix spreadsheet in which findings were organized according to the following categories discussed previously between MdV and KS, based on the type of information we wanted to obtain from the review. Finally, information of each category was compared to find commonalities and differences between the different selected papers.

Results

Selection process, research period and location

Thirty-seven studies were found that fulfilled all inclusion criteria. Full reference details for these studies are presented in Table 1. Figure 1 explains the entire review process, from the database import phase to the final inclusion assessment. First, 226 duplicates found by Covidence were eliminated, leaving 709 studies for screening titles and abstracts. Of these, 449 studies were considered irrelevant because they did not match the objective of the review. Subsequently, 223 studies out of the 260 remaining for "full-text assessment for eligibility" were excluded for different reasons, such as "wrong focus" (190), "not available" (19), "wrong type of document" (13) and "duplicate" (1). Covidence did not initially find the last duplicate. The list of excluded studies categorized according to exclusion criteria is separately provided in Supplementary Table 1. The selected papers cover the period 2013–2021, concentrated especially between 2018 and 2020 (n = 25; 68%), so studies linking the two concepts are relatively new. However, it should be noted that as the review was carried out between May and April 2021, studies published after the latter date were not considered for the selection process. Most selected papers belong to studies developed in Europe (33%) and to reviews and/or studies with no specific settings (32%), while in contexts commonly described as "low- and middle-income countries," only a 11% of studies were found. All the studies were scientific papers.

Processes of food governance

Food governance can be understood as the "architecture of food systems" (Berry, 2019) that allows formal and informal interactions between institutions and people to enable the environment in which food systems perform (Candel, 2014; Kennedy et al., 2017; Béné et al., 2019). These interactions can be vertical when different levels interact (global, regional, national, local, etc) and horizontal, where diverse stakeholders per level are involved (Allen et al., 2019; Hunter et al., 2016). Different levels and stakeholders involved implies interests and a strong presence of power and decision-making rules, availability and use of data, and economic incentives and disincentives, among others (Voß and Kemp, 2006; Lang and Barling, 2013; Zurek et al., 2018; Swinburn et al., 2019). Some authors also understand governance as a social value of sustainability, by making clear that the balance of power, decision-making, and access to information among the different actors in food systems is what allows people to govern their food according to their own values and principles (Lang, 2014; Béné et al., 2019).

Together with balancing power over food systems, the selected studies also describe that strong governance is needed for other purposes. For example, it helps to build a common vision, to support evidence-based policies, and to promote effective coordination and collaboration (Dupouy and Gurinovic, 2020). Other authors highlight how governance has ensured the right to food (Pott et al., 2016), strengthening local food systems and leading their transformations toward sustainability (Hawkes and Popkin, 2015; Kennedy et al., 2017; Blay-Palmer et al., 2018; Galli et al., 2020a; Delabre et al., 2021). At the same time, when governance is deficient, for example when existing policies are inconsistent or fragmented (Balázs et al., 2021), crises are more likely to occur and progress in achieving sustainable diets can be threatened, as well as the efforts to address climate change, stop biodiversity loss, and achieve better incomes for farmers and food system workers (De Schutter et al., 2020).

Food governance levels and focuses

From a global, regional, and national perspective, food governance is a requirement for food policies performance (Boylan et al., 2019) as they operate across many levels shaped by international, national, and regional agreements (Balázs et al., 2021). Food policy integration

TABLE 1 Sustainability dimensions of diets from selected studies.

Group	Category	Studies
1	Sustainability focused on the environmental dimension	Hawkes and Popkin, 2015; Hunter et al., 2016; Pott et al., 2016; Kennedy et al., 2017; Blay-Palmer et al., 2018; Zurek et al., 2018; Lawrence et al., 2019; Swinburn et al., 2019; De Schutter et al., 2020; Dupouy and Gurinovic, 2020; Détang-Dessendre et al., 2020; Galli et al., 2020a; Graça et al., 2018; Lee et al., 2020; Leip et al., 2021; Parker et al., 2021; Vermeulen et al., 2020; Balázs et al., 2021.
2	Environmental and sociocultural aspects	Lang, 2014; Mattioni and Caraher, 2018; Allen et al., 2019Berry, 2019; Béné et al., 2019; Downs et al., 2017; Galli et al., 2020b; Hawkes, 2007; Calistri et al., 2013; Melesse et al., 2020; Delabre et al., 2021; Kennedy et al., 2021.
3	FAO definition	Lang and Barling, 2013; Lang and Mason, 2018; Lundqvist and Unver, 2018; Boylan et al., 2019, 2020.

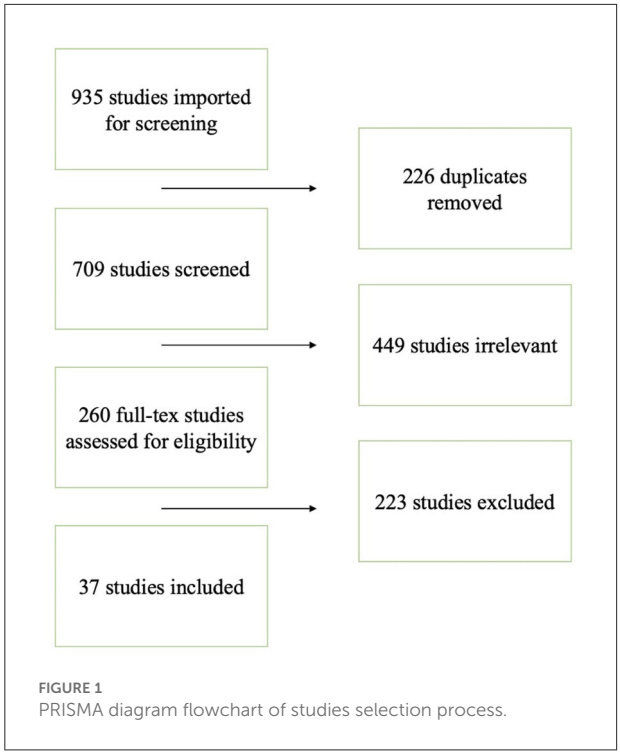

FIGURE 1
PRISMA diagram flowchart of studies selection process.

and coherence are commonly described as a way in which actions from different sectors converge to meet public health and sustainability objectives, and a proper environment as a product of governance is key to achieve that (Graça et al., 2018; De Schutter et al., 2020; Farmery et al., 2020).

From a local perspective, community organization, food policy councils, learning garden programs and the incorporation of local knowledge are commonly described as another way of the interactions that occur as part of food governance actions (Sonnino, 2013; Wilkins et al., 2015; Del Valle et al., 2019). In these cases, farmers' decisions about which animal breeds and vegetables varieties to produce are more influenced by community interests, natural resources, and agronomic skills than by market forces (see Wilkins et al., 2015 an example of sustainable diets through seasonally intake). It is also described that city-region is a key-level of governance to unlock food systems transformation and where collaboration between civil society and municipal government are effectively observed (Vermeulen et al., 2020). For example, food policy councils aim to forge new alliances between producers and consumers and between urban centers and their natural hinterlands (Sonnino, 2013).

Most of the papers selected for the review were strictly focused on food systems governance (n = 20; 54.1%), while a smaller portion (n = 9; 24.3%) although focused on food systems governance, had some other considerations, such as mentioning agriculture (Allen et al., 2019; Swinburn et al., 2019; Vermeulen et al., 2020), ecosystems relevance (Lang and Barling, 2013; Lang, 2014; Lang and Mason, 2018; Downs et al., 2017; Galli et al., 2020a) and earth systems (Lawrence et al., 2019). In addition, there was a last portion of papers focused strictly on agriculture governance from different approaches. For example, some papers discussed the relevance of agricultural systems governance (Hunter et al., 2016; Pott et al., 2016; Détang-Dessendre et al., 2020) and there was also one focused and governance over agriculture and environment (Dupouy and Gurinovic, 2020).

Sustainability approaches in sustainable diets

Finally, and related to the definition and scope of sustainable diets, it was possible to find different approaches to and definitions of "sustainability." Three approaches were grouped together: Group 1 (n = 18; 48.6%) were those papers mentioning health and sustainability as two complementary dimensions of diets, being the last only referred to environmental concerns, such as carbon and water footprint and/or GHG emissions; Group 2 (n = 14; 37.8%) was composed by all the papers that explored other dimensions of sustainable diets beyond the "health and environment duality"; Group 3 (n = 5; 13.6%) were all those papers which used the FAO (2010) definition[1] as a theoretical framework for their discussion, meaning another approach to go beyond the health and environment duality. Table 1 shows which papers are in each group.

Discussion

In order to answer the research question "How can food governance transform food systems to ensure better access to sustainable diets?", the result of this review allows us to focus our attention on the way food governance allows an appropriate environment with context-specific characteristics for food systems to perform.

Regarding sustainable diets, most authors from group 2 agreed that a multi-criteria approach should be adopted when defining them, giving equal importance to health and environment, but also to sociocultural issues, preferences and values, socioeconomic wellbeing, diet quality and equitable access (Downs et al., 2017; Mattioni and Caraher, 2018; Béné et al., 2019; Melesse et al., 2020; Delabre et al., 2021; Kennedy et al., 2021). Is it necessary then to focus on other aspects besides

1 Sustainable diets are 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.

health and the environmental impact? We believe so, especially because the interrelationships that characterize food systems should no longer be seen as something purely economic focused strictly on food production, but also agronomic, political, institutional, and social, grounded in knowledge, culture, consumer preferences and ways of life, among others (Sonnino, 2013; Eakin et al., 2017; Kennedy et al., 2017). However, this reality arises two related challenges. In the first place the nature of the dimensions involved could represent a special difficulty giving the different approaches and methodologies for addressing the same problem, most of the time not used to work together. And secondly, the fact that these actions are performed by the institutions that compose food systems imply that power, philosophies, values, and interests are involved. The above might imply the arise of tensions, making it difficult to act coordinated to address a major problem. This can be seen, for example, when asking if our contemporary food problems are strictly due to insufficient production and/or to the results of power differentials that results into a "structural violence" (Chappell, 2018). According to the values and interests involved, the answer will vary, meaning that the way of facing this problematic and the actions taken to address it will be different.

In this sense, food systems governance can be considered as a value itself for sustainable diets, as implies a way of designing the "architecture" needed to achieve its goals (Berry, 2019). This means that food governance allows, among other things, an appropriate environment for food systems to transform in order to perform in a sustainable way. However, what makes "an appropriate environment" will depend on the context-specific characteristics around it. Thus, as sustainable diets need a context specific approach in terms of the socio-cultural characteristics at different levels, food governance represents a value that can help achieving its objectives. However, the results of this review are also focused on a national/regional scale, meaning that less attention has been paid to the effects local structures of food governance might have on improving the access to sustainable diets. This is especially important as one of the sustainability dimensions has to do with cultural preferences, knowledge, and ways of life, considered by some authors as "political dimensions" of food security. As mentioned in the introduction to this review, "agency" is an approach to food security that fits and rightly emphasizes the sustainability of food systems based on the power of people to govern them according to their own values and beliefs and to determine their own agricultural and food policy, organize their production and consumption to meet local needs and secure access to land, water and seed (Chappell, 2018). However, only two papers (Mattioni and Caraher, 2018; Galli et al., 2020a) mentioned "agency" as a relevant concept in food and nutrition security discussion when analyzing sustainable diets.

In the third place, and although agriculture production is one component of food systems, according to this review, food governance still does not adequately encompass governing agriculture, considering its relevance for leading food systems transformations (Hawkes and Popkin, 2015). The agricultural sector should be understood, not only as food provider, but also as a relevant stakeholder in public health planning in respect of nutrition and diets. Thus, the way in which the agricultural sector is governed might be crucial to improve the access to sustainable diets all year round, offering a route to provision of universal healthy diets within the planet's environmental capacity (Vermeulen et al., 2020). Agriculture governance could also support the environmental health of ecosystems, especially regarding biodiversity, and to reduce the risk to global health shocks (Hawkes, 2007; Détang-Dessendre et al., 2020). This review is focused on some examples of vertical governance, but less information was found in relation to how horizontal governance can be achieved. This is especially important, as is it at the same level where other dimensions of sustainable diets interact. In this sense, the coherence of agricultural and food policies as the result of robust governance is described as a way to ensure that nations comply with the obligation to ensure the right to food for their inhabitants. But, again, to focus on governing agriculture should also imply the local levels, as many dimensions of socio-cultural sustainability are based there.

Finally, is important to note that this study has an important limitation that should be considered, as only a 11% of the selected studies belonged to low- and middle-income countries, which are those whose population suffer stronger effects from crises related to food and nutrition security. In this sense, successful governance examples in wealthier countries must be analyzed carefully when trying to replicate them in different contexts, especially given the importance of socio-cultural values and power management. In addition, the frequency with certain terms that appear in the selected studies must be carefully analyzed. As mentioned in the results section, this review considered studies published between 2013 and 2021. This does not mean that there was no related research in previous years, but rather that it was probably due to other terms and search criteria around food policy.

Conclusions

The results of this study allows to conclude important considerations of food governance and sustainable diets as independent, but also interrelated, concepts. From the food governance perspective, the 37 studies reviewed in this paper indicate that regardless of if we talk about vertical or horizontal governance, it is key to both ensure the sustainability of food systems performance and to avoid crises that could lead into threatening progress related to food and nutrition security. Also, due to the diversity of stakeholders involved, food governance is crucial to balancing power, decision-making

and access to information across the food system, which is particularly important when diverse interests are present. We also found that, although being a key component of food systems, agriculture governance is under-developed as a field of study and more research in this area is essential to achieve food systems transformations that could led into improve the access to sustainable diets. Related to the above, agricultural governance must be developed to determine which diets changes can simultaneously benefit public health and the environment, and which policy instruments may promote their adoption by the different food systems relevant actors.

Regarding the sustainability of diets standpoint, most of the studies selected in this review understood sustainability strictly from the known "health-environment" duality. However, less attention has been paid to discuss other dimensions of sustainability, especially those related to socio-cultural aspects of diets. In this sense, "agency" appears a as a political dimension that goes on that direction and emphasizes the sustainability of food systems based on the power of people to govern them according to their own values, beliefs and needs.

However, the major contribution of this review has to do with reflecting on how food governance and sustainable diets are related, especially since food governance plays a role in supporting the socio-cultural dimension of sustainable diets. This highlights the question regarding how power is managed by different institutions immersed in food systems and the importance of focusing our attention not only in national/regional levels of governance, but also in how local levels organize their knowledge management and decision-making processes to improve the access to sustainable diets. Considering the above, we believe that future research should be focused on continue exploring the value food governance represents for sustainable diets and how the process of governing agriculture can contribute to understand that sector beyond food production for commercialization and visualize new opportunities as a relevant actor both in health and environmental sectors.

Author contributions

MdV, KS, and AA: conceptualization and methodology. MdV: investigation and writing. KS and SB: supervision, review, and editing. AA: review and editing. 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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.784264/full#supplementary-material

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A comparative analysis of sustainability of the usual food intakes of the Iranian population, Iranian food-based dietary guidelines, and optimized dietary models

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Promoting sustainable diets might contribute toward achieving sustainable development goals. Considering the importance of national food-based dietary guidelines (FBDGs), this study aimed to assess and compare the sustainability dimensions of the usual Iranian dietary intakes with sustainable optimal diets based on Iranian (2006 and 2015 versions), Mediterranean, and vegetarian FBDGs. The usual dietary intakes of Iranian households were estimated using household expenditure survey data. Diet sustainability, including environmental (water, carbon, and land) footprints, cost, and nutrient-rich food (NRF) index, was calculated for the usual diet and compared with those of different FBDGs. Using linear and goal programming, optimal food models were calculated by minimizing environmental footprints and cost and maximizing NRF simultaneously for each FBDG, while maintaining nutritional considerations recommended by the FBDGs. Replacing the usual dietary intake of Iranians with the optimal diet based on the 2016 Iranian FBDG was associated with reductions equal to 20.9% for water footprint, 22.48% for carbon footprint, 20.39% for land footprint, 31.83% for cost, and 7.64 % increase in NRF index. The optimal model based on the 2016 Iran FBDG was 10% more sustainable compared with the 2005 version. Changing the usual consumption of Iranians to the optimal model based on the Mediterranean pyramid was accompanied by the highest NRF index, lower environmental footprints, and cost compared to other models. The recent Iranian FBDG, compared with the older one, was more sustainable. Considering the dimensions of a sustainable diet for future FBDG revisions is recommended.

KEYWORDS

Iran, sustainable diet, goal programming, optimization, food-based dietary guidelines

Introduction

Economic and environmental issues confronting modern food systems threaten global long-term food security and natural resource management (El Bilali et al., 2019). On the one hand, the triple burden of malnutrition (micronutrient deficiencies, undernutrition, and diet-related noncommunicable disease) continues as one of the most serious socioeconomic and health problems (Horton et al., 2009), and on the other hand, 29–30% of all greenhouse gas emissions (Vermeulen et al., 2012) are produced due to the current food system. Therefore, an urgent transition toward a sustainable food system that provides for a healthy diet is proposed as one of the solutions to provide planetary health, fulfill adequate and healthy food for the growing population, and might contribute toward achieving SDGs by 2030 (El Bilali et al., 2019; Fanzo, 2019). Such a transition requires changes in food production and processing subsystems as well as consumer education and empowerment to adopt a sustainable diet. Sustainable diets are not only healthy, safe, nutritionally adequate, culturally acceptable, and accessible but also have reduced environmental impacts. The composition of a sustainable diet is context-specific and based on the health and disease profile of each country, the current food habits, and the associated socioeconomic factors (Tuomisto, 2019). For example, typical vegetarian or Mediterranean diets are considered sustainable, but they might not be applicable in many lower-middle-income countries (LMICs) without taking into account considerations based on specified micronutrient deficiencies within the population (Tuomisto, 2019). Therefore, evaluation and integration of sustainability aspects while considering context-specific adaptations in the current food and nutrition action plans and consumer education programs is an essential step to promoting sustainable diets in each country (Downs et al., 2017; Sobhani et al., 2018; Tuomisto, 2018; Ahmed et al., 2019).

Food-based dietary guidelines (FBDGs) are tools used to guide consumers and policymakers toward nutritionally protective dietary patterns at national, regional, and international levels (Montagnese et al., 2019). The Food and Agriculture Organization (FAO) promotes incorporating sustainable diets into national FBDGs to ensure a win-win situation for health and the environment (Montagnese et al., 2019). However, only a few countries, e.g., the Netherlands and Sweden, have integrated sustainability into FBDGs and revised their FBDG to take into account environmental sustainability, e.g., by limiting meat consumption and choosing sustainably produced fish (Horgan et al., 2016). Measuring the magnitude of benefit from the aspects of the incorporation of a more sustainable diet into FBDGs is an initial step to understanding the impact of adding sustainability to FBDGs. There have been some studies in western countries that evaluated the sustainability aspects of dietary recommendations promoted by different FBDGs and compared usual public dietary intakes with them (van Dooren et al., 2014; Kesse-Guyot et al., 2020). In addition, some studies projected the changes associated with substituting the sustainable diet models with usual dietary intakes while adhering to different FBDGs (Blackstone et al., 2018; Brink et al., 2019; Kesse-Guyot et al., 2020; Springmann et al., 2020). However, such efforts are still rare in low- and middle-income countries.

The Eastern Mediterranean region, based on the World Health Organization (WHO) regional classification, comprises 22 countries and is a region experiencing health and nutrition transition over the last decades (Galal, 2003). The development of official FBDGs in the countries of the region is fairly recent, and so far only 10 countries have their own official FBDGs (Montagnese et al., 2019). Iran is one of the first countries in the region with an official FBDG launched in 2006 and updated in 2015 (Safavi et al., 2007). The new version of the Iranian FBDG has eight food groups and is accompanied by a list of 13 recommendations (Safavi et al., 2007). In the new version, the meat and egg group has been separated from plant sources of protein, including legumes, nuts, and seeds which are categorized into a separate group. This change was intended to put more emphasis on the daily intake of plant sources of protein (Safavi et al., 2007).

In Iran, due to the emerging concerns regarding the aging population, climate change, drought, and water resource limitations (Lotfalipour et al., 2010; Abarghouei et al., 2011; Tabari et al., 2011), moving toward a sustainable FBDG is a priority. Therefore, considering the research gap in this regard, and to provide a basis for evidence-informed policymaking, this study aimed to assess and compare nutritional, environmental, and economic aspects of recommendations promoted in the new version of Iranian FBDGs-2016 with its old version FBDGs-2005, as well as the Mediterranean, flexitarian, and vegan food pyramids.

Materials and methods

Setting and study design

This study was performed in two phases. First, the old (2005) and new (2016) Iran FBDGs, the Mediterranean, flexitarian, and vegan food pyramids, and a proxy of household food consumption based on the Iranian Households Income and Expenditure Survey (HIES) data of 2018[1], were evaluated with regard to sustainable diet components. To calculate real consumption in this data, FAO estimates of waste percentages for each food group in the consumption step "from supply to consumption chain" were considered (Eini-Zinab et al., 2021).

1 Available online at: https://www.amar.org.ir/english/Metadata/Statistical-Survey/Household-Expenditure-and-Income. This link is accessible with an Iranian IP and may not be accessible outside Iran. Please contact the corresponding author if more information is required.

Diet sustainability components included (a) environmental components (water footprint, carbon footprint, and land use), (b) nutritional quality (The Nutrient Rich Food (NRF) index), and (c) cost (see Supplementary Table 1). In the second phase, sustainable food baskets were developed based on the different FBDGs, using linear and goal programming, and the changes required in the usual consumption were calculated. Details of each step are described as follows.

Data collection

Measuring the sustainability of FBDGs

To calculate the five dimensions of sustainable diets in this study, the serving size of each food item in each food group recommended in different FBDGs was converted to equivalent grams. Then each dimension was calculated as follows:

Environmental footprint

Water footprint quantifies the amount of direct and indirect water use for a processed product or sector. The green and blue water footprints refer to both consumptive use of rainwater, surface, and groundwater, respectively. The gray water footprint shows the freshwater needed to dilute pollutants, ensuring that the quality of the water remains above existing quality standards. In this study, the green, blue, and gray water footprint data for Iran were matched to food items in our study and were converted into the water volume in cubic meters per gram (m^3/gr) (Hoekstra et al., 2009). The water footprint data for each food item, usually reported as water volume in cubic meters per ton (m^3/ton), is available for Iran. Water footprint data were converted to water volume in cubic meters per gram (m^3/g) of the foods.

To calculate the amount of carbon dioxide emission produced during food production, the 'carbon footprint' method was used. "The carbon footprint is a measure of the exclusive total amount of carbon dioxide emission that is directly and indirectly caused by an activity or is accumulated over the life stages of a product." We used a global database for carbon dioxide emissions of each food item from the "BCFN Double Pyramid Database" (Ruini et al., 2016). The specific land requirements per food item (m^2 yearkg-1) values were obtained from different resources (Song, 2017; Kesse-Guyot et al., 2020). To calculate the water, carbon, and land footprints of each FBDG, the amount of water used, carbon food print, and land use for each food item were calculated by multiplying the related footprint by its recommended or actual consumption amount.

Diet quality

The Nutrient Rich Food (NRF) index was used as a proxy for the quality of the diet. The NRF index provides an overall nutrient density score based on the amount of selected nutrients per reference amount of food (100 kcal, 100 g, or serving size) (Afzali et al., 2020). The development of NRF index scores involves several methodological issues, including the selection of key nutrients, the choice of recommended daily allowances (RDA), and the basis of calculation (per 100 g, 100 kcal, or portion sizes). The NRF index has been previously used to assess Iranian diets. In this study, NRF was calculated in 100 g of each food item and based on nineteen recommended nutrients and three nutrients that should be limited. The positive scores, i.e., recommended nutrients, included protein, PUFA, MUFA, dietary fiber, potassium, vitamin A, vitamin C, vitamin D, vitamin E, thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, magnesium, zinc, calcium, and iron; and the negative scores were related to saturated fat, sodium, and total sugar. By subtracting the negative sub-scores from the positive sub-scores, NRF in 100 g of each food item was calculated. RDA introduced by the WHO and FAO was used as the reference recommended intake (Rahmani et al., 2011; Taghavifar and Mardani, 2015; Mirzaie-Nodoushan et al., 2020; Eini-Zinab et al., 2021).

Cost of diet

The Households Income and Expenditure Survey (HIES) data in Iran includes the price of each food item paid by households. The average price paid for 1 g of each food item over the last year was used to calculate the cost of each diet to consider the economic aspect of the sustainable diet.

Optimization of diets

Linear programming (LP) and goal programming (GL) techniques were used to optimize the sustainable food basket. The MS Excel (version 2013). Solver add-on was used to incorporate the LP and GL techniques (Mirzaie-Nodoushan et al., 2020). LP was used to optimize the sustainable food basket based on the different FBDGs, including the 2016 and 2005 Iranian FBDGs, as well as the Mediterranean, flexitarian, and vegan food pyramids. The main elements of LP models are objective, changing variables, and constraints. For each dietary guideline, LP models were applied to obtain the optimal diets, considering each goal of the sustainable food basket separately, including (1) maximum NRF, (2) minimum cost, (3) minimum water footprint, and (4) minimum carbon footprint. *Changing variables* are those decision variables manipulated to reach the objectives by considering constraints to reach the goal. The *decision variables* in this study were the amount of 194 food items. The model-produced diet is constrained to have energy intake, macronutrients, and the four most limiting micronutrients in the Iranian food basket (i.e., calcium, iron, vitamin A, and riboflavin) to the amount recommended. In addition, salt intake was limited to <5 g/day, according to the WHO recommendation (Edalati et al., 2021). The decision variables are also constrained to follow the advised serving size of food groups by the different dietary pyramids. By changing these constraints, the effect of following each dietary guideline on different aspects of the sustainable diet was investigated. The recommended number of servings for the examined FBDGs

TABLE 1 Sustainability dimensions (water, carbon, and land footprint, NRF index, and cost) of optimized diet models based on different FBDGs and the usual diet of Iranians.

Sustainable diet aspects	Usual consumption of Iranians based on HIES	Optimal model based on Iranian 2006 Pyramid		Optimal model based on Iranian 2015 Pyramid		Optimal model based on Mediterranean Pyramid		Optimal model based on Flexitarian Pyramid		Optimal model based on Vegan Pyramid	
	Total	Total	%change*	Total	%change	Total	%change	Total	%change	Total	%change
Water footprint (m^3)/day	3.9	3.6	−9.4	3.1	−20.9	3.4	−13.3	3.0	−24.01	3.0	−24.0
Carbon footprint (Kg)/day	2,323.9	1,962.9	−15.3	1,801.3	−22.4	1,841.9	−20.7	1,542.9	−33.6	1,542.9	−33.6
Land footprint (m^2)/day	5.1	3.9	−23.2	4.1	−20.3	4.5	−13.0	5.4	5.6	5.3	3.4
NRF index	23.5	21.7	−7.6	25.34	7.6	39.8	69.1	31.5	33.8	29.8	26.7
Cost (Rial)	91,993.9	63,828.7	−30.6	62,705.8	−31.8	72,058.6	−21.6	53,757.8	−41.5638	53,757.8	−41.5
The Area of Radar Chart	4,320.4	5,568.9	28.8	6,166.5	42.7	6,367.5	47.3	6,640.1	53.6	6,579.9	52.3

Percent change in optimized dietary models compared with the usual consumption.

is presented in Table 1. After running the model, the values obtained for each food item were multiplied by its footprint and the total footprint was calculated by adding these values.

To consider the food preferences (cultural acceptance) of the Iranian population, the decision variables were constrained to vary between 50% lower and 50% higher than usual food intake (Eini-Zinab et al., 2021). The usual food intake of Iranians was obtained from the Households Income and Expenditure Survey (HIES) data (2018, $n = 29{,}473$) converted to the adult male equivalent units of food intake by Eini-Zinab et al. (2021).

Maximizing the NRF index and minimizing cost, water footprint, land footprint, and carbon footprint has been done by utilizing the LP technique, which was applied to each dietary guideline separately. To design sustainable models for each FBDG that simultaneously maximizes/minimizes the five aforementioned goals, the goal programming technique was used. Similar weights ($w = 1$) were allocated to the five dimensions, including water footprint, carbon footprint, land footprint, NRF index, and cost, based on the research team members' opinions. The subsequent changes in the NRF index, cost, water footprint, land footprint, and carbon footprint related to substituting these optimized diets with the usual diet were investigated.

Radar charts were used to plot the values of each aspect of the sustainable diet of usual consumption, as well as the five sustainable models by converting all indicators to a fixed value. Since each of the indicators, including NRF index, cost, water footprint, land footprint, and carbon footprint, did not have a bounded range of possible values, the following equation was used to derive a 0–100 score:

$$\textit{Metric indicator}_i = 100 \times \exp[\ln(0.5) \times (F_i/F_{50})]$$

Where F_i is the factor (e.g., GHG emissions) for the i_{th} unit (e.g., food dietary guideline) under consideration, and F_{50} is the median (50th percentile) of the full range of values for this factor across all units of interest. Therefore, each of the indicators was scored from 0 to 100, with higher values being desirable (Gustafson et al., 2016). To align the changes in the NRF index with other dimensions, the sign of its value was reversed. The area of the radar chart was also calculated. The bigger the area, the higher the sustainability.

Results

Water footprint, carbon footprint, land footprint, NRF index, and cost of the usual diet and the five optimized diets, based on different FBDGs, as well as percent difference from usual consumption and the area of radar chart for each of the five models, are presented in Table 1.

The optimal model based on the new version of Iran FBDGs-2016 compared with its old version (2005) had a 10% bigger area of the radar chart, i.e., 10% more sustainable; however, the

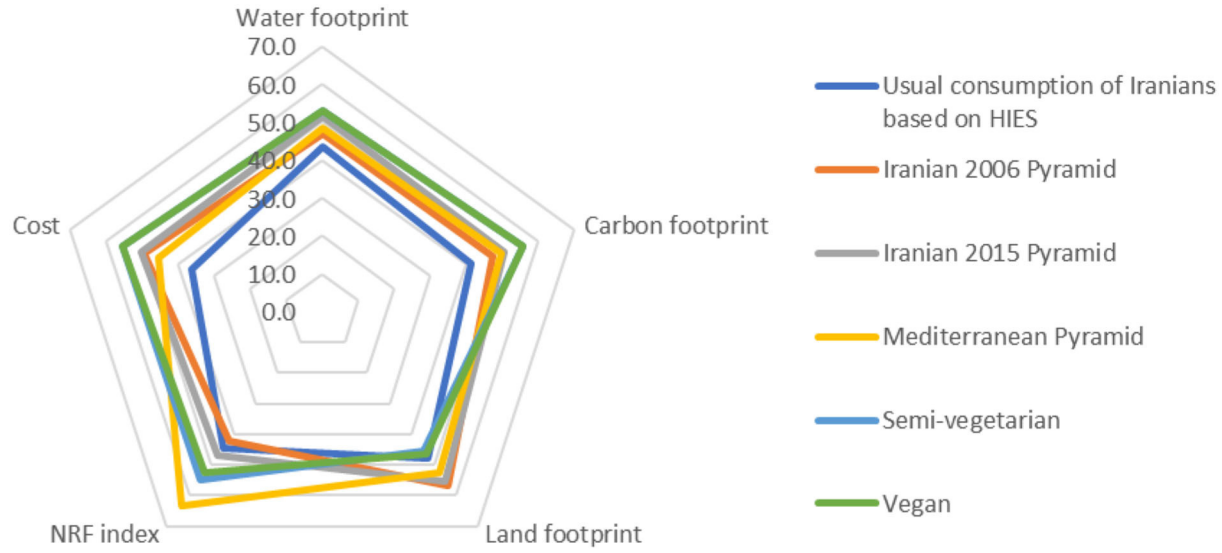

FIGURE 1
Comparison of dimensions of sustainability for the usual diet of Iranians and the optimized five sustainable diet models.

2005 version had a lower land footprint. The recent Iran FBDGs-2016 can result in lower cost, water footprint, and carbon footprint and provide equal nutritional value compared with its old version (2005).

The radar chart compares each dimension of sustainability for the usual Iranian consumption and the five diet models (Figure 1). The models based on flexitarian and vegan diets were overall the most sustainable, considering the higher area of the radar chart. The usual consumption of Iranians deviated the most from the vegan pyramid model in terms of environmental dimensions (water footprint, carbon footprint, and land footprint) and price. Changing the usual consumption of Iranians to the optimal model based on Mediterranean Pyramid was accompanied by the highest NRF index, as well as lower water footprint, carbon footprint, land footprint, and cost.

In addition, the model based on both Iranian dietary guidelines was more sustainable than the usual food consumption of Iranians (Table 1).

The servings for each food group of the five optimal diets are presented in Supplementary Tables 2–6.

Discussion

This study is the first attempt to evaluate the sustainability of Iranian FBDG in comparison with the usual diet and some other food pyramids. Findings show that following an optimized diet, based on recommendations of the recent Iranian FBDGs-2016, can be more sustainable compared with the previous FBDGs-2005 as well as the usual diet. Adhering to this diet can result in a lower cost (31.83%), water (20.9%), and carbon footprint (22.48%) and provide higher nutritional values (7.64%).

Previous studies found that reducing meat consumption, including the main livestock species, by 50% (from 110 to 55 g daily per capita intake) and replacing it with 50 g of beans per day is associated with a 20% reduction in environmental footprint. In addition, this substitution can result in an increased intake of dietary fiber and nutrients such as folate (Röös et al., 2020). It has been shown that a 50% reduction in animal product content in the American diet reduces total water use by 37% (Renault and Wallender, 2000). A high proportion of the water footprint for animal products is due to their consumption of feed, which accounts for 98% of the total water footprint (Alizadeh et al., 2013). Throughout the world, 29% of the total water footprint is related to the production of animal products in the agricultural sector, of which one-third is related to beef cattle production (Alizadeh et al., 2013).

The traditional Iranian diet is rich in legumes and plant-based proteins, and consumption of these elements has decreased over time and been replaced with refined grains and red meat, specifically in urban areas (Sobhani et al., 2021). In a study, the sustainability of three traditional and local foods in northwest Iran (Ashe Reshteh, Mirza-Ghassemi, and Tabrizi Koofteh) was compared with three popular western foods (pizza, beef-stroganoff, and pasta), and found that the traditional cuisine had lower environmental effects compared to the selected western foods (Eini-Zinab and Sobhani, 2017). The traditional Iranian main dishes are mainly composed of combinations of cereals (mainly rice or flat wheat bread) along with beans and vegetables, with a small amount of meat. Herbs are frequently used, along with fresh and dried fruits such as plums, prunes, apricots, raisins, pomegranates, and quince (Eini-Zinab and Sobhani, 2017). Considering the positive role of legumes in increasing the sustainability of the Iranian

FBDGs-2016, emphasis on their consumption through the promotion of traditional cuisines with high content of legumes should be explored in future studies. Such efforts can support evidence-informed policies through a food system approach to increasing the consumption of legumes and nuts.

Despite the high capacity to produce legumes in Iran, the country is presently one of the largest importers of beans in the world. The significant negative trend of drought in many parts of Iran, the traditional agricultural system, and the lack of support for small farmers are the main obstacles that have prevented adequate legume production (Sayari et al., 2015; Veisi et al., 2017). Improving agricultural infrastructure and supporting farmers can pave the way for increased production, improved quality, and reduced prices. Therefore, further emphasis on the consumption of legumes and nuts requires policy, planning, and implementation in order to supply this product by government agencies, NGOs, policymakers, farmers, and rural communities (Alizadeh et al., 2013).

Legumes are known as functional foods, rich in phytochemicals with a low glycemic index, which are all health-protective (Mirmiran et al., 2014; Bahadoran and Mirmiran, 2015). A systematic review conducted by Rebello et al. (2014), aimed to assess the association between legume intake and risk factors for cardiovascular disease, showed that eating more legumes reduced the risk of cardiovascular disease by 10% compared to those with fewer intake of legumes (Rebello et al., 2014). Drewnowski et al. also found that legumes are in a very good position in terms of the number of micronutrients supplied relative to their price (Drewnowski and Rehm, 2013). In addition, there are some studies on the positive effects of increasing legume production on soil quality, biodiversity, and lower need to use nitrogen fertilizers (Meena et al., 2018).

This study also found that the usual food consumption of Iranians is associated with higher water, carbon, and land footprint, as well as cost and lower NRF, compared to optimized diets based on the Iranian FBDGs. Consistent with our findings, Bayer et al. found that the usual dietary intakes of the Spanish population had a higher carbon footprint and lower nutritional quality than the recommended national food pyramid developed in Spain (Batlle-Bayer et al., 2019). Doren et al. found that changing the current dietary patterns of the Dutch population to their national FBDG could reduce carbon and land footprint by 11 and 38%, respectively (van Dooren et al., 2014). This study highlights the need for policies and programs to educate people about the benefits of adherence to Iranian FBDGs in order to ensure more NRF, less cost, and better environmental outcomes. Further qualitative studies are needed to understand the main barriers to adhering to FBDGs.

Although the impacts of the food sector on sustainability are widely accepted, efforts to design and implement integrated policies that address sustainable food production and consumption are largely absent (Sedlacko et al., 2013). For example, the compliance of the Iranian National Nutrition and Food Security Policy (2012–2020) with the components of a sustainable diet was 41.79% when both importance and adequacy were weighted. In this national document, the ecological, social, and cultural components of a sustainable diet have received less attention compared with health and nutrition dimensions (Sobhani et al., 2018).

The results of this study also showed that the mean usual consumption of Iranians has a higher mean carbon footprint, water footprint, land footprint, and cost compared to the optimal diet based on the Mediterranean dietary pyramid. Almendros et al. also found that shifting dietary intakes to more adherence to Mediterranean FBDG resulted in lower carbon, land, and water footprints of 72, 52, and 72%, respectively (Sáez-Almendros et al., 2013). Van Doren et al. also found that substituting the usual intakes of the population in the Netherlands with their FBDG was associated with an 11 and 38% reduction in carbon and land footprints (van Dooren et al., 2014). The findings of this study also showed higher environmental sustainability of the vegan dietary pyramid vs. Iranian FBDG. However, cultural acceptance is important when we make any dietary recommendation to the public (Gazan et al., 2018) and the Iranian usual dietary pattern is too far from the vegan diet. The current findings provide insight into the direction of change in order to move the Iranian diet toward a more sustainable one.

This study adds to the literature regarding the need for further modifications to achieve more sustainable food consumption in Iran and can help to clarify some of the changes required to improve the next national FBDG. However, more research is needed to consider local context and trade-offs as well as health and socioeconomic factors when choosing strategies to develop sustainable diets (Adesogan et al., 2020). When interpreting the results of this study, some limitations need to be considered. Our calculations for the land and carbon footprints were based on international evidence, not specifically for Iran. In addition, we used the Households Income and Expenditure Survey (HIES) data to reflect an estimate of household intake rather than individual intake. Finally, although AME and FAO estimated waste percentages are used to estimate individual real consumption, some overestimation is expected (Eini-Zinab et al., 2021).

Conclusion

Complying with the Iranian FBDGs while optimizing sustainable aspects can result in a more nutritious diet with lower cost and environmental effects compared to the usual diet. The recent version of Iran's FBDG, through the separation of legumes and nuts from meats and animal sources of a protein group, may result in a more sustainable diet compared to the older version. To achieve this, promoting

national FBDG and adjusting food production and provision policies to improve its economic access and cultural desirability can help to improve the sustainability of the food and nutrition system.

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

This study was conceptualized and designed by NO, SS, HE-Z, and SE. SS performed linear and goal programming and data interpretations. SE contributed to calculating the environmental footprints of food items. SS and SE reviewed the literature and wrote the first draft of the manuscript. NO, HE-Z, and GK revised critically the manuscript. All authors reviewed the manuscript, provided feedback, 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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.838741/full#supplementary-material

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Potential of traditional Chilean blood-fleshed peach to support livelihood opportunities in local agriculture

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The blood-flesh peach or vineyard peach is an older heritage cultivar with juicy red-flesh and tart-sweet flavor. They are popular in France, where more than 200 years ago wine growers used to plant them on the vineyards as biological markers to detect the presence of powdery mildew. It is present in countries such as China, Italy, New Zealand, Australia and USA however, it remains a very rare variety worldwide. In Chile, the blood-flesh peach has a centenary presence in rural orchards where is called "Durazno Betarraga." Reproduced by seeds, it has pass through generations of family farmers and has been adapted to local environmental conditions. This red-flesh peach is a local variety considered part of their traditional diets, however, cultural changes in food consumption, short postharvest life and water scarcity due to climate change are threatening its conservation. One of the objectives of the International Year of Fruits and Vegetables, as defined by the FAO, is to integrate small holders and family farmers into value chains for sustainable production and consumption of fruits and vegetables recognizing the contributions of farmer's landraces to their food security, nutrition, livelihoods and income. To promote this objective, we present the work we have been carry out for several years with a farming community. We have conducted ethnographic research to provide a qualitative description of the agricultural value of the blood peach in a limited territory of the Maule Region defined as the study area. For the quantitative section of our research we analyzed the antioxidant capacity (ORAC) and total polyphenol content and compared them with those of other fruits. To gather information on the presence of the blood-fleshed peach in other regions of Chile, we used a citizen science approach through social networks. We propose that this local variety is an innovative raw material to develop healthy fruit-based food, thus encouraging its conservation and consumption with a positive social and economic impact for the community and the local food system.

KEYWORDS

blood-flesh peach, food innovation, Chile, antioxidant, peach [*Prunus perica* (L) Batsch], heritage, agrobiodiversity

Introduction

Peach [*Prunus persica* (L.) Batsch] is a fruit specie that belongs to the Rosaceae family. Is one of the most consumed fruit worldwide and economically important for temperate climate countries. Based on archaeological evidence, early peach selection and domestication began 7,500 years ago, in the Yangtze River valley, from an unknown wild ancestor (Zheng et al., 2014). Genomic analyses of 480 widely collected peach accession including wild relatives, landraces and improved cultivars, shows that two thirds of the genetic diversity have been lost during peach domestication. Fruit size was predominantly selected during domestication, and fruit-taste was associated with successive breeding processes. As a consequence, peach cultivars produced today in China, Europe and America harbor a very low level of genetic diversity (Li et al., 2019). The conservation of landraces and heirloom varieties are valuable resources for future breeding programs to introgressing genetic diversity to breed fruit cultivars more resilient to extreme weather conditions or other threats (Carrasco et al., 2013).

Flesh color is one of the most important selection attributes, related to consumption preferences and nutritional attributes. According to this character, peaches are classified as white, yellow and red-flesh. Red-flesh or blood-flesh peaches, as they are known worldwide, were cultivated in China by the TANG dynasty (618–917 ADC) in the vicinity of the Yangtze river where they are still being grown. The most cited Chinese cultivars are the "Dahongpao" (Zhou et al., 2015), Wujingzaobaifeng (Zhao et al., 2015), and the Wu Yue Xian (Wang and Zhuang, 2001).

The blood-flesh peach was first described in France during the 17th century by Friar Triquel as "Peche Beterave" or "Sanguinole" (Hedrick et al., 1917). The variety was described as a round and slightly elongated fruit, with thin skin and adherent to the pulp, dark red pulp, rather dry, sour and bitter, not a very pleasant taste. The pit separated from the pulp, small and ovoid. It ripens from the end of September and beginning of October. In temperate climates its flavor is sweeter. It is mainly used for canning since the flavor of the cooked fruit is better than the raw one [William Robert Prince, Pomological manual for the orchard and garden, New York, Prince and Prince (1831)]. In France's Bordeaux region the blood-flesh peaches are known as Pêche de Vigne. It is a generic designation for different varieties of peaches that were related to the practice from the 18th century of having them planted at the ends of the rows in the vineyards. The high susceptibility these peaches have to the oidium fungus was used as a biosensor to detect the presence of the fungus in the vineyard and to allow in advance the treatment of the vines. The Pèche de Vigne has been considered a heritage food from the Lyonnaise region (Coteaux du Lyonnais). Since 1980 a French plant breeder called René Monteux-Caillet has developed many new varieties of peaches and nectarines, now branded as "Les Sanguines" (PêcheVigne® and Nectavigne®) by Star Fruits company.

Historian have postulated that the peach trees were introduced into United States in 16th century by French explorers. The mild climate of the new world was favorable to fast growing, high productivity and delicious flavor development and the peaches were widespread in the American continent by seeds. The abundance of the peach trees from Pennsylvania trough Georgia and Alabama caused that most European explorers mistakenly though the peach was an indigenous American product (Thornton, 2015). In 1871 it was entered in the catalog of the American Society of Pomology under the name Indian Blood Cling (Hedrick et al., 1917).

Despite its presence in China, France and USA, Blood-flesh peaches are scarce and rare varieties worldwide. They also exist in Canada (Harrow blood), New Zealand (Black-boy peach) and Australia where they were probably introduced by French and Spanish explorers into colonial European Settlements.

Peach trees were introduced to Chile in the 16th century, along with orange, apple, quince, pomegranate and olive trees and were easily propagated in central and southern Chile due to the Mediterranean climate (González de Nájera, 1614; Muñoz, 2011). In the 18th century, and according to court records and rural and urban property inventories, more than 12 varieties of peaches were grown, some of which have disappeared. However, no mention is made of red-fleshed peaches (Lacoste et al., 2011). Today, the Chilean blood-flesh peach is found just in small orchards and home gardens in rural areas of the country. Commercial cultivars with longer shelf life, the standardization of agricultural products driven by globalization, cultural changes in food consumption, water decrease due to climate change and the rural to urban transition are transforming the local food systems and threatening its conservation.

Considering the cultural and genetic value of local plant resources and agrobiodiversity to ensure food security in communities, in 2015 we initiated a process of conservation of this variety of peach, with a community of farmers in the district of Constitución, Maule Region. We propose that the heritage blood-flesh peach is an innovative raw material for food innovation and can contribute positively to the economy and social welfare of the farming community.

Materials and methods

We have carried out both ethnographic research and laboratory analysis to provide a qualitative and quantitative description of the agricultural value of the blood peach. For the qualitative ethnographic research we interviewed farmers currently engaged in blood peach cultivation in a limited territory of the Maule Region defined as the study area.

For the quantitative section of our research we analyzed the antioxidant capacity (ORAC) and total polyphenol content and compared them with those of other fruits. To gather information on the presence of blood-fleshed peach in other regions of Chile, we used a citizen science approach through social networks.

Study area

Constitución commune (the smallest administrative subdivision in Chile) is situated in the eastern side of the Maule Region, covering an area of 1,344 km^2. Constitución is the capital district of the city of Constitución. The city is located on the 72° 25′ 00″ South longitudes and 35° 20′ 00″ South latitudes, about 14 m above sea level. Hosting over 50.000 habitants of which 50.06% are women and 49.93% are men. The population density is 44.3 inhabitants per km^2 and one third of the population is rural. It has an economy based mainly on exotic forestry industry and secondly agriculture, animal husbandry and fishing.

The geography of the commune is characterized by the predominance of the coastal mountain range with hills between 300 and 700 meters that form hills and valleys. Toward the ocean, the mountain range disappears abruptly forming the coastal plains with a width of ∼5 km, long beaches, and dunes. Only 17.7% of the area is covered by native forest, with 10% corresponding to deciduous forest, 5% to sclerophyllous forest and 2.7% correspond to dune and wetland vegetation. Most of the surface is covered by exotic tree plantation. The climate of the coastal zone of Constitución, is classified as coastal Mediterranean, with an annual rainfall of 809 mm, an average temperature of 9.6°C in the winter and 16.7°C in the summer (Santibáñez, 2016).

Thirty-three kilometers to the west of Constitución, in the coastal mountain, the village of Las Corrientes is located. It is a rural area formed by small farms and surrounded by extense forestry properties. The soil in this area is granitic and with a high percentage of clay, which originated the local clay handicrafts tradition. There is a high level of soil erosion, mainly due to deforestation, watershed management, and forest fires. There is basic electricity service, but no potable water or sewage system. The families obtain water from springs and streams and there is just one primary rural school.

Twenty-two kilometers to the North of Constitución city, by the coast, there is the small village of Putu, located between sand dunes and wetlands. It hosts over 2,000 inhabitants with many either working or studying in Constitución. The urban area of Putu has basic service, paved road, electricity, potable water and sewage system. There is a rural health service, a primary and scientific-humanistic secondary school, a police station as well as a fire station.

Ethnographic research

Based on public information provided by The Latin American Center for Rural Development—RIMISP—an international organizations dedicated to promoting sustainable and inclusive territorial policies among the rural populations of Latin America (Schejtman and Berdegué, 2004; Ranaboldo and Schejtman, 2009), we have defined the concept of Agrifood Heritage as: "The set of knowledge, rituals, traditions and symbols that have been historically built in the relationship between man and nature to satisfy basic subsistence needs such as food. It is related to the ways of producing, preserving, transforming, cooking, sharing, and consuming food." We will use this definition to analyze the Chilean blood-flesh peach as a symbol of the agri-food heritage in the coastal zone of the Maule Region food system and an ethnographic analysis based on fieldwork research and structured interviews. The fieldwork was based on an ethnographic approach in which qualitative techniques were applied to collect data and produce information. According to Geertz (1982), the ethnographic approach implies placing the focus of the narrative record on the point of view of the study participant in his or her real environment. In this sense, cultural facts are networks of meanings and senses, whose expression is textual and must be interpreted within this framework. In this study, the ethnographer interacts with the farmers for 2 weeks, recording the observations, testimonies and interviews. We selected 15 farmers that belong to the PRODESAL [Local Developmental Program from the Chilean Ministry of Agriculture (https://www.indap.gob.cl), to support technically and economically the family farming] who have at least one blood-flesh peach in their farms or home gardens. Prior to each interview, informed consent was obtained. The structured interview covered the following: (a) Information regarding age, educational level and economic activity, (b) number of blood-flesh peach trees, origin and management, the way blood-flesh peach is consumed, recipes, economic use and (c) cultural practices, traditions, social relationships and histories and memories related to the peach. The interviews were recorded, transcribed, and analyzed, and complemented with an ethnographic register.

The studies involving human participants were reviewed and approved by Marcela Celis and Claudio Contreras, members of CONVERSA ethics committee. The participants provided written informed consent to participate in this study.'

Fruit harvest

Five trees were selected. From each one, five peaches fruits were harvested and randomly selected for analyzes. The trees are located in Putu's orchard (35°12′51″S 72°17′01″O). The harvest was done in March 8th 2020, at 8 pound of pressure using a fruit

pressure tester (IMERI, Italy) and 10–12° Brix using a pocket refractometer (ATAGO, Japan). Immediately after harvest were transfer to cold chamber and store at 4°C until processing.

ORAC and total soluble phenolic analysis

The peaches from each tree were washed and milled with skin. The total soluble phenolic contents analysis was assayed by the Folin-Ciocalteu method, according to Coseteng and Lee (1987). The results were expressed as mg Gallic acid (GAE)/100 g of fresh material based on a standard calibration curve daily prepared using gallic acid (3,4,5-trihydroxybenzoic acid). The antioxidant capacity was determined by ORAC (Oxygen Radical Absorbance Capacity) methodology according to Huang et al. (2002) and Prior et al. (2003). The results were expressed in μmoles ET/100 g of fresh material, which corresponds to the number of micromoles of Trolox equivalents (TE) per 100 grams of fresh weight. For this purpose, a Biotek Synergy HT microplate reader for absorbance, fluorescence and luminescence was used.

Social media data collection and fieldwork research of Chilean blood-peach

The use of on-line technology and social media has expanded the opportunities for citizen science, that means "the involvement of volunteers in science" (Roy et al., 2012). Citizen scientists have made important contributions in conservation and surveillance of many species of animals, insects and plants, through the collection of data over extensive areas in long periods of time. The use of social-media such as facebook has provided positive experiences to support participants and encourages them to be active and create forums for learning and community of practice (Kampen et al., 2015; Liberatore et al., 2018). Based on that strategies we open a Facebook group to recruit participants who wants to share information and some history about the blood-flesh peach from their communities along Chilean territory. The Facebook group is public and all content is freely available online. There were no further exclusion criteria. We gathered 317 records which refer to having blood-flesh peach. One hundred and eighty-seven records are from people who have either 20 years-old or older trees or young trees propagated from seeds from older trees. The existence of 53 of them was confirmed personally or by a photographic register and mapped in Google maps. The fieldwork research was conducted between July 2015 and March 2019. Sixty percent of the participants were female and 40% were male. Seventy-two percent stated that the trees were planted on their own properties, while the rest (28%) stated that they were in a parent's or grandparent's house. Eighty-nine percent of the trees are distributed in the rural area and only 11% are in the urban area.

Results

Distribution of red-fleshed peaches in Chile

Using a citizen science approach and Facebook social media platform we gathered information about the presence and distribution of blood-flesh peaches in Chile. Fifty-three, 20 years-old blood-flesh peach trees were found distributed between O'Higgins and Los Lagos region.

Figure 1 shows a map of Chile (A), where box B points out O'Higgins, Maule and Ñuble regions, and box C Bio-Bio, Araucanía, Los Rios and the northern part of the Los Lagos region. The purple dots represent the presence of at least one 20 years-old or older blood-flesh peach. The place can be either a home garden in an urban sector (city or town) or an orchard in a rural sector. The purple stars represent the presence of a population of at least 10 trees older than 20 years of age. Our results show that the geographical distribution of blood-flesh peaches is wide, covering six regions of the country equivalent to 900 Kilometers in a north-south direction. It is observed that its distribution is wide in an east-west direction, being found in the foothills (east) in the intermediate valleys and in areas near the sea (west). These distributions suggest a great adaptability of the variety to different climatic zones and geographic conditions. The blood-flesh peach has different popular names depending on the territory being Beetroot peach (Durazno Betarraga) the most common. In the southern's regions (BioBio, Araucania, Los Rios, and Los Lagos region) it is also known as Purple peach (Durazno Morado) and in the central regions (O'Higgins and Maule) it is known as Wine peach (Durazno Vino o conchovino) and Strawberry peach (Durazno Frutilla).

In the Maule region there are two closed zones with abundance of red-flesh peach: Las Corrientes and Putu.

Traditional blood-peach as a valuable heritage fruit in local farming

The group of farmers selected for the qualitative research included fifteen people, five of them living in "Putu" and 10 living in "Las Corrientes" (Figure 1B). All of them declare to know the blood-flesh peach since childhood (named as "Durazno Betarraga") and to have at least one blood-flesh peach tree in their home gardens. The farmers age range is from 42 to 82 years. Seven of them are over 60 years. Most of the informants reported to live alone or with their partner ($n = 11$), and the remainder ($n = 4$) to live with more than two people either

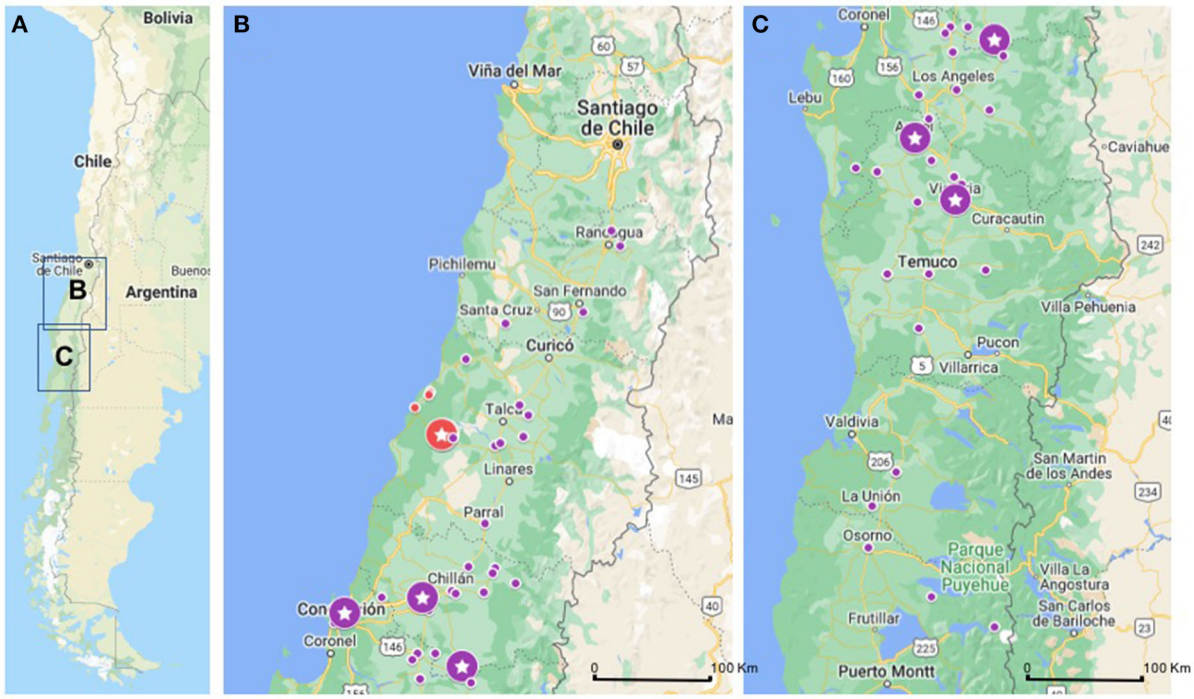

FIGURE 1
Chilean distribution of blood-flesh peach. **(A)** Chilean map, southern part of America continent. The squares indicate two selections areas. **(B)** O'Higgins, Maule and Ñuble regions, **(C)** Bio-Bio, Araucanía, Los Rios and Los Lagos regions. The purple dots represent the presence of at least one blood-flesh peach 20 years-old or older. The purple stars represent the presence of a population of at least 10 trees more than 20 years old. The red dots and start represent the population and territory under study.

children or parents. Nine of the farmers indicated that only one person in their household is engaged in agricultural work, and for the remaining ($n = 6$), there are two or more people who share these tasks. The fact that almost half of the farmers are over 60 years-old is a trend affecting all the countryside nationwide and threatens the survival of traditions and peasant wisdom. The young population is migrating to the city to pursue higher education or is being employed in logging operations that offer salary on a permanent basis. Fourteen of the 15 participants have children, and none of the children or grandchildren are engaged in farming. One of the farmers said: "*We wanted to educate our children. But we did not realize that the countryside was going to be left without people. The young people no longer want to work in the fields. I have 5 children and none of them work with me.*"

Regarding the educational level of the farmers, 11 of them did not complete primary education and only one has university education level. Data from CASEN (2011) (National Socioeconomic Characterization Survey by Social Development Ministry) reveal that just a 31% of the adult population of Constitución has completed secondary education and 39% of the adult population does not have formal education or has incomplete primary education. The average years of schooling (primary and secondary) in the region (9.8 years) is lower than the national average (11.0 years). The total is 12 (CASEN, 2015).

It is interesting to notice that for most of the interviewees, during the ethnographic research, the "Durazno Betarraga" evokes childhood past experiences and strong emotions: "*This is a very old peach, I used to eat it at my grandmother's house. I remember that it was dripping and it was all painted red…like beetroot.*" This quote is another example: "*I love them! they bring back memories of my dear godmother back in the countryside of Talca…she used to pass us a knife and let us go into the garden and eat as many as we could.*"

Participants expressed that more than 50 years ago the peach was abundant and together with a white-flesh variety called "blanquillo" were the only two peach varieties present in the orchards. Nowadays the blood-flesh peach is scarce and has been replaced by other varieties and fruits. Quoting some of them: "*When I was a child we only knew the beetroot peach. But this fruit was lost. The elders used to say that it was good for cancer, anemia and diabetes.*"

For some farmers the reasons for such a loss would be the low valuation by the community due to its short shelf life after harvest and the dark color of its skin compared to modern peach cultivars available at retail. Because of the scarcity of this variety

at present, it is unknown by the new generations, an additional factor that also has a negative impact on its commercialization. One of the farmers reported: "*The beet-peach is very delicate. You have to take it very carefully. That is why it is not marketable, the peach falls off the branch easily. The beet peach is not very popular. You take it to the local market and nobody buys it because they don't know it…and they find it ugly*."

Several interviewees appreciated the "Durazno Betarraga" because the trees are stronger than other fruit trees and does not need as much water. The majority of the farmers do not take special care of their trees, just pruning during winter season and some watering in summer. This is especially important for farmers in the Las Corrientes sector, which in recent years has suffered a severe water deficit and forces farmers to prioritize the use of water for human consumption and greenhouse horticulture.

Putu and Las Corrientes areas have a strong rural identity expressed in everyday life and peasant tradition, characterized by lifestyles linked to field work and attachment to the land, inherited from colonial times. The way they perceive the world and reality is marked by a syncretism between tradition and modernity, between Catholic religion and popular religiosity, which is revealed in various dimensions. The agricultural practices are highly influenced by tradition and popular beliefs. Knowledge has been passed down from generation to generation through oral tradition. Most commonly, farmers reported that the transplants and trees pruning have to be done during waning moon. To quote one of the farmers: "*I was taught that you never transplant before 12 o'clock noon. Always transplant in the waning of the moon and the sun. We wait for the waning of the moon because the plants grow better and more beautiful*." Most of them said they were obtained by spontaneous germination from an older tree that was on the same property or from seeds from their parent's home. Some of them said they were obtained *via* exchange or as a gift.

The farmer's interviewees consume the blood-flesh peach in different ways: fresh as a fruit during the summer season and cooked, dried, canned or processed as jam during the rest of the year (Figures 2A–C). The most popular preparations is sundried as "huesillo" (dry peaches) and jam, for two reasons: they allow for the fruit to be preserved for longer and, on the other hand, they have greater marketing possibilities. To dry peaches they are harvested green, peeled, and are exposed to the sun covered by a thin cloth. Once dried (Figure 2C), they are stored in a dry place. For consumption they are soaked overnight and boiled in hot sugary water. This preparation is served cold with "mote," which is peeled and cooked wheat. This is one of the most traditional Chilean preparations consumed on hot days and during the celebrations of Independence Day (September 18th). The sun-drying process is an ancient practice that was very important in 18th century for Chilean agribusiness to preserve peaches, pears, prunes, grapes and figs. The drying processes of peaches can be with or without stone and cut into slices, which are called "orejones" (Lacoste et al., 2011). The color of its flesh is a distinctive characteristic of this variety that is used as an advantage in many preparations. One female farmer that sells preserves and jam in Constitución said: "*The jam is very easy to make and it looks nice because it is red. I take advantage of the red color to dye for example cooked yellow-canned peaches with the color of the Durazno Betarraga*."

FIGURE 2
Traditional products based on Durazno Betarraga. **(A)** Fresh fruit from Putu farmers, **(B)** Peaches in preserves and jams prepared by farmers and packaged under their own brand name **(C)** dried blood-flesh peaches.

Fourteen farmers defined themselves as small farmers, and just one as a merchant. The range size of their land is from 0,5 hectare (ha) to 25 ha. All of them culture different kinds of crops and fresh vegetables on their properties like garlic, peppers, onions, potatoes, tomatoes, beans, coriander, peas, lettuce, etc. All the farmers cultivated outdoors and four of them also cultivated in greenhouses. In addition, they have orchards or home gardens with diverse fruit species like peach, lemon, orange, walnut, fig, avocado, apple, pear, and plum trees. Six of them have small vineyards from which they produce handmade wine for their own consumption. The majority of the farmers ($n = 10$) produce exclusively for their own consumption and five sell vegetables, flowers, dried fruit, fresh and dried herbs, jams and eggs, offering them to neighbors by cell phone, setting up a roadside stand or at the local market ("Feria Libre") in Constitución.

Potential of the traditional blood-peach for food innovation

The antioxidant activity and total polyphenols of blood-flesh peach was expressed as means of the five trees samples (Table 1). The antioxidant activity (ORAC) of the fresh blood-flesh peach is 1,1406 ± 671 (ET/100 g) of FW and the total phenolics, as determined by the Folin-Ciocalteau assay was 572 ± 18 mg GAE/100 g of FW. This value is higher than the range reported for commercial cultivar of white and yellow-flesh peaches and nectarines (14–77 mg of GAE /100 g of FW) and for blood-flesh varieties (83.75–108.19 mg of GAE/100 g of FW) (Cantin et al., 2009; Aubert and Chalot, 2020). Using the public fruit

TABLE 1 Comparison of ORAC and total polyphenol between blood-flesh peach and other peaches varieties and fruits.

Fruit sample	ORAC (umol ET/100 g FW)	SEM	PFT (mg GAE/100 g FW)	SEM
Calafate	25,662	3,322	1,201	104
Maqui	19,850	966	1,664	83
Murtilla	10,770	453	863	30
Peach (Blood-flesh)	11,406*	671	572**	18
Peach (Elegant -Lady)	3,127	441	123	24
Nectarine (Brite pearl)	3,063	1,441	170	42
Stawberry	3,775	273	231	17
Raspberry	6,903	1,019	380	32
Plum (black)	8,379	483	270	29
Cherry (Lapins)	3,847	87	152	6
Cherry (Rainier)	4,225	1,014	142	16
Cherry (Bing)	6,608	967	200	11
BlueBerry (Elliot)	8,869	334	529	5
Blueberry (Duke)	4,864	409	339	301
Blueberry (Legacy)	6,771	481	421	16

The graphics were made using the public fruit antioxidant database provided by INTA, University of Chile (www.portalantioxidantes.com).
All the data was obtained from the public fruit antioxidant database: www.portalantioxidante.com.
SEM: Standard error of the mean.
*95% CI [9,543, 13,269].
**95% CI [521, 622].

antioxidant database provided by INTA, University of Chile (www.portalantioxidante.com) we compared our results with commercial cultivars of blueberry, cherry, strawberry, raspberry and peaches. The antioxidant activity of the Chilean blood-flesh variety is higher than antioxidant activity of elegant-lady peach variety, Brite pearl Nectarine, cherries (Bing, Lapins and Regina varieties), raspberry and strawberry. Compared with blueberry, the ORAC value is similar to Elliot variety, but is higher than Legacy and Duke. A similar pattern is observed with the total phenolic content. Additionally, the graphic shows the antioxidant activity and total polyphenol of three native Chilean berries: murta (*Ugni molinae* Turez), maqui (*Aristotelia chilensis (Mol.)* Stuntz) and calafate (*Berberis buxifolia* Lam.). These fruits are a well-known source of a wide range of polyphenol compounds with high antioxidant capacity and a valuable raw material for functional foods and nutraceutical development (Fredes, 2009; Céspedes et al., 2010; Rubilar et al., 2011; Romero-Roman et al., 2021).

Discussion

Chile has a prominent position in the global fruit market and is the leading export country of contra-seasonal fresh-fruit to Asia and The United States. Out of the total fruit produced by Chile, nearly 75% is exported fresh and 18% processed (juice, canned, frozen and dried) (ODEPA, 2021). This large-scale agricultural production of fresh fruit is mainly based on modern varieties with longer-shelf life to support the long trip to distant markets. However, this globalization of fruit productivity driven by exportation has led to the standardization of food production with the consequent loss of the value of traditional varieties that are not players of the global market. Many traditional crop species and fruit varieties have been neglected and replaced for cultivar developed by modern genetic programs.

Using a citizen science strategy and Facebook as a social platform, the most widely used for citizen science projects (Oliveira et al., 2021), we collected information on the presence of the blood-flesh peach in Chile. Limited internet access and digital literacy can be considered a barrier to equitable access and, as a consequence, many citizens would be excluded. However, the popularity of Facebook use in rural areas is an opportunity to engage individuals or communities from different regions and obtain data that would otherwise be impossible to obtain in person. The fields related to agriculture and food science have not taken full advantage of the knowledge being generated in citizen science, and there are only a few citizen science projects focused on these topics. However, citizen science has the power to help democratize science and engage communities to address grand challenges in agriculture and food security (Ryan et al., 2018; Edmonson et al., 2019; Sykes et al., 2021). A recently published example of citizen science is the "Historic Fruit Tree Working Group of North America" whose mission is to facilitate the conservation of heirloom apples by collaborating on cultivar documentation and identification (Dunbar-Wallis et al., 2022).

The "Durazno Betarraga," as popularly is known, was found in rural orchards and homegardens of seven Chilean regions (central and southern) with different popular's names: "Durazno Vino," "Durazno Morado," "Durazno Conchovino" or "Durazno Frutilla." Reproduced by seeds and handled by local farmers who rely purely on local knowledge, it has pass through generations of smallholders family farmers and has adapted to different environmental and geographical conditions. For the farmers interviewed it is a valuable resource, part of their traditional diets, consumed fresh during summer season and dried or processed during the winter when the fresh fruit is scarce. Altogether, these results allow us to conclude that the "Durazno Betarraga" is considered part of the cultural heritage of the territory and is a patrimonial or heritage food for the community and requires to be protected, promoted and conserved for future generations. This blood-flesh peach has been also included into the Heritage Products and Preparations catalog from Bio-Bio Region (FIA, 2016).

There is no official bibliographic information about when the blood-flesh varieties arrived in Chile. Its early introduction during 16th century together with different fruit species is not

documented. In the text "The South American Agronomist" published in 1872, the existence of a small, strong-flavored hairy peach known as the Vineyard Peach is mentioned. Furthermore, the existence of purple varieties such as the cardinal of Furstenberg, described as medium size, low red on the outside and marbled on the inside are also described. The name Furstenberg cardinal is mentioned in the peach in New York (Hendrick, 1916) as one of the French sanguine varieties of the mid-17th century. It is described as fibrous flesh colored with deeper streaks of red and orange-yellow skin. One possible hypothesis about the appearance of the blood-fleshed varieties in Chile is that they arrived along with the French vignerons or European vineyard-owning families who brought with them the ancient practice of planting them at the ends of the rows in vine plantations. However, the predominance of the French influence in Chilean vitiviniculture and the introduction of old and rare French varieties was mainly during the second half of the 19th century in the central regions of Chile (Briones, 2006; Pszczolkowski et al., 2018). The fact that we have not found ancient trees or testimonies in the central zone, but we have in the southern regions (Maule, Ñuble, Bio Bio and Araucanía), makes this theory unlikely. However, the role of European or North American migrants in the introductions of rare and heritage fruit cultivars cannot be ruled out.

Our observations during the fieldwork reveal that even when it was very common more than 50 years ago, nowadays it is rarely found in local markets, it remains unknown for new generations and it is not commercially cultivated, converting it into an underutilized and neglected fruit crop variety (Williams and Haq, 2002; Kour et al., 2018). The farmers produce the blood-flesh peach among other fruits and a variety of vegetables for their own consumption and subsistence in their home gardens. The home gardens are small-scale agroforestry systems that play a vital role in household food self-sufficiency, providing fresh and quality food for better nutrition and are frequently a source of income generation (Ferdous et al., 2016; Castro et al., 2018). Homegardens also function as center of conservation of plant genetic resources such as traditional and indigenous crops along with medicinal plants and are places for the transmission of traditional knowledge and cultural practices. The disappearing of the blood-flesh peach is a loss that along with decreasing agrobiodiversity threatens cultural food heritage and local economy.

Locally adapted varieties with higher genetic diversity can provide useful genes to breed cultivars with enhanced resistance to abiotic stress or disease, improved fruit size, texture and quality or to increase bioactive compounds concentrations. Furthermore, as mentioned in a recent report by the FAO, entitled "The state of the World's Biodiversity for Food and Agriculture" (FAO, 2019), crop wild relatives and traditional landraces are important resources for future resilience breeding programs in a global climate crisis scenario. This is particularly important for peach (*Prunus persica* L.), one of the most economically important fruit crop in temperate region. Population genetic analysis of domesticated, landraces and wild peach reveal that nearly two thirds of the genetic diversity has been lost during peach domestication suggesting a narrow domestication bottleneck. During the domestication the fruit size has been mostly selected with the consequence of decline in genetic diversity at loci related with fruit taste (Yu et al., 2018; Li et al., 2019). In this sense the use of landrace and heirloom peach varieties in modern selection programs has the potential to introgressing relevant genetic diversity.

Some neglected and underutilized species have the potential to make an important contribution to food security in local communities and vulnerable social groups, to combat micronutrient deficiencies, protect against market disruptions and climate uncertainties (Kour et al., 2018). In addition to the role as a nutrient, traditional crops and vegetable species are part of the cultural heritage of rural communities. The human activities related to traditional knowledge to producing food, based mainly in agroecology, are one of the rural world's main assets (Espluga-Trenc et al., 2021). Our interview reveal that the agricultural practices are highly influenced by tradition and popular beliefs passed down from generation to generation through oral tradition. These are cultural heritage elements essential for the sustainable support of farmers because create collective identities around local agricultural production. However, the low education level of the farmers, the lack of trained technical stuff in fruit growing and the emigration of young people to the cities could act as threats to conservation of agrobiodiversity and cultural heritage. The Putu and Las Corrientes farmers are supported by PRODESAL (government program) in eight specific areas: vegetables, beekeeping, cattle, poultry, pastures and livestock. Fruit production is not included as a training area, which contrasts with the fact that the Maule region is the main export fruit producing region. Local educational programs for the community on ecology, biodiversity, sustainable food production, nutritional importance of agrobiodiversity and agroecological management of homegardens, among other related topics as innovation and entrepreneurship, are necessary to potentiate the community and increase the engagement of the young people. The involvement of elderly farmers in this learning community is crucial to ensure biodiversity-related traditional knowledge safekeeping.

Traditional varieties that are not cultivated extensively have considerable economic importance in local food system since they are used for the preparation of processed products that are highly valued by the community and traded in local markets. In the case of "Durazno Betarraga," although their fast-ripening is an obstacle for fresh sales therefore, dehydrated products, jams and preserves are alternatives highly valued by the community. In this sense, we encourage the local people to conserve and produce blood-flesh peaches in a way to support improvement of their economic wellbeing. After the ethnographic research

results were presented to the community we developed a series of workshops to promote collaborative work and associativity. As a result, the farmers formed a community association with the aim of protecting the "Durazno Betarraga" and promoting its use and care. They produce jams, preserves and "huesillos" which are sold in local markets under their own brand (Figure 2B).

Fruits contain a wide range of health-promoting compounds, including vitamins, fiber and antioxidants. All fruits high in polyphenols compounds have gained attention due to their antioxidant capacity and potential biological effects in human health (Lourenco et al., 2019). Polyphenols are plants-secondary metabolites wide family ranging from simple molecules such as phenolic acids to more complex like flavonoids. Flavonoids-family members like antocyanins, catechins and procyanidins are known as having a strong antioxidant activity, protective effect against coronary heart disease, and anti-inflammatory properties (Auger et al., 2004; Dragsted et al., 2006; Shin et al., 2006; Butelli et al., 2008; Garzón, 2008; Ottaviani et al., 2018). Fruits like blueberry, blackcurrant, cranberries, grapes and cherries, with high content of polyphenols and high antioxidant capacity have been very used for nutritious and functional food and beverage development (Sun-Waterhouse, 2011).

Our results show that total phenols concentration and antioxidant activity of "Durazno Betarraga" is comparatively elevated against selected fruits listed on the public fruit antioxidant database provided by INTA, University of Chile like cherries, plums, strawberries and raspberries. There are many published studies referring to antioxidants compounds presents in yellow and white-flesh commercial peaches and nectarines (Tomás-Barberán et al., 2001; Cantin et al., 2009; Zhao et al., 2015). Using spectrophotometrics methodologies it has been found that blood-flesh cultivars present high content of anthocyanins and polyphenols (Chaparro et al., 1995; Cevallos-Casals et al., 2006; Vizzoto et al., 2007). Quantitative analysis of individual phenolic compounds have been carried out in Chinese cultivars (Zhao et al., 2015; Yan et al., 2017) and more recently in French blood-flesh peach cultivars (Aubert and Chalot, 2020).

There is growing interest in peach breeding programs to select germplasm with a high content of bioactive compounds to develop new peach varieties with improved nutritional value. Variability in antioxidant capacity and bioactive compounds concentration within peach germplasm provides genetic opportunities for breeding programs (Abdelghafar et al., 2018; Ding et al., 2020). However, some production factors, such as ripening season, environmental conditions, such as temperature and precipitation, and management conditions, such as nitrogen fertilization, also introduce variability in the accumulation of bioactive compounds and antioxidant capacity (Heimler et al., 2016; Abdelghafar et al., 2018). Considering that polyphenol content is dependent on genetic and environment, and in order to evaluate the influence of environmental factor on variation of polyphenol content, we established three genetically identical orchards in different pedoclimates. Based on phenolic profiling by HPLC (Personal communication, H. Silva, 2021), six ecotypes with the highest levels of polyphenols (especially anthocyanins) were selected and propagated by grafting on two different rootstocks, establishing three identical orchards of 200 individuals in different soil and climates conditions. These orchards will enter the production phase in March 2023.

Considering that consumers today are seeking for healthy, functional and clean label foodstuff we propose that one strategy to incentivize the conservation and production of the blood-flesh peaches is through its use as a functional raw material for food innovation. This approach would be an alternative process to the traditional dried and cooked peach and responds to the farmers' concern about the short shelf-life- of the peach. Consumers today are more aware of the nutritional properties of their food and are actively seeking for healthy, functional and clean label foodstuffs. In general terms, functional food products are those who have physiological benefits beyond its basic nutritional function, for example food high in fiber, omega-3, probiotics or antioxidants. Research about food and beverage development has been actively pursued to incorporate natural bioactive ingredients and to conserve their health properties during its processing. A key issue is related to preservation of the biological properties and color of polyphenols after fruit harvesting and processing. The content and stability of polyphenols and other antioxidants and bioactive compounds, such as vitamins, are affected by food processing such as roasting, boiling, drying and pasteurization. Emerging processing technologies such as High-pressure processing (HPP) used for non-thermal pasteurization of foods (Al-juhaimi et al., 2018) offer preservation of the nutritional and functional properties of fruits and vegetables and longer shelf life (Sánchez-Moreno et al., 2005; Bisconsin-Junior et al., 2015). However, these new food processing technologies are expensive and not easily accessible for farmers.

To boost the Durazno betarraga production it is necessary to create a value chain that includes food innovation as a driving force. In this model some fundamental stakeholders are chefs, restaurants, food entrepreneurs and research centers that can build networks between small producers and urban customers and act as knowledge transfer agents of agrobiodiversity and gastronomic heritage. There are many case studies about restaurants and food festivals that have contributed to increase the demand for traditional and local products provided directly by local producers along with the rediscovery of neglected food (Lane, 2011; Pereira et al., 2019; Fontefrancesco and Zocchi, 2020; Zocchi and Fontefrancesco, 2020). On the other hand, the linkage with food enterprises and research centers in processed foods allows the adoption of technologies to add value to food

by transforming them into more complex ones that allow the opening of new markets.

One model to follow in the future is the productive arrangement based on the SYAL approach trough the integration of tangible elements like natural resources, production systems, manufacture and institutional organism, with intangible resources like tradition and cultural heritage that brings cohesion to its elements (Mascarenhas and Touzard, 2018). The SYAL approach emerges in France in the 90's and is defined as "production and services organizations -units of agricultural production, enterprise, local markets, restaurants and services- linked by their characteristics and by their relationship to a specific territory" (Muchnik et al., 2008). In this way, governance that emerges from the territory and involves all stakeholders can create a powerful value chain for the Durazno Betarraga that brings social and economic wealth to farmers in rural territories while promoting the conservation and revaluation of this heritage variety.

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 the Ethics Committee of Consultora Conversa SPA. The participants provided their informed consent to participate in this study.

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

Authors LM and CR were employed by Botania. Authors JC and JL were employed by Conversa.

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.

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