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Measuring diets and food choice in the context of a changing world

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Measuring diets and food choice in the context of a changing world

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Editorial: Measuring diets and food choice in the context of a changing world

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Editorial on the Research Topic
Measuring diets and food choice in the context of a changing world

Rapid changes to the food environments that consumers interact with, and the broader food system drivers that influence them, have led to a nutrition transition that is impacting the health of people and the planet (1–3). Global trends in the prevalence of underweight and obesity point to a worsening of malnutrition in all its forms in most countries (4), the world is off track to meet most of the global nutrition goals (5), and poor-quality diets remain a leading cause of disease worldwide (6). To begin addressing these issues, increased collection of representative quantitative dietary intake data—particularly in low- and middle-income countries—is necessary. However, this is not sufficient (7, 8); there is also a clear need for innovative approaches to improving food choices and diets that are grounded in the realities of a changing world that is grappling with conflict, climate variability and change, political instability, and the strong influence of corporate interests, among others.

As incomes rise and local food environments undergo rapid changes providing consumers with a wider array of options at competitive prices, understanding the underlying drivers of food choice including the preferences and values that underpin them has become increasingly important (9, 10). In recent years there have been renewed efforts to understand the drivers of food choice in the context of changing food environments and broader food systems, and how these drivers link with food consumption (11, 12). The goal of this Research Topic was to look beyond dietary consumption (what people eat) by considering more holistically the various drivers of food choice (how and why people eat the foods they do), to better understand what underpins individual decisions (13). Ultimately, by understanding why people make the choices they do—especially when situated in the local food environment and/or broader food system—we can identify important entry points for improving diets, reducing malnutrition, and strengthening food systems to better support food choice.

This Research Topic comprises 15 manuscripts, including perspectives, reviews, and original research undertaken in Europe, North America, Latin America, West Africa, Southeast Asia, and the Pacific Islands. The manuscripts contribute to our knowledge of the role of food environments in influencing food access, the factors that influence food choices in diverse contexts, including new ways of measuring those factors, how to capture and analyze dietary data in innovative, and less labor-intensive ways, as well as insights into ways to intervene within food systems to improve food choices and health outcomes.

We know that the food environments that people get food from, as well as the characteristics of those environments such as food availability, affordability, promotion, etc., interact with personal factors to influence the foods that consumers eventually acquire, purchase, and consume (14). Four papers in the Research Topic explore the importance of different food environment types on promoting food access. The articles by Coffin-Schmitt et al., Downs et al., and Zeitler et al. examine the importance of the natural food environment (where people access wild and cultivated foods) in supporting food security across diverse contexts including upstate New York, the Mekong River region of Cambodia, and among indigenous populations in Thailand. Together these papers provide us with a better understanding of where people access their food from, what motivates them to access food from these spaces, and how their decisions change across seasons or in the face of climate, economic, or other shocks, such as the COVID-19 pandemic. While accessing food from the natural food environment can be an important coping strategy to help address food insecurity (15), as countries move through the stages of the nutrition transition, there tends to be a shift away from the natural food environments toward more built environments (3, 16). Domínguez-Barreto et al. explored the shift in built food environments from more informal to formal food outlets that has coincided with a reduction in the reliance on public markets in Mexico between 1994 and 2020. These changes in how consumers engage with their food environments have implications in terms of food purchasing and consumption, particularly as it relates to the consumption of fresh foods compared to ultra-processed foods.

Consumers' lived experiences accessing food are influenced by their food environments as well as the personal factors or drivers that they value and consider when making decisions about which foods to consume. Five papers in the Research Topic examine drivers of food choices among Italian, Fijian, Senegalese, and American populations. Carfora and Catellani examined psychosocial drivers of local food purchasing among Italian consumers finding that the availability of local food was the main driver of its purchase along with other important factors such as trust in local food producers, authenticity, taste, social sustainability such as workers' rights, and appearance. Boxer et al. conducted a rapid review to examine factors influencing dietary behaviors in Fiji, finding that individual preferences for processed foods (particularly among younger populations) and gender and social dynamics that favored meat and overconsumption (particularly among men) were influencing food choices, despite knowledge about what constitutes a healthy diet. Other key drivers of dietary behaviors included food safety and climate variability, the latter of which created difficulties in planting and growing crops and disrupted supply chains leading to an increased reliance on processed and packaged foods. In recognition of the important role women play in influencing food choices within families, Hamam et al. aimed to examine the relationships between involvement in food choices and eating patterns. Through cluster analysis, they identified four types of women's eating behaviors, including: hedonic food consumers, sustainable- and balanced-diet consumers, food experimenters, and consumers with no food fondness. Vanderkooy et al. assessed the relationship between unhealthy food and beverage consumption with diet quality among 12–35 month children in Senegal finding that children who consumed diets high in unhealthy food and beverages had lower micronutrient intakes, tended to be older, and were more likely to be food insecure than those with lower intakes. They also explored the drivers of commercial processed food and beverages which included child preferences, the use of these products as behavioral management tools, or as treats and gifts. These findings can help provide insight into behavior change communication strategies that promote nutrient-rich foods that children enjoy in lieu of commercial processed foods. Gutjahr et al. designed and validated a dietary protein assessment questionnaire to explore US college students' knowledge and attitudes toward dietary protein. The final questionnaire includes questions that assess views on the relationships between meat production and consumption and the environment and the importance of organic sources of protein in terms of the health of people and the environment. With further testing and validation, this tool could potentially be used to create more effective nutrition interventions for college students.

We know that capturing dietary data is labor intensive and it requires skills and training to collect it in a way that generates high quality data (17). One of the contributions that we set out to make with this Research Topic was to identify novel methods for collecting and analyzing data that can then be used to inform what people are eating, and what motivates people to eat (or not eat) the foods they do. Both Gligorić et al. and Schäufele-Elbers and Janssen leverage routinely collected consumer sales and purchase data to measure food choices with a particular focus on sustainability, the latter of which examined the gaps between intentions and real-world food purchasing in the context of sustainability. Treitler et al. used citizen science (i.e., when members of the general public participate in the scientific process) with adolescents in Virginia, USA, and compared it with the National Health and Nutrition Examination Survey data, to assess adolescent nutrient intakes, demonstrating the potential for novel citizen science approaches to provide insight into diet quality. Di Maso et al. adapted the Nutritional Functional Diversity indicator, derived by ecologists, to examine dietary diversity finding that it was strongly associated with common dietary quality scores, specifically the Mediterranean Diet Score (18) and the Healthy Eating Index (19). These papers provide insight into novel methods for both collecting and analyzing dietary data in ways that can help inform which aspects of the diet need to be targeted in interventions, programs, or policies as well as the evaluation of the impact of those strategies on dietary outcomes.

One of the main reasons for striving to better understand the food environments that consumers are exposed to, and how the drivers of food choice interact with them to influence food choices, is to better inform the development of interventions, programs, and policies aimed at shifting consumers toward higher quality diets and improved nutrition and health outcomes. Brooker et al. reviewed the existing evidence of the effectiveness of interventions implemented in food retail settings and found that pricing strategies had the most favorable impacts on food purchasing outcomes, particularly among rural populations and those with low socio-economic status. They also found that promotional strategies combined with other initiatives were effective among the general population. It is likely that drawing on the evidence related to the

drivers of food choice within specific populations can help tailor interventions such as the ones examined in the article by Brooker et al. and lead to larger improvements in food choice. In addition to interventions that are prevention-oriented and implemented at the population level, as countries undergo the nutrition transition, those interventions will need to be complemented with programs targeting individuals with existing diet-related non-communicable diseases, such as diabetes. However, there are often resource and capacity constraints that create barriers to reaching people in need (20). As part of this Research Topic, Chisaguano-Tonato et al. helped to address this gap by creating an Ecuadorian food exchange list comprised of 404 foods to assist health professionals and researchers streamline the process of meal planning in an efficient and effective way that is aligned with cultural practices and habits.

While continued efforts are needed to increase the collection of representative quantitative dietary intake data—particularly in low- and middle-income countries—the papers included in this Research Topic demonstrate the importance of going beyond what people eat and exploring the underlying drivers and contexts that influence food choice to better design interventions that are tailored to people's lived experiences. It is likely that many of the interventions that will be truly impactful in terms of shifting the burden of poor-quality diets and malnutrition in all its forms will need to be context-specific and co-created in a way that centers people's lived experiences. As we move toward this type of approach, innovative methods, including leveraging citizen science, will have an integral role to play in designing and evaluating these types of food systems actions.

Author contributions

SD: Conceptualization, Writing – original draft. WB: Conceptualization, Writing – review & editing. CB: Conceptualization, Writing – review & editing.

Conflict of interest

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

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Trends in food and beverage purchases in informal, mixed, and formal food outlets in Mexico: ENIGH 1994–2020

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Background: The retail food environment in Mexico is characterized by the co-existence of both, formal and informal food outlets. Yet, the contribution of these outlets to food purchases over time has not been documented. Understanding the longitudinal trends where Mexican households purchase their foods is critical for the development of future food retail policies.

Methods: We used data from Mexico's National Income and Expenditure Survey from 1994 to 2020. We categorized food outlets as formal (supermarkets, chain convenience stores, restaurants), informal (street markets, street vendors, acquaintances), and mixed (fiscally regulated or not. i.e., small neighborhood stores, specialty stores, public markets). We calculated the proportion of food and beverage purchases by food outlet for each survey for the overall sample and stratified by education level and urbanicity.

Results: In 1994, the highest proportion of food purchases was from mixed outlets, represented by specialty and small neighborhood stores (53.7%), and public markets (15.9%), followed by informal outlets (street vendors and street markets) with 12.3%, and formal outlets from which supermarkets accounted for 9.6%. Over time, specialty and small neighborhood stores increased 4.7 percentage points (p.p.), while public markets decreased 7.5 p.p. Street vendors and street markets decreased 1.6 p.p., and increased 0.5 p.p. for supermarkets. Convenience stores contributed 0.5% at baseline and increased to 1.3% by 2020. Purchases at specialty stores mostly increased in higher socioeconomic levels (13.2 p.p.) and metropolitan cities (8.7 p.p.) while public markets decreased the most in rural households and lower socioeconomic levels (6.0 p.p. & 5.3 p.p.). Supermarkets and chain convenience stores increased the most in rural localities and small cities.

Conclusion: In conclusion, we observed an increase in food purchases from the formal sector, nonetheless, the mixed sector remains the predominant food source in Mexico, especially small-neighborhood stores. This is concerning, since these outlets are mostly supplied by food industries. Further, the decrease in purchases from public markets could imply a reduction in the consumption of fresh produce. In order to develop retail food environment policies in Mexico, the

historical and predominant role of the mixed sector in food purchases needs to be acknowledged.

KEYWORDS

food purchases, retail food environment, food outlets, households, informal food outlets

1. Introduction

The retail food environment is an important determinant of population nutrition and nutrition-related chronic diseases, including obesity (1–4). Retail food environments comprehend the availability, affordability, and quality of foods and beverages. Such factors influence the food choices of individuals by making the purchase of certain foods more convenient (5). Yet, interventions targeting the retail food environment remain scarce (6), and most of available literature seeking to understand the retail food environment has focused on high-income countries (HIC). Thus, understanding local household food purchasing preferences in low- and middle-income countries (LMIC) is key to identify the outlets where most people shop for food (2, 5, 7, 8).

In a cross-sectional analysis in 2018, Mexican households purchased most of their foods and beverages in outlets of the mixed sector, which are traditional small outlets that can be fiscally regulated or not (9, 10). Up to 70% of the food and beverage purchases were done in the mixed sector, including purchases at small neighborhood stores, specialty stores, public markets, and low-budget restaurants. In contrast, only 15% of purchases were made in the formal sector (i.e., supermarkets, chain convenience stores, restaurants), 14% corresponded to the informal sector (street vendors, street markets and acquaintances), and 1% to other (9). This purchase pattern diverges from purchases in HIC, which are concentrated in the formal sector, but it is similar to what has been observed in other LMICs (2, 3). While these analyses were informative of the status of food purchases in 2018, they did not provide information about changes in purchases over time. Understanding the foods and beverages purchasing trends could shed light into the contribution of the mixed, formal, and informal sectors to the populations health and nutrition status over time.

Extensive literature has documented how the number of formal food outlets, especially supermarkets and chain convenience stores, has increased over time in LMIC (11–16). During the 1990s, the trade liberalization led to the "modernization" of local markets which resulted in a rapid growth of supermarkets and chain convenience stores in LMIC, affecting the supply, demand, and the number of small traditional stores (10, 13–15). However, in Mexico, this trend is slowing down, and while the relative increase in the number of supermarkets and chain convenience stores is high, traditional stores (mixed food outlets) continue to be the main source of food and beverages (15). Nonetheless, the market "modernization" led to an increased demand for non-staples and ultra-processed foods, making small traditional stores an important source of ultra-processed foods as they started to be supplied by the food industries (3, 17). While this has provided a clear picture of the recent trends in the number of food outlets from the formal and mixed sector, longitudinal information on where households' shop for food in general and across socioeconomic and urbanicity strata remains unknown.

The description of the contribution of mixed, formal and informal outlets to food purchases in Mexico over time is key to identify which food outlets are the best target for policies that aim to regulate and improve the retail food environment. Moreover, understanding these trends is important because it can establish the limits of the regulatory capacity of the retail food environment, especially for the informal and mixed sectors. To address these gaps, we estimated the trends of food and beverage purchases in outlets of the mixed, formal, and informal food sectors from 1994 to 2020 using Mexico's National Income and Expenditure Surveys (ENIGH) and evaluated whether these trends differed across socioeconomic and urbanicity strata.

2. Methods

2.1. Data sources

We used 14 cross-sectional surveys of the National Income and Expenditure Survey (Encuesta Nacional de Ingresos y Gastos de los Hogares, ENIGH) from 1994 to 2020 conducted by the National Institute of Statistics and Geography of Mexico. All ENIGH surveys, except for 1994, were collected biennially, between August and November. The ENIGH is a probabilistic survey with a two-stage stratified clustered sampling design, representative at a national level (18). Starting in 2016, surveys also became representative at the state level. ENIGH uses the household as the study unit and collects information on income as well as daily expenses. Additionally, ENIGH collects information on household's sociodemographic characteristics and city size (18).

Food and beverage expenditure was collected by surveying households daily for seven consecutive days. Household food and beverage expenses were reported by the household member responsible for the purchases and complemented by a food diary kept by each household member. The food diary contains information on the name of foods and beverages purchased, quantity purchased (liters or kilograms), the price paid (Mexican pesos), and the type of food outlet where purchases were made (19).

Outlet categories in ENIGH varied across time, thus, to analyze different food outlets within the informal, mixed and formal sectors, we used two samples covering different time periods for this study. The first, included data from 1994 to 2020, providing a greater temporary coverage of food purchasing trends. Starting in 2006, ENIGH collected more disaggregated data for outlet types that were previously collected as a single outlet. Thus, the second sample included information from 2006 to 2020. This second analysis was conducted to provide a deeper understanding of the individual outlets

TABLE 1 Food and beverage outlet classifications and their characteristics (18).

1994–2020 classification	2006–2020 classification	Characteristics	Fiscal regime
Street markets (*tianguis*) and street vendors	Street markets (*tianguis*)	Set of vendors who are not fixed and set up in a certain time during the day to market their products in stands.	Informal
	Street vendors	Stands in public roads or spaces, vendors from home to home, and vehicles that offer goods or services (mobile vendors) are considered street vendors.	Informal
Acquaintances	Acquaintances	People dedicated to the sale of products and food that do not have a fixed establishment. They sell foods to neighbors, friends, family, or workplaces.	Informal
Public markets	Public markets	Public space where retail sales take place in different fixed establishments	Mixed
Specialty and small neighborhood stores (*abarrotes*)	Specialty Stores	Outlets that are dedicated to the commercialization of a single product or service: chicken shops, tortilla shops, butcher shops, among others.	Mixed
	Small neighborhood stores (*abarrotes*)	Outlets dedicated to the retail sale of various products.	Mixed
Low-budget restaurants	Low-budget restaurants	Small establishments that sell prepared foods and offer low-budget, affordable meals and the selection of foods is restricted to specific meals. (e.g., *fonda*, *cocina económica*, *lonchería*, *taquería*)	Mixed
Restaurants, cafes, bars	Restaurants, cafes, bars	Public establishments that sell prepared foods and beverages, and are consumed *in situ*, they offer alcoholic beverages, accept credit cards, and offer a menu.	Formal
Supermarkets and department stores	Supermarkets	Large commercial stores, divided into specialized departments, by items or products and have self-service for the public. They are distinguished by the sale of fresh and canned products.	Formal
		Department stores are big establishments with specialized departments. These usually exclude the sale of fresh or perishable foods (e.g., *Liverpool, Sears, El Palacio de Hierro*).	
Chain convenience stores	Chain convenience stores	Commercial chains that sell food products, packaged snacks and cookies, soft drinks, bottled water, alcoholic beverages, among others. These outlets are less than 500 m^2, with >18 business hours, and open 365 days a year. (e.g., *7-eleven*, *Oxxo*).	Formal
Others	Others	Wholesalers, department stores (in the 2006–2020 classification), international purchases, government establishments that provide food, and internet purchases (included from 2010 onwards).	Other

from the informal and mixed sector. From 1994 to 2020, ENIGH included a total of 428,122 households, varying from 12,815 households in 1994 to 89,006 in 2020. We excluded households that did not report any food or beverage purchases ($n = 4,232$, 0.99%), resulting in an analytical sample of 423,890 households. For the analyses of 2006 to 2020, the analytical sample included 340,443 households.

2.2. Food and beverage outlets

Surveys conducted between 1994 and 2000 included 12 outlet categories, while surveys collected between 2010 and 2020 included 18 categories (Supplementary Table 1). We created two outlet classifications (Table 1). The first classification (1994 to 2020) included nine categories: (1) street markets (*tianguis*) and street vendors; (2) acquaintances (starting in 2010); (3) public markets; (4) specialty stores and small neighborhood stores (*abarrotes*); (5) low-budget restaurants; (6) restaurants, cafes, bars; (7) supermarkets and department stores; (8) chain convenience stores (starting in 2006); and (9) others (outlets included in "others" are described in Table 1). We used the second food outlet classification to look at specialty stores and small neighborhood stores separately, as well as street markets and street vendors. In this classification we also analyzed supermarkets as a sole category (excluding department stores). The second classification (2006 to 2020) included 11 categories: (1) street markets (*tianguis*); (2) street vendors; (3) acquaintances; (4) public markets; (5) specialty stores; (6) small neighborhood stores (*abarrotes*); (7) low-budget restaurants; (8) restaurants, cafes, bars; (9) supermarkets; (10) chain convenience stores; and (11) others. We categorized street markets, street vendors, and acquaintances in the informal sector, defined as unregistered establishments under tax or social security laws (20). Public markets, specialty stores, small neighborhood stores, and low-budget restaurants can either belong to the formal or informal categories, since these outlets are small, they tend to be family-owned, and could be fiscally unregulated. Yet, ENIGH does not provide the necessary information to classify these types of outlets by fiscal or labor regimes. Therefore, we classified these outlets as mixed. Finally, we classified as formal outlets those that are most likely fiscally regulated establishments such as restaurants, cafes, bars, supermarkets, and chain convenience stores.

2.3. Urbanicity and education level of the head of the household

ENIGH classifies the localities' urbanicity according to the number of inhabitants. Rural localities are those with less than 2,500 inhabitants, small cities with 2,500 to 14,999 inhabitants, medium cities with 15,000 to 99,999 inhabitants, and metropolitan cities with more than 100,000 inhabitants (19). The definition of income in ENIGH has varied over time. Thus, we used the highest level of completed education of the head of the household as a proxy for socioeconomic status. ENIGH considers nine categories of education,

that we grouped into 4 mutually exclusive categories: (1) without formal education, (2) primary school, (3) high school, and (4) higher education.

2.4. Statistical analysis

For each survey, we calculated the contribution of the households' food and beverage expenses by food outlet type to the total food and beverages expenses (percent expenditure by outlet type. From here onwards, we refer to this as food purchases). Households that did not report food or beverage purchases in a specific outlet were included in the analysis with a percentage contribution of zero. Additionally, for each survey, we estimated the contribution of each outlet type to total household food and beverage purchases stratified by urbanicity and education level. All analyses were conducted in Stata 16 using the SVY command to account for the complex survey design and weighed to generate nationally representative estimates. Weights were created for every ENIGH survey to account for the selection probabilities and survey non-response to match the estimated population for every survey year from the National Institute of Statistics and Geography (21).

3. Results

Table 2 shows the sociodemographic characteristics of the ENIGH sample over time among households reporting expenditures on food and beverages. The proportion of households in the lowest education levels decreased over time, while households with the highest educational levels increased. For example, in 1994, 16.9% of head of households reported having no formal education. By 2020, this proportion decreased to 6.3%. In contrast, households with higher education increased from 7.3 to 14.1% from 1994 to 2020. Over time, the distribution of households by urbanicity remained stable, with 50% of the households located in metropolitan cities.

3.1. Trends in food and beverage purchases (% expenditure) in the informal, mixed and formal sectors from 1994 to 2020

At baseline, the highest proportion of food purchases was represented by mixed outlets (73.4%), followed by formal (12.8%) and informal outlets (12.3%). By 2020, mixed outlets decreased 1.8 percentage points (p.p.), (95% CI −2.6, −0.9), formal outlets increased 2.7 p.p. (95% CI 2.0, 3.3) from 1994 to 2018 and decreased 2.0 p.p. (95% CI −2.4, −1.7) by 2020. Food purchases in informal outlets increased 1.3 p.p. (95% CI 0.7, 1.9) over time (Figure 1).

3.2. Trends in food and beverage purchases (% expenditure) by outlet type from 1994 to 2020

Figure 2A shows the trends of food and beverage purchases by outlet type from 1994 to 2020. In 1994, the highest proportion of food purchases was represented by mixed outlets. Particularly, specialty stores and small neighborhood stores (53.7%), followed by public markets (15.9%). Over time, the contribution of specialty stores and small neighborhood stores to total food and beverage purchases increased 4.7 p.p. (95% CI 3.8, 5.7), while public markets decreased 7.5 p.p. (95% CI −8.2, −6.9). Purchases in low-budget restaurants increased 3.3 p.p. (95% CI 2.9, 3.7) between 1994 and 2018 and decreased 2.3 p.p. (95% CI −2.5, −2.0) in 2020. At baseline, purchases from informal outlets were mostly represented by street vendors and street markets (12.3%), and decreased 1.7 p.p. (95% CI −2.3, −1.1) over time. Food purchases from acquaintances represented 2.6% of the total purchases in 2010 and remained stable over time. The highest proportion on food purchases in formal outlets in 1994 was from supermarkets and department stores (9.6%), followed by restaurants, cafes and bars (3.2%). Over time, food purchases from supermarkets and department stores remained stable (+0.5 p.p., 95% CI 0.0, 1.1). Food purchases from restaurants, cafes, and bars increased 0.7 p.p. (95% CI 0.4, 1.1) between 1994 and 2018 and decreased 1.9 p.p. (95% CI −2.0, −1.7) in 2020. Convenience stores contributed 0.5% at baseline (2006) and increased to 1.3% by the end of the period.

The outlet categorization from 2006 to 2020 allowed us to study household purchases from small neighborhood stores (abarrotes) and specialty stores separately. The largest contribution to total food and beverage purchases in 2006 was from small neighborhood stores (31.2%), followed by specialty stores (20.9%). Food purchases from specialty stores increased 7.6 p.p. (95% CI 7.0, 8.2), but decreased in small neighborhood stores by 1.3 p.p. (95% CI −2.00, −0.6). This categorization also allowed us to study household purchases from street markets and street vendors separately. We found that street vendors accounted for most of the food purchases from the informal sector in 2006 (8.7%), while street markets represented 3.7%. Food purchases from street vendors decreased 1.9 p.p. (95% CI −2.3, −1.5), while purchases from street markets remained stable. In this categorization, supermarkets were studied excluding department stores. However, trends were similar to those described earlier (Figure 2B).

3.3. Trends in food and beverage purchases (% expenditure) by outlet type stratified by education level of the head of the household and urbanicity from 2006 to 2020

Figure 3 shows the trends in household food purchases by outlet type stratified by education level (percentage data with standard errors are available in Supplementary Table 2). At baseline, households with lower education levels purchased a higher proportion of their foods and beverages at mixed outlets, compared to those with higher education levels. However, purchases from mixed outlets among households without formal education decreased over time (−2.4 p.p., 95% CI −4.6, −0.3), but increased 10.4 p.p. (95% CI 7.8, 12.9) for households with higher education. Trends from specific stores of the mixed outlet show that, purchases from public markets decreased 5.3 p.p. (95% CI −6.9, −3.7) among households without formal education and 3.4 p.p. (95% CI −4,1, −2.8) in households with primary school, but remained stable for households with higher education. Purchases from small neighborhood stores remained stable across education levels. Purchases at specialty stores increased over time, but the magnitude of the increment was higher for more educated households

TABLE 2 Sociodemographic characteristics of households by year: the National Income and Expenditure Survey, 1994–2020.

Year	1994	1996	1998	2000	2002	2004	2006
Total households (n)	12,527	13,795	10,670	9,929	16,914	22,276	20,608
Education level[a], %							
Without formal education	16.9	13.6	12.8	12.4	13.5	11.1	9.8
Primary school	49.6	49.7	49.5	46.5	45.0	46.2	56.8
High school	24.4	27.3	27.8	29.4	31.5	32.2	22.3
Higher education	7.3	7.2	7.8	10.0	8.6	10.5	11.1
Urbanicity, %							
Rural localities	23.2	22.2	22.3	22.4	23.3	22.3	22.1
Small cities	13.4	13.5	13.4	13.4	13.4	13.7	13.1
Medium cities	14.3	13.4	13.3	13.4	13.4	13.9	14.7
Metropolitan cities	49.1	50.9	51.0	50.9	49.9	50.1	50.1
Year	2008	2010	2012	2014	2016	2018	2020
Total households (n)	29,217	27,415	8,924	19,355	69,850	74,194	88,216
Education level[a], %							
Without formal education	9.3	8.9	8.9	7.7	7.1	6.7	6.3
Primary school	44.6	42.4	39.9	38.0	36.2	34.5	33.6
High school	35.1	36.7	39.8	41.5	43.6	45.0	46.0
Higher education	11.0	11.9	11.4	12.8	13.1	13.9	14.1
Urbanicity, %							
Rural localities	21.3	21.3	21.9	21.9	21.7	23.0	21.5
Small cities	13.8	13.8	13.3	13.5	13.9	14.0	13.7
Medium cities	14.5	14.4	14.4	14.8	14.5	14.7	14.8
Metropolitan cities	50.3	50.5	50.5	49.8	49.9	48.2	50.0

[a]Completed education level of the head of the household.

(13.2 p.p., 95% CI 11.5, 14.9), increasing the most from 2018 to 2020 (6.9 p.p., 95% CI 5.8, 8.0) in these households. In the informal sector, purchases of households without formal education were twice the proportion of purchases of households with higher education. Purchases in street markets and street vendors from the informal sector decreased 2.2 p.p. (95% CI −4.1, −0.4) among less educated households and remained stable among more educated households. This is explained by the decrease of 1.8 p.p. (95% CI −3.4, −0.2) in purchases from street vendors among less educated households. Yet, food purchases from acquaintances also increased in less educated households from 2010 to 2020 (1.1 p.p., 95% CI 0.2, 2.0). Overall, purchases from the formal sector remained stable among households without formal education, but decreased 1.8 p.p. (95% CI −3.9, 0.1) among households with higher education. Purchases at chain convenience stores increased for all education levels; yet, they still represent a very small proportion of overall purchases. Trend results from 1994 to 2020 show similar patterns and are presented in Supplementary Figure 1; Supplementary Table 4.

Figure 4 shows trends in household purchases in food and beverages by outlet type, stratified by urbanicity (percentage data with standard errors are available in Supplementary Table 3). In 2006, households in rural localities purchased most of their foods in mixed outlets, decreasing 2.4 p.p. (95% CI −3.8, −0.9) over time. In contrast, households living in metropolitan cities increased 3.1 p.p. (95% CI 2.1, 4.1) their purchases in mixed outlets from 2006 to 2020. Purchases from small neighborhood stores remained stable over time across localities, except in small cities, where purchases decreased 3.0 p.p. (95% CI −5.0, −0.9). Food purchases in public markets decreased 6.0 p.p. (95% CI −7.0, −5.1) among households in rural localities, but remained stable in households living in metropolitan cities. Purchases at specialty stores increased from 2006 to 2020, however, the largest increment was observed in metropolitan cities (8.7 p.p., 95% CI 7.8, 9.6) in contrast to rural localities (4.7 p.p., 95% CI 3.5, 5.9). Over time, rural localities relied more on the informal sector than metropolitan cities. Food purchases in street markets and street vendors from the informal sector decreased 0.8 p.p. (95% CI −1.4, −0.1) and 2.9 p.p. (95% CI −4.0, −1.8) respectively from 2006 to 2020 in rural localities. Trends in the formal sector (without considering restaurants, bars and cafes) showed a small increase in both, rural localities and metropolitan cities. Purchases in supermarkets remained stable across localities, except in small cities, where purchases increased in 1.7 p.p. (95% CI 1.0, 2.4). Regardless of urbanicity, purchases in convenience stores increased. Trend results from 1994 to 2020 show similar patterns and are presented in Supplementary Figure 2; Supplementary Table 5.

4. Discussion

Our study provides a deep understanding of the role that the mixed, informal, and formal sectors have played over time in food and

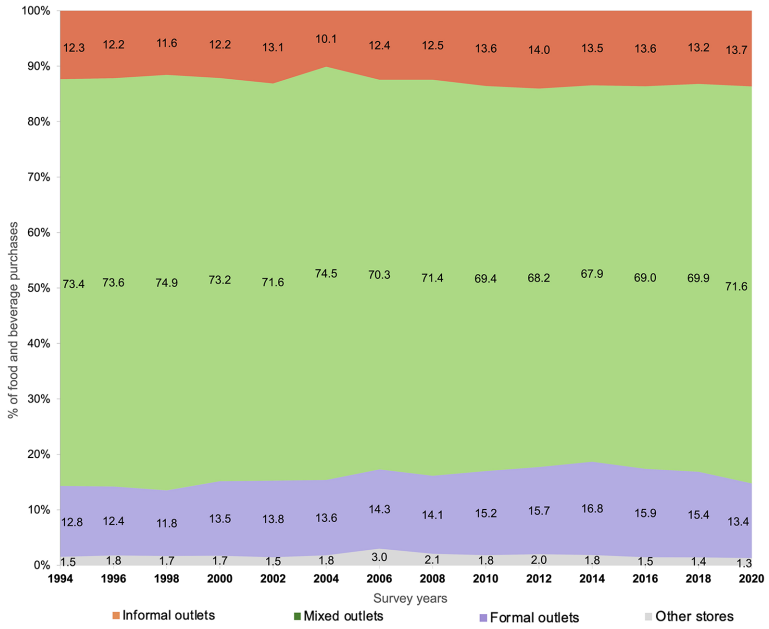

FIGURE 1
Trends in food purchases (% expenses) at the informal, mixed and formal sector: ENIGH 1994–2020. *Informal* outlets include street markets, street vendors and acquaintances (orange); *mixed* outlets include public markets, low-budget restaurants, and specialty stores (green); *formal* outlets include supermarkets, department stores, restaurants, cafes, bars, and chain convenience stores (purple).

beverage purchases for the Mexican population, for different socioeconomic sectors and locality sizes. We found that over time, the highest proportion of purchases were made at small neighborhood stores and specialty stores, followed by public markets. One of the most important changes in the mixed food sector was the increase in the contribution of specialty stores, which showed the largest increment in households with higher education and those living in metropolitan cities. Another important finding was the overall decrease in purchases from public markets, showing the largest decrease among households with lower educational levels and those living in rural localities. Street vendors accounted for most of the food purchases from the informal food sector. However, purchases at these outlets decreased over time, especially among households with lower educational levels and in rural localities. In contrast, purchases from street markets remained stable. Regarding the formal food sector, supermarkets represented the most important source of food purchases in this sector and remained stable over time. Trends by education showed that food purchases in supermarkets decreased among households with higher education and remained stable in households without formal education. Food purchases at restaurants, bars, and cafes were also stable over time, until 2020, when they showed an important decrease in 2020. This could be explained by COVID-19 pandemic. Starting in 2020, restaurants, bars, and cafes were either closed or had limited hours of operations by a national mandate. These restrictions had an important impact in social behavior and thus, in food purchases (22, 23). There was an overall increase in purchases from chain convenience stores, however, they still represent a minimum proportion of the total purchases across all education levels and localities.

Our study showed an overall increase in food purchases from specialty stores and chain convenience stores, and a slight decrease in food purchases from small neighborhood stores. However, we show that over time, purchases from small neighborhood and specialty stores are still higher, compared to purchases from supermarkets and chain convenience stores. Two recent studies (15, 16) that used Mexico's economic census data (National Statistical Directory of Economic Units, DENUE) from 2010 to 2020 found a decrease of 12% in the number of small neighborhood stores at the municipality level (15, 16). While purchases from small neighborhood stores decreased over time, the decrease in the number of outlets seems higher than the overall decrease in purchases in this type of outlet. The same studies (15, 16) found an increase in the number of specialty stores of up to 22% over the same period. This trend is in line with the increasing trend of purchases from specialty stores in our sample. Interestingly, the study by Ramirez-Toscano et al. reports a 77.5% increase in the number of chain convenience stores, and 80% increase in the number of supermarkets at the municipality level from 2010 to 2016 (15). Our results show that despite the increase in the number of supermarkets, purchases do not follow the same trend. It is likely that, over the period studied, increases in the availability of supermarkets has not been translated to increases in food purchases.

Food purchases in supermarkets and chain convenience stores increased the most in rural localities and small cities. However, these households have relied over time on the mixed and informal sector for most of their food purchases. In contrast, supermarkets have represented one of the food outlets in which over time, households with higher education and living in metropolitan cities have made most of their food purchases. These households also showed the largest increase in purchases from specialty stores and small neighborhood stores. In line with our results, Ramírez-Toscano et al. (16) found that in Mexico, non-urban areas had the largest increase in chain convenience stores, supermarkets, and

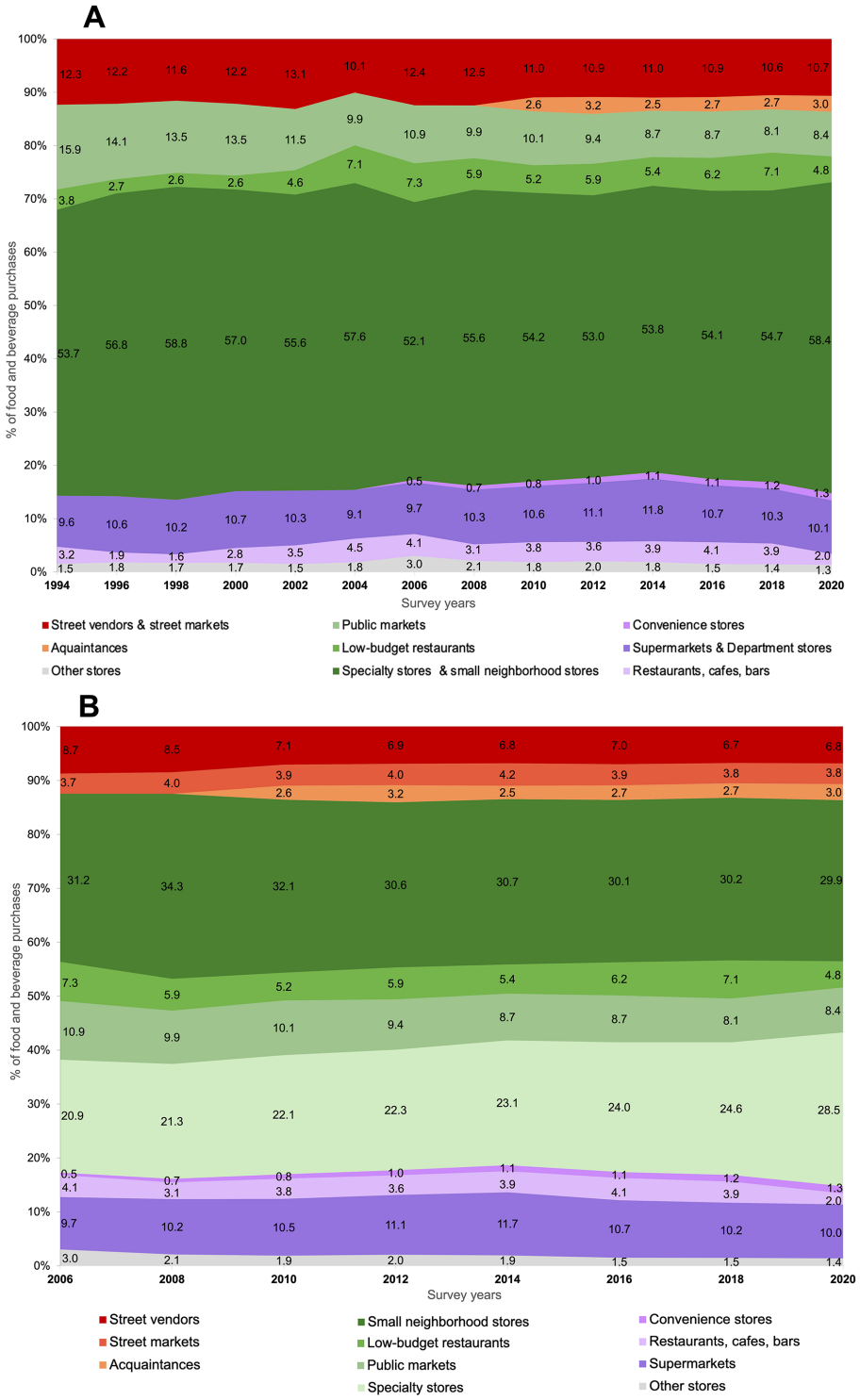

FIGURE 2
Trends in food purchases (% expenses) by outlet type. **(A)** ENIGH 1994–2020, **(B)** ENIGH 2006–2020. *Informal* outlets include street markets, street vendors, and acquaintances (red and orange); *mixed* outlets include small neighborhood stores, public markets, low-budget restaurants, and specialty stores (green); *formal* outlets include supermarkets, restaurants, cafes, bars, and chain convenience stores (purple).

specialty stores. This study also found that the number of small neighborhood stores slightly decreased in both, urban and non-urban areas (16). Similarly, a previous study that used data from Mexico's Nielsen Consumer Panel from 2012 to 2015 documented that low socioeconomic households obtained most of their foods from traditional retailers (outlets from the mixed sector in our study), while high socioeconomic households shopped more at supermarkets (24). However, traditional retailers were not differentiated in that study, and when analyzed separately, we found that specialty stores are also an important source of food for

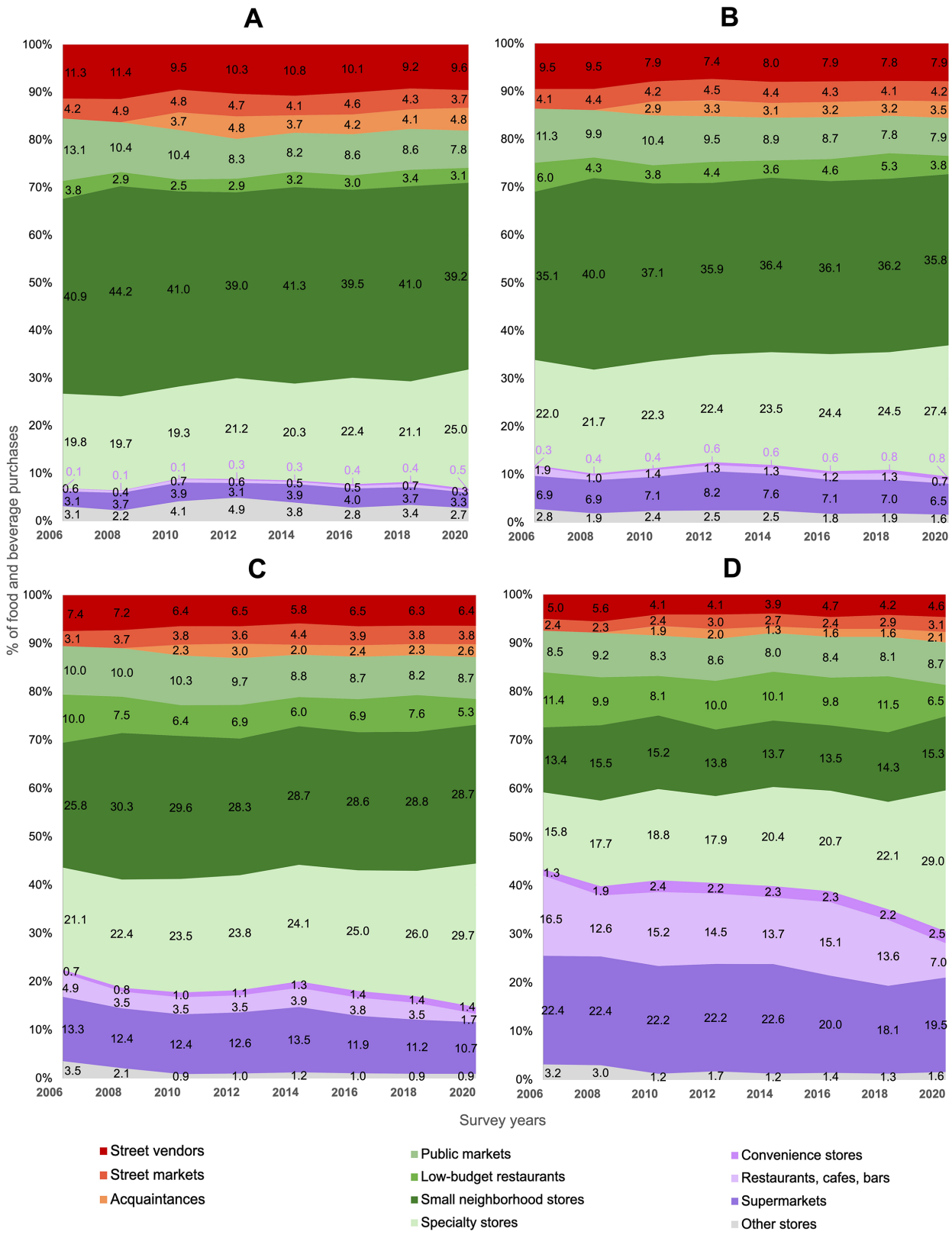

FIGURE 3
Trends in food purchases (% expenses) by outlet type according to the educational level of the head of the household: ENIGH 2006–2020. **(A)** Without formal education, **(B)** primary school, **(C)** high school, and **(D)** higher education. *Informal* outlets include street markets, street vendors, and acquaintances (red and orange); *mixed* outlets include small neighborhood stores, public markets, low-budget restaurants, and specialty stores (green); *formal* outlets include supermarkets, restaurants, cafes, bars, and chain convenience stores (purple).

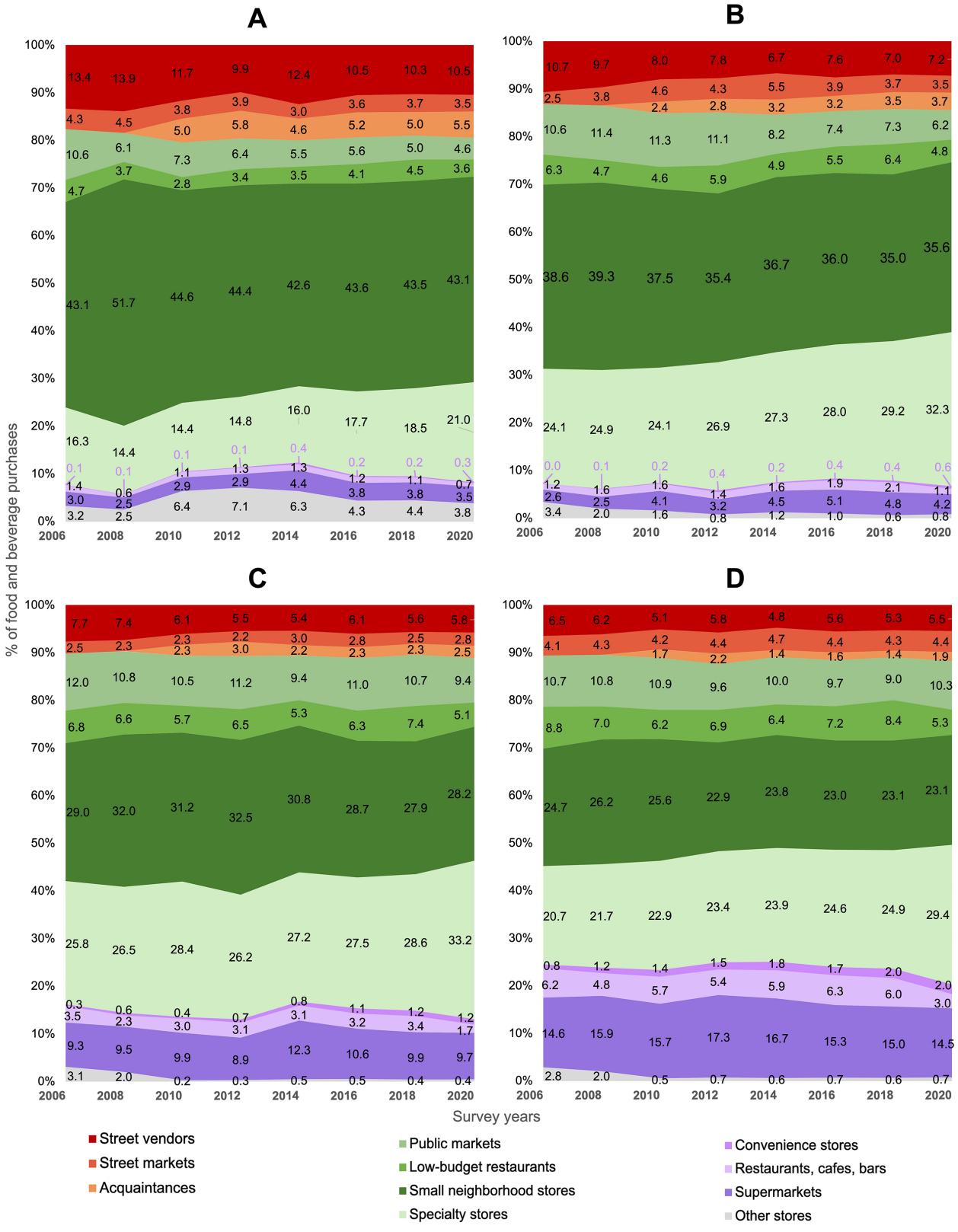

FIGURE 4
Trends in food purchases (% expenses) by outlet type according to the urbanicity: ENIGH 2006–2020. **(A)** Rural localities (<2,500 inhabitants), **(B)** small cities (2,500–14,999 inhabitants), **(C)** medium cities (15,000–99,999 inhabitants), and **(D)** metropolitan cities (>100,000 inhabitants). *Informal outlets* include street markets, street vendors and acquaintances (red and orange); *mixed outlets* include small neighborhood stores, public markets, low-budget restaurants, and specialty stores (green); *formal outlets* include supermarkets, restaurants, cafes, bars, and chain convenience stores (purple).

households with higher education levels and have increased significantly over time.

Our results show that, over the years, the informal food sector has been an important source of food purchases for Mexican households, especially for those residing in smaller localities and those with lower education levels. Yet, households living in cities and with higher levels of education, also rely on the informal food sector for their food and beverage purchases. In fact, purchases from street markets in these groups increased over time. However, trends show an overall decline in purchases from street vendors, and a decline in purchases from street markets among households living in rural localities and those without formal education. This could be explained by the fact that local governments have favored the promotion and expansion of formal outlets over informal ones (25), and by the expansion of supermarkets and chain convenience stores from metropolitan cities to small cities and rural areas (11–13, 26). In order to generate healthy and equitable food environments in Mexico, local authorities should consider informal retailers as part of their development initiatives (26–28). Over the years, the informal food sector has provided autonomy and a source of income to marginalized populations, while contributing to a fair distribution of local resources in LMIC (26, 27, 29, 30). Women in poor communities have particularly taken advantage of the informal food sector to contribute to their families' food security (26, 27). For consumers, the informal food sector offers culturally appropriate food at convenient locations and affordable prices (27). However, informal outlets also have problems in terms of food safety and access to potable water, particularly outlets where street food is prepared (26). Additionally, since the informal sector is not regulated, it does not comply with tax laws and does not pay social security to its employees (26, 27). Thus, local governments need to recognize the importance of the informal food sector as well as the challenges that come with it. Given the lack of regulation, informal outlets are a more complex area to intervene in contrast to the formal food sector (3, 28).

For the last two decades, the mixed sector has represented the largest proportion of food and beverage expenditure in Mexico. Over time, there was an increase in food and beverage purchases in specialty stores, especially in larger cities, and an important decrease in purchases from public markets. Overall, small neighborhood stores remained stable and an important food source over time. The increase in purchases from specialty stores can be explained by the increase in the number of these food outlets (16). Also, the three most purchased food items in Mexico City are tortillas, fresh chicken, and vegetables, which most households tend to purchase in specialty stores (31). It is important to note that the highest increment in food and beverage purchases from specialty stores happened from 2018 to 2020, which could be related to the COVID-19 pandemic. A possible explanation for this increase could be that specialty stores are usually located at street level, and are smaller than other types of stores. Thus, people might have perceived less danger purchasing foods in specialty stores, than small-neighborhood stores or supermarkets. The decrease in purchases from public markets could be partially explained by the fact that these outlets depend on government funding; thus, as funding has decreased, public markets may have lacked maintenance, hygiene, and good infrastructure for food preservation (32). It has been shown that food quality, freshness, price and diversity of products are important reasons for people to keep purchasing their food at public markets (32). However, because public markets are outlets with high availability of fresh and natural foods, it is of concern that households with lower socioeconomic levels are purchasing less in these outlets. Regardless of socioeconomic level, households purchase an important proportion of their foods in small neighborhood stores. Yet, over time, these food outlets have been the most important food source for households in rural localities and with lower education levels. Households in lower socioeconomic levels find small neighborhood stores convenient, since they tend to be at a walking distance from their homes and people can purchase smaller amounts of foods (24, 29, 31, 33). Moreover, mixed outlets in Latin America, especially small neighborhood stores, had to evolve in order to compete with the modern sector. Around the 1990s, these outlets shifted to self-service and increased the diversity of their products, since they started using the food industry as suppliers of their products (17, 34, 35). Unfortunately, this supply includes a high proportion of sugary drinks, snacks, and sweets. Historically, when it comes to public health interventions, outlets from the mixed sector have been overlooked. The food policy agenda should start considering strategies to regulate small neighborhood stores' food supply and distribution, while maintaining purchases from specialty stores, and increasing local governments' funds directed toward the improvement of the environment within public markets.

The number of formal outlets in Mexico has increased over time (15, 16). We found that food purchases in supermarkets had a slight increase over time, while in chain convenience stores purchases doubled. Given that a higher density of chain convenience stores have been associated with poor nutrition and health outcomes such as diabetes (15), the rapid increase in food purchases in chain convenience stores could represent a threat to the population's nutrition state. However, food purchases in chain convenience stores still represent a very low proportion of total food and beverage expenditure. A recent review documented that in some Latin American countries, including Mexico, the growth in the number of supermarkets happened from the late 1990s to mid 2000s, increasing from a 5–10% to a 30–50% (53% in Mexico) (3). Additionally, previous studies have argued that the expansion of chain convenience stores and supermarkets in LMIC might threaten the informal and mixed sectors (11–13, 26). While households with higher education and residing in metropolitan cities have bought a higher proportion of their foods and beverages in supermarkets, these same households increased their purchases in specialty stores and small neighborhood stores over time. On the other hand, households in smaller localities still purchase most of their foods in the mixed sector, although purchases in the formal sector in less urbanized localities increased over time. Supermarkets and chain convenience stores have been the target of many policies aimed at increasing the healthfulness of the retail food environment (36). However, only focusing policies on these types of outlets in Mexico would mostly benefit the segments of the population that purchase most of their foods there, which are households with a higher education level and those who reside in metropolitan cities.

Food policies targeting the retail food environment face important challenges. Most of the interventions involving the food environment in Mexico have targeted consumers' food choices (3, 24, 37, 38). Yet, very few interventions have focused on the retailers themselves or have considered retailers as policy actors for the modification of the retail food environment (6, 38). Currently, there are no policies in place targeting the retail food environment in Mexico. In fact,

according to The INFORMAS Healthy Food Environment Policy index in Mexico, the level of implementation of interventions in food retailers is very low, compared to international practices (6). As our results show, to reach better health outcomes at the population level, interventions within specific outlet types are essential to the transformation of the retail food environment (3, 6, 26, 36, 39). Specifically, given the importance of the different outlet-types to total food and beverage purchases for different population sectors, our study highlights the need to prioritize interventions in small neighborhood stores, specialty stores, and public markets.

A major strength of our study was the use of a nationally representative survey to describe trends in purchases in the mixed, informal, and formal food sector in Mexico. However, some limitations should be considered. While ENIGH has a temporary coverage from 1984 to 2020, we excluded from the analysis surveys prior to 1994 since ENIGH's oldest outlet classification did not allow us to distinguish formal sector food purchases from purchases made in the informal sector. Moreover, the name of the establishments where purchases were made are not provided by ENIGH. Thus, our classification of formal, mixed, and informal outlets is limited to the type of food outlet reported by ENIGH. As a result of this, we are not able to determine whether a specific mixed outlet tends more toward a formal or an informal establishment. Food and beverage purchases from certain outlets could be underreported, especially if purchases were not planned. However, there is no reason to believe that underreporting is differential over time. While it could be possible that household purchases to differ by education level within each urbanicity category, we did not consider this in our study and would be important to explore in future research. One limitation of the ENIGH food outlet classifications is that some stores, such as specialty stores and street vendors, could sell a wide variety of foods. Thus, the impact of the changes in the proportion of purchases in these types of store could be hard to interpret without knowing what they sell. This study is not capturing changes in the number of stores over time. Therefore, our results are a combination of food store availability and where households choose to shop. Additionally, since the COVID-19 pandemic shifted both, purchase behaviors and changed the food environment, especially with closures of businesses, the interpretation of the 2020 data should consider the impact of the COVID-19 pandemic. Finally, this study did not look at the food groups that households are purchasing at the different food outlets. Future studies are needed to understand the quality of food purchases by store type.

5. Conclusion

In conclusion, we found that over time, food purchases increased the most in specialty stores and chain convenience stores but decreased in public markets and street vendors. This decrease was more important among households with lower education levels and those living in rural localities. Even though we observed an increase in food purchases from the formal sector, the predominant source for food in Mexico continues to be the mixed sector. Future policies targeting the retail food environment should consider that all households, except the ones with formal education and residing in metropolitan cities, make most of their food purchases in small neighborhood stores, which is concerning, given that these outlets are mostly supplied by the soft drink and processed food industries. A worrisome finding is the decrease in purchases in public markets, particularly for lower socioeconomic levels and smaller localities, which could imply a reduction in the consumption of fresh produce that are the staple of these outlets.

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

AD-B conducted the statistical analysis. AD-B and DS designed the study, interpreted the results, and led the writing. IF, NL-O, CP-F, YR-T, and TB-G contributed to the interpretation of results and critical review of the manuscript. All authors read, edited, and approved the final version of the manuscript.

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Conflict of interest

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

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1151916/full#supplementary-material

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High unhealthy food and beverage consumption is associated with poor diet quality among 12–35-month-olds in Guédiawaye Department, Senegal

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Background: High consumption of unhealthy foods and beverages (UFB) during early childhood is cause for concern, with growing evidence from low- and middle-income countries finding associations with poor diet quality and malnutrition. Research from sub-Saharan Africa remains limited, with no studies quantifying the contribution of UFB to total energy intakes among young children or exploring the relationship between such intakes and diet quality or anthropometric outcomes.

Objectives: Assess UFB consumption patterns and their contribution to total energy intake from non-breastmilk foods/beverages (TEI-NBF), assess the association between high UFB consumption and dietary/nutrition outcomes, and explore drivers of unhealthy food choice among young children in Guédiawaye Department, Senegal.

Methods: We conducted a cross-sectional study of a representative sample of 724 primary caregivers and their 12–35.9-month-old children. The study included a questionnaire, a quantitative four-pass 24-h dietary recall, and anthropometric measurements. The contribution of UFB to TEI-NBF was calculated and terciles generated. Logistic and linear models were used to compare outcomes of high versus low UFB consumption terciles.

Results: UFB contributed on average 22.2% of TEI-NBF, averaging 5.9% for the lowest tercile and 39.9% for the highest. Diets of high UFB consumers, as compared to low, were significantly less dense in protein, fiber, and seven of the 11 micronutrients assessed and significantly denser in total fat, saturated fat, and total sugar. No associations were found with anthropometric outcomes. High UFB consumers were older and more likely to be living in food insecurity. The most common drivers of commercial UFB consumption were related to child preference, the use of these products as behavior management tools, treats, or gifts, and the sharing of these products by someone else eating them.

Conclusion: High UFB consumption is associated with poor diet quality among 12–35-month-olds in Guédiawaye Department, Senegal. Addressing high UFB consumption during this critical developmental period should be prioritized in young child nutrition research, programming, and policy development.

KEYWORDS

unhealthy foods and beverages, complementary feeding, infant and young child nutrition, dietary assessment, nutrient density, food choice, Senegal

1. Introduction

The global food system has been marked by growing production and availability of highly processed foods (1), with increasing consumption of these foods occurring across low- and middle-income countries (LMIC) in recent decades (1–3). In conjunction, a 'nutrition transition' has been identified in many LMIC - as nations experience economic growth, diet patterns tend to move away from traditional diets and move towards westernized diets, with higher intakes of added sugars, unhealthy fats, and refined carbohydrates (2, 3). These diet shifts are occurring across age groups and increasingly, LMICs are experiencing a 'triple burden' of malnutrition among children - undernutrition, micronutrient deficiencies, and overweight/obesity - driven by the poor quality of children's diets (4).

Senegal is among the countries leading the nutrition transition in sub-Saharan Africa (5). Overweight/obesity has steadily risen among Senegalese school age children in the past two decades and is projected to continue rising (6, 7). Poor dietary outcomes and undernutrition among infants and young children in Senegal remains a challenge. Only 13.5% of children 12–23 months achieve a minimum acceptable diet in terms of recommended dietary diversity and feeding frequency and stunting and wasting affect 22.5 and 7.3%, respectively, of children 12-35-months (8). Unhealthy food and beverage (UFB) consumption among infants and young children is prevalent, especially among urban populations (8, 9). A study in Dakar found that unhealthy commercial snack foods (e.g., biscuits, chips, candy) were the second most commonly consumed food group among 12–23-month-olds (10).

A nutritious diet for infants and young children below 3 years of age is vital to ensure optimal childhood nutrition, growth, and development (11, 12). UFB high in sugar/salt are inappropriate for infant and young child feeding and may contribute to both under- and over-nutrition (12–14). Their impact may be even more serious in lower and middle-income contexts, where the nutritional quality of diets during the complementary feeding period tends to be limited (11). Early diets also shape future dietary preferences (15–17). Given rising rates of overweight/obesity in LMIC (18, 19), high UFB consumption early in life could have significant, long-term dietary, health, and economic consequences (2, 3, 5, 18). However, there is limited information quantifying UFB consumption and its association with young child nutritional status in LMIC, and to our knowledge no prior research on this subject for young children in sub-Saharan Africa (20). This research, therefore, aims to explore the relationship between consumption of UFB and nutritional outcomes among young children living in Guédiawaye Department, Senegal. The specific objectives were to: (1) describe UFB consumption patterns and their contribution to total energy intake; (2) assess associations between high UFB consumption and dietary quality and anthropometric status outcomes; and (3) explore drivers of commercial UFB food choice.

2. Materials and methods

2.1. Study design and sampling

This cross-sectional study was conducted among a representative sample of 12–35.9-month-old children and their primary caregivers living in Guédiawaye Department, Senegal. The study included a questionnaire, a quantitative four-pass 24-h dietary recall (24HR), and anthropometric measurements of each child and caregiver. Data collection took place from November to December 2021. Ethical approval for the research was obtained from the Senegalese National Ethics Committee for Health Research (CNERS) and the London School of Hygiene and Tropical Medicine. Written informed consent was obtained from caregivers prior to study participation.

The survey's sample size estimations were based on anticipated differences in z-scores for height-for-age (HAZ) and weight-for-height (WHZ). These calculations used means and standard deviations for HAZ and WHZ for children under 5 years of age in Dakar (21). Power was first calculated for a difference between two groups, and because terciles would be used for comparisons the sample size was multiplied by three. In the absence of appropriate data to determine the specific intra-cluster correlation for this study, the design effect of 2 was chosen as a conservative estimate. The sample size calculations indicated that a minimum sample size of 648 caregiver-child pairs would allow detection of a 0.5 difference in HAZ and WHZ between low and high terciles of UFB consumption ($1\text{-}\beta = 0.8$; $\alpha = 0.05$).

A two-stage cluster sampling protocol was used to randomly select a representative sample of participants. First, 81 clusters were randomly assigned across the 140 *quartiers* (neighborhoods) of Guédiawaye Department using probability proportional to size (22). Secondly, for each cluster, a random starting GPS point within the *quartier* was determined. Approximately two days before the cluster's data collection, caregivers were systematically recruited using standardized procedures (23). Recruiters faced north from the starting point then approached the first household to their right to assess child/caregiver eligibility. They continued approaching households on both sides of the street, walking in the same direction until reaching the end of the street or the edge of the *quartier*, at which point they turned right to continue recruitment. To ensure a minimum of eight available caregivers per cluster on the day of interview, 11–12 caregivers were recruited. Child/caregiver pairs were excluded if they were non-residents of Guédiawaye Department, the child had a malformation that inhibited feeding, or the child was severely ill. In households with multiple eligible children, one was selected randomly. On the morning of interview, recruited caregivers were contacted to confirm availability. Of available caregivers, 8–9 per cluster were randomly selected for interview.

2.2. Study procedures

Questionnaires and 24HR were administered in caregivers' households to facilitate participation and enable access to cooking/feeding utensils for portion size estimations. Anthropometric measurements were conducted at a central location within the neighborhood where available. If a central location was not available, measurements were conducted in households. The interviewer-administered questionnaire collected data on demographic and socioeconomic characteristics of the child, caregiver, and household; child morbidity and immunization status; caregiver social desirability bias; and the child's consumption of commercial UFB (frequency in the previous week and reasons for consumption). Questionnaires and 24HR standardized text were translated to French and Wolof, and back translated to ensure accuracy. All tools and methods were tested prior to data collection to ensure respondent and interviewer comprehension.

During questionnaire administration, caregivers were asked about their child's consumption of eight categories of commercial UFB in the previous week: biscuits/cookies; chips/puffs; crackers/salty popcorn; cake/donuts; candy/sweets/lollipops/chocolate; soft drinks; sweet milk/chocolate drinks (excluding breastmilk substitutes); and juice/fruit-flavored drinks. The eight categories were developed in prior research to capture key types of commercial UFB consumed by young children in Dakar (9). Local experts adapted these questions for use in this study by identifying sentinel examples within each category. If a category was consumed at least once in the previous week, caregivers were asked to cite the main reasons why their child consumed the category. Interviewers probed for multiple responses, classifying the caregiver's response in an existing category or as a new response option. Existing categories were developed based on input from local experts and drivers of young child commercial UFB consumption previously identified in urban Senegal (9) and Nepal (24).

Trained interviewers administered the four-pass 24HR to collect details and estimate quantities of foods/beverages consumed by the child in the previous day and night (25). In the first pass of the 24HR, caregivers listed all foods/beverages consumed by the child – excluding water and breastmilk – and the time consumed. In the second pass, caregivers were asked food/beverage-specific questions to provide further details on each item. In the third pass, caregivers estimated the quantity of each food/beverage consumed. In the fourth pass, the interviewer verified the first pass information with the caregiver, adding or removing foods/beverages as necessary. If multiple individuals supervised/fed the child, information was collected from all relevant respondents. During recruitment, caregivers were provided a pictorial recall aid for use the day before data collection. Interviewers collected these recall aids prior to 24HR administration and reviewed the aid with caregivers after the fourth pass, adding or removing foods/beverages from the 24HR if necessary.

The 24HR were conducted on all days of the week to eliminate day-of-the-week effect at the group level. To facilitate estimation of quantities consumed by the child, household utensils and portion size estimation aids (PSEA) were used. As eating around one large bowl is common in Senegalese households, caregivers were provided a small bowl during recruitment and instructed to use this specifically for child feeding to aid portion size estimation during the 24HR. Estimated portion sizes were weighed using digital scales (Model 1,024 WHDR14, Salter; ±1 g precision). A pictorial portion size estimation guide was developed for common vegetables and fruits. Standard recipes were created for mixed dishes consumed >10 times and conversion factors were calculated to convert PSEA weights to weights of the actual foods/beverages consumed. Energy and nutrient intakes were calculated using a food composition table (FCT) compiled by this study, following FAO International Network of Food Data Systems (INFOODS) guidelines (26). This FCT used values from relevant published FCT (27–33), as well as nutrient content information from product labels and values from laboratory-analyzed food samples. Eleven of the most frequently consumed, packaged foods/beverages were analyzed by an accredited (ISO/IEU 17025:2005) laboratory for energy and nutrient content (total fat, saturated fatty acids, total sugar, carbohydrate, fiber, protein, Ca, Fe, Zn, and Na). This included: two chips/crisps, one biscuit, one chocolate drink powder, two infant cereals, two breastmilk substitutes, one cheese, and one fortified soft wheat flour (used in local bread product fabrication). Retention factors were applied to FCT values to account for nutrient losses during cooking (34).

Interviewers collected all data on tablets using CommCare. The 24HR data was collected using INDDEX24 Mobile App, developed for electronic 24HR data collection (35). Programmed skip patterns and constraints limited interviewer error during administration. Data were also checked immediately after interviews by supervisors and the full database downloaded from CommCare daily for comprehensive quality checks.

Trained pairs of anthropometrists used standardized methods (36) to measure the length/height and weight of each child, primary caregiver, and mother (if the primary caregiver was not the mother). Length/height was measured to the nearest 0.1 cm using stadiometers (Model S0114540, UNICEF, New York), with recumbent length used for children below 2 years of age. Weight was measured to the nearest 0.1 kg using SECA digital scales (Model 874 1021659, Hamburg), with scales calibrated daily using standard weights. Anthropometrists took two sequential measurements of length/height and weight; the mean was used in analysis. If the two length/height measurements varied by over 0.5 cm for children or 1 cm for adults, or the two weight measurements varied by over 0.5 kg, measurements were discarded and taken again. To ensure precise and accurate measurement, an anthropometry standardization session was conducted prior to data collection, following WHO methods for assessing technical error measurement (TEM) (37). Precision was 0.15 (child length/height) and 0.32 (caregiver height) for the expert measurer and ranged 0.45–0.48 for child length/height and 0.27–0.30 for caregiver height for the study's anthropometrists (cutoff was <0.60, i.e., within ±2x the expert's TEM). Accuracy ranged 0.61–0.66 for child length/height and 0.23–0.41 for caregiver height for the study's anthropometrists (cutoff was <0.80, i.e., within 2.8x the expert's intra-observer TEM).

2.3. Exposure and outcomes

Exposure for this study was high consumption of UFB. To define exposure, a food/beverage was classified as an UFB if it fell into one of the three WHO/UNICEF unhealthy food/beverage categories for infant and young child feeding (sweet beverages, sweet foods, and fried/salty foods) (12) and was nutrient profiled as "unhealthy" based on the United Kingdom Food Standards Agency's (UK-FSA) nutrient profiling model (38). The UK-FSA model is used to identify products that should have restricted marketing to children. It has been validated (39) and used in prior research to identify unhealthy foods/beverages for infants and young children in lieu of a nutrient profiling model for this young age group (13). The model categorizes foods/beverages as "healthy" or "unhealthy" based on their energy, total sugar, saturated fat, sodium, fiber, protein, and percent fruit/vegetable/nut content per 100 g. Terciles of low/moderate/high UFB consumption were created based on the contribution of these UFB to each child's proportion of total energy intake from non-breastmilk foods/beverages (%TEI-NBF). High tercile UFB consumers (i.e., exposed) were then compared to low tercile UFB consumers for primary outcomes of interest.

Primary outcomes included: median nutrient density (ND) and nutrient density adequacy (NDA) of non-breastmilk foods/beverages consumed per day for each of 11 micronutrients, mean NDA (MNDA) across all 11 micronutrients, and HAZ and WHZ. Energy and nutrient intakes are associated with age during young childhood, and

breastmilk intake is variable among individual children (it was not feasible to measure breastmilk intake at the scale of this study). As such, ND (amount of nutrient/100 kcal non-breastmilk foods/beverages (NBF)) was used to describe diet quality, rather than total nutrient intake. To determine NDA and MNDA, desired ND were first calculated. For non-breastfed children, this involved dividing the appropriate Reference Nutrient Intake (RNI) value (40) by the estimated total energy requirement (kcal/day) for that age group (41) and multiplying by 100. Estimated total energy requirement was calculated using the sample's mean child weight for each age group. For breastfed children 1–2 years of age, average breastmilk intake of children of this age in developing countries (549 g/day) was assumed (42), with the nutrient contribution from breastmilk subtracted from each RNI (using nutrient values from the West African Food Composition Table (27)) and from the estimated total energy requirement for that age group. Moderate bioavailability of iron and zinc were assumed. NDA was then calculated for each child by dividing their complementary feeding diet's density for a given nutrient by the appropriate desired ND and multiplying by 100, to represent the percent of the desired ND satisfied by NBF consumed. MNDA was calculated for each child by averaging their NDA across the 11 micronutrients, with each NDA capped at 100%. Breastfed children 2–3 years of age ($n = 7$) were excluded from NDA and MNDA analysis, given the lack of data on average estimated breastmilk intakes for this age. HAZ and WHZ were calculated (43) using the Box-Cox-power-exponential method with curve smoothing by cubic splines, the method selected by the WHO in 2006 for constructing child growth curves (44).

2.4. Analysis

Data were cleaned and analyzed using Stata/SE-15.1 (Stata Corp). Descriptive statistics included proportions, means ± SD for normal distributions, and medians and interquartile ranges (IQR) for non-normal distributions. To compare outcomes between low and high UFB terciles, cluster-adjusted ANOVA of log-transformed data and Bonferroni corrections were used for ND, NDA, and MNDA, and unadjusted and adjusted linear regression with random effects for HAZ and WHZ. Adjusted regression models contained explanatory variables associated with child growth (42), namely household (wealth quintile, food security), caregiver (education), and child (age, sex, birthweight, breastfeeding status, vitamin A supplementation or deworming in previous 6 months, immunization, and morbidity in previous 2 weeks) characteristics. Wealth scores and quintiles were created using principal components analysis (45). The Household Food Insecurity Access Scale was used to determine household food security (46). A 13-item scale, Short Form C from (47), was used to assess caregivers' social desirability bias, measuring their tendency to answer questions or behave in a way viewed favorably by others.

Results

Results from participant sampling are shown in Figure 1. Response rate was high, with >90% of eligible participants accepting participation during recruitment and able to participate on the day of interview. The final sample included 724 child-caregiver pairs. Socio-demographic characteristics of the children, their primary caregivers, and households are presented in Table 1. Almost all children were ever breastfed, with 66.8 and 2.0% of 12–23.9 and 24–35.9-month-olds, respectively, currently breastfeeding. Caregivers were most commonly the child's mother, followed by the child's grandmother (4.7%) or aunt (2.6%). Over one-quarter of caregivers had no formal education, but the majority (63.7%) had attended primary or secondary school. Approximately one-third had performed paid work in the last 7 days and 43.8% in the last 12 months; most of this work was partially or entirely conducted from home and with the child present. Half of caregivers were overweight or obese. Just over half of households were 'food secure'. As compared to high UFB consumers (see Supplementary Table S1), low UFB consumers were significantly younger, more likely to still be breastfeeding, more likely to have received vitamin A supplementation in the previous 6 months, and more likely to be living in a food secure household.

In total, 205 unique foods/beverages that were consumed by the 724 children in this study corresponded to one of the WHO/UNICEF unhealthy food/beverage categories. Almost all of these (95.1%) were nutrient profiled as 'unhealthy' and therefore classified as UFB. Exceptions included fried potato and sweet potato (primarily home-prepared); 100% fruit juices (two commercial, one home-prepared); one sweetened drinking yogurt (commercial); and one juice drink (commercial).

Close to 90% of children consumed at least one UFB in the previous 24 h (Table 2). Mean contribution of UFB to %TEI-NBF was 22.2%, with mean contribution by tercile at 5.9% for low UFB consumers, 20.7% for moderate, and 39.9% for high consumers. Of the three WHO/UNICEF categories, unhealthy sweet beverages provided the highest %TEI-NBF, followed by unhealthy sweet foods and then unhealthy fried/salty foods. Ready-to-eat commercially branded UFB and home- or vendor-prepared UFB contributed similar %TEI-NBF (11.3 and 10.8% respectively, $p = 0.423$).

Table 3 details median ND of NBF, for all children and by UFB tercile. Compared to low UFB consumers, median ND of total fat, saturated fat, and total sugar were significantly higher in high UFB consumers' diets and median ND of protein and fiber were significantly lower. For seven of the 11 micronutrients assessed (Ca, Fe, Zn, vitamins B1, B2, B6, and B12), median ND was significantly lower for high UFB consumers as compared to low consumers. However, median ND of folate was significantly higher for high UFB consumers, driven by greater consumption of fried products made with folic acid fortified flour, such as donuts and fataya (deep-fried pastries with meat/fish filling). There were no significant differences between high and low UFB consumers in median ND for sodium, or vitamins A, C, or B3.

Table 4 details median NDA of NBF, for all children and by UFB tercile. Among the 11 micronutrients assessed, median NDA for Ca, folate, and vitamins B1 and B3 were the lowest (<65%), indicating these nutrients were important problem nutrients for children in this context. Median NDA exceeded 100% for vitamins A, C, B2, and B12. Compared to low UFB consumers, high UFB consumers had significantly lower median NDA for Fe and Zn, but significantly higher median NDA for folate.

There were notable differences in NDA by age group. The MNDA for 12-23-month-olds was significantly lower than 24-35-month-olds (medians of 67.2 and 83.2% respectively, $p < 0.001$), and the NDA of all micronutrients assessed were significantly lower for the younger than older age group (analyses not shown). The UFB group comparisons

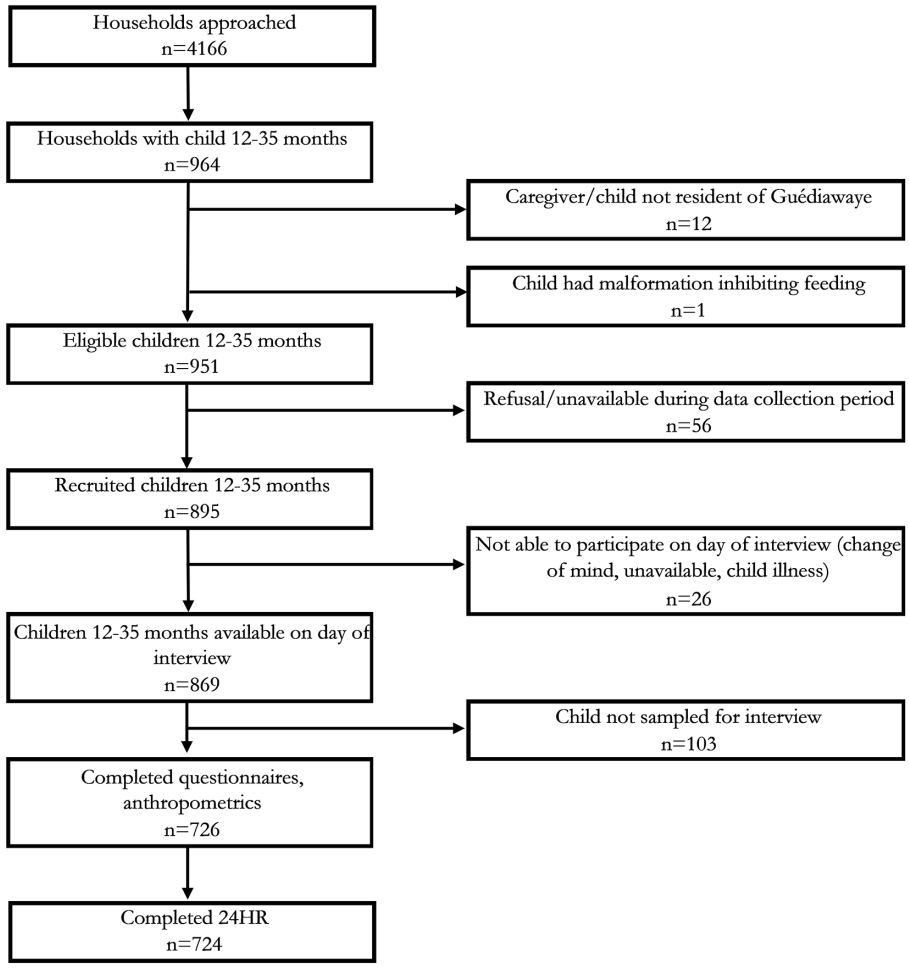

FIGURE 1
Participant recruitment, exclusion, and inclusion; 24HR, multiple pass 24-h recall.

were thus analyzed by age group (see Supplementary Tables S2, S3). Among 12-23-month-olds, high UFB consumers, as compared to low UFB consumers, had significantly lower NDA for seven of 11 micronutrients assessed (Ca, Fe, Zn, vitamins B1, B2, B6, and B12) and for MNDA (Supplementary Tables S2). Among 24-35-month-olds, high UFB consumers, as compared to low UFB consumers, had significantly lower NDA for three of the 11 micronutrients assessed (Fe, Zn, and vitamin B6) and significantly higher NDA for folate (Supplementary Tables S3).

Stunting, underweight, and wasting affected 8.2, 9.1, and 6.4% of children, respectively. Only 0.6% of children were overweight/obese. No differences in HAZ or WHZ were noted when comparing low and high UFB consumers (HAZ unadjusted model: $\beta = 0.11$; 95% CI = −0.08 to 0.30, $p = 0.270$; HAZ adjusted model: $\beta = 0.08$; 95% CI = −0.12 to 0.28, $p = 0.452$; WHZ unadjusted model: $\beta = 0.03$; 95% CI = −0.14 to 0.20, $p = 0.756$; WHZ adjusted model: $\beta = 0.01$; 95% CI = −0.17 to 0.19, $p = 0.925$).

Child preference (child asked for it, child likes eating it/likes taste) was cited by the highest proportion of caregivers as a main reason for their child consuming commercial UFB in the previous week (Table 5). Other highly cited reasons (>50% of caregivers) included: given as a treat/gift, someone else was eating it, and child behavior management. Reasons related to availability (readily available/close by), affordability (affordable/inexpensive), convenience (easy to prepare/ready-eat, can be fed to child easily/child can consume independently), perceived healthfulness (caregiver/other people think it's safe/clean, caregiver/other people think it's good for child's health/development), and marketing (package/advertisements say it's good for child's health/development) were rarely cited. As compared to high UFB consumers, a significantly lower proportion of low UFB consumers' caregivers cited reasons related to their child's preference, although it remained one of the most common reasons for children's commercial UFB consumption across all UFB consumption terciles. Availability of commercial UFB was the other reason cited by a significantly lower percent of low versus high UFB consumers' caregivers, although this reason was relatively uncommon in all UFB consumption terciles (<10%).

Discussion

The role of UFB consumption in dietary quality, and its association with nutritional status of young children, has not been extensively studied in LMIC. To our knowledge, no prior research has measured the contribution of UFB to total energy intakes nor explored the

TABLE 1 Child, primary caregiver, and household characteristics (n =724).[1]

Child	
Age, months	23.2 ± 7.0
Female	50.4 (365)
Ever breastfed	97.4 (705)
Still breastfeeding	35.5 (257)
Age breastfeeding cessation, months	18.6 ± 4.2
Age complementary food introduction, months	5.5 ± 1.5
Illness in last 2 weeks[2]	28.3 (205)
Fully immunized[3]	94.2 (682)
Dewormed in last 6 months	74.2 (537)
Vitamin A supplementation in last 6 months	74.2 (537)
Child anthropometric status	
Stunted (HAZ < -2)	8.2 (59)
Wasted (WHZ < -2)	6.4 (46)
Primary caregiver	
Child's mother	90.5 (655)
Age, years	31.7 ± 9.1
Muslim	95.3 (690)
Education (highest level attended)	
No formal education	27.1 (196)
Primary	31.4 (227)
Middle/Secondary	32.3 (234)
Tertiary	9.1 (66)
Engaged in paid work in last 7 days	35.4 (256)
Maternal weight status[4]	
Underweight	7.5 (51)
Overweight	32.1 (217)
Obese	18.5 (125)
Household	
Food secure	56.6 (410)

[1]Values are % (n) or mean ± SD.
[2]Any of fever, diarrhea, cough.
[3]1 dose of BCG; 1+ dose of measles; 3 doses of DPT-Hep B; 3 doses of polio.
[4]Pregnant caregivers are excluded. World Health Organization global cut-offs (48) are used for weight categories: underweight, BMI < 18.5 kg/m^2; overweight, BMI 25 – <30.0 kg/m^2; and obese, BMI > 30.0 kg/m^2.

TABLE 2 Unhealthy food and beverage (UFB) consumption and contribution to total energy intakes from non-breastmilk foods (TEI-NBF).[1]

Food categories	Consumption by children	%TEI-NBF
ALL UFB	89.8 (650)	22.2 ± 15.8
Commercial products[2]	76.4 (553)	11.3 ± 11.3
Home- or vendor-prepared	70.3 (509)	10.8 ± 11.4
UNHEALTHY SWEET BEVERAGES	68.1 (493)	9.3 ± 10.0
Commercial products	33.7 (244)	3.3 ± 6.1
Sweet milk	2.5 (18)	0.3 ± 1.7
Fruit drinks	24.3 (176)	2.4 ± 5.4
Fruit juices	4.6 (33)	0.4 ± 2.1
Soft drinks	5.1 (37)	0.2 ± 1.1
Home- or vendor-prepared	53.3 (386)	6.0 ± 8.2
Hot beverages[3]	49.9 (361)	5.2 ± 7.4
Local juices	5.9 (43)	0.8 ± 3.4
Other[4]	0.8 (6)	0.0 ± 0.5
UNHEALTHY SWEET FOODS	63.5 (460)	8.7 ± 10.7
Commercial products	47.7 (345)	5.1 ± 8.0
Cakes	1.1 (8)	0.1 ± 0.9
Biscuits	28.6 (207)	3.5 ± 7.0
Candy/chewing gum/chocolate	23.6 (171)	1.0 ± 2.9
Sweet chips/crisps	2.2 (16)	0.2 ± 1.3
Ice cream/frozen yogurt	3.5 (25)	0.3 ± 1.8
Home- or vendor-prepared	33.8 (245)	3.6 ± 6.9
Cakes[5]	2.6 (19)	0.2 ± 1.4
Donuts	12.4 (90)	1.8 ± 5.7
Creme (frozen juice treat)	22.1 (160)	1.4 ± 3.3
Other[6]	1.9 (14)	0.1 ± 1.1
UNHEALTHY FRIED/SALTY FOODS	50.4 (365)	4.2 ± 6.2
Commercial products	42.3 (306)	3.0 ± 4.7
Chips/crisps	42.3 (306)	3.0 ± 4.7
Home- or vendor-prepared	15.6 (113)	1.3 ± 3.9
Fataya	7.7 (56)	0.8 ± 3.2
Akara	5.0 (36)	0.2 ± 1.3
Other[7]	4.3 (31)	0.3 ± 1.7

[1]Values are % (n) and mean ± SD.
[2]Commercially produced, packaged, and branded products that are ready-to-eat. Commercial products that are ingredients in home- or vendor-prepared foods/beverages (e.g., milk or drink powders, flour etc.) are not included in this category.
[3]Namely milk with sugar, hot chocolate, and sweet tea/coffee.
[4]Includes juice drinks made from powder/syrup and unbranded vendor-sold flavored milks.
[5]Includes cakes made by bakeries and small vendor/home-prepared cakes.
[6]Includes sweet popcorn, *bouye carré* (baobab squares), *mbourake* (breadcrumbs or millet with peanut powder, sugar etc.), and *gerté suuker* (sweetened nuts).
[7]Includes homemade/vendor prepared chips/crisps, mini pizza, and *nem* (spring rolls).

relationship between UFB consumption and dietary/growth outcomes among young children in sub-Saharan Africa (20). In Guédiawaye Department, UFB made up a substantial part of young child diets and were associated with compromised nutritional quality of diets when consumed in high amounts. However, there was no association between UFB consumption and either linear or ponderal growth outcomes. Key drivers of young child commercial UFB consumption included child preference, the use of these products as behavior management tools, treats, or gifts, and the sharing of these products by someone else eating them.

UFB comprised on average 22.2% TEI-NBF for children 12-35-months of age in this study. This is comparable to findings among 12-23-month-olds in urban Nepal, where similar foods/beverages comprised 24.5% TEI-NBF (13) and findings in Thailand, where "snacks" (definition not provided) comprised 19.3% TEI for 12-23-month-olds and 23.6% TEI for 24-35-month-olds (50). Much lower levels were found among 12-59-month-olds in Mexico, with "ultra-processed foods" contributing 7.6% TEI (51), while much higher levels were found among 12-23-month-olds in urban

TABLE 3 Median nutrient density of non-breastmilk foods among children ages 12–35 months, overall and by UFB tercile.[1]

Nutrient (per 100kcal)	All children (*n* =724)	Low consumers (*n* =241)	Moderate consumers (*n* =242)	High consumers (*n* =241)	*p*[2]
Protein, g	2.3 (2.0–2.7)	2.5 (2.1–2.9)[a]	2.3 (1.9–2.7)[b]	2.2 (1.9–2.5)[c]	<0.001
Carbohydrate, g	15.7 (14.4–16.8)	15.7 (14.3–17.1)	15.5 (14.3–16.6)	15.7 (14.5–16.7)	0.542
Fiber, g	0.7 (0.6–0.9)	0.8 (0.6–0.9)[a]	0.7 (0.6–0.8)[a,b]	0.6 (0.5–0.8)[b]	0.002
Total fat, g	3.0 (2.5–3.5)	2.9 (2.3–3.4)[a]	3.1 (2.6–3.5)[b]	3.0 (2.6–3.6)[b]	0.011
Saturated fat, g	1.0 (0.8–1.2)	0.9 (0.7–1.2)[a]	1.0 (0.8–1.2)[a,b]	1.0 (0.8–1.3)[b]	0.008
Total sugar, g	6.3 (5.0–7.7)	5.9 (4.5–7.1)[a]	6.1 (4.9–7.5)[b]	7.1 (5.7–8.3)[c]	<0.001
Sodium, mg	109 (83–132)	112 (79-140)[a,b]	113 (88-135)[a]	101 (82-120)[b]	0.002
Calcium, mg	36 (22–53)	41 (24-64)[a]	34 (22-50)[b]	33 (21-48)[b]	0.004
Iron, mg	0.7 (0.6–0.9)	0.8 (0.6–1.0)[a]	0.7 (0.6–0.8)[b]	0.6 (0.5–0.8)[c]	<0.001
Zinc, mg	0.37 (0.31–0.44)	0.42 (0.37–0.53)[a]	0.39 (0.31–0.42)[b]	0.31 (0.27–0.38)[c]	<0.001
Vitamin C, mg	3.2 (2.0–5.5)	3.4 (2.0–6.8)	3.2 (2.0–4.8)	3.2 (2.0–5.4)	0.847
Thiamin (B1), mg	0.037 (0.029–0.052)	0.040 (0.031–0.075)[a]	0.035 (0.029–0.045)[b]	0.036 (0.029–0.046)[b]	<0.001
Riboflavin (B2), mg	0.065 (0.046–0.090)	0.078 (0.049–0.105)[a]	0.063 (0.043–0.085)[b]	0.060 (0.046–0.084)[b]	0.002
Niacin (B3), mg	0.404 (0.309–0.539)	0.422 (0.320–0.571)	0.396 (0.306–0.516)	0.404 (0.309–0.530)	0.173
Vitamin B6, mg	0.057 (0.045–0.076)	0.066 (0.050–0.087)[a]	0.055 (0.044–0.072)[b]	0.053 (0.041–0.070)[b]	<0.001
Vitamin B12, µg	0.128 (0.081–0.205)	0.152 (0.088–0.286)[a]	0.125 (0.080–0.196)[a,b]	0.117 (0.076–0.168)[b]	0.010
Folate, µg	11.7 (8.7–14.7)	11.6 (8.5–14.5)[a]	11.1 (8.3–13.6) [a]	12.8 (9.5–16.9)[b]	0.001
Vitamin A (RAE), µg	46.3 (32.7–59.5)	46.5 (29.2–62.0)	47.4 (35.1–60.1)	45.3 (32.7–56.3)	0.934

[1]Values are median (inter-quartile range). ANOVA of log-transformed data with cluster adjustment used and Bonferroni *post hoc* tests conducted to compare between groups. Significant differences between groups shown when overall $p < 0.05$, where labeled medians in a row without a common letter differ ($p < 0.05$). Low consumers = children in lowest tercile of percentage of total energy intake from non-breastmilk foods (%TEI-NBF) from unhealthy foods and beverages (UFB) (mean = 5.9% TEI-NBF); moderate consumers = children in middle tercile of %TEI-NBF from UFB (mean = 20.7% TEI-NBF); high consumers = children in highest tercile of %TEI-NBF from UFB (mean = 39.9% TEI-NBF). RAE = retinol activity equivalents.
[2]Overall value of *p* of association between UFB consumption terciles and nutrient density.

TABLE 4 Median nutrient density adequacy of non-breastmilk foods among children ages 12–35 months, overall and by UFB tercile.[1]

Nutrient	All children (*n* =717)	Low consumers (*n* =237)	Moderate consumers (*n* =242)	High consumers (*n* =238)	*p*[2]
Calcium	57.4 (35.3–83.0)	61.4 (37.0–92.7)	57.3 (35.1–83.5)	53.5 (35.0–76.8)	0.264
Iron	94.7 (65.9–120.0)	97.6 (65.3–130.2)[a]	98.6 (72.6–120.0)[a]	88.8 (61.2–109.8)[b]	0.007
Zinc	76.0 (59.1–93.8)	81.7 (65.4–104.5)[a]	77.4 (63.3–92.8)[b]	66.5 (50.9–83.8)[c]	<0.001
Vitamin C	115.8 (67.4–215.4)	142.4 (66.7–271.9)	103.9 (65.3–171.2)	117.7 (70.3–196.6)	0.293
Thiamin (B1)	61.2 (43.6–82.1)	62.9 (43.9–101.0)	60.5 (44.4–76.8)	59.8 (42.9–79.8)	0.218
Riboflavin (B2)	115.7 (81.0–157.6)	126.9 (81.6–172.2)	114.6 (78.8–150.3)	109.1 (82.6–146.5)	0.083
Niacin (B3)	52.5 (36.7–77.5)	51.0 (34.6–70.4)	52.9 (39.1–76.7)	52.5 (36.3–81.7)	0.200
Vitamin B6	90.8 (60.5–123.5)	95.7 (61.6–130.1)	91.3 (66.1–122.9)	86.0 (55.2–116.2)	0.119
Vitamin B12	117.6 (71.3–185.0)	134.1 (70.5–229.5)	120.8 (74.1–177.7)	110.5 (65.7–165.1)	0.146
Folate	59.5 (41.4–80.3)	51.6 (36.5–71.6)[a]	60.5 (42.0–79.4)[b]	66.3 (46.1–90.9)[c]	<0.001
Vitamin A (RAE)	129.2 (91.9–223.6)	139.8 (92.3–271.7)	122.2 (92.1–189.9)	124.2 (88.4–207.5)	0.087
MNDA[3]	76.6 (64.2–86.5)	76.7 (64.4–87.9)	77.4 (65.3–86.3)	74.8 (62.2–86.3)	0.475

[1]Values are median (inter-quartile range). Breastfed children 24–35.9 months of age ($n = 7$) are excluded from analysis (see Methods). Desired nutrient densities are based on FAO/WHO 2002 RNIs and estimated energy requirements are from FAO 2001. Assumed average breastmilk intake, using WHO 1998, with nutrient values for breastmilk from WAFCT 2019. ANOVA of log-transformed data with cluster adjustment used and Bonferroni *post hoc* tests conducted to compare between groups. Significant differences between groups shown when overall $p < 0.05$, where labeled medians in a row without a common letter differ ($p < 0.05$). Low consumers = children in lowest tercile of percentage of total energy intake from non-breastmilk foods (%TEI-NBF) from unhealthy foods and beverages (UFB) (mean = 5.9% TEI-NBF); moderate consumers = children in middle tercile of %TEI-NBF from UFB (mean = 20.7% TEI-NBF); high consumers = children in highest tercile of %TEI-NBF from UFB (mean = 39.9% TEI-NBF).
[2]Overall value of *p* of association between UFB consumption terciles and nutrient density adequacy.
[3]Average nutrient density adequacy for all 11 micronutrients, with each capped at 100%.

TABLE 5 Reasons for unhealthy commercial food/beverage consumption in previous week, overall and by UFB tercile.[1]

	All children (*n*=714)	Low consumers (*n*=233)	Moderate consumers (*n*=240)	High consumers (*n*=241)	*p*[2]
Child preference	*81.5 (582)*	*70.0 (163)*[a]	*85.8 (206)*[b]	*88.4 (213)*[b]	*<0.001*
Child asked for it	65.4 (467)	51.1 (119)[a]	75.4 (181)[b]	69.3 (167)[b]	<0.001
Child likes eating it/likes taste	58.3 (416)	49.8 (116)[a]	58.3 (140)[a,b]	66.4 (160)[b]	0.001
Given as a treat/gift	75.8 (541)	71.2 (166)	79.2 (190)	76.8 (185)	0.121
Someone else was eating it	58.3 (416)	56.7 (132)	56.7 (136)	61.4 (148)	0.478
Child behavior management	*51.5 (368)*	*46.8 (109)*	*51.3 (123)*	*56.4 (136)*	*0.109*
Given to calm child down/stop them from crying	46.5 (332)	42.1 (98)	47.1 (113)	50.2 (121)	0.202
Given to keep child busy/entertained/distracted	19.9 (142)	20.2 (47)	17.9 (43)	21.6 (52)	0.599
Child got it by themself	11.2 (80)	7.3 (17)	13.3 (32)	12.9 (31)	0.069
Readily available/close by	4.8 (34)	2.6 (6)[a]	3.8 (9)[a,b]	7.9 (19)[b]	0.017
Convenience	*2.8 (20)*	*3.9 (9)*	*2.5 (6)*	*2.1 (5)*	*0.471*
Easy to prepare/ready-to-eat	2.0 (14)	2.6 (6)	1.3 (3)	2.1 (5)	0.577
Can be fed to child easily/child can consume independently	1.3 (9)	1.7 (4)	1.7 (4)	0.4 (1)	0.352
Perceived healthfulness	*2.4 (17)*	*3.0 (7)*	*2.1 (5)*	*2.1 (5)*	*0.750*
Caregiver/other people think it's good for child's health/development	2.2 (16)	2.6 (6)	2.1 (5)	2.1 (5)	0.916
Caregiver/other people think it's safe/clean	0.1 (1)	0.4 (1)	0.0 (0)	0.0 (0)	0.357
Diversify diet/introduce a new food/taste	1.4 (10)	1.7 (4)	0.8 (2)	1.7 (4)	0.656
Package/advertisements say it's good for child's health/development	1.3 (9)	0.9 (2)	1.3 (3)	1.7 (4)	0.737
Affordable/inexpensive	1.1 (8)	0.9 (2)	1.3 (3)	1.2 (3)	0.899

[1]Values are % (*n*). Children included if they consumed at least one UCFB category in the previous week. Reason counted if it was cited for at least one of the UCFB categories consumed. Multiple responses possible. Significant differences between groups shown when overall $p < 0.05$, where labeled values in a row without a common letter differ ($p < 0.05$). Low consumers = children in lowest tercile of percentage of total energy intake from non-breastmilk foods (%TEI-NBF) from unhealthy foods and beverages (UFB) (mean = 5.9% TEI-NBF); moderate consumers = children in middle tercile of %TEI-NBF from UFB (mean = 20.7% TEI-NBF); high consumers = children in highest tercile of %TEI-NBF from UFB (mean = 39.9% TEI-NBF).
[2]Overall value of *p* of association between UFB consumption terciles and reason for consumption.

Cambodia, with "snacks" (definition not provided) and sugar-sweetened beverages contributing 38.2% TEI-NBF (52). We are not aware of any studies among this age group in sub-Saharan Africa that estimate %TEI-NBF from UFB and thus allow for comparison. The contribution of UFB to %TEI-NBF in our study is also comparable to levels found among children in high-income contexts (53, 54). Unhealthy sweet beverages were the UFB category that contributed most to %TEI-NBF in our study, particularly home−/vendor-prepared beverages with added sugar. This is concerning given the potential risks of high consumption of high-sugar beverages during childhood, including dental caries, long-term weight gain leading to overweight/obesity, and preference for sweet tastes later in life (16, 17, 55–58).

We found that diets of high UFB consumers were significantly less dense in protein, fiber, and seven of 11 micronutrients studied and significantly denser in total fat, saturated fat, and total sugar. UFB consumption was associated with lower NDA for some micronutrients assessed, especially among 12-23-month-olds, where high UFB consumers had significantly lower NDA for seven of 11 micronutrients and for MNDA. This supports the theory that UFB may be displacing healthier food options and compromising diet quality during young childhood. Previous research in LMIC has found similar results. A study of 12-23-month-olds in peri-urban Nepal (13) found that high consumption of UFB was associated with lower micronutrient intakes and poorer dietary adequacy and a South African study found that high consumption of added sugar among 12-47-month-olds was associated with lower intakes for most micronutrients studied (59). 12-23-month-olds have higher desired nutrient densities for complementary feeding diets than 24-35-month-olds, reflecting higher nutritional needs relative to energy requirements during this critical age period (11). High UFB consumption may therefore displace more nutritious food options and compromise nutrient adequacy to a greater extent at this age than later during the preschool years, with potential consequences including compromised linear growth and brain development (11, 60). In contrast to other micronutrients assessed in this study, ND and NDA for folate were significantly higher in high UFB consumer diets. This was due to greater consumption of unhealthy fried products made with folic acid fortified flour. Fortification of widely consumed staples can mitigate micronutrient inadequacies within young child diets. In this context, children across all UFB consumption terciles commonly consumed fortified staples such as wheat flour, milk powder, and cooking oil. These staples were prepared into foods/beverages of varying levels of healthfulness (e.g., bread, donuts, fried pastries, prepared milk powder without sugar, prepared milk powder with sugar). Awareness-raising could encourage those preparing foods/beverages to privilege cooking fortified staples into healthier options and those consuming foods/beverages to seek out these relatively healthier options.

There was no association between UFB consumption and growth outcomes measured in our study. This finding contributes to the limited

and mixed evidence on associations between UFB consumption and growth among young children in LMIC. A study in peri-urban South Africa found no association between daily consumption of "inappropriate foods" and HAZ, weight-for-age z-scores, or BMI-for-age z-scores (BMIZ) among 12-month-olds (61). In contrast, a study in urban Nepal found a negative association between unhealthy snack food/beverage consumption and length-for-age z-scores among 12-23-month-olds (13) and a longitudinal study in urban Brazil found that higher usual consumption of nine sentinel groups of ultra-processed foods/beverages was positively associated with BMIZ and negatively associated with HAZ from two to four years of age (14). Given evidence of high UFB consumption among young children in many LMIC across the globe, large, well-designed cohort studies following children from 6 months to at least 36 months of age in different LMIC contexts are needed to clarify the relationship between UFB consumption and young child growth. Unhealthy early diets' implications beyond young childhood are also of concern. In Senegal, the prevalence of child, adolescent, and adult overweight/obesity is increasing, with especially high prevalence among adult women (6). Our study found high prevalence of maternal overweight (32.1% with BMI 25.0–29.9) and obesity (18.5% with BMI ≥30.0). This is relatively comparable to projected national prevalence among women aged 18 years and over, estimating overweight at 37.9% and obesity at 15.1% in 2019 (6). It is crucial that future research investigate causal relationships between high UFB consumption in early life and later nutrition and health outcomes such as dietary preferences, growth/weight status, and diet-related non-communicable diseases in this context.

In the current study, high UFB consumers were older and more likely to be living in food insecurity. Previous research on UFB consumption in LMIC also generally finds the contribution of UFB to %TEI-NBF increases with age during early childhood (20, 23, 50), although a cross-sectional study of 6-23-month-olds in Egypt found the %TEI-NBF from junk food was decreasing with age during this period (62). Positive associations between food insecurity and UFB consumption have also been widely reported in research from both high-income and LMIC contexts (49, 63–65). This association is likely due in part to higher financial constraints in food insecure households. UFB are relatively more affordable than healthier options (66). They are also less likely to be rejected by young children; resource-constrained caregivers may therefore offer hyper-palatable UFB to young children rather than risk wastage of limited resources by offering perishable, more expensive options such as fruit or fortified cereal (67). Convenience, availability, accessibility, and use of UFB to cope with the stress of food insecurity have also been identified as factors contributing to associations between UFB consumption and food insecurity in various contexts (49, 63, 65, 68). Evidence-based action to address high UFB consumption in food insecure households is essential given the nutritional vulnerabilities of these young children. Also, as Senegal continues along the path of nutrition transition (5), high-energy, processed UFB may become even more affordable relative to healthier options. Thus, UFB consumption by young children in food insecure households might increase unless timely action is taken to enable healthier food choices for young children living in these circumstances (69).

Drivers of food choice are complex and context specific (70, 71). In this study, key drivers of young child commercial UFB consumption included child preference and the use of these products as behavior management tools. Child preference and the use of commercial UFB to manage child behavior have been widely identified in other research as important drivers of unhealthy food choice in urban food environments, in both high income (Australia (72)) and LMIC contexts (Ethiopia (73); Nepal (24); Dakar Department, Senegal (9)). The high proportion of Guédiawaye caregivers reporting their young child being fed commercial UFB for these two reasons is concerning, as evidence indicates that food choices routinely prioritizing child preference and/or using child-preferred foods to manage behavior are linked to a lower consumption of fruits and vegetables (72), higher consumption of UFB (74), lower attention to nutritional value when making food choices (75), lower adherence to dietary recommendations (76), and surplus energy intake and overweight (77–79). Other key drivers of commercial UFB feeding in this context were their use as a treat/gift and someone else sharing them with the child; these were also drivers identified in prior research in Nepal (24).

Availability, affordability, convenience, and health reasons were cited by few caregivers in the current study. Excepting convenience, this corresponds with prior findings in Dakar Department (9) and northern Senegal (80); convenience was identified by caregivers in northern Senegal as an important reason for feeding young children packaged and snack foods (80). While few caregivers in our study directly cited convenience as a reason for feeding commercial UFB, several other highly cited reasons are indirectly related to convenience, including child preference (which may lead to readier/quicker consumption) and the use of UFB for behavior management (which may free caregivers to perform other productive tasks). It is important to note that drivers of commercial UFB consumption that were cited by only a few caregivers could nonetheless constitute drivers or barriers to healthier food choices. For example, in this study, affordability was only cited by a few caregivers as a reason for feeding commercial UFB, but higher UFB consumption in food insecure than food secure households suggests that a relatively higher price of healthier options (66) may be an important barrier to healthy food choices. Similarly, health reasons were cited by few caregivers as a reason for feeding commercial UFB, but this does not clarify whether health is a driver for feeding nutritious foods/beverages. Further research is necessary to better understand what motivates healthy/unhealthy food choice during young childhood and identify promising interventions in this context.

This research has several limitations. First, the study's cross-sectional design limits our ability to draw causal conclusions regarding the relationships between UFB consumption and outcomes studied. This is not a major limitation for our diet quality outcomes, given that they cover the same time period as the 24HR data and that a key characteristic of UFB is that they are generally higher in salt, saturated fats, and/or sugar, and lower in micronutrients than other foods/beverages. High UFB consumption in a 24-h period could therefore directly compromise ND over that same 24-h period. However, the cross-sectional design and our use of single, rather than repeated, 24HR do significantly limit our ability to draw causal conclusions regarding the relationship between UFB consumption and anthropometric outcomes; our dietary data represent a single day's consumption and may therefore misclassify children's habitual UFB consumption levels. A well-designed cohort study with repeated 24HR would be necessary to illuminate causal relationships between habitual UFB consumption and growth outcomes. Secondly, to improve caregiver estimation of quantities consumed during family meals, we distributed an individual bowl for child feeding. This may have modified consumption patterns, given that young Senegalese children often consume lunch and dinner

around a common bowl; future research examining the impact and trade-off of distributing individual bowls in this context is merited. Lastly, in this study, the children's energy intakes were overestimated, which is a known limitation of 24HR data among young children (81) and could lead to underestimation of the percentage of children at risk of inadequate nutrient intakes. We mitigated this limitation by analyzing nutrient densities rather than total intakes, but certain foods/beverages may have been more subject to overestimation than others, potentially introducing error or a differential bias in ND estimations in our data. Weighed food records reduce errors related to food portion size estimations or memory but are subject to considerable time and financial investments, making this dietary assessment method unfeasible for this study.

This study contributes to a small but growing body of evidence regarding the role and nutritional risks of UFB in the diets of young children in LMIC contexts. Given young children's high nutrient requirements (11, 12) and the influence of early diets on food preferences later in life (15–17), there is a pressing need for further research to better understand drivers and consequences of young child UFB consumption in understudied contexts such as sub-Saharan Africa. There is also a need to investigate and rigorously test policy and programming interventions aiming to limit UFB consumption. Promising policy interventions include guidelines that explicitly recommend limiting young child UFB consumption, taxes on UFB, subsidies on nutritious food options, and/or front-of-package labels (3, 82). Promising programming interventions include raising awareness among health providers and influencers of young child food choice, as well as counseling caregivers on the risks of, and alternatives to, high UFB consumption and child-driven food choices. Broad food environment and advertising changes are necessary to ensure that healthier options are more available, affordable, appealing, and aspirational than UFB. Research and action to create child-centered food systems (83) could guide young children and their caregivers towards healthier dietary choices.

Data availability statement

The Food Composition Table, recipes, conversion factors, and food tags developed for this study can be found on the Global Food Matters Database globalfoodmattersdatabase.org (Workspace 39 ID 60). Individuals can request access by registering on the International Dietary Data Expansion Project (INDDEX) website https://inddex.nutrition.tufts.edu/global-food-matters. All study materials, data, and code developed for this study are available upon request.

Ethics statement

The research involving human participants was reviewed and approved by the Senegalese National Ethics Committee for Health Research (CNERS) and the London School of Hygiene and Tropical Medicine (LSHTM). Written informed consent to participate in this study was provided by the adult participants and the children's legal guardian.

Author contributions

AP and EF conceptualized and designed the study, with input from AV, NS, RK, and MD. AV led data collection, with support from AM. AV performed the analysis, with input from AP and EF. AV drafted the manuscript, with input from AP. All authors reviewed and provided input on the final article.

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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/fnut.2023.1125827/full#supplementary-material

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Consumer segmentation based on three dimensions of sustainable food consumption: a simultaneous analysis of meat, organic food, and sweet snack purchases based on household panel data in Germany

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The literature on sustainable food consumption laments two major gaps: First, the majority of previous studies analyzed consumer behavior based on survey data on consumers' self-reported behaviors and attitudes. Second, most existing studies focused on one dimension of sustainable food choices. This paper identifies and analyzes consumer segments based on the actual purchases of 8,400 households recorded in the GfK household panel data from Germany. We used three indicators of sustainable food consumption behavior: (1) the purchase of organic products as a proxy for the environmental impact of diets, (2) the purchase of meat as a proxy for the climate impact of diets, and (3) the purchase of sweet snacks as a proxy for the healthiness of a diet. The analysis yielded two larger segments with high expenditure shares for one type of unsustainable food (meat/sweet snacks, respectively), two small segments with above average (medium/high) expenditure shares for organic food, and a large 'mainstream' segment. The five consumer segments were further analyzed regarding the observed attitude-behavior gap, and the actual prices paid in different product categories. Clear gaps between stated and actual behavior were revealed with interesting differences between the five segments and the three sustainability characteristics. The analysis is a vital starting point for designing a holistic policy instrument mix to close the gaps and to reach a sustainable transformation of the food system.

KEYWORDS

sustainable food consumption, organic food, meat reduction, healthy diets, actual purchase data, household panel data

1. Introduction

Current food production systems and dietary patterns prevalent in Western countries have significant negative impacts on the environment and human health and are therefore considered unsustainable. Sustainability problems arise along the entire value chain from primary agricultural production to food processing, transportation, and consumption. The production of food is very resource intensive and consumes a lot of land, water, and energy. The current

food system in high-income countries contributes significantly to climate change, biodiversity loss, and diet-related diseases (1–3).

The necessary transition of food consumption patterns in high-income countries encompasses two elements (4). First, is the shift toward food produced with (more) sustainable methods, e.g., organic food. A second challenge is the transformation of dietary patterns away from animal and highly processed foods toward a whole food and (more) plant-based diet (5). The reduction of meat consumption is an all-encompassing objective to mitigate climate change and other externalities, but also to reduce health-related problems. In particular, the reduction of red and processed meat is associated with positive health and environmental effects (6). In addition to the reduction of meat, a healthy diet should reduce the intake of highly processed food (high in sugar, fat, or salt) and contain an unrestricted consumption of a variety of plant foods (e.g., legumes, whole grains, fruits, and vegetables) (5).

According to previous studies, there has been an increase in consumers' preferences for sustainable and healthy diets in many Western European countries (7, 8). However, the market share of organic food is still at a low level, meat consumption is far too high and the consumption of food with high added sugar is predominant in the Western world. The discrepancy between consumers' positive attitudes and purchase intentions and the low level of action ("attitude/intention-behavior gap") is one of the key issues in consumer behavior research (9, 10). The reasons for the discrepancy are socially desirable responses that overestimate attitudes (11) on the one hand and contextual factors that prevent positive attitudes from transforming into behavior on the other hand (12).

The literature on sustainable food consumption laments two major gaps: First, the majority of previous studies segmented consumers based on survey data on consumers' self-reported behaviors and attitudes. Real market data, i.e., food category specific expenditures and real prices paid, is scarcely examined because it is challenging for researchers to acquire such data and link it to data on consumers' psychological constructs. However, relying on self-reported preferences and willingness-to-pay can have serious implications for the validity and reliability of segmentation studies and probably overestimate the segment of sustainable consumers. It is vital to analyze real purchase data and categorize to what extent food consumers can contribute to the transformation of the food system (8). Second, most existing studies focus on one dimension of sustainable food choices, e.g., organic food, local food, or fair-trade products (as prominent examples of food produced with more sustainable production methods), or plant-based food or healthy food choices (as prominent examples of more sustainable types of food).

Only a few segmentation studies have analyzed *several* types of sustainable food behaviors simultaneously (13). However, it is important to analyze sustainable food choices in a more holistic way to shed light on the preferences of different consumer segments to account for the complexity of the subject and the potential diversity among consumers. Some consumer segments may focus on the purchase of food from sustainable production systems (e.g., organic food), others may focus on dietary changes to behave more sustainably (e.g., eat less meat), some may do both, while yet others may not behave sustainably in any regard (13).

The aim of this paper is to identify and analyze consumer segments based on three dimensions of sustainable food choices: (1) the purchase of organic products as a proxy for the environmental impact of diets, (2) the purchase of meat as a proxy for the climate impact of diets, and (3) the purchase of sweet snacks as a proxy for the healthiness of a diet The consumer segmentation analysis presented in this paper is based on *actual* purchases of 8,400 households recorded in the GfK household panel data from Germany. The data further allows us to detect mutual relations between the three dimensions of sustainable food choices. The identified segments will be profiled and compared according to food values, purchase intentions, and socio-demographics. In addition to that, the available data allows for the analysis of real prices paid in different product categories. Knowledge of real consumer behavior in three dimensions of sustainable diets combined with real prices paid, psychological and sociodemographic data is a vital starting point for policymakers to design instruments to reach a sustainability transformation of the food system.

2. Segmentation studies in the field of sustainable food consumption

Dividing consumers into different homogeneous segments allows for the capture of heterogeneous consumer preferences and non-linear relationships, and gives the opportunity to develop targeted strategies to support the development of sustainable food systems (14). Not accounting for heterogeneity and just relying on mean preference coefficients runs the risk of overlooking (relatively small) consumer segments, especially in the case of opposing preference structures (e.g., preference for organic food versus aversion toward organic food) since differences can cancel out at the aggregated level (15).

Segmentation studies in the field of sustainable food consumption predominantly analyze consumer preferences for *one* specific sustainable product characteristic (e.g., organic production or local origin) or the degree to which a specific behavior, for example meat reduction, is carried out.

We found only two studies (7, 13) that focused on both types of sustainable behaviors, namely sustainable product choices *and* specific dietary behaviors. The study by Verain et al. (13) analyzed different sustainable product choices (organic, free-range, and products with a sustainability label) in different product groups (meat, dairy, and fruits and vegetables) and focused on two specific meat consumption behaviors (reducing meat portion size and reducing meat consumption frequency). The study by Brunin et al. (7) focused on organic food choices for 264 food and beverage items and considered healthy and plant-based diets.

Actual purchase data has hardly ever been used in segmentation studies. One exception is the study by Sarti et al. (8), which analyzed actual shopping behavior for sustainability *and* health-related product labels (social equity, ecological, health products, organic, and vegan); three consumer segments were identified with only one small segment of sustainable consumers (7%) that purchased relatively high numbers of products with health, environmental, and social benefits. However, the study only focused on product choices and not on sustainable dietary behaviors such as meat reduction. Moreover, the sample was limited to relatively few customers of one supermarket chain in Italy (UniCoop Tirreno) who were members of the voluntary loyalty card program ($n = 132$). The authors point to the fact that future research should study consumer purchases across larger samples to identify more differentiated consumer segments.

Two large-scale epidemiological studies used detailed information on types and amounts of food actually consumed. Brunin et al. (7) analyzed individuals' dietary behavior as well as organic food consumption in France. Participants completed self-administered food frequency questionnaires in 2014 and 2018 that covered the consumption of 264 foods and beverages ($n = 13,292$ consumers). The segmentation study was based on a set of variables that reflected nutritional quality of the food consumed, as well as the consumption of plant-based food and organic food, to analyze sustainable consumption patterns between 2014 and 2018; six clusters were identified, referred to by the authors as 'clusters of changes in consumption' (7). Vieux et al. (16) analyzed national food consumption surveys in 5 European countries based on 48 h recalls and 3-, 4-, and 7-day dietary records (diaries; $n = 8,302$ consumers), and carried out a segmentation analysis based on dietary greenhouse gas emissions and nutritional quality resulting also in a six-cluster solution (16).

Most other segmentation studies were based on antecedents of real purchase behavior, i.e., the internal psychological processes of decision-making, which are necessarily related to real behavior but can only be used as proxies for the 'real' economic activity. Key proxies to explain and predict sustainable consumer behavior are foremost 'values and concerns' regarding personal health and the environment [see for example (17)], and 'attitudes' toward sustainable products [see for example (18)]. These processes in turn influence the formation of 'intentions' to purchase sustainable products or to change dietary behavior [see for example (19)].

The following sections give a brief overview of the results of previous segmentation studies that used antecedents of actual sustainable consumption behavior, i.e., values, attitudes, intentions and reported consumption behavior in order to allocate consumers to segments of sustainable consumption. To be considered for inclusion, studies had to conduct empirical analyzes of primary data, leading to the identification of consumer segments related to sustainable food consumption. The following section is structured according to the three most frequently identified consumer segments (14): 'sustainable consumers', 'non-sustainable consumers', and segments that lie 'in-between' these two distinct groups of consumers.

2.1. Sustainable consumers

The segment of 'sustainable food consumers' is often described as being involved in sustainability issues, environmentally concerned, and more likely to buy organic or animal welfare products [see the literature review of (14)]. The size of the sustainable food consumer segment has been explored in various survey studies that used stated preferences, concerns, values and/or attitude, and it has been found that it typically ranges from around 30 to 40% of the total sample. This segment was identified in a Dutch study focused on food consumption in general (13), as well as in an Italian study on canned tuna fish (20). Additionally, a cross-national study on wine consumers (21), an Italian wine consumer study (22) and a German wine study (23) also reported that a similar proportion of the population belonged to this segment.

Fewer studies considered sustainable consumption more holistically and addressed health aspects in addition to environmental ones. This stream of research provides evidence that a substantial segment of sustainability oriented wine consumers in the United States, the United Kingdom, and Germany (17), as well as food consumers in Poland and the Czech Republic (24), in Hungary (25), in four EU countries (United Kingdom, Germany, Belgium, and the Netherlands; 26) and in the Netherlands (27) prioritize environmental and health factors when making purchasing decisions. These studies suggest that a considerable share of consumers holds preferences for environmentally-friendly *and* healthy diets (28, 29). The segment of 'committed organic consumers', for example, is predominantly motivated by the desire for healthy and natural food as well as concern for the environment (30, 31). This observation was also confirmed by the two large-scale epidemiological studies that used detailed information on foods actually consumed, i.e., reported consumption behaviors. Brunin et al. (7) found a segment of French consumers that had already initiated a transition toward sustainable diets (16%): high levels of organic products, healthier food choices, more plant-based foods. Similar findings were observed by the cross-European study of Vieux et al. (16): the segment the authors referred to as, more sustainable' (18%) was characterized by high levels of plant-based food consumption and healthy dietary patterns (slightly higher intake of dairy products, lower intake of meats, and lower intake of sugar/confectionaries, soft drinks, and alcoholic beverages), which the authors referred to as the 'best compromise' between nutritional quality and dietary greenhouse gas emissions.

2.2. Non-sustainable consumers

Studies based on stated preferences, values, and/or attitudes have consistently revealed that the proportion of 'non-sustainable consumers', those who do not prioritize sustainability in their purchasing decisions, is small across a range of food products and countries. Specifically, research on milk, yogurt, and apples in Germany (32), canned tuna fish in Italy (20), wine in Germany (23), and a Romanian study on food consumption in general (33) all found that this segment was around 10% in size. Consumers who belong to this segment hold rather negative attitudes toward sustainably produced products and are often very price-conscious.

In the two epidemiological studies, the share of this consumer group was somewhat higher Brunin et al. (7) identified a segment of 16% with a low level of organic food consumption in 2014 that further decreased in 2018. Moreover, this segment revealed changes toward an unhealthy diet (increase in consumption of unhealthy plant products, animal products and alcohol). Interestingly, the study of Vieux et al. (16) revealed two clusters with different types of unsustainable behaviors. The "Highest greenhouse gas emissions" segment (14%) was characterized by high consumption of meat, animal fats and alcoholic beverages and low consumption of meat substitutes, vegetable fats, and plant-based composite dishes. The "Lowest greenhouse gas emissions" segment (24%) showed unhealthy consumption patterns characterized by the highest intake of soft drinks, sugar/confectionaries, and snacks/desserts.

2.3. Consumers 'in-between'

The segment that lies in-between these two rather distinct clusters was found to be by far the largest segment (around 40 to 70% of the sample) in the majority of studies This consumer group is very

heterogeneous and previous studies have given them very different names, for example 'potential consumers' to characterize its diverse nature. Some studies even identified more than just one segment in-between the 'sustainable consumers' and the 'non-sustainable consumers' (14). Due to this heterogeneity, this cluster will be described in more detail here.

Several studies refer to individuals in this segment as 'average consumers' because the variables related to sustainable behaviors are very close to the sample means (34) and less distinct (32). This implies that consumers are rather indifferent and/or unaware regarding different sustainability issues. Other food attributes such as price (14, 35), health (14) or country of origin (37) seem to be more important to the consumers of this segment. Some studies describe this cluster as 'inconsistent' regarding certain values and behaviors. In the studies by Forleo et al. (20) and Gazdecki et al. (18), consumers in this segment generally hold rather positive attitudes toward sustainable consumption but they do not (yet) translate their positive predisposition into sustainable behaviors. In the context of organic product choices, high prices and low availability are often given as reasons for this attitude-behavior gap; the corresponding segment is named 'occasional organic buyers' in this stream of literature (36). Health motives are the predominant purchase driver for 'occasional organic buyers'; environmental and ethical motives are less relevant (37).

Studies that analyzed different dimensions or types of sustainable consumption (additionally) identified segments that performed well with regard to one sustainability dimension/type, but not with regard to others. Some studies identified a segment of consumers only attentive to health aspects (not interested in environmental issues) which was described as 'egoistic' to highlight the contrast to the cluster motivated by 'altruistic' values such as environmental attributes (for example 38). The study of Verain et al. (13) identified one segment with a strong preference for the purchase of sustainably produced products (but showed relatively low performance of meat reduction) and one segment that reduced meat consumption (but had a low share of sustainable product choices).

Similar results were observed in the epidemiological studies of Brunin et al. (7), and Vieux et al. (16). Brunin et al. (7) found three consumer segments ('cluster toward healthy food' (13%), 'cluster toward plant food' (23%) 'cluster toward healthy plant food' (7%)') that improved at least one sustainability dimension in their diets over the period 2014 to 2018 (but had not yet achieved sustainable dietary transition). Vieux et al. (16) found a huge segment of consumers (33%) with intermediate dietary greenhouse gas emissions and nutritional quality and, moreover, a rather small segment (10%) with high dietary greenhouse gas emissions and contradictory values of dietary quality indicators (high in beneficial nutrients, but also high in sodium, free sugars, and saturated fatty acids).

In summary, the results show that the segment of 'non-sustainable consumers' is rather small compared to the segment of 'sustainable consumer'. However, epidemiological studies show slightly higher shares for the segment of 'non-sustainable consumers' and one study even found two clusters with different types of unsustainable behaviors. Moreover, the results highlight the relation between environmental and health concerns as potential drivers of organic food purchase behavior and reduced meat consumption and that both dimensions are linked to either environmental concerns, or health concerns, or both under a 'good for me good for the planet' concept. Furthermore, the segment between sustainable and non-sustainable consumers is by far the largest segment and very heterogeneous. This group is often referred to as 'average consumers' with less distinct sustainable behaviors, other food attributes such as price and health are more important to them. Overall, these studies highlight the need and the potential for more targeted interventions to promote sustainable behaviors among this consumer group.

3. Materials and methods

3.1. GfK household panel data

Household panel data are most appropriate to measure real purchase behavior and analyze attitude-behavior relations, but they are expensive and difficult to access for researchers. Surveys and purchase experiments are more commonly used, despite their limitations in measuring behavior accurately. Surveys rely on self-reporting, which can be subjective and influenced by social desirability, while purchase experiments are often hypothetical and not incentive-compatible. Thus, the notable strength of household panel data is its relatively high degree of validity, which is deemed to be a critical advantage.

This research study is based on two panels of consumers from the GfK market research institute: ConsumerScan, which includes purchases of pre-packaged foods, and ConsumerScan FreshFood, which covers purchases of unpackaged foods. The sample for this study is comprised of 8,400 households in Germany who participated in both panels throughout 2016. The dataset includes information on total food purchases at the household level, including details on organic and conventional purchases. Additionally, the dataset includes information on purchases in various food categories such as meat and sweets. Throughout 2016, the households that participated in the study utilized an electronic device called the ElectronicDiary to register their food purchases. The device scanned the European Article Number (EAN) code, and additional details like price and store name were entered via the scanner's keypad. In cases where the food items were not packaged and did not have an EAN code, like fresh produce, a code book was supplied. Additionally, every year, the head of each household was required to complete a written questionnaire containing more than 120 survey items that covered topics such as consumer lifestyle, values and attitudes toward food, and socio-demographic characteristics. The purchase data and survey questions were interconnected through a unique identification number, allowing for the linkage of purchases with food values in the database.

3.2. Indicators of sustainable food consumption behavior

The study considers three indicators to cover three dimensions of sustainability, i.e., environmentally-friendly farming practices, climate-friendly food choices, and healthy food choices. While this approach oversimplifies the complex issue of healthy diets from sustainable food systems (39–42), it is a very useful starting point from

a methodological perspective to gain insights into food consumption and its multidimensional nature.

Household-level expenditure share aggregated on an annual level in 2016 was used to calculate the three indicators. Using expenditure share as a measure is preferable because it takes into account the relative importance of different food categories within the household's overall budget. This can provide a more accurate reflection of the household's priorities and preferences when it comes to food consumption. Moreover, using expenditure share adjusts for differences in household size and allows for comparisons across households with different budgets. The calculation of the indicators was performed as follows:

- expenditure share for organic food: expenditures for organic food (in €) in relation to the total expenditures for food (in €) as a proxy for environmentally-friendly food choices.
- expenditure share for meat: expenditures for meat (in €) in relation to the total expenditures for food (in €) as a proxy for the climate impact of diets, and
- expenditure share for sweet snacks: expenditures for sweet snacks (in €) in relation to the total expenditures for food (in €) as a proxy for the healthiness of a diet

Expenditures for meat comprise purchases of fresh pork, beef, and poultry, including both organic and conventional options. The food category of sweet snacks includes sweets, chocolates, and sweet bakery products, also in both organic and conventional varieties. Organic food includes organic products in all food categories (unpackaged and packaged food).

3.3. Cluster analysis

Cluster analysis was preferred over regression analysis in this study, as it allowed for the examination of the multi-dimensional nature of the phenomenon under investigation, involving three explanatory variables related to sustainable consumption. The cluster analysis was conducted with the R function for k-means clustering to identify homogeneous groups regarding sustainable purchase behavior. This method is most appropriate for huge samples as in our case. While latent class models are an option for conducting segmentation analysis, we opted to utilize K-means cluster analysis due to its ability to facilitate post-hoc examination of the clusters in terms of profiling variables, such as indicators of sustainable food consumption.

The k-means algorithm used was the Euclidean distance metric; target criterion was the minimization of variance within the clusters. A critical point is that the cluster assignment depends on the choice of the starting positions. Therefore, the analysis was carried out 2,000 times with random start values and the solution which minimized the error sum of squares to the largest extent was chosen (43).

The k-means cluster algorithm is very sensitive to extreme values, which is why we conducted a hierarchical cluster analysis (method: single linkage) to identify outliers. Two cases were identified as outliers and excluded from the cluster analysis.

For determining the optimal number of clusters, the k-means algorithm was run for five different numbers of clusters (from 3 to 7 clusters). The five solutions were then evaluated and compared based on three criteria (elbow method/within-sum-of-squares, silhouette score, and gap-statistic) as suggested by Malik and Tuckfield (44). A minimum of three clusters was chosen due to content-related considerations and previous knowledge; a maximum of seven clusters was chosen due to the considerations of manageability from a marketing perspective. First, the elbow method was used, which strives to find a compromise between the minimization of the within sum of squares (WSS) and the manageability of high cluster numbers. The error sum of squares declines with an increase in the cluster number, but the rate of decline might drop at some point, creating the 'elbow' shape and hinting toward the optimal number of clusters. Second, the gap statistic was examined (45), which compares the WSS value of the observed dataset to a dataset with no cluster structures (random distribution) and chooses the cluster number with the maximum value of the gap statistics (44). Finally, the silhouette coefficient was examined, which measures the similarity of each data point to its own cluster compared to other clusters (46). To confirm a real existing cluster structure, the average silhouette coefficient should be larger than 0.25, and preferably larger than 0.5 (46).

Finally, the clusters were analyzed for statistically significant differences in food values, purchase intentions, socio-demographics, and purchase behavior with the method of one-way analysis of variance (ANOVA) and pairwise comparisons of column proportions (z-test).

As a pre-step, scales for 10 food-related values were created based on 55 items included in the GfK annual survey of panel households. Cronbach's alpha was used as a measure for internal scale reliability; all food-related value scales had Cronbach's alpha values larger than 0.7. Appendix Table 1: Food-values scales.

4. Results

4.1. Description of the sample

Table 1 displays the socio-demographic features of the sample used in the study, which are compared with those of the general German population. However, it is not easy to make a direct comparison as the federal statistical office uses distinct age and income categories not directly comparable with the categories of the GfK consumer survey. Moreover, the education categories of the GfK survey incorporate both school-leaving and vocational qualifications. This makes it challenging to compare with the two separate statistics provided by the German federal office.

Concerning age, the sample seems to be lacking in representation of young households, particularly those in the youngest age group, with only 2% of the sample compared to 17% in the overall population. In a third of the households, the person responsible for the purchase diary had a university-entrance diploma or a university degree, which aligns with the distribution of the highest school-leaving qualification of the German population. However, it appears that high-income households were not adequately represented in the sample.

TABLE 1 Socio-demographic characteristics of the sample and the German population.

Socio-demographics (*N*=8,400)	Sample %	Population %	
	Age of the head of household	Age of German residents older than 18 years[1]	
Up to 29 years	1.9	17.0	
30–39 years	10.1	14.2	
40–49 years	17.2	19.9	
50–59 years	24.8	50 up to under 75 years 37.8	
60–69 years	23.3		
70 years and older	22.6	75 years and older 11.2	
	Formal education of the diary keeper (including vocational school and university)	School-leaving qualification of German residents[2]	Vocational qualification of German residents[3]
Secondary general school	22.5	29.6	–
Intermediate secondary school	32.9	29.9	–
Qualified dual vocational training program	–	–	47.5
Special upper secondary school (vocational school)	8.0	–	8.8
University entrance diploma	14.1	32.5	–
University	22.5	–	18.0
Others	–	8	25.7
	Household net income	Net income of private households in Germany[4]	
Up to 749 Euro	3.5	Under 1,500 26%	
750–1,249 Euro	12.9		
1,250–1749 Euro	16.2	1,500-3,200 43%	
1750–2,249 Euro	18.8		
2,250–2,749 Euro	15.6		
2,750–3,249 Euro	12.8		
3,250–3,749 Euro	7.7	Over 3,200 31%	
3,750–4,999 Euro	9.2		
5,000 Euro and more	3.3		

[1]German Federal Statistical Office (47), table 12, 111–0004.
[2]German Federal Statistical Office (48), p. 88.
[3]German Federal Statistical Office (48), p. 90.
[4]German Federal Statistical Office (47), table 12, 111–0004.

Overall, the findings indicate that the sample utilized in the study may not accurately reflect the characteristics of the German population. Therefore, it is important to exercise caution while generalizing the results to the overall population.

4.2. Descriptive analysis

The average expenditure share for organic food was 3.9% (mean = 0.039, SD = 0.081), with a highly skewed distribution. Half of the consumers spent less than 1.2% of their food expenditures on organic products (one quarter less than 0.04%) and only one quarter spent more than 3.5%, which is quite low compared to the high share of consumers (39%) who stated they preferred organic food when purchasing groceries upon being asked this question in the survey (Table 2).

The average expenditure share for fresh meat was 5.6% (mean = 0.056, SD = 0.039). On average, pork accounted for half of the expenditures, beef for a quarter, and poultry for another quarter. A quarter of the consumers spent more than 7.6% of their food budget on meat.

Regarding sweet snacks, the average expenditure share was 6.6% (mean = 0.066, SD = 0.042). A quarter of the consumers spent more than 8.6% of their food budget on sweet snacks.

The relationships between the three sustainability dimensions are significant but very weak. The expenditure share for organic food is negatively correlated with the expenditure share for sweet snacks ($r = -0.134$) and the expenditure share for meat ($r = -0.114$). However, the expenditure shares for meat and sweet snacks are also negatively correlated ($r = -0.193$), suggesting that sustainable consumption behavior in one dimension of sustainability does not necessarily go hand in hand with sustainable consumption behavior in other dimensions. This leads to the proposition that a unidimensional and linear data analysis approach is not sufficient to capture the complexity, and highlights the need for cluster analysis to analyze sustainable food choices in a more holistic way so as to account for the potential diversity among consumers.

TABLE 2 Indicators of sustainable food consumption–whole sample and by segment in %.

		Expenditure share organic	Expenditure share meat	Expenditure share sweet snacks
Overall sample ($N = 8,398$)				
Mean value		3.91	5.56	6.63
SD		8.07	3.92	4.17
Quartiles	25	0.44	2.73	3.73
	50	1.23	4.99	5.84
	75	3.55	7.64	8.64
Heavy organic buyers ($N = 132$)				
Mean value		51.28[a]	3.68[bde]	4.14[a]
SD		14.68	4.05	2.87
Quartiles	25	39.83	0.00	1.98
	50	45.50	2.56	3.75
	75	59.97	5.64	5.51
Medium organic buyers ($N = 635$)				
Mean value		18.15[b]	4.41[b]	5.24[ce]
SD		6.31	3.86	3.33
Quartiles	25	13.00	1.62	2.80
	50	16.57	3.69	4.58
	75	21.87	6.25	6.76
Heavy meat buyers ($N = 2,067$)				
Mean value		1.58[c]	10.55[c]	5.17[ce]
SD		1.99	3.21	2.59
Quartiles	25	0.30	8.28	3.24
	50	0.81	9.62	5.02
	75	2.03	11.91	6.92
Heavy sweet buyers ($N = 1,691$)				
Mean value		1.64[c]	3.84[d]	12.78[d]
SD		2.01	2.67	3.96
Quartiles	25	0.34	1.66	10.14
	50	0.86	3.61	11.63
	75	2.16	5.64	14.12
Mainstream ($N = 3,837$)				
Mean value		2.19[d]	3.90[de]	5.04[e]
SD		2.35	1.99	2.14
Quartiles	25	0.49	2.39	3.41
	50	1.27	4.02	5.08
	75	3.09	5.57	6.76

[a,b,c,d,e]Mean values of segments with different letters differ significantly ($p < 0.05$).

4.3. Cluster analysis

The graphical analysis of the elbow criterion as well as the gap statistic suggested choosing the 5-cluster solution. The silhouette coefficient achieved the highest value for the 3-cluster solution but still confirmed an acceptable cluster structure for the 5-cluster solution with an average silhouette width of around 0.3. We therefore chose the 5-cluster solution. It is important to note that the non-inclusion of processed meat in the meat indicator due to data unavailability, might have led to biased results. Hence, it is advisable to approach the following findings with caution. Figure 1 shows the relative size of the five consumer segments identified; Figure 2 displays the cluster centers of the k-means cluster analysis. The analysis yielded two larger segments with high expenditure shares for one type of unsustainable food (meat/sweet snacks, respectively), two small segments with above average

(medium/high) expenditure shares for organic food, and a large 'mainstream' segment:

- Heavy meat buyers: The second largest cluster (25% of all households) spent a high share of expenditure on meat (11%). Their expenditure share for organic food was below average (1.6%), sweet snacks purchases were on an average level.
- Sweet snacks enthusiasts: The third largest consumer segment (20% of all households) purchased sweet snacks extensively (13% of all food expenditures). The expenditure share for organic food was below average and similar to the heavy meat buyers (1.6%). The expenditure share for meat was on an average level.
- Medium organic buyers: This smaller segment (8% of all households) spent 18.2% of their expenditure on organic food. Their expenditure shares for meat and sweet snacks were on an average level.
- Heavy organic buyers: The smallest consumer segment (2% of all households) had a very high expenditure share for organic food. On average, they purchased every second item in organic quality (expenditure share of 51.3%). Sweet snack consumption was significantly lower compared to all other clusters (expenditure share: 4.1%). Their expenditure share for meat was slightly below average (expenditure share: 3.7%).
- Mainstream consumers: The largest segment (46% of all households) had relatively low expenditure shares for organic food (2.2%), below average expenditure shares for meat (3.9%), and average expenditure shares for 'sweet snacks' (5.0%).

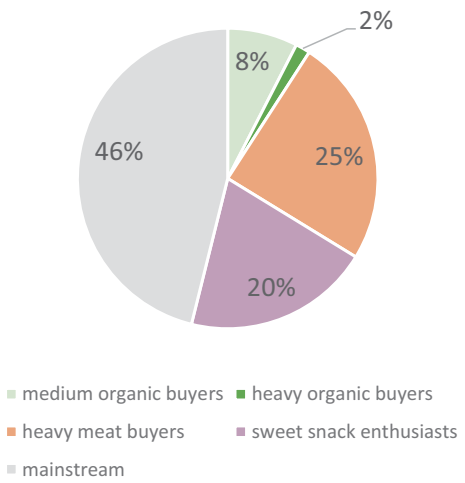

FIGURE 1
Share/size of the segments.

4.4. Food values, purchase intentions, dietary behavior, and socio-demographics

In the following sections, the segments are profiled according to food values (Table 3), purchase behavior (Tables 4, 5), intentions (Table 6), and socio-demographics (Appendix Table 2).

4.4.1. Medium and heavy buyers of organic food

The two segments of 'medium / heavy organic food buyers' (together 10% of the sample) had high preferences for local, natural, and fair-trade food and placed great importance on environmental protection, significantly higher than the three other segments (Table 3). Heavy organic buyers placed slightly higher importance on the above food values than medium buyers (differences statistically significant except for local food). Both segments had very low preferences for convenience food and for 'simple and easy cooking'. Moreover, 'medium and heavy organic food buyers' paid high mean prices for sweet snacks (Table 5), which indicates they preferred high-quality products.

Despite these similarities between the two organic segments, we found that the 'heavy organic buyers' purchased significant lower quantities of sweet and salty snacks (Table 4) as well as meat compared to all other clusters (Table 2; 'medium organic buyers' were in the middle range). Even though two thirds of 'the medium organic buyers' had the intention to reduce their meat consumption (Table 6), they bought relatively high amounts of meat, even at the same level as the 'mainstream' segment (Table 4). However, differences between the types of meat were found: medium organic buyers consumed less pork but the second highest amount of beef and poultry (only the 'heavy meat buyers' purchased more) (Table 4).

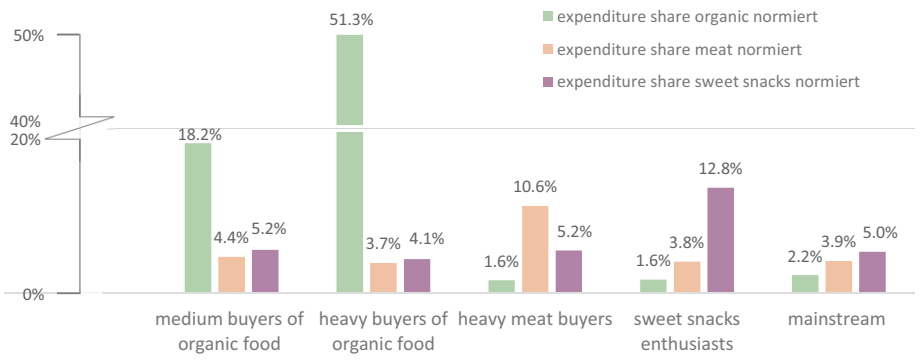

FIGURE 2
Cluster centers of the k-means cluster analysis.

TABLE 3 Psychographic profiles of the segments–food values.

Food values	Medium buyers of organic food	Heavy buyers of organic food	Heavy meat buyers	Sweet snacks enthusiasts	Mainstream
Body consciousness	2.83^{c}	2.70^{abc}	2.71^{ab}	2.66^{b}	2.77^{ac}
Convenience food	2.11^{a}	1.88^{c}	2.51^{b}	2.76^{c}	2.60^{d}
Environmental protection	3.76^{a}	4.03^{c}	3.24^{b}	3.24^{b}	3.30^{d}
Fair trade	3.80^{a}	4.18^{c}	2.89^{b}	2.96^{be}	3.00^{de}
Fast food	1.65^{ab}	1.66^{ab}	1.58^{b}	1.85^{c}	1.72^{a}
Avoiding health risks	2.59^{a}	2.55^{a}	2.56^{a}	2.59^{a}	2.60^{a}
Local food	3.97^{a}	4.04^{a}	3.51^{bc}	3.45^{c}	3.53^{b}
Natural food	3.81^{a}	4.18^{c}	3.10^{b}	3.10^{b}	3.14^{b}
Quality and enjoyment	3.33^{a}	3.38^{ab}	3.23^{b}	2.98^{d}	3.17^{c}
Simple and easy cooking	3.17^{a}	3.08^{ac}	3.03^{c}	3.44^{b}	3.23^{a}

^{a,b,c,d,e}Values of segments with different letters differ significantly ($p < 0.05$).

TABLE 4 Average price paid by different consumer segments (in €).

Price in €/Kg	Medium organic buyers	Heavy organic buyers	Heavy meat buyers	Sweets snacks enthusiasts	Mainstream	Overall
Fresh beef	8.49^{a}	7.76^{ac}	8.61^{a}	5.44^{b}	6.71^{c}	7.07
Fresh pork	6.53^{a}	5.83^{abcd}	5.85^{b}	5.03^{c}	5.55^{d}	5.60
Fresh poultry	7.09^{a}	7.50^{ab}	5.85^{b}	5.40^{c}	5.64^{c}	5.78
Sweet snacks	10.13^{a}	12.88^{b}	7.92^{c}	7.49^{d}	8.56^{e}	8.37

^{a,b,c,d,e}Values of segments with different letters differ significantly ($p < 0.05$).

TABLE 5 Average purchases in kg/l per household in different product groups for consumer segments.

	Medium organic buyers	Heavy organic buyers	Heavy meat buyers	Sweets snacks enthusiasts	Mainstream	Whole sample
Alcoholic beverages	64	49	108	47	106	91
Ready to eat desserts	4	3	7	10	7	7
Sweet and salty snacks (including nuts and seeds)	26	21	28	51	25	31
Fish	8	6	9	6	8	8
Poultry	6	4	13	5	5	7
Beef	4	3	8	2	3	4
Pork	8	6	27	10	10	14
Poultry products	2	1	3	2	2	2
Cheese	16	17	15	14	16	16
Frozen food	22	15	33	32	30	30

A high share of people in the two organic segments belonged to the highest income group and held a university degree. Heavy organic buyers were more likely to be in the youngest age groups (under 40 years old).

4.4.2. Heavy meat buyers

The segment 'heavy meat buyers' (25%) showed low preferences for 'simple and easy cooking' and 'fast food' and high preferences for 'quality and enjoyment' compared to the segments 'sweet snacks enthusiasts' and 'mainstream consumers'. The awareness of environmental issues and the preference for fair-trade food was low (Table 3). 'Heavy meat buyers' purchased the highest amounts of beef, pork, meat, fish, and poultry products and had a relatively high consumption of alcoholic beverages (Table 4). For beef, they paid the highest average price of all segments (but no statistically significant difference to the medium and organic buyers (Table 5). Approximately a third of the consumers in this segment reported intentionally reducing their meat consumption; half of the segment stated they did not do so. Only a small share of heavy meat buyers was younger than 40 years

TABLE 6 Share of agreement (in %) with statements on intentions to follow a sustainable diet.

	Medium organic buyers	Heavy organic buyers	Heavy meat buyers	Heavy sweet buyers	Mainstream	Overall
'We intentionally reduce our meat consumption'						
I fully disagree	8.7[a]	4.8[a]	23.5[b]	18.2[c]	17.9[c]	18.4
I rather disagree	11.2[a]	5.6[a]	24.3[b]	22.0[b]	19.2[c]	20.2
Neither nor	17.1[a]	13.6[a]	24.0[b]	23.1[b]	23.4[b]	22.9
I rather agree	31.6[a]	31.2[a,c]	22.5[b]	25.7[c]	27.1[c]	26.1
I fully agree	31.4[a]	44.8[c]	5.7[b]	11.0[d]	12.4[d]	12.5
'When I buy food, I prefer organic products'						
I fully disagree	3.1a	1.5a	33.6b	31.6b	28.1c	18.4
I rather disagree	9.3a	2.3c	29.3b	28.3b	28.1b	20.2
Neither nor	14.6a	4.6c	21.9b	24.4b,d	24.7d	22.9
I rather agree	44.1a	21.5c	13.1b	13.1b	16.2c	26.1
I fully agree	28.9a	70.0c	2.1b	2.6b	2.9b	12.5
'In my diet, I avoid everything that is harmful to health'						
I fully disagree	7.2[a,b,c]	3.8[b]	9.4[c]	9.6[a,c]	8.9[a,c]	18.4
I rather disagree	16.2[a]	15.4[a,b]	22.5[b]	21.9[b]	21.7[b]	20.2
Neither nor	27.8[a]	20.0[a]	34.2[b,c]	35.1[b]	32.3[c]	22.9
I rather agree	35.7[a]	46.9[c]	24.9[b]	25.0[b]	27.9[d]	26.1
I fully agree	13.0[a]	13.8[a,c]	9.0[b,c]	8.4[b]	9.2[b,c]	12.5

[a,b,c,d]Shares of segments with different letters differ significantly ($p < 0.05$).

old; most were aged 50–69 years old. Income and formal education of the segment were relatively low.

4.4.3. Sweet snacks enthusiasts

Sweet snacks enthusiasts (20%) had the highest preferences for 'convenience food', 'fast food' and 'simple and easy cooking' of all segments. Moreover, the segment attached low importance to 'quality and enjoyment' and 'environmental protection'. This segment paid the lowest mean prices in all food categories (Table 3). In line with their high consumption of sweet snacks, they purchased the highest amount of ready to eat desserts. Alcohol consumption was, however, low (Table 5). Moreover, they purchased the lowest quantities of cheese. Income and formal education of the segment were relatively low, but did not differ significantly from the 'heavy meat buyers'. People in this segment were more likely to be 40–49 years old.

4.4.4. Mainstream

The segment of 'mainstream consumers (46%)' shared many similar food values with the heavy meat buyers' and the 'sweet snacks enthusiasts'; only that the mainstream consumers were slightly more environmentally oriented than the two latter segments. Moreover, the mainstream consumers were a little more body-conscious and quality-oriented than the 'sweet snacks enthusiasts', and slightly more convenience and fast-food oriented than the 'heavy meat buyers'. Mainstream consumers purchased relatively high quantities of alcoholic beverages. People above 70 years of age were overrepresented in this segment. Formal education and income were in the middle range.

5. Discussion and conclusions

The main contribution of this study is the use of data on real purchase behavior and the simultaneous inclusion of behavior regarding food produced with more sustainable production methods (organic food) as well as dietary food choices concerning the types of food consumed (meat consumption and healthy eating). This made it possible to identify consumer segments with different *levels* and *types* of (un)sustainable consumption behavior and to analyze the gap between behavioral intentions and real purchase behavior.

Overall, consumer segments with more positive attitudes and intentions regarding sustainability showed more positive actual sustainable purchase behaviors. Thus, the results confirm the study of Brunin et al. (7) that food motives are useful predictors of sustainable consumption behavior. However, food values and intentions did not completely transmit into actual behaviors. Gaps between stated and actual behavior were revealed, and these gaps differed between the consumer segments and the different sustainability characteristics. The gap was highest for the segment of 'heavy sweets buyers' and 'heavy meat buyers': even though they showed rather unhealthy consumption patterns, one third of these segments agreed to avoid everything in their diet that is harmful to their health. Moreover, a considerable amount of 'heavy meat consumers' (27%) stated to consciously reduce meat consumption. Compared to statements on health and meat reduction, the attitude-behavior gap for the purchase of organic food seems to be relatively low. This finding is in line with several studies that

confirm a relatively strong attitude-behavior relationship for organic food (49).

Only a small part of the population shows relatively sustainable consumption behaviors in all consumption dimensions considered (high consumption of organic food, low consumption of meat, sweet snacks, alcohol, processed foods) and is composed of younger people with higher education, which is in line with a recent large-scale epidemiologic study by Brunin et al. (7). However, even this relatively sustainable segment consumes a considerable amount of beef, 50% of it coming from organic livestock. Even though this alternative farming method is probably associated with positive effects for biodiversity compared with conventional beef production, organic meat production does not have particular advantages regarding climate impact (50). Moreover, cheese consumption (a product with high greenhouse gas emissions), is also relatively high in this segment. This result is similar to the study of Brunin et al. (7) who found that the segment with the lowest meat and processed meat consumption showed the highest quantity of dairy products.

The meat consumption quantities of medium organic buyers show that buying organic food does not necessarily go hand in hand with low meat consumption. While pork consumption in this consumer segment is on an average level, they consume relatively high amounts of beef and poultry. However, it is noteworthy that two-thirds of medium organic buyers state that they consciously reduce meat, i.e., they claim to already limit their consumption. Nevertheless, it cannot be clearly determined whether there is a gap between intention and behavior because the study did not examine the purchase of processed meat. It is possible that the medium organic buyers may have already reduced the consumption of processed meat, given their high environmental values and their low preference for processed food.

Almost half of the households clearly behave in a non-sustainable way, either due to high meat consumption ('heavy meat buyers', 20%) or due to high consumption of sweet snacks ('sweet snack enthusiasts', 25%). This proportion is significantly higher than in past studies based on self-reported values and intentions, where the proportion of non-sustainable consumers was around 10%. However, our results are similar to those by Vieux et al. (16) who found two non-sustainable segments, one with high greenhouse gas emissions (14% of the sample) and one with unhealthy dietary patterns (24% of the sample). Looking at the choice of organic-labeled food, our study reveals that 90% of consumers do not purchase organic food to a considerable extent, which is comparable to the study of Sarti et al. (8) which is based on actual purchase data as well. The authors found a segment of 71% which was not interested in the purchase of sustainability labels.

The present study identified several consumer groups that differ in their unsustainable purchase behaviors, which has important implications:

Interestingly, the 'sweet snacks enthusiasts' (20%) segment which attaches low importance to 'environmental protection' behaves sustainably with regard to the low climate impact of their diet. They do not attach a strong importance to environmental protection and the intention to reduce meat is average. Nevertheless, they have a low consumption of beef and cheese, which is positive for the greenhouse gas footprint. In addition, the diet of these consumers is composed of high proportions of sweets and processed foods, products with rather low greenhouse gas emission, however, with a high energy density and few nutrients (16). This segment has many similarities with the 'lowest greenhouse gas emissions' segment (24%) in the study of Vieux et al. (16): high intake of sugar/confectionaries and snacks/desserts and low meat and dairy consumption. The rather unhealthy eating behavior of the 'sweet snack enthusiasts' goes hand in hand with a preference for convenience and low-priced food, which is comparable to the findings of Brunin et al. (7).

The second segment of concern in terms of sustainability is that of 'heavy meat buyers' (20%) with a high consumption of all types of meat. The diet of this segment causes high amounts of greenhouse gas emissions, which is also reflected in the low importance these consumers attach to environmental protection and other sustainability aspects. This segment is comparable to the segment of 'highest greenhouse gas emissions' in the study of Vieux et al. (16), both in size, and high meat and alcohol consumption. Surprisingly, a large proportion of 'heavy meat buyers' (28%) in this study state they are consciously eating less meat. Moreover, the 'heavy meat buyers' attach importance to high-quality food. These results are in line with the study by Bakker and Dagevos (51) who found that a quarter of the Dutch population are so-called 'heavy meat buyers'. They suggest that the image of meat as healthy and the culture and traditions surrounding the preparation and consumption of meat, especially the association of superiority, are responsible for the gap between attitudes and behavior.

The present study suggests that many consumers behave sustainably in only *one* dimension of sustainability (either climate-friendly, healthy, or environmentally-friendly) while they follow rather unsustainable dietary patterns in other dimensions. Most policy instruments for fostering sustainable consumption are 'one-dimensional' by design, i.e., they focus on *one* specific dimension of sustainability, e.g., health aspects *or* organic production (52). The introduction of climate labels or climate taxes are currently discussed with great controversy (53–56). One of the paradoxes with one-dimensional sustainability measures is the danger of 'licensing effects'. For example, 'heavy sweet snack consumers' could use a widely introduced climate label to justify high sweet snack consumption. In this case, the climate label would thus act as a 'license' for unhealthy eating.

We therefore recommend considering interactions with other sustainability dimensions before introducing 'one-dimensional' policy measures. A positive example of a multi-dimensional policy measure for sustainable food consumption is the recent introduction of national dietary guidelines inspired by the principles of the planetary health diet recommended by the Lancet Commission (42), e.g., in the Nordic countries.

In light of the fact that our study revealed consumer segments with different 'areas of concern', the current discussion about multi-dimensional sustainability labels (e.g., 'Eco-score' in France) seems highly relevant, yet not without dangers. It seems especially important to stop the silo thinking and merge the dimensions of healthy and nutritious diets, the environment, the climate, and social impacts into comprehensive policy instruments.

5.1. Limitations and future research

Cluster analysis is a widely used approach for segmenting individuals based on similarities in their behaviors, however, there are some limitations associated with this method. One of the major drawbacks of cluster analysis is its subjective nature, as the researcher has to make decisions regarding the number of clusters and which clustering technique to use. Additionally, clusters are never fully homogeneous, i.e., there may be individuals in each cluster who do not

completely fit into the defined group. Another limitation of cluster analysis is, that it is a descriptive method, and it does not allow to draw conclusions about cause-effect relationships between variables. This means that while cluster analysis can be useful in identifying differences between groups, it cannot explain the causes behind those distinctions. Despite those limitations, cluster analysis was chosen for this study because it facilitated the exploration of the multi-dimensional nature of the phenomenon being studied, which involved three explanatory variables associated with sustainable consumption behavior.

Moreover, using only one indicator to measure healthy food consumption (consumption of sweets, chocolates, and bakery products) is a clear weakness of the study. Moreover, using expenditure value for meat probably hides differences in consumption quantities of different types of meat (e.g., the climate impacts of beef and poultry are very different). Additionally, the indicator for meat consumption did not include data on purchases of processed meat, which is another limitation, e.g., because organic consumers are likely to eat less processed meat (7). However, the additional profiling variables used to characterize the segments purchase patterns suggest that the indicators were successful in measuring sustainable food consumption behavior.

A further constraint of this study is, that the GfK did not provide information on the gender of the survey participants, which is a variable that has been identified as highly pertinent to sustainable consumption. Furthermore, the purchase data was available only at the household level. However, the purchase of sweet snacks is most often an individual choice. Some purchase behaviors (e.g., buying a snack at work) are probably underrepresented in the data.

Future research should further analyze real purchase data and explore whether consumers' behavior changes regarding different sustainability dimensions and how the attitude-behavior gap develops *over time*. Future research might also investigate how consumers with positive attitudes toward different sustainable production methods (e.g., environmentally friendly, local, animal welfare) could be motivated to transform these attitudes into purchase intentions and finally real purchase behavior. This is specifically interesting for the large segment of 'mainstream consumers'. Future research should put emphasis on this rather indifferent segment and find ways to nudge people of this cluster to behave more sustainably. Moreover, a further dimension of sustainable food consumption should be added in future studies: food waste behavior. It would be interesting to analyze how the reduction of food waste relates to healthy, environmentally-friendly and climate-friendly food choices.

Data availability statement

The datasets presented in this article are not readily available because we got the household panel data from the research institute GfK and are not permitted to share the data. Requests to access the datasets should be directed to ischaeufeleelbers@unibz.it.

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Author contributions

IS-E: methodology, formal analysis, writing–original draft, and visualization. MJ: supervision, conceptualization, and writing–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/fnut.2023.1140636/full#supplementary-material

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Rapid review of factors influencing dietary behaviors in Fiji

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Introduction: In Fiji, multiple burdens of malnutrition including undernutrition, overweight/obesity, and micronutrient deficiencies coexist at the individual, household, and population levels. The diets of children, adolescents, and adults are generally unhealthy. The objective of this review was to understand how the dietary behaviors of children, adolescents, and women in Fiji are influenced by individual, social, and food environment factors.

Methods: This rapid review was conducted to synthesize existing evidence, identify research gaps in the evidence base, and make recommendations for future research. The Cochrane Rapid Reviews Methods and the updated guideline for reporting systematic reviews were used. The search strategy for this rapid review was based on the Population Context Outcome [P(E)CO] framework, including search terms for population (children, adolescents, and adults), context (Fiji), and outcome (dietary behaviors). Searches were conducted in PubMed, Scopus, PsycINFO, and Google Scholar.

Results: The 22 studies included in this review identified different factors influencing dietary behaviors in Fiji. Individual preferences for processed and imported foods, especially of younger generations, and social dynamics, especially gender norms and social pressure, to serve meat and overeat appeared to be prominent in driving dietary habits. The ongoing nutrition transition has led to increasing availability and affordability of ultra-processed and fast foods, especially in urban areas. Concerns about food safety and contamination and climate change and its effect on local food production also appear to influence dietary choices.

Discussion: This review identified different dynamics influencing dietary behaviors, but also research gaps especially with regard to the food environment, calling for an integrated approach to address these factors more systemically.

KEYWORDS

food environment, obesity, malnutrition, social influences, unhealthy foods

1. Introduction

Globally, diets are rapidly shifting from traditional diets to highly processed high-energy diets, which has resulted in both undernutrition and obesity occurring simultaneously in many countries (1). WHO reported that this double burden of malnutrition contributes to 78% of deaths in middle- and low-income countries (2). In Fiji, multiple forms of

malnutrition coexist at the individual, household, and population levels. The prevalence of underweight in the adult population of Fiji was 1.7% with overweight at 65.6% and obesity and high blood pressure at 33.4 and 21.4%, respectively, with similar rates of overweight and obesity reported in adolescents (34.0 and 12.8%) (3).

Diets of older children, adolescents, and adults in Fiji are generally unhealthy, characterized by low intake of fruits, vegetables (particularly very few consume indigenous and traditional varieties of starchy crops and green leafy vegetables), whole grains, legumes, milk, and nuts/seeds, and high intake of sodium and sugar-sweetened beverages (SSBs) (4). In Fiji, as well as in other Pacific Island Countries (PICs), these unhealthy dietary trends have been associated with the rapid food system transformation that has taken place over the past decade (5–8).

A review of the determinants of overweight and obesity in PICS concluded that environmental-related factors and socio-cultural-related dynamics play an important role (9). However, no comprehensive review of the literature exists on what influences dietary behaviors in Fiji. Few studies have identified potential factors such as price, convenience, availability, accessibility, healthfulness, food safety, taste, and familiarity that influence the dietary behaviors of Fijians (10). Due to the diversity in cultural and ethnic backgrounds of the population and the geographical location of communities across the country, factors influencing dietary behaviors can be complex. Furthermore, identifying and exploring these influencing factors can reveal a new perspective to addressing the double burden of malnutrition in Fiji. The aim of this review was, therefore, to understand how feeding practices and dietary behaviors of children, adolescents, and women in Fiji are influenced by individual, social, and food environment factors to identify the state of awareness among target groups and knowledge and identify gaps.

2. Methods

This rapid review was conducted to synthesize existing evidence, identify research gaps in the evidence base, and make recommendations for future research (11). Rapid reviews are an approach to synthesize information to inform decision-makers on time. The Cochrane Rapid Reviews Methods Group was used as guidance for the rapid reviews (12) and the updated guideline for reporting systematic reviews (13).

2.1. Conceptual framework

For this review, we used a framework to develop the search terms and the coding structure for data extraction and to guide the analysis (Figure 1). The framework was based on existing frameworks and theories that conceptualized how different factors influence the dietary behaviors of children, adolescents, and women (14, 15, 17). Based on the "best fit" framework synthesis approach, we have deconstructed the elements of different existing frameworks to develop a framework that fits the purpose of this review (18). The Innocenti food systems framework was used as a basis (15), which covers the factors in the personal and external food environment (17), food supply, as well as external drivers. As part of the drivers, this review focused on political, economic, and environmental systems, which were reported and discussed as "macro-level" factors in line with the socio-ecological framework of Story et al. and Osei-Kwasi et al. (14, 16). Since the individual and social level concepts were addressed more comprehensively in other frameworks (14, 16), the framework developed by Raza et al. (15) was further complemented with additional concepts related to individual and socio-cultural factors.

2.2. Search strategy

The search strategy was developed based on the Population (Exposure) Context Outcome (P(E)CO) framework (19), combining terms for population (any age or population group), context (Fiji), and outcome (dietary behaviors). The following search terms were used in PubMed (diet*[All Fields] OR nutrition[All Fields] OR meal*[All Fields] OR eat*[All Fields] OR Diet, Food and Nutrition[MESH Terms] AND (Fiji[All Fields] OR Fijian*[All Fields]) and adapted for the other databases. Searches were conducted in PubMed (http://www/ncbi.nlm.nih.gob/pubmed), Scopus (https://www.scopus.com), and PsychINFO (https://www.ebsco.com/products/research-databases/apa-psycinfo) using the list of key search terms. Searches were limited to human studies and English language publications. Gray literature and unpublished literature were sought through Google Scholar, where the first 10 pages were screened for titles. Additionally, references from reviewed articles or those brought to the attention of the authors by members of the team were also considered. All identified references were imported into Mendeley and then to Excel, where title and abstract screening was conducted.

2.3. Eligibility criteria

In terms of the population group, all age groups were included. Studies that included populations defined by specific diseases or health conditions such as heart disease, hypertension, diabetes, dementia, coeliac, anorexia, preterm birth, HIV, and depression diagnosis, or populations being treated in a clinical therapeutic setting, hospital settings, or extremely niche populations with specific nutritional requirements such as professional athletes were excluded. The exposure of interest was any influencing factor related to the individual level, such as socio-economic background, knowledge of the individual, social-level dynamics referring to family and peers, and factors in the personal and external food environment, as well as on the macro level such as political, economic, and environmental factors. The outcome of interest of our review was dietary behaviors, comprised of consumer behaviors (acquisition/preparation/storage/meal practices) and diets (quality/quantity/safety) (20). Study designs included in the review were qualitative, quantitative, as well as mixed methods approaches. Purely descriptive studies not identifying any associations between influencing factors and dietary outcomes were excluded.

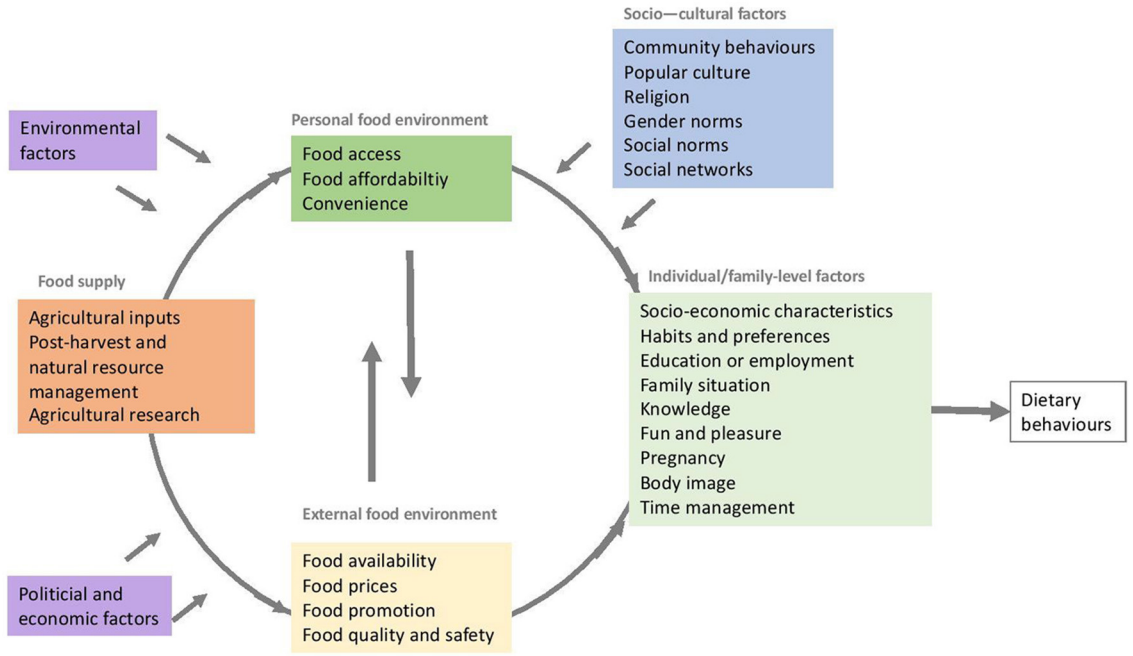

FIGURE 1
Framework on factors influencing dietary behaviors of children, adolescents, and women [adapted from Osei-Kwasi et al. (14), Raza et al. (15), Story et al. (16), and Turner et al. (17)].

2.4. Screening and study selection

The references identified through the searches were imported into Excel, where duplicate records were removed. BB and UT conducted the title and abstract screening in duplicate. The full-text screening was done by two reviewers (UT and BB), and 20% were double-screened by the same reviewers. Justifications for exclusion based on the eligibility criteria were recorded at the full-text screening stage. Any disagreements arising at any stage of the screening process were resolved via discussion between reviewers.

2.5. Data extraction and synthesis

The following data were extracted in Excel: title, author, year, geographic division, or island of Fiji (northern, western, central, and eastern), setting (rural and urban), population (age), sex (male/female), sample size, study design, outcome (type of dietary behavior), level of influence (individual, food environment, and socio-cultural), type of influencing factor based on the framework concepts (individual level, socio-cultural dynamics, personal and external food environment, food supply, and environmental and economic factors), and main finding. Data extraction was conducted by BB and extraction of all articles was checked by UT. Data from all factors were grouped by the concepts of the framework and screened for key themes. Illustrative quotations and the number of relevant references were summarized.

3. Results

3.1. Study characteristics

The search identified 700 references. After de-duplication, title, abstract, and full-text screening, this review resulted in 22 qualitative, quantitative, and mixed-methods studies (Figure 2). The included studies were conducted between 1984 and 2022. Most studies were conducted with adults above 18 years ($n = 8$), children or adolescents aged under 19 years ($n = 8$), and adolescents and adults from 15 years and above ($n = 3$), with three studies not reporting the age of participants. Only one study was conducted with caregivers of children under 5 years of age. Sample sizes of studies ranged from 14 to 6,871 participants. Sixteen studies were conducted with male and female participants and six with women only. Twenty-one studies looked at diets as an outcome, which was either measured as fruit and vegetable intake, dietary diversity, or food consumption in general (Table 1).

3.2. Main findings by framework category

3.2.1. Individual/family-level

3.2.1.1. Family dietary habits and preferences

Four studies found that family members preferred processed foods over traditional home-grown foods, and this influenced what parents purchased and cooked with taste being the main influence on dietary intake rather than nutritional content (22, 24, 30, 33). The following quote from a study participant highlights how preferences differ between generations:

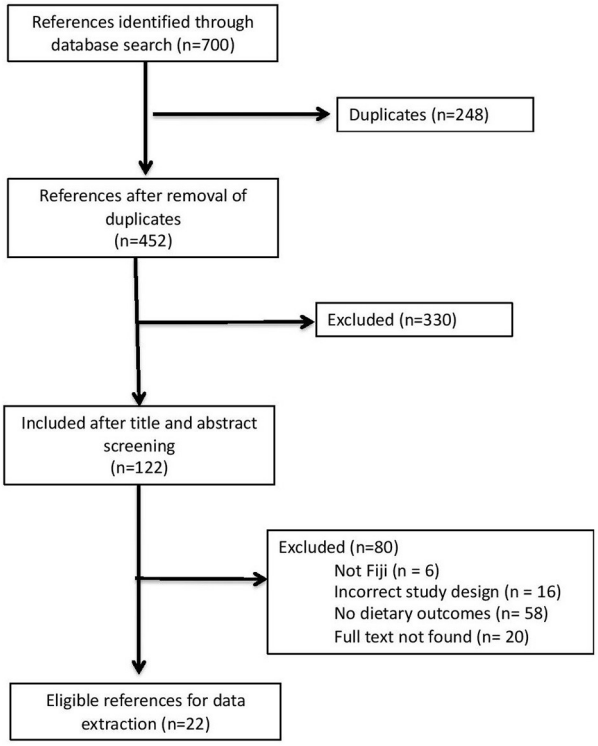

FIGURE 2
PRISMA diagram showing the systematic screening process.

> *"I went fishing last week at the creek. I caught a lot of tilapia but my eldest son doesn't eat tilapia he went bought tinned tuna for himself"* [Male, adult] (24).

In addition, mothers tended to try to please their children through food offerings, and it was emphasized that any additional money the family had was often spent on processed food due to the changing preferences for such foods. A mother said:

> *"My kids love the blue packet Twisties [extra-cheese-flavored snack] and whenever we have extra [money] so then we buy some"* [Female, adult] (22).

Despite trying to please their children, parents appear to have a positive influence on fruit and vegetable consumption (33) and showed concern about the increased preference for processed foods and encouraged their children to reduce their consumption of unhealthy foods such as recommending them to "*cut down on oily foods*" (30).

In addition to individual family member's preferences, the opinions of other family members were reported to influence food preferences with a particular emphasis placed on parents and grandparents (25, 37). The dietary advice from parents was both positive as well as negative and centered around advice relating to losing weight (37). The influence of grandparents was often seen as positive. However, one study described this influence as negative, as a mother said:

> *"I ban my children from going to see their grandparents because every time they go, they come back with some junk foods like bongo, and lollies"* [Female, adult] (25).

The differing attitude toward dietary intake among children, parents, and grandparents may reflect generational changes in dietary preferences with younger people eating less traditional foods (30, 33).

3.2.1.2. Individual dietary habits and preferences

There were four main themes under individual diet/habits/preferences. The first theme is related to the ease of preparation and consumption of processed food with ample availability, taste preference, and ease of access (26, 33). The second theme referred to the shift in family preferences toward processed foods and relates to individual preference for processed foods rather than meals prepared using traditional ingredients and vegetables (4, 25, 31, 32, 37). Participants reported a preference and consumption of highly processed and imported foods such as high-sugar foods or drinks, cookies, and fried foods and vegetables (4, 25, 31, 32, 38).

3.2.1.3. Knowledge

The perceived benefits of homegrown/traditional food were themes that participants referred to in four studies. Participants of included studies believed that "*healthy foods are the foods that we grow*" [Female, adult] (24) which would include fish cooked in coconut milk and vegetables (30, 37), and there was a significant positive correlation between the consumption of traditional starches and perceived health (39).

Participants also seemed to be aware of government guidelines to reduce the burden of NCDs and the link between diet and disease with sugar, salt, and fat being identified as key nutrients of concern (24, 31):

> *"A lot of high blood pressure, diabetes.... heart attack, kidney failure and lungs, this is simply because we are not taking a lot of locally produced food, like the vegetables. We eat a lot of processed food from the shop"* [Female, Adult] (31).

Knowledge regarding the relation between diet and diseases, such as diabetes, heart disease, and poor dental health (30), and individual diagnosis of such diseases caused some participants to change their diet:

> *"Before we were eating a lot of root crops, but when we were diagnosed with some sickness we are trying to adhere to doctors' advice to cut down on certain foods"* [Female, adult] (24).

In addition to being able to identify the link between diet and disease, most participants could identify what constituted a healthy diet (37) and a balanced diet *"like eating fruit (and) three different food types"* [Student] (30, 37). Mothers were also aware that the dietary habits that children pick up during their childhood could continue into adult life, negatively impacting long-term health outcomes:

TABLE 1 Key characteristics of all included studies ($n = 22$).*

References	Setting	Design	Sex	Age (range and/or mean)	Sample size	Individual/ family level	Socio-cultural level	External FE	Personal FE	Macro level
Bhagtani et al. (21)	Urban and rural	QUANT, CS	M, F	> 15 y	186	x	-	-	-	-
Buksh et al. (22)	Urban	QUAL, CS	F	23–48 y Mean: 36.3 y	15	x	x	-	x	-
Darfour-Oduro et al. (23)	Not reported	QUANT, CS	M, F	13–17 y	1,664	-	-	-	-	x
Guell et al. (24)	Urban and rural	QUAL, CS	M, F	Not reported	76	x	x	x	x	x
Hawea et al. (25)	Urban	QUAL, CS	M, F	≥18 y; 6 m to 5 y	72	x	x	-	x	-
Haynes et al. (26)	Urban and rural	QUANT, CS	M, F	≥15 y	186	-	-	x	x	x
Henrich et al. (27)	Rural	QUANT, CS	F	Not reported	75	-	x	-	-	-
Hidalgo et al. (7)	Rural	QUANT, CS	F	Not reported	64	x	x	x	x	x
Katz et al. (28)	Not reported	QUANT, CS	M, F	7–50 m	35	x	x	x	x	-
McCabe et al. (29)	Not reported	QUANT, CS	M, F	Mean: 16.2 y (Fijians) 15.2 y (Indo-Fijians)	1,091	-	x	-	-	-
McKenzie et al. (30)	Peri-urban and rural	QUAL, CS	M, F	Mean: 49 (women) 44 (men) y	46	x	x	x	x	x
Morgan et al. (31)	Urban	QUAL, CS	M, F	>18 y	57	x	x	x	x	-
Neill et al. (32)	Urban and rural	QUANT, CS	M, F	5–16 y	578	x	-	x	-	x
O'Meara et al. (4)	Rural	QUANT, CS	M, F	>18 y	161	x	x	x	x	-
Singh et al. (33)	Rural	QUAL, CS	M, F	> 18 y	14	x	x	x	x	x
Taylor et al. (34)	Urban and rural	QUANT, CS	M, F	≥20 y	846	-	-	x	-	x
Thompson-McCormick et al. (35)	Peri-urban/rural	QUANT, CS	F	Mean 16.7 y	523	-	x	-	-	-
Toren et al. (36)	Not reported	QUAL, LONG	M, F	<14 y	45/47/100	x	x	x	x	-
Waqa et al. (37)	Not reported	QUAL, CS	M, F	16–18 y	48	x	x	-	x	-
Wate et al. (38)	Peri-urban	QUANT, CS	F	13–18 y	6,871	x	-	-	-	-
Withrow-Wong et al. (39)	Rural and urban	QUANT, CS	F	Mean 43.6 y 18–87 y 18–87 y	68	x	-	-	-	-
Witter et al. (40)	Urban and rural	QUANT	M, F	>15 y	-	x	x	x	x	x

*CS, cross-sectional; LONG, longitudinal; QUAL, qualitative; QUANT, quantitative; F, female; M, male; SES, socio-economic status; FE, Food environment.

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> *"It's all upon the mothers to teach the children [about healthy eating] at home. The type of vegetables and fruits you give them, they'll eat it. If you won't—if you just force them or just give them the junk foods, they'll just be trained on that"* [Female, adult] (31).

Although participants were aware of the negative health effects of consumption of nutrient-poor and energy-dense foods such as high in fat, sugar, and salt foods, they were less aware of the relation between the quantity of food consumed and health issues (7).

3.2.1.4. Fun and pleasure

Participants of one study highlighted that food was an indicator of generosity, love, happiness, and affection for others with the phrase *"kana meda bula"* (eat to live) being a commonly used phrase in Fiji (22):

> *"Kana meda bula! The more you eat, the more you live, in fact the better you live [Laughs]. You leave your, what you say, your diet, or worries about health and enjoy the vibe, the environment, and the company [laughs]. Basically, enjoy now and worry about those things later. And so, you get tempted, I mean, who wouldn't?"* [Female, adult] (22).

3.2.1.5. Pregnancy

Only one study reported data related to overeating during pregnancy. Pregnant women in this study were encouraged to overeat during pregnancy for the wellbeing of the child, but then lose weight post-partum:

> *"I remember when, when I got pregnant, in my early months of pregnancy I was still skinny, and oh my elders were telling me you're not healthy the baby is suffering, you need to eat a lot, and I'm thinking, "What? What does that have to do with the baby?" … when I was pregnant with my daughter. They like, "Eat, eat, eat!" and then when I was breastfeeding, "Eat, eat, eat!" and after I had my daughter and I weaned off my daughter, they started "Stop eating, stop eating, stop eating!"* [Female, adult] (22).

3.2.1.6. Time management

Adult participants in three studies in the review reported consuming fast food due to a lack of time to tend to agricultural activities (7) or to prepare food (22, 30):

> *"Nowadays, we only access fast food or take away foods, because we have no time to cook at home, so we go for Pizza and other fast foods"* [Female, adult] (30).

Children also stated that lack of time impacted their dietary intake leading to them skipping breakfast (37).

3.2.2. Socio-cultural factors

Our review identified four socio-cultural factors: community habits, social norms, gender norms, and social networks.

3.2.2.1. Community behaviors

Under community habits, our review identified two main themes: the community's perceptions of traditional compared to modern foods and the importance of eating together at social gatherings. Ten studies included data related to community habits. Fruits and vegetables were perceived as essential components of the traditional diet, but transitions to more unhealthy food consumption and preparation methods were described (31, 35, 40). Changes in preparing food referred to the use of oil and frying of food (7). While dietary behaviors associated with Westernization such as breakfast skipping were perceived as unhealthy, traditional foods were perceived as healthy (24, 35, 40):

> *"Healthy foods are the foods that we grow. It makes our body healthy like cassava. Our forefathers used to have tea with cassava"* [Female, adult] (24).

The social aspect of eating was identified as another key theme. Six studies discussed how eating together with family, friends, and neighbors at special cultural and religious celebrations is an important part of iTaukei culture (22, 25, 29, 30, 33, 36). The food served at these gatherings was served in large amounts and usually contained meat and little fruits and vegetables (22, 25, 30):

> *"In our culture, we present to funerals, weddings, birthdays, or other functions there are a lot of meat like pig, beef, chicken, fish, and dalo, cassava or yams"* [Female, adult] (25).

The success of an event was judged by an abundance of food, especially meat, which was associated with "generosity, happiness, love, affection and the buying-power of the host" (22).

Even though study participants were aware of the benefits of fruits and vegetables, in social gatherings, it was expected to serve meat to show the status of the family since serving vegetables might mean that the family cannot afford meat. The preparation of such foods was, therefore, not necessarily in line with what people usually eat and might interfere with healthy dietary behaviors (22, 33), as this iTaukei participant explained:

> *"Yes, like you know how we alternate between veggies and meat or fish every day? And we enjoy simple meals, generally boiled leafy greens? All that goes out the window when we have people over [laughs]. You have to make something special and maybe a few types of dishes with meat and generally more rich food like add lolo (coconut cream) to the dishes. Like if we have a lovo, it's a lot of meat, a lot of coconut cream. So, the meal does become very unhealthy. In fact, the meal becomes exactly what I discourage at home"* [Female, adult] (22).

3.2.2.2. Gender norms

Traditional gender roles of women preparing and serving food, men receiving preferential provision of food, and changes related to these roles were identified as the main themes in seven studies. The traditional role of women was perceived as the one having to prepare and serve food for the family and take care of the health of the family and domestic responsibilities, while men were seen as the ones responsible for earning money to feed the family (28, 30, 33).

Women preparing food for the family was associated with women's love and care for their families (30). Mothers were also perceived as having a more positive influence on the diets of children compared to men, as this mother reflected:

> "*When I buy, I look for fruits unlike my husband, he likes to buy something cheap, especially junks when they sell for a cheap price. I tell him, our son will get sick and it is more expensive being sick than eating fruits and remaining well, he doesn't see it that way*" [Female, adult] (25).

The perceived role of men as the breadwinner was also associated with the need to be fed first and receive more food of higher quality (22, 30, 33, 36). This practice of giving preference to the man when it comes to food within the household was perceived as a "form of showing respect" (30).

> "*Men are generally encouraged to eat more, because men are heads of family, they sort of take the top place and they are expected to do hard work*" [Female, adult] (22).

Men are not only receiving food first but they also get the best and largest portions, while the women wait for their husbands to finish eating before they start eating whatever is left (30, 33, 36). Eating the leftovers could lead to binge eating habits as one study participant said:

> "*Normally that's culture. That is the Fijian culture. Men used to eat first and then the women will eat later but normally eating later that means everything that's left they are going to have it…*" (Adult) (33).

However, three studies discussed how these roles might be changing with men doing less of the hard labor such as farming or fishing and engaging in more sedentary activities while women increasingly work out of the house (7, 22, 30). Despite these changes, men seem to get preferential treatment when it comes to food allocation:

> "*Men are not doing their work […] before they used to plant cassava and we always have plenty of it, only the elders used to do that, and we just eat them (the cassava). Now, the men are sleeping*" [Female, adult] (30).

Study participants reflected on these changes, requesting a change in food being allocated since women work just as hard as men (30).

The fact that more women work outside the house limited their time to prepare food at home, making families more dependent on processed food. Equally, a study reported that men who still work in agricultural production focused on cash crops, which also forces the family to rely more on purchased processed foods (7).

3.2.2.3. Social norms

This review identified seven publications discussing social norms related to social pressure to overeat at social and religious gatherings as well as specific foods and larger body sizes being associated with higher social status. Large gatherings which are an important part of iTaukei culture encourage overeating since guests are encouraged to eat more and feel the social pressure to show respect to the host (22, 25, 29, 36).

> "*In our culture, if anyone offers food, it's kind of disrespectful to decline. Like it's a bit rude and times you feel that when you decline you are giving the message that the food isn't good either. So, it both sides [sic] and ends with people eating way more than they should*" [Female, adult] (22).

The pressure is also felt by the hosts who are expected to serve plenty of food to present themselves as generous hosts.

> "*And so, we keep refilling the bowls on the serving table and we encourage our guests to eat well. It looks bad if a serving bowl is empty or if run out of food. So, when you cook or cater, you always make sure there's leftovers*" [Female, adult] (22).

Three studies reported on food taboos (27) and certain foods being associated with high social status, such as meat, seafood, and fast food, while vegetables were perceived as poor people's food (22, 25). Owning livestock was also considered a privilege (25). Eating out of the home, especially fast food, was perceived as something that could only be done by rich people or at certain moments when people had more income (22, 24, 40):

> "*So, it's only when we can afford it. I think people only eat out when they can afford it so they have the money, they are rich, they can afford to go out for burgers and chicken and chips, pizza and all those kinds of food...*" [Female, adult] (22).

Good social status was also associated with larger body size and the size of children, or a man reflected how well a woman took care of her family (22, 30, 33, 40).

3.2.3. Personal food environment

3.2.3.1. Food affordability

The affordability of food was the central theme in eight studies (22, 24, 25, 30, 31, 33, 40). Affordability could determine what people purchase and eat, limiting the options people have. Foods that are filling such as carbohydrate-rich foods like rice or bread were prioritized over fruits and vegetables when people faced financial challenges (30). Certain foods such as fruit and vegetables, tin fish, and packed instant noodles were considered more affordable, while fresh meat, fish, seafood, and fast food were seen as more expensive (22, 25).

> "*So, it's really the price. I always opt for tuna, tinned fish, or sausages because you can. spread it to a few meals. Mel: I will do tinned fish and tuna, and corned mutton and, especially, sausages because we can't afford fresh beef and pork*" [Female, adult] (22).

A study in a rural setting showed that people relying on lower incomes were forced to buy cheaper options at small stores in the villages or get takeaway food from the cities where they sold the vegetables they grew. However, consuming homegrown food

was seen as an affordable way to get fruits and vegetables for farmers or people who had home gardens (24). Consumption of food from home gardens was found to be associated with higher fruit consumption (24, 26).

3.2.3.2. Food access

Increase access to unhealthy foods to both urban and rural populations was reported by three studies (7, 30, 33). Improved infrastructure of roads and transport made food, especially unhealthy ultra-processed food, more accessible to people living in villages (30, 33). At the same time, access to traditional and homegrown food was decreasing with the effect of climate change on food production (30).

3.2.4. External food environment

3.2.4.1. Food availability

Food availability was also associated with the types of food vendors raised by participants in 4 studies. A study found that more than half of the participants purchased food from supermarkets more than once a week (21). However, for people affected by poverty, smaller shops were more accessible and therefore an important source of food. However, small shops were also associated with food insecurity and lower dietary diversity, higher intake of sugar-sweetened beverages, and red and processed meat (21, 26). While healthy, minimally processed food appeared to be available to people, the omnipresence of processed foods tempted people to buy them (30):

> "*There is a lot of processed food. We should eat the food that lives free, like taro leaves. It is around us, the food that we supposed to eat and then we are going to the shop to buy tinned fish and things like that*" [Male, adult] (30).

The availability of different foods was a theme identified in two articles (30, 37). The food available at schools such as snacks high in sugar, salt, and fat influenced students to buy them even if canteens provided curries and rice (37). Study participants expressed concerns about the availability of unhealthy snacks in and around schools, which are even sold by teachers, which puts parents in a difficult situation (30).

3.2.4.2. Food promotion

Two studies provided data on widespread food advertising, especially of unhealthy, processed food, which influences especially rural people to buy unhealthy food (33, 40).

3.2.4.3. Food quality and safety

Study participants of 3 studies expressed concerns about chemical and pesticide contamination of local foods (24, 30, 31). These concerns were related to the perception of poorly regulated pesticide use on local agricultural produce and affected the taste and the quality of food (24, 30).

> *"I've noticed that most of the farmers they are using a lot of chemicals on chauraiya (amarnath leaves). Once I bought it from the market. . . . We could smell the chemical . . . I refused to eat chauriya. Before it used to be my favorite"* [Male, adult] (31).

However, imported processed foods were also associated with a fear of chemicals. Buying food from trusted vendors and avoiding tinned and frozen food was an approach participants took to avoid chemical threats from these foods (31).

3.2.5. Food supply

Six studies addressed the issue of food supply and how it may affect consumption (7, 24, 30, 32, 33, 40). Access to land was limited due to far distances, even for people living in villages. This appears to be a limiting factor for people to produce their own food, forcing them to purchase food from shops, even if people owned a farm (24). However, in rural areas, access to land was still better than for urban populations. Neill et al. found that 75% of rural and 47% of urban populations had access to food products for home consumption (32). Besides the distance and general lack of access for people living in urban settings, they also mentioned a lack of time and interest in home gardens (24, 32).

> [. . .] P: *Where I'm renting now, we don't have that luxury to plant what you want to so you just gotta buy everything. From market or the supermarket, sometimes it's imported. "previously we use to get food from the garden however now we seem to be buying a lot"* [Female, adult] (24).

Another important mechanism limiting food production mentioned in a study was the lack of government subsidies, equipment, and knowledge transfer for local production of fruits and vegetables (33).

3.2.6. Political and economic factors

Global trade appeared as an important issue reported in three studies (7, 24, 31). Imported foods, especially white flour, white rice, and added sugars, were perceived as widely available, but with mixed impacts on health. Some participants associated imported food with unhealthy food and negative health impacts related to obesity and non-communicable disease. However, some participants considered local food to be equally unhealthy than imported food:

> "F: *Does it matter if they are local or from abroad? Any difference? P: I don't believe so. Maybe even unhealthier? F: Fiji products have a lot of oil content, [same brand name of tinned fish] has a lot of oil, overseas product is dry instead*" [Male, adult] (24).

Food imports were also mentioned as a positive influence on the availability of especially fruits and vegetables, such as apples and carrots, which would not be available throughout the year if they were not imported (34).

Urbanization or the difference between urban and rural diets was addressed in four studies (21, 32, 34, 40). Rural populations were reported to consume higher quantities of energy, especially in the iTaukei population, such as traditional root crops, which were lower in urban diets (40). Rural diets were also described as less processed and lower in diversity, and higher in carbohydrates but lower in fats than urban diets (21, 32, 34).

3.2.7. Environmental factors

Four of the included studies in this review highlighted that climate change is making it harder for individuals to plant and grow crops. Participants stated that previously they were able to grow crops year-round but now it was too dry in some months, and in addition to inconsistent rainfall, natural disasters were affecting the supply chain leading to an increased reliance on processed, packaged foods. Studies emphasized that increasing temperatures and limited water availability were adversely affecting their ability to grow fruits and vegetables (7, 32). In addition to the increasing temperatures and limited water availability, rising sea levels were mentioned regarding lower land availability for growing crops (30). Cyclones were also reported to impact market access and limited food availability (7, 30). These natural disasters impacted food prices and consequently individuals' food choices (31).

4. Discussion

This rapid review aimed to synthesize existing data on factors influencing diets in Fiji. Individual and social dynamics as well as the ongoing nutrition transition, food safety concerns, and climate change appeared to be prominent in driving dietary habits with a preference for processed and imported foods with social norms around feasting leading to overconsumption.

On the individual/family level, we found good knowledge related to traditional, local food being healthy and the need to reduce salt, fat, and sugar. However, changing preferences of younger generations were linked to more modern, processed foods compared to older generations. These dietary shifts, defined as the "nutrition transition" (1), were also described in a review of qualitative evidence which found that grandparents were eating healthier and consuming more unprocessed, local foods compared to their adolescent grandchildren (41).

Parents were concerned about the increased preference for processed foods of their children, and as recent research from Kenya showed, they need to balance their parenting related to food between tradition and the modern realities of daily life (42).

With regard to socio-cultural dynamics, an important theme was overeating in a social context. A sign of a gracious host was to provide an abundance of meat and energy-dense foods with a high value placed on such foods. Meat and energy-dense foods were perceived as an indicator of high social status whereas vegetables were seen as an indication of poverty (22). Studies showed that consumers in high-income countries but in lower socioeconomic positions tended to eat more meat than consumers of higher socioeconomic backgrounds (43), which might be driven by the desire for a higher social status (44). In addition to meat consumption, our review found that large body size was indicative of higher social status. A review of African studies also described the association between larger body size and social standing as well as the importance of gaining weight after marriage symbolizing that the woman is well-cared for (45). Our review also found this with regard to the body size of the husband and children associated with how well a woman was perceived to take care of them (22, 30).

Gender roles were also influencing dietary behaviors, especially of women. In the included studies, men were encouraged to consume more food and were given priority of higher quality foods than women due to men historically being the breadwinner of the household, performing hard manual labor on the farm. Prioritizing men's food consumption affects women's dietary decision-making power and has also been shown to change women's dietary behaviors by adapting their diets to their husband's preferences (41). Having to fulfill their expected roles in the household and family while also working outside the house was shown to limit women's time to prepare food at home, making families more depended on processed food (22, 30, 37). However, no studies in this review focused on women's diets related to the workplace, which could have offered valuable insights into possible interventions for women given their increasing presence in the workforce. These types of time limitations have been associated with obesity in women (46).

With regard to the food environment, we found an increased reliance on processed foods, especially in urban settings where access to land is more limited reducing the accessibility of homegrown foods. However, studies in our review found that rural settings have also seen an increase in ultra-processed food consumption with improved infrastructure, and limited access to land with only 75% having access to food produced for home consumption (32). Fiji has seen a nutrition transition from traditional homegrown foods to modern highly processed imported foods with a 28% increase in processed foods sales between 2004 and 2018 (6). This nutrition transition in Fiji, and other low- and middle-income countries, has been driven by the movement of transnational food and beverage companies into emerging markets such as Fiji (1) and the globalization of food trade with several ultra-processed foods now playing a key role in Pacific diets. Studies on food imports found an increase in imports of healthy as well as unhealthy foods and beverages such as SSBs over 14 years in Fiji (6). Ravuvu et al. suggest that these changes in food imports are related to Fiji's membership to the World Trade Organization in 1995, which led to increases in tariffs on healthy foods from 2000 to 2010 and an increase in the import of highly processed and energy-dense foods between 2000 and 2010 (47). These food imports affect availability but also the affordability of food and are a phenomenon occurring across all the Pacific nations (6). In the Federal States of Micronesia for instance nutritious food items, such as tuna, are exported to high-income countries, while it has become unaffordable to the local population (48). The nutrition transition has led to unhealthier diets in the Pacific Islands (49), which in turn may have contributed to higher rates of overweight and other non-communicable diseases (50). In addition to the effects of the globalization of trade, the proliferation of the mass media has influenced the dietary intake of individuals in Fiji. Exposure to social mass media was reported to negatively impact eating behaviors in adolescent Fijians, leading to pathological eating behaviors associated with eating disorders (51).

Concerns about chemical or pesticide contamination of local food but also chemicals in imported food were reported in this review (24, 30, 31). These concerns related to the consumption of vegetables grown on land treated with pesticides may subsequently cause individuals to shift purchasing and consumption behaviors away from fruit and vegetables and toward ultra-processed foods due to their perceived hygienic packaging (52). Food safety issues place a large burden on the Pacific (53). More than 125 million people in the Pacific region fall ill from unsafe food, and more

than 50,000 die (53). However, in a low- and middle-income country setting such as Fiji concerns regarding food safety may outweigh those of the nutritional properties of food, as was reported by a review on food safety concerns (52). These food safety concerns could overshadow or even distract from equally pressing issues related to the dietary transition such as increasing rates of overweight and obesity (54).

Environmental factors identified in this review were related to climate change and how it affects agricultural production. We found that Fijians were concerned about climate change, due to its impact on local food production and the interference with the food supply chain. Climate change is a pressing issue affecting the whole world but is particularly evident and immediate in Fiji with its low elevation and rising sea levels by 5.5 cm between 1992 and 2009 (55), increasing natural disasters such as cyclones, floodings, and droughts, and unpredictable seasons (56). The WHO cited malnutrition as a key climate-sensitive health risk alongside NCD-related illnesses, psychological impacts, and decreased access to health services (57). Studies included in this review reported that climate change has made it harder for Fijians to plant and grow crops which subsequently leads to a reduction in local food production. This increased reliance on imported, processed foods has a negative impact on individuals' dietary intake whilst simultaneously causing a greater economic burden, especially if any interruptions to the food chain occur due to climate change. Individual food choices can also influence climate change through changed demand for (un)sustainable foods, food waste, or social movements to mitigate climate change (58). However, our review could not find evidence of individuals' dietary choices and their influence on climate change, nor individuals adapting their diets due to concerns about climate change.

4.1. Research implications

This review identified only 22 studies assessing influencing factors of diets with only a few studies comprehensively examining multiple factors. Most of the studies assessed only dynamics at the individual or family level. There is a need for more studies assessing the underlying reasons for dietary behaviors in Fiji, especially related to the food environment. The few studies assessing how food supply or food environments influence diets relied on respondents' perceptions of food availability, promotion, and affordability. More research at the local level is needed using valid and reliable measures and study designs that allow for multi-level assessment of relationships between what kinds of foods are available, promoted, and affordable in people's food environments and their dietary behaviors. This could be achieved through quantitative and qualitative analysis of the personal and external food environment. The quantitative analysis could be achieved through mapping of vendors such as by using Geographical Information System mapping and qualitative analysis by interviewing caregivers to better understand people's lived experience in the food environment (59). Mixed-methods approaches are needed to link quantitative methods assessing actual food availability, prices, and advertising with the lived realities of residents in different neighborhoods (60).

4.2. Programme and policy implications

This review identified that Fijians largely understood what constituted a healthy diet and the importance of following a healthy diet to prevent non-communicable diseases such as obesity and diabetes. However, there was a disconnect between knowledge of what constituted a healthy diet and the consumption of healthy foods in practice, due to deeply ingrained cultural norms that promote the consumption of an unhealthy diet. Social and Behavior Change Communication strategies are needed to address these cultural and social norms related to the high status of energy-dense foods or meat, the pressure to overeat at social events as well as traditional gender roles, and intrahousehold food distribution.

Furthermore, policy actions should take climate-sensitive approaches, by revitalizing traditional farming practices, experimenting with salt and drought-tolerant crops or other innovative climate strategies, and building on the experience of small island states (56).

Policy actions should also ensure the availability of safe and affordable food by assessing trade policy commitments and strengthening risk-based food safety policies that contribute to the availability, nutritional quality, and safety of the food supply and help individuals make informed judgements about food safety hazards (47, 61).

4.3. Strength and limitations

Our review followed a rigorous review methodology for rapid reviews (12), searching three databases to identify relevant peer-reviewed quantitative, qualitative, and mixed methods studies. However, limiting the search to databases for published literature might have missed research from a Master's or PhD thesis that was not published. In addition, our study provides a good overview of the individual, social, and food environment dynamics influencing dietary behaviors in Fiji. However, as the study focused solely on Fiji, these results cannot be generalized to other Pacific Islands.

5. Conclusion

This rapid review identified factors at individual, social, and food environment levels influencing the dietary behaviors of Fijians, and also evidence gaps especially with regard to the food environment, calling for an integrated approach to research and programming to address these issues more systemically.

Author contributions

SG, BB, and UT defined the scope of the review. UT conducted scoping searches to inform the search strategy. BB and UT conducted the search, screening, data extraction, and conducted the data synthesis. SG served as a reviewer for verifying data extraction. BB, UT, AN, and VL wrote the first draft of the article. All authors

advised on the search, data extraction, analysis format, and read and approved the final article.

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Conflict of interest

BB, UT, VL, AN, AI, and SG were employed by Nutrition Research, Dikoda.

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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Food exchange list based on macronutrients: adapted for the Ecuadorian population

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Background: Food exchange lists allow health professionals to generate healthy eating plans adapted to individual or population needs. The objective of this study was to develop the first food exchange list based on the macronutrients and energy provided by the various food groups of the Ecuadorian diet.

Methods: The list of Ecuadorian food exchanges was constructed by going through the following phases: (1) Selection of household measurements; (2) Selection of tables and databases of the nutritional composition of food items; (3) Definition of food groups and quantities; (4) Determination of the average energy and macronutrient values of each group; and (5) Photographic record. For the definition of food quantities, statistical criteria were applied according to a standard deviation of ±2SD; thus, for carbohydrates: ±5 g, total fat: ±2 g, and protein: ±3 g. To ensure the inclusion of the food items in the groups, a coefficient of variation of less than 30% and a Z value of ±2 were also considered.

Results: The list of food exchanges is presented with eight general groups according to the predominant nutrient (carbohydrates, proteins, or fats), and, where necessary, subgroups are included according to the second predominant nutrient. The list includes 404 food items with their photographic record, represented by their net weights and corresponding household measurement. All food items met the statistical criteria that help to reduce the variability of the nutritional composition of the food items in each group.

Conclusion: This is the first list of Ecuadorian food exchanges based on statistical criteria. It represents a novel tool for public health professionals as well as researchers. Resulting healthier eating plans may improve daily dietetic practice, facilitate better clinical trial designs and help establish guidelines according to Ecuador's cultural and dietary patterns. The described methodology can further be used to develop other food exchanges lists for patients with specific nutritional requirements.

KEYWORDS

food exchanges, exchange portions, dietary planning, Ecuador, serving sizes, macronutrients

1. Introduction

Food exchange lists or systems are educational tools that have allowed nutrition and dietetic professionals to plan healthy meals without altering the macronutrient or energy content in a fast, practical, and reliable manner according to people's tastes and habits and that meet nutritional requirements (1). The exchange lists were originally created for the nutritional

management of patients with diabetes, who are required to control their carbohydrate intake (CHO) since the CHO count is used to plan their meals and focuses on estimating the macronutrient content that mainly influences the postprandial glycemic response (2). However, nowadays the use of the lists has been extended to other metabolic pathologies, such as obesity or cardiovascular diseases (3). In addition, lists have been developed for populations with specific needs, such as athletes (4), vegans (5) or those using supplementation for malnutrition (6).

Furthermore, food exchange lists allow experts to consider the reality of each country in order to develop appropriate food guides and nutritional education programs at local and national levels for the prevention and control of diseases. The lists guarantee individuals' and target communities' welfare and nutritional requirements, as applied in countries such as the United States (7), Spain (8), Greece (9), Jordan (10), Lebanon (11), and Sri Lanka (12). In Latin America, few countries have achieved the construction of exchange lists adapted to their cultural and dietary patterns, thus neighboring countries such as Peru (13), Colombia (14), or Chile (15) have acted as references in the region. In Ecuador, these exchange lists have been used both in clinical practice and in the training of nutrition professionals. However, a national food exchange list in Ecuador has not been available previously due to a lack of reliable information on the nutrient composition of many food items, as well as the scarcity of data concerning serving sizes as standard kitchen measurements (spoons, cups, glasses, etc.) and their weight in grams. Nevertheless, there is already a record of the most commonly used household measurements in the country (16).

The absence of a national exchange list has made it difficult for nutritionists working with Ecuadorian patients suffering from obesity or other chronic diseases to diversify their diets. In fact, Ecuadorian nutritionists still use food exchange lists from Mexico (17) and the United States (18), even though the use of an external list increases the risk of introducing possible biases, especially those related to dietary patterns since these are specific to each country. Thus, the lack of a national food exchange food has limited the design and creation of dietary plans at various levels of care, the development of research projects, and the generation of dietary guidelines or programs.

Therefore, the objective of this study was to build the first food exchange list in Ecuador, ensuring that it respects the country's food culture, according to macronutrient and energy contents. It also enables the conversion of each food item's weight measurements with the most commonly used household measurements in the country, supported by the photographic record that facilitates the use of the tool.

2. Materials and methods

The number of food items, portion sizes, and photographic record were defined according to the following phases.

2.1. Phase 1: selection of household measurements

Given that one of the objectives of the exchange lists is the management of quantities in grams through the use of household measurements, for this study, those measurements were selected by considering two stages, as follows. (i) *The most frequently sold household measurements in key retail centers, such as hypermarkets and specialized stores, were recorded and a preliminary list was set out*. At this stage, a list of the household measurements most frequently sold by the retail center was requested. Based on that, the 10 most frequently sold measurements in each category were chosen and a preliminary photographic record was made. (ii) *The preliminary list was evaluated by a group of experts in food intake recording*. At this stage, nutritionists and experts in dietary intake from different regions of the country (the coastal, Highland, and Amazon regions) were contacted and they voluntarily agreed to evaluate the preliminary list with the respective images. On this matter, the experts were asked to choose the measurement or measurements most used in their population through the images provided.

Finally, the experts' answers were contrasted, the criteria were unified with the research group, and the most commonly used household measurements in the country were defined.

2.2. Phase 2: selection of the tables and databases of the nutritional composition of food items

The list of food items and nutrients was selected according to the food and culinary culture and eating habits of the Ecuadorian diet, based on the food consumption database from the National Health and Nutrition Survey (ENSANUT 2011–2013) (19). Food items selected from the general database were included according to region and sex.

The nutritional information of food items was obtained using the food composition tables (FCT) from countries in the region. Data were obtained mainly from eight information sources, where the Central American food composition table (20) was the main reference source. For those food items not found in this table, other sources were used: FoodData Central in the United States (21); Peruvian food composition tables (22); Colombian food composition table, 1st and 2nd ed. (23, 24); food composition table in Cuenca, Ecuador (25); standardized recipes, nutritional labeling, and scientific articles (26).

Once the nutritional composition of each food was established, an analysis of variability was performed to detect the variation between individuals according to the following nutrients: energy, carbohydrates, proteins, fats, iron, calcium, zinc, and vitamins A and C. Therefore, the preliminary list included food items that are frequently consumed and those that provide critical nutrients for the Ecuadorian population.

2.3. Phase 3: definition of food groups and quantities

The exchange list was constructed by considering the food groups recommended by FAO and WHO in the Codex Alimentarius (27, 28). In order that the amount of each food item could be interchanged with any other food within the same group without presenting significant differences in its nutritional value, different amounts of each item were entered into an Excel database that enabled us to compare the value of

energy and macronutrients until we reached the most appropriate amount, according to the established statistical parameters.

In all cases, for each food item, the amount in grams was evaluated according to Ecuadorian dietary and culinary practices and, when necessary, we followed the recommendations of the national guidelines INEN 1334-2 that regulates the portion size for packaged food products (29). Subsequently, the quantity was also estimated using the usual household measurements of the Ecuadorian population (16).

For each food group, food items whose amounts met the statistical criteria for macronutrients were included. The values established by Wheeler et al. (30) were used, taking as a reference the representative macronutrient for each food group, where a standard deviation of ±2SD was considered, i.e., ±5 g for carbohydrates, ±2 g for total fat, and ± 3 g for protein, as appropriate. Furthermore, once the criteria for macronutrients were met, the energy and caloric value of each food item was calculated by multiplying the carbohydrate (4 kcal/g), fat (9 kcal/g), and protein (4 kcal/g) content by their respective Atwater factors (8). If the SD value was outside these limits, the food item was removed from the group and relocated to a more appropriate group. Once the SD was adjusted, the coefficient of variation (CV) was estimated to be less than 30%. In addition, for those groups in which the CV was high, the Z value for each food was calculated in order to eliminate foods with high variation. The *Z* value was considered to be ±2. This statistical criterion was applied to homogenize the number of food items within each group (8).

Once the quantities were defined in the database, raw and cooked weights were recorded for all food items in an experimental kitchen, using an electronic scale (METTLER TOLEDO, 0.5–3,100 g; ±0.01 g), depending on the most common form of consumption. A triplicate record was applied to each measurement [(weight (g), length (cm), width (cm), and height (cm)] to reduce measurement variability.

2.4. Phase 4: determination of the average macronutrient and energy values for each food group

The macronutrient values for each exchange group correspond to the average in grams of the food list in each group and are presented as whole numbers (values less than 0.5 were rounded down and values greater than 0.5 were rounded up). Finally, in the case of the energy of each exchange group, the values correspond to the average amount in kilocalories (kcal) and were rounded to the nearest ten; for example, for the low-carbohydrate fruit group, an average intake of 47 kcal was recorded, which was rounded up to 50 kcal in order to present easy-to-remember numbers for the practitioner.

2.5. Phase 5: photographic recording

A professional photographer took photographs of all the food items, It is noted that a professional photographic set was organized next to the food preparation area to keep the food fresh, thus simulating a real-life consumption situation.

For this, we worked with a professional camera (Canon EOS 7D) and a lighting scheme for products, which consisted of two softbox lights with flash triggers (Hensel Integra 500), a zenithal side light as the main light and a semi-zenithal side light as a secondary light, plus a silver reflective bouncer to help reduce shadows and maintain the volume. An ISO of 100 was used, so as not to produce marked grain detail, along with a 70 mm medium telephoto lens (Zeiss Canon Mount) so as not to produce any distortion, and an average camera angulation of 50 degrees. In addition, a grayscale color pattern was used for the background to facilitate the focus on the food rather than the surroundings.

Due to the great variety of food ítems and their shapes, colors, and arrangement on the plate or household measurement used, the focal distance between the camera and the food varied between 99 and 138 cm, and for the height of the tripod a range of 146–163 cm was used.

In this research, the aim of the photography was not to beautify the food, as happens in the commercial field. On the contrary, what was sought was for the food to look natural and be perceived as if the consumer was seeing it in order to consume it. This concept was the driving force for the inclination of the camera and the technical decisions of the photography (31). It was necessary to change the framing and settings on several occasions due to the type of food and household measurement that contained it, because it is different to, for instance, photograph a food item in a cup than one in a spoon.

3. Results

3.1. Household measurements

The process of selecting the household measurements most frequently used by Ecuadorian homes made it possible to define the most commonly used sizes. Figure 1 shows the selected household measurements. Additionally, measurements such as length, width, and height were established for those food items that required them.

3.2. Definition of the food groups and amounts of the exchange portions

The list of food groups was established according to the predominant macronutrient (carbohydrates, proteins, or total fats). For example, in the group of legumes, proteins were considered the most representative nutrient, while carbohydrates were the most representative for the group of cereals, tubers, and plantains. Finally, 8 general food groups were derived, including each food item's net weight that met statistical requirements and the equivalent in household measurement. They were organized as follows: cereals, tubers, and plantains; fruit; vegetables; dairy; meat, fish, and eggs; legumes; fats and nuts; and sugars and sugary foods.

Moreover, to differentiate the high, medium, or low content of the predominant macronutrient, certain food groups were also organized into subgroups. For example, in the vegetable group they were classified according to their carbohydrate content into (a) low in carbohydrates (CHO = 5 g) and (b) freely consumable (CHO = 3 g). When necessary, a predominant secondary nutrient was considered in order to organize the subgroups, as in the case of the cereals, tubers, and plantains group where the main macronutrient was carbohydrates

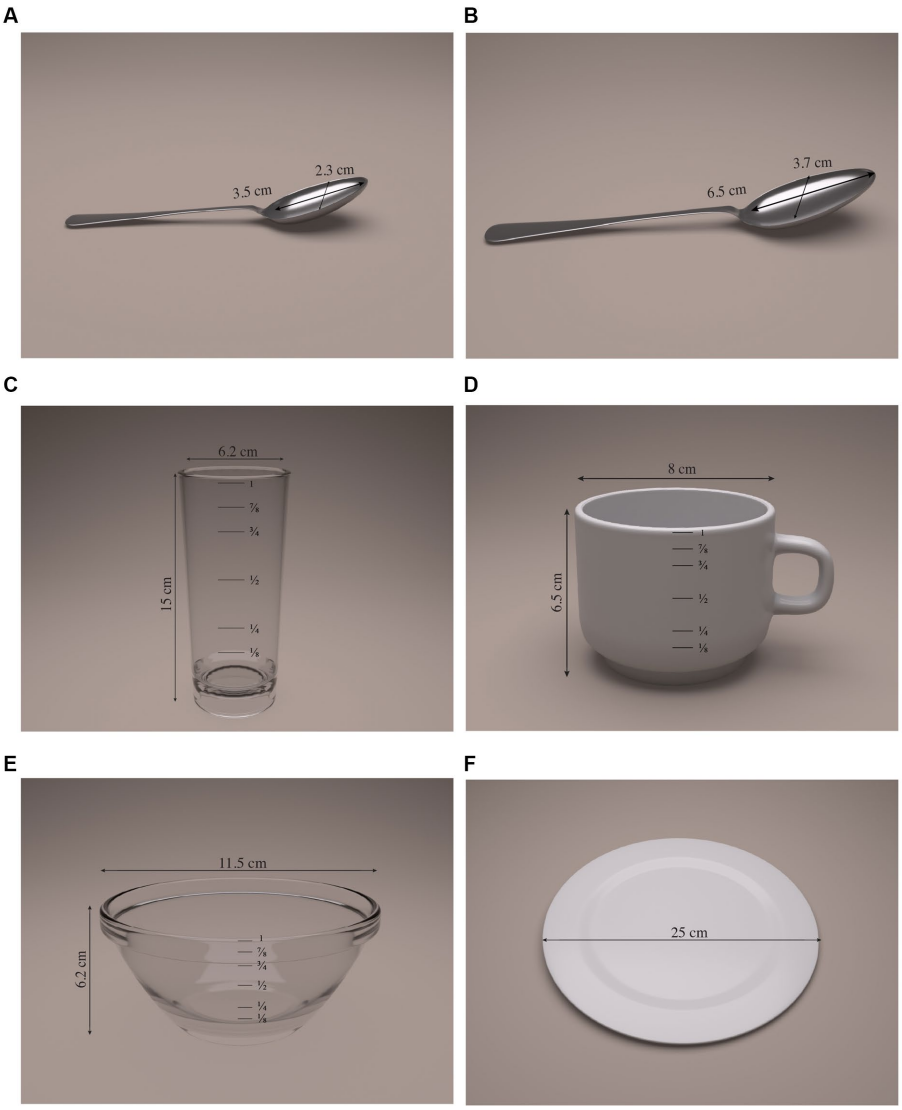

FIGURE 1
Selected household measurements for the Ecuadorian food exchange list. **(A)** Teaspoon (tsp), 5 mL. **(B)** Tablespoon (Tbsp), 10 mL. **(C)** Large glass, 330 mL. **(D)** Cup, 250 mL. **(E)** Bowl, 320 mL. **(F)** Large plate, 25 cm.

and the secondary nutrient was fats, resulting in subgroups with (a) medium or (b) low total fat content; this same criterion was established in the dairy group. Tables 1, 2 show examples of the organization of the food items that make up each group, accompanied by their names in Spanish and English, net weight (g), and household measurement. Supplementary Tables S1 and S2 from the supplementary material show the food exchange lists for the group of fats and nuts, and sugars and sugary foods, respectively.

3.3. Average values of macronutrients and energy in the food groups

The average nutritional content of the exchange portions for each food group is shown in Table 3. In addition, the respective subgroups are shown, according to the high, medium, or low content of any of the predominant macronutrients and secondary nutrients, when applicable.

3.4. Photographic record

A total of 2,600 photographs were recorded since several photographic proofs were needed for each food item, given that between one food item and another the parameters of lighting or framing were adjusted when necessary. The selection and editing process focused on standardizing and/or correcting minor aspects without altering the proportions, colors, or shapes of the images. Finally, 586 photographs were obtained, corresponding to 404 food items, which constitute the photographic record of the food exchange list. Figure 2 shows an example of the exchange portions for the fruit group, considering the variety and quantity of the food items.

4. Discussion

Dietary intervention is an essential part of the prevention and treatment of metabolic pathologies, such as chronic

TABLE 1 Food exchange list for the legume group.

Name in Spanish	Name in English	NW (g)	Household measurement
Arveja, grano seco, sin sal, cocida	Pea, mature seed, without salt, cooked	100	4½ heaped tbsp., ½ cup
Arveja, grano seco, cruda	Pea, mature seed, raw	35	3 level tbsp., 1/8 cup
Chocho, con sal, cocido	Lupine, mature seed, with salt, cooked	60	½ cup
Fréjol, blanco, sin sal, cocido	Bean, white, without salt, cooked	90	½ cup
Fréjol, blanco, grano seco, crudo	Bean, white, mature seed, raw	35	3 level tbsp., 1/8 cup
Fréjol, negro, sin sal, cocido	Bean, black, without salt, cooked	90	½ cup
Fréjol, negro, grano seco, crudo	Bean, black, mature seed, raw	40	3 level tbsp., 1/8 cup
Fréjol, rojo, sin sal, cocido	Bean, kidney, without salt, cooked	90	3 full tbsp., ½ cup
Fréjol, rojo, grano seco, crudo	Bean, kidney, mature seed, raw	35	2 full tbsp., 1/8 cup
Garbanzo, sin sal, cocido	Chickpea, without salt, cooked	90	¾ cup
Garbanzo, grano seco, crudo	Chickpea, mature seed, raw	35	¼ cup, 2 full tbsp.
Haba, grano seco, cruda	Broadbean, mature seed, raw	35	3 level tbsp.
Haba, grano seco, tostada	Broadbean, mature seed, toasted	35	3 full tbsp., ¼ cup
Harina de garbanzo	Chickpea, flour	30	3 heaped tbsp.
Harina de haba	Broadbean, flour	30	1½ heaped tbsp.
Lenteja, grano seco, sin sal, cocida	Lentil, mature seed, without salt, cooked	90	3 heaped tbsp., ¾ cup
Lenteja, grano seco, cruda	Lentil, mature seed, raw	35	3 full tbsp., ¼ cup
Soya, bebida	Soy, beverage	200	7/8 cup, ¾ glass
Soya, brote	Soy, sprout	75	raw: 1½ cup; cooked: 1 cup
Soya, polvo	Soy, milk powder	30	3 heaped tbsp.

NW, Net weight; S, small unit; M, medium unit; L, large unit.

non-communicable diseases like diabetes, obesity, or metabolic syndrome, which are becoming more and more widespread, reaching epidemic levels in various countries (32, 33). This situation requires an adequate management of the food portions from each food group that make up a healthy eating pattern. Thus, a food exchange list providing food options that are achievable and sustainable within the culture, preferences, and capabilities of each country's population enables dietary planning because it includes a list of foods with similar contributions of energy and macronutrients. In this way, the list ensures that the intervention covers the individual or collective nutritional requirements in order to help people adopt appropriate lifestyle modifications related to diet.

To the best of our knowledge, this is the first study to develop a national list of food exchanges for the Ecuadorian population, which includes a diversification in food groups and subgroups, created to improve nutritionists' effectiveness in planning convenient and culturally sensitive diets and in turn patients' adherence to their dietary treatment. From now on, a list of food exchanges with 404 foods commonly consumed in Ecuador will be available to be used by nutritionists, dietitians, educators, health professionals, and researchers. The food exchange system has been designed to help convert evidence-based nutrition recommendations into food choices according to Ecuador's dietary patterns. For the development of the food exchange list, it was first necessary to establish the most commonly used household measurements in the population since these tools allow the patient to manage their diet in an autonomous way. For this reason, the process of defining said measurements was based on the identification of the measurements that are most commonly sold in large-scale vending centers on the one hand, and on the other hand, based on the recommendations of the team of experts in food intake in the different regions of the country. We identified six household measurements that include teaspoon, tablespoon, cup, glass, bowl, and plate (16). Experts such as Marques-Lopes (8, 34) and Jayawardena (12) also recommend defining household measurements based on regular units and, if necessary, distinguishing small, medium, and large units, and accompanying the use of the country's own household measurements. Following these recommendations, commercial units were included in the Ecuadorian list for packaged foods and for those that require a presentation based on length, width, and height, as in meat and fish. The criterion that allows one to differentiate the size of the food into small, medium, and large, as in the case of vegetables or fruits, was also included. This is an essential step prior to the definition of food quantities.

Since the 1950s to the present day, different lists and food groups have been created, which have been updated as data on the chemical composition of food items have increased and dietary recommendations for the population have been updated. The Ecuadorian list considers eight food groups organized according to the predominant macronutrient (see Table 3) and when necessary, subgroups were created depending on the variability mainly in the fat content, considered as a secondary nutrient in most groups. The introduction of the different subgroups of this list respects statistical inclusion criteria. Given that it is observed that an individual chooses foods for many reasons and the food items selected over the years can make a significant difference in the health of that individual, the diversity of foods included in this list will allow the patient to have

TABLE 2 Food exchange list for the vegetables group.

Name in Spanish	Name in English	NW (g)	Household measurement
Low in carbohydrates			
Achogcha, cruda o cocida	Balsam-pear (bitter gourd), raw or cooked	100	S: 5 units; M: 2½ units; G:1½ unit
Alcachofa, sin sal, cocida	Artichokes, without salt, cooked	45	½ unit
Alcachofa, leaves y corazón, cruda	Artichokes, leaves, and heart, raw	50	½ unit
Arveja, tierna, enlatada	Pea, canned	35	1/8 cup
Arveja, tierna, sin sal, cocida	Pea, without salt, raw or cooked	35	¼ cup
Berenjena, sin sal, cocida	Eggplant, without salt, cooked	60	5 slices
Berenjena, cruda	Eggplant, raw	70	7 slices, ½ unit
Brócoli, sin sal, cocido	Broccoli, without salt, cooked	70	S: 20 units; M: 3 units; L: 2 units
Brócoli, crudo	Broccoli, raw	70	S: 27 units; M: 4 units; L: 2 units
Cebolla roja o paiteña, cruda	Onions, raw	85	½ unit
Choclo, dulce, enlatado	Sweet corn, canned	30	2 full tbsp.; ¼ cup
Choclo, amarillo o blanco, en grano, crudo o cocido	Tender corn, yellow or white, raw or cooked	20	2 full tbsp.; ¼ cup
Col blanca, sin sal, cocida	Cabbage, without salt, cooked	95	2 leaves; 1 heaped cup
Col blanca, cruda	Cabbage, raw	100	2 cups
Coliflor, sin sal, cruda o cocida	Cauliflower, without salt, raw or cooked	108	1 cup
Espárrago	Asparagus	125	Raw: 9–10 units; Cooked: 9 units
Espinaca, sin sal, cocida	Spinach, without salt, cooked	120	1 ½ cup
Espinaca, cruda	Spinach, raw	120	3 cups
Frejol, tierno, toda variedad	Tender bean, all varieties	15	Raw: 1 full tbsp.; 1/8 cup; Cooked: 2 full tbsp.
Haba, tierna, cruda o cocida	Broad beans, immature seeds, raw or cooked	40	S: 28 units; M: 22 units; L: 12 units; ¼ cup
Nabo raíz, crudo o cocido	Turnips, without salt, raw or cooked	90	1½ cup
Palmito, enlatado	Heart of palm, canned	100	¾ cup
Pimiento, rojo	Pepper, red	75	½ unit
Remolacha, sin sal, cocida	Beetroot, without salt, cooked	50	1/3 cup
Remolacha, cruda	Beetroot, raw	50	½ cup
Sambo, crudo o cocido	Gourd, white, flowered raw or cooked	95	¾ cup
Tomate cherry, tomatillo	Cherry tomato	70	½ cup, 7–8 units
Tomate riñon, rojo	Tomato, red	100	½ cup, 3 slices
Vainita, sin sal, cocida	Bean, without salt, cooked	60	Raw: ¾ cup; Cooked: ½ cup
Zanahoria, jugo	Carrot, juice	50	1/8 cup, 1/8 glass
Zanahoria, sin cascara, cruda o cocida	Carrot, peeled, raw or cooked	50	1/3 cup
Zapallo o calabaza, amarilla	Pumpkin	60	Raw: ½ cup; Cooked: ¼ cup
Zuquinni, crudo o cocido	Squash/courgette, raw or cooked	150	1 full cup
Free consumption			
Acelga, sin sal, cocida	Chard, Swiss, without salt, cooked	80	1 level cup
Acelga, cruda	Chard, Swiss, raw	90	4 heaped cups
Alfalfa, brotes	Alfalfa, sprouts	80	2 ½ cups
Apio, tallos en palitos o cubos	Celery, sticks or cubes, raw	130	Sticks: 1 cup; Cubes: ½ cup
Berros, frescos	Watercress, raw	100	4 heaped cups
Champiñones, sin sal, crudo o cocido	Champignon mushrooms, without salt, raw or cooked	75	5 units
Lechuga, romana, crespa	Lettuce, cos, romaine, raw	100	1 small unit
Lechuga, criolla	Lettuce, green leaf, raw	125	6 leaves

(Continued)

TABLE 2 (Continued)

Name in Spanish	Name in English	NW (g)	Household measurement
Pepinillo	Cucumber	150	¾ unit; 20 slices; 1 ½ cups
Rábano	Radishes, raw	200	2 full cups
Rúcula	Arugula, raw	85	2 ½ cups

NW, Net weight; S, small unit; M, medium unit; L, large unit.

different options and greater flexibility in their diet. In addition, the management of local household measurements was added, which is expected to increase the probability of better adherence to specific diets such as those to be applied in patients with non-communicable diseases (3). This type of classification has been established in lists created in Spain (8), Mexico (17), Peru (13), and the United States (18). It should be noted that each country has included subgroups of food items depending on their cultural and dietary context. For instance, Mexico includes a group called "energy-free foods" to refer to sweet and savory spices, e.g., Tabasco sauce; this is because they are consumed frequently and in representative quantities. Spain, on the other hand, includes the subgroup "confectionary and others" to refer to sweet pastry products high in sugar, such as the traditional consumption of croissants. In the more Latin American context, Peru highlights the consumption of the subgroup "stewed beans" to refer to local dishes prepared with dried legumes. In Ecuador, due to the frequent consumption of cereals, tubers, and plantains such as rice, sweet potato, and green plantain, the subgroup "high in carbohydrates and low in fat" was created. On the other hand, groups such as vegetables, dairy products, and meat, fish, and eggs are framed within the criteria of their high, médium, or low content with respect to their primary macronutrients.

The first group presented in this list is that of cereals, tubers, and plantains since these form the basis of the Ecuadorian diet (35). Due to the great diversity of foods rich in carbohydrates, this group was organized into three subgroups according to the CHO content (20–30 g), where their total fat content (1–6 g) was considered as a secondary nutrient since their nature or degree of processing – as happens with bakery products – increases their average total fat content to 6 g ± 2 per exchange portion. This classification was established by taking into account that carbohydrates are consumed as the main source of energy in the population (27); in this way, a list of 88 foods that will allow patients to diversify their diet was created. The needs of the clinical approach where the exchange lists are used were also considered since, depending on the high, medium, or low CHO content, their recording is facilitated, for example in patients with Type 1 or Type 2 diabetes, and gestational diabetes, who need to combine their pharmacological treatment with a contribution and subdivision of CHO in their diet (2, 36). Other countries in the region have also developed their lists by considering the group of cereals, tubers, roots, stewed beans, and plantains as basic food items for the population, while always respecting each nation's food culture (13–15). With respect to the lists from other countries in the region, we emphasized in our list the inclusion of subgroups that enable people to eat a varied diet while also considering the high, medium, or low content of macronutrients.

The second group of foods where the classification by subgroups was also applied is the dairy group, which was organized by considering its protein content as the primary nutrient, and total fat content as its secondary nutrient, resulting in high-, medium-, and low-fat subgroups (Total fat: 1–8 g). Given the existence of low-fat products that are rich in CHO, we saw the need to include an appropriate subgroup since the average CHO content of these products reaches 25 g ± 1, resulting in a caloric intake equal to a high-fat dairy product. These low-fat, CHO-rich products are generally associated with a higher content of simple sugars, and their inclusion in dietary plans can influence the nutritional education of patients who require strict CHO control, such as patients with diabetes. Moreover, in this group it was necessary to include a subgroup exclusively for the types of cheese sold in the Ecuadorian market (n:18), ordering the list from highest to lowest according to their fat content, with an average fat intake of 7 g ± 3. The exchange portion sizes were measured in terms of length, width, and height for those types of cheese that are not sold in regular sizes. This kind of classification associated with dairy products has been applied around the world (8, 13, 15, 34) since the consumption of these products is increasing; therefore, it is necessary to differentiate those with higher fat and sugar content, as established by Marques-Lopes et al. (8) in Spain, where they also include subgroups related to the consumption of sweetened dairy desserts, which is very common in that country (8). For the Ecuadorian list, this type of food was not considered since there is not a significant demand for them and they are not yet cataloged as frequently consumed foods.

Given the diversity of protein-rich foods, such as meat, fish, and eggs, commonly consumed by the Ecuadorian population, it was necessary to organize them into four subgroups also according to a secondary macronutrient, in this case total fat content (Total fat: 2–15 g). This is because evidence has indicated that fat intake should not exceed 35% of the requirement, since fats can play a positive or negative role in the prevention or treatment of diseases (37, 38). Along these lines, a single group was also determined for foods with medium and high fat contents, defined as fats and nuts (Total fat: 7–12 g), which includes food items like oils, solid fats (e.g., butter), nuts, and seeds. Thus, the list will allow the patient to make more suitable choices.

Finally, the groups of fruits, vegetables, legumes, and sugars and sugary foods were organized only according to their primary macronutrient, and the carbohydrate content was established for all of them since no statistical variability was found that would show the need to create subgroups of food items according to a secondary nutrient. For each item, the most appropriate household measurement was used according to the form of consumption.

Thus, within a food group, one exchange is approximately equal to another in terms of energy, carbohydrates, protein, and total fat, and can be exchanged for any other food in the same list. To achieve this goal, the estimation of the coefficient of variation was applied, which had to be CV < 30%, evidencing that it was strictly complied with for the primary macronutrients in all groups. The cold meats subgroup is the only one that exceeds this limit (CV = 35%) in caloric

TABLE 3 Nutritional content of exchange portions for each food group, respecting statistical limits.

Food group	*N*	Energy (kcal)	SD	CV (%)	Carbohydrates (g)	SD	CV (%)	Proteins (g)	SD	CV (%)	Total fats (g)	SD	CV (%)
Cereals, tubers, and plaintains													
High in carbohydrates and low in fat	55	150	±	20	14	30	±	4	12	4	±	2	53	1	±	1	95
Medium carbohydrate and medium fat	18	145	±	11	8	20	±	2	12	2	±	1	37	6	±	2	28
Medium carbohydrate and low fat	15	105	±	16	14	20	±	2	9	3	±	1	47	1	±	1	83
Fruit																	
Medium carbohydrate	34	90	±	13	15	20	±	3	14	1	±	1	52	0	±	0	119
Low carbohydrate	22	50	±	9	19	10	±	2	19	1	±	1	99	0	±	0	98
Dried fruit	10	95	±	13	14	20	±	4	17	1	±	1	79	0	±	0	125
Vegetables																	
Low in carbohydrates	34	30	±	4	16	5	±	0	8	1	±	1	63	0	±	0	73
Free consumption	11	25	±	4	16	3	±	0	10	2	±	1	44	0	±	0	49
Dairy products																	
Whole milk, high in fat	3	150	±	2	2	11	±	0	2	8	±	0	3	8	±	0	1
Semi-skimmed, medium fat	2	110	±	7	6	11	±	0	3	8	±	0	0	4	±	1	15
Skimmed, low fat	2	90	±	9	10	12	±	0	2	8	±	0	3	1	±	1	79
Skimmed and high in carbohydrates	2	150	±	7	5	25	±	1	4	6	±	0	4	3	±	1	40
Cheese	18	95	±	21	23	1	±	1	104	7	±	1	10	7	±	3	42
Meat, fish, and eggs																	
High in fat	8	180	±	25	14	1	±	2	208	11	±	2	18	15	±	3	19
Medium fat	20	110	±	16	14	0	±	0	242	11	±	2	17	7	±	1	19
Low in fat	55	65	±	11	16	0	±	1	204	11	±	1	10	2	±	1	54
Cold meats	9	100	±	34	35	1	±	1	59	7	±	1	20	7	±	4	52
Legumes	20	120	±	15	12	20	±	5	29	9	±	1	9	1	±	2	113
Fats and nuts																	
High in fat	19	120	±	18	15	1	±	2	161	1	±	2	168	12	±	2	19
Medium fat	8	75	±	8	11	2	±	2	110	1	±	1	107	7	±	1	16
High in fat and low in carbohydrates	8	140	±	15	11	8	±	4	51	4	±	2	42	10	±	2	20
Medium fat and low in carbohydrates	5	125	±	23	19	12	±	4	28	2	±	1	49	7	±	1	14
Sugars and sugary foods	26	40	±	10	23	10	±	2	16	0	±	0	156	0	±	0	196

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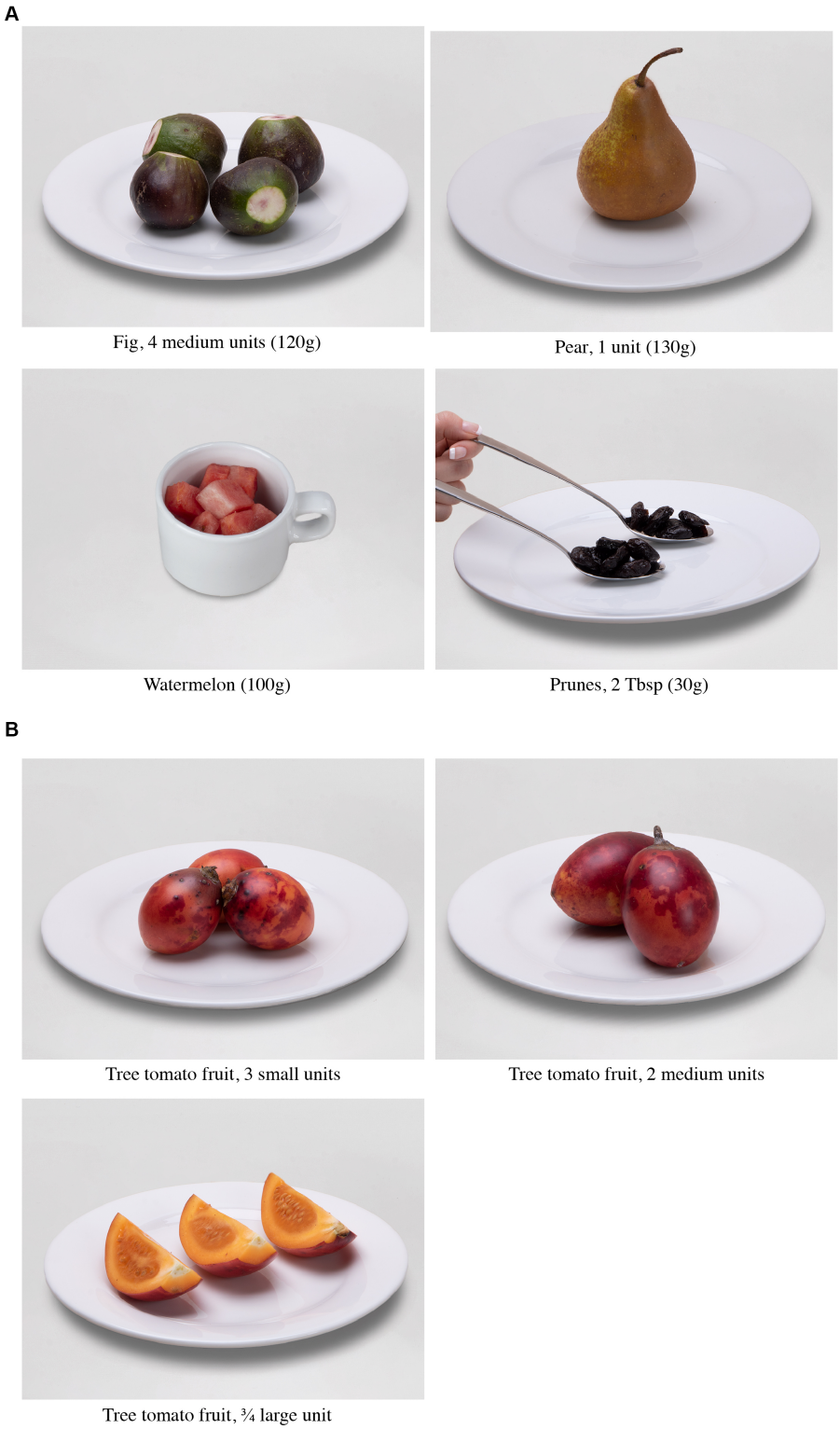

FIGURE 2
Fruit exchanges according to variety and quantity. **(A)** Variety of fruits. **(B)** Amount based on the size of the food item (small, medium, or large).

value; however, thanks to the Z parameter, this caloric variability does not seem to be representative, since all the foods in this subgroup show a Z value equivalent to ±2. This variability may be due to the fact that in these food items, the regular and commercialized size was respected, instead of a size based on the use of household measurements, and added to this, the effect of the nutritional compositions of the products themselves was taken into account.

Therefore, the Ecuadorian list can be used in clinical practice, for example in the case of patients with diabetes since local food items were included in the general groups, such as fruit, legumes, and

cereals, tubers, and plantains, and these were organized on the basis of 10–30 g of CHO per exchange portion, which facilitates carbohydrate counting. This organization allows the nutritionist to evenly distribute the CHO count in the patient's daily menu. Protein quantification is also essential in clinical practice, especially in patients with differentiated requirements, such as renal, burn, or malnourished patients (3), as well as in special situations in healthy populations with high protein-energy requirements, such as athletes (39). In this regard, the Ecuadorian list also organizes the food groups according to their average protein contribution (6–11 g of protein per exchange portion). In particular, the information for meat, fish, and seafood, dairy products, and legumes will allow both patients and athletes to define their food plans with a greater diversity of options.

For each exchange portion, a photographic record was taken according to the most common forms of consumption, that is, the same exchange can be presented in a cup, glass, or units consumed depending on the size– small, medium, or large. This will allow a nutritionist to add a visual tool to nutrition education because in several studies it has been shown that the use of photographs improves the perception of the size of the portion consumed (40, 41).

This food exchange list was created based on the food context of the Ecuadorian population. Yet this study has certain limitations, as outlined below. One of the limitations is related to the sources where the information on the nutritional composition of foods was obtained. Most of these data were taken from composition tables from other countries because in Ecuador the last reference of a National FCT where bromatological analyses have been performed dates back to 1965 and to correctly estimate intake, it is necessary to have an updated Ecuadorian FCT. The Ecuadorian table (1965) analyzed very few food items and presented non-updated analytical methods, so the latest updates of the FCT in Ecuador have been carried out by applying using data borrowed from other FCTs or databases in the region. It is known that composition has different factors that can modify it, that it varies from one geographical area to another, according to the analytical method applied or even depends on the cooking techniques used for the food (42). Nonetheless, it has been possible to observe less variability in the macronutrients of natural or minimally processed foods. Therefore, to compile the Ecuadorian list, we searched for these food groups in the most complete sources in the Latin American context, which encompass most of the foods consumed in Ecuador and often furnish its food database. That is why the Central American FCT developed by INCAP has been taken as a regional reference. In addition, the nutritional information was complemented with small national databases, such as the one produced in Cuenca, Ecuador, or for more processed or ultra-processed food items the nutritional information was obtained directly from the food labeling provided by the food industry. The USDA database allowed us to complete the nutritional composition for more processed food items, i.e., fast food. Therefore, the list should be used with caution if the objective in planning is to consider the content of micronutrients since many of the foods might be fortified or supplemented.

Another limitation is not including traditional cuisine in the exchange list, such as soups (e.g., potato locro) or rice (e.g., rice with seafood). The reason for this is the absence of official records of nutritional composition analysis measured in laboratories that inform one of their standardized contributions, hence they simply could not be included; this could limit their inclusion in meal plans or food guides. Nonetheless, an extensive list of foods or ingredients with which food alternatives can be generated according to the region is included. For example, exchanges for cooked rice, cooked shrimp, or cooked fish are presented, which facilitates the combination and therefore the generation of new recipes. Another limitation that the list may present is non-standardization, especially considering critical micronutrients in the Ecuadorian population (e.g., iron, zinc, calcium, and vitamins A and C). Such an analysis should be performed in future studies since their relationship with typical health problems in the country has been demonstrated. Despite these limitations, this study provides health professionals and consumers with a system of food exchanges that facilitates menu planning, as it can be used in individualized dietary planning or collective nutritional.

This food exchange list targeted at the Ecuadorian population is the first list to be made using a process that respects statistical criteria, thus categorized as a good source of information on macronutrient and energy content divided into eight major food groups, all supported by their photographic record. It provides detailed information on food quantities using household measurements to allow dietitians, nutritionists, researchers, and other health professionals to develop culturally sensitive meal plans with healthier choices tailored to clinical or population needs. Diets planned from exchange lists that include local food items are more likely to be successfully implemented, helping to reduce problems related to adherence, limited food choices, or exchange portion sizes that are unrealistic for the country context.

Data availability statement

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

Author contributions

AMC-T, MH-F, and GV-R designed the project, were involved in data and sample collection, and wrote the manuscript. AMC-T, and MH-F participated in the analyses and interpretation of data after performing the statistical analyses. All authors performed a critical review of the final manuscript, contributed to the article, and approved the submitted version.

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Conflict of interest

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

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2023.1219947/full#supplementary-material

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Wild and backyard food use during COVID-19 in upstate New York, United States

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Introduction: COVID-19 acutely shocked both socio-economic and food systems in 2020. We investigated the impact of COVID-19 on production and consumption of gardened produce, backyard poultry, wild game and fish, and foraged mushrooms, berries, and other plants in New York State, aiming to understand crisis influenced food choice and motivations, including food security.

Methods: We conducted an online, cross-sectional survey in October–December 2020 with a convenience sample of participants (n = 505) with an interest in gardening, poultry rearing, foraging, hunting, and/or fishing from six counties in upstate New York. We recruited through the New York Department of Environmental Conservation, Cornell Cooperative Extension, and other relevant email and social media pages.

Results: Across the wild and backyard food production strategies, 4.0–14.3% of respondents reported engaging for the first time and 39.6–45.7% reported increased production (a little or a lot more), and 31.6–42.7% of respondents' production was the same as the previous year. Consumption of foods produced was widespread, including fruit and vegetables (97.6% of producers also consumed), backyard eggs (92.7%), and foraged foods (93.8%). For meats, a majority consumed backyard poultry meat (51.2%), wild-caught fish (69.7%), and wild game they hunted (80.1%). The frequency of consumption of fruit and vegetables (average of 13.5 times/month) and eggs (16.4 times/month) was very high, while average consumption of poultry meat, foraged foods, fish, and wild game ranged from 3.1 to 5.8 times/month. The number of respondents who reported "have more control over food availability" as motivation to produce all wild and backyard foods increased from 2019 to 2020 ($p < 0.05$ - $p < 0.001$). There was also a significant relationship between experiences of COVID-19 related hardship (i.e., food insecurity, income loss) with gardening and poultry-rearing ($p \leq 0.05$), but not with other production methods or with consumption of wild and backyard foods.

Discussion: Our findings help to locate wild and backyard foods within COVID-19 impacted food environments, and describe food security as a particularly relevant motivation, among others, reported by respondents in 2020. Given this, New York State service providers can use these findings to tailor current future support for households exerting control over their own food environments with wild and backyard foods, allowing the state to be better prepared for future crises.

KEYWORDS

hunting, fishing, foraging, backyard poultry, gardening, food security, pandemic, food choice

Introduction

The COVID-19 pandemic constituted a global shock, with far-reaching, interconnected impacts on global socio-economic and food systems beginning in 2020 (1). Lost jobs, cut hours, and furloughs impacted incomes and well-being (2). At the same time, food supply chains faltered amid soaring demand for nonperishable, low-cost foods; forced closures of restaurants; and challenges in providing COVID-safe working conditions (3, 4). These parallel economic and food system impacts in early 2020 acutely shifted global food environments. For households and individuals, food choices had to be made in the face of uncertainty about food availability due to unstable supply chains, as well as variable lock down orders, income changes, and food safety concerns. Consequent shifts in eating behavior have been observed around the world, with diet quality largely found to have worsened during the early pandemic (5). Global food insecurity worsened precipitously (6, 7).

Here we examined how early responses to the COVID-19 pandemic shifted food environments and food consumption patterns. We used the case of New York State in 2020 to analyze production and consumption of wild and backyard food in a food environment stressed by a large-scale crisis.

Wild and backyard foods use expanded during COVID-19

To contextualize our analysis, we review the literature regarding shifts in wild and backyard food production early in the pandemic. We include geographies around the world, but emphasize United States, Canadian, and European settings most like our study site in upstate New York, United States.

Within the altered food environments and public health lockdown restrictions, wild and backyard food production – including gardening, raising backyard poultry, foraging, fishing, and hunting – was reported both as a pastime and a food access strategy (8, 9). Reports of widespread engagement in backyard gardening and poultry production, as well as upticks in use of private and wild lands for foraging, hunting, and fishing were soon widespread across the United States, Canada, Europe and other Global North settings (10–12). Alongside these shifts came calls for a resurgence of victory gardens, stock-outs of seeds and tomato cages, and unprecedented demand for hunting and fishing licenses (8, 9, 13).

Researchers found shifting roles and growth in gardening, a range of food safety concerns stemming from backyard poultry expansion, high participation in hunting and fishing, and isolated reports of increased foraging. In contrast to a growing literature on participation in wild and backyard food *production,* very limited information ties these activities to shifts in food *consumption patterns* or other health outcomes, though we incorporate these findings wherever available.

The early stages of the pandemic saw widespread proliferation of gardening. A global analysis of search terms showed that online interest in gardening (from Google Trends data) was strongly synchronized with the initial waves of infection (14). In Louisiana (United States), 82% gardeners responding to a consumer survey increased gardening effort (15), and in Kentucky (United States), increases in gardening were linked directly to changing food environments (16). In other Global North settings, similar trends were observed. In Canada, 17.4% of gardeners surveyed began gardening in 2020 (17). In parts of Europe, there was an approximately 10% increase in all types of home gardening (18). A study in Taiwan found that pandemic-related stress indirectly promoted intentions to garden (19).

Gardeners and community garden support organizations also reported facing pandemic-related barriers (20–22). In the early pandemic, survey respondents across the Global North reported more challenges from COVID-19 and put a higher value on gardening to produce food and save money (20). However, pandemic-related reasons for gardening or not gardening were highly variable depending on age, gardening experience, and time at home in a 2020–2021 survey in the United States (23). This indicates that access to gardening as a pandemic coping strategy was far from universal, despite its desirability and usefulness, in agreement with studies in diverse locations from Europe to Benin to China (24–26).

Many studies showed pandemic gardening was related to physical, mental, and social well-being. Pandemic gardening supported access to healthy food, spaces for creativity, and created safe and positive social connections in worldwide locations (20, 22, 27). In urban upstate New York, it facilitated connection with other gardeners and nature, supported mental and physical well-being, and contributed to community resilience efforts (21). Increased gardening was spurred by ethos around seeking well-being and self-sufficiency for communities at risk of poor food access in Italy and in Arizona, United States (28, 29). In Benin, a study found that access to gardens protected food security in rural and urban areas from pandemic associated impacts (24). Several studies found a widespread perception that gardening mitigated pandemic-related stress from lockdowns in parts of Europe, North and South America, Australia, China, and Taiwan (19–21, 26, 30–33).

A few studies used established measures to assess the health of gardeners. Gardening showed a generalized protective effect on the Depression, Anxiety, and Stress Scale (21-item) in India (34). In the United States, gardening showed a stronger protective effect on Generalized Anxiety Disorder (7-item) scores for experienced gardeners while age, geographical location, and gender also moderated the protective effect (35). However, in Scotland, while gardening was associated with self-reported improvements in health, it was not associated with better health outcomes such as body mass index, anxiety, depression, diabetes, or cardiovascular disease (36).

While we found little evidence on the extent of backyard poultry production shifts and who participated, expansions in backyard poultry production have quickly given way to concerns about disease transmission for new producers. In Vermont, production of backyard chickens was most common in rural areas and among wealthier and more educated households (37). Larsen et al., also showed low uptake of biosecurity practices among backyard poultry rearers, and that nearly 20% of backyard flocks have *Salmonella enterica*. Across the United States, 2020 saw more than 1,700 Salmonella outbreaks linked to privately owned poultry, an increase over previous years driven by COVID-19 pandemic engagement in poultry rearing (38).

Hunting participation generally increased during the pandemic. A survey of wildlife biologists across the United States revealed that during turkey hunting season 2020 many states saw an increase in hunting license sales, hunting effort, and harvest compared to the mean from the previous 3 years; this change was not due to an increase in turkey abundance (13). In another example, while non-resident

turkey permits were closed in Nebraska to discourage travel, the number of resident hunters increased by 23% and resident permits rose by 26% (39). In Calakmul region, Campeche, Mexico, twice as much hunting effort and take of white tail deer was observed during mid 2020 (40).

Fishing within traditionally 'recreational' fisheries (41) largely increased during the early phases of the pandemic. Although in several surveys anglers noted access barriers at some points during COVID-19 (42–44), the COVID-19 lockdown policies of more than 90% of United States and Canadian provinces ultimately permitted recreational fishing (45). In many settings, fishing flourished. Over a quarter of respondents in an European survey reported increasing fishing trips (46), and anglers credited fishing as an important support to their mental health. In a survey across ten United States, the number of trips per angler significantly increased (43). In a survey of recreational fishers in Ontario (Canada), 21% of respondents said they had resumed fishing or newly began fishing (47) and radio telemetry showed an 8-fold increase in exploitation rate (48). In Wisconsin (United States), in-state license sales increased a striking 71% and lakes with public shorelines saw increased visitors (49).

While limited evidence about shifts in foraging specifically has emerged, those studies that address it did see changes. One study found that during the pandemic foraging was integrated into urban food provisioning strategies (50), while another found that all outdoor activities (including gardening and foraging) increased (51).

Impacts of COVID-19 on New York state

While the pandemic also impacted policies and supply chains in ways that affected access to wild and backyard foods, locales largely permitted these activities (45). The few studies of shifting participation in wild and backyard food production have shown growth in participation in the early phases of the pandemic. A representative survey in Vermont found over a third of households participated in wild and backyard food production, with half of participants engaging for the first time or more intensely as a result of the pandemic (52). Yet, while food insecure households more intensely produced wild and backyard foods, only food secure households saw higher fruit and vegetable consumption from these sources (52).

The specific context of New York state's COVID-19 timeline and control measures affected its wider food environment, as well as access to wild and backyard food production during the study period. A state of emergency was declared March 7, 2020. By the end of March, New York State was 'On Pause' with non-essential workers at home and schools closed. Residents were told to stay home. All events were canceled. Over 2 months later, on May 15, 2020, New York implemented a phased re-opening of non-essential businesses. Each region within the state was assigned one of four phases weekly, depending on the COVID-19 health metrics at that time. This study was conducted in counties that are part of three New York regions, but those regions had similar trajectories through the phase system; individuals in the studied counties largely experienced similar restrictions at any given time. For example, all 6 counties were assigned to phase one on May 15, 2020, and to phase two by May 28, 2020.

The relevant restrictions for wild and backyard food production were as follows: in phase one individual fishing and hunting was allowed by the state, contingent on any additional guidance of local governing bodies (i.e., cities, municipalities). However, commercial fishing services and for-hire fishing vessels were required to follow state-level public health guidelines (53). Indoor retail stores selling gardening, poultry-rearing, fishing, and hunting supplies reopened in phase two.

Wild and backyard food production in New York is supported by several different local service providers which host a variety of educational, licensing, and supportive services. Hunting and fishing are administered by the New York Department of Environmental Conservation in collaboration with the New York Department of Health; both have an in-depth but sometimes difficult to navigate online presence. Cornell Cooperative Extension acts at county and state level, supporting gardening and poultry raising at large and small scales, as well as agroforestry. Its county offices host detailed and locally variable educational resources online, and sometimes have social media presences as well. Education and support for foraging, however, is largely decentralized and privately run for profit.

When "NY On Pause" was initiated, all in-person educational events were canceled. This included hunter education classes, gardening classes, fishing promotion events, foraging education courses, expert consultations for troubleshooting, and more. However, fishing and hunting licenses were consistently available throughout for online purchase. Beginning April 15, 2020, the New York hunter education certificate became fully available online, removing the requirement for in-person classes. In general, service providers had to lean on whatever previously developed remote and online resources they had at first, and then adjust to each change in policy as they were rolled out.

This work is guided by two primary research questions: (1) how did production and consumption of wild and backyard foods shift during the early months of the COVID-19 pandemic, (2) do associations exist between food insecurity and the production and consumption of wild and backyard foods. These findings have implications for food access and well-being during a time of acute systemic stress on food environments and may assist local and regional wild and backyard food service providers and support organizations to help individuals and households cope better in the future.

Materials and methods

We conducted an online cross-sectional survey with a convenience sample of upstate New York residents ($n = 505$). We chose six counties (Broome, Cortland, Onondaga, Oswego, Cayuga, and Seneca counties) that provided local opportunities for all five food production activities and encompassed both rural and urban areas within central and upstate New York. The survey was open between October 26 – December 10, 2020. The study was exempted from IRB review by the Cornell IRB (Protocol ID#: 2008009765).

Survey distribution and eligibility requirements

Cornell Cooperative Extension offices in each of the six counties and the New York Department of Environmental Conservation

supported recruitment of adults with an interest in gardening, poultry rearing, foraging, hunting, and/or fishing. Cornell Cooperative Extension offices shared information about the survey through their websites, relevant email lists (e.g., 4-H, Volunteer Network), and social media presence (e.g., Facebook and Twitter for Cornell Cooperative Extension-Broome County). The New York Department of Environmental Conservation distributed the survey through their Hunting, Fishing, Sustainability, and Becoming an Outdoors-Woman email lists. In addition, the survey was distributed through social media community groups and message boards in relevant topics (i.e., the page for a town in the sample area, an Upstate New York hunting and fishing group, Central New York Gardeners, etc.), mutual aid groups, and a local newspaper.[1] This resulted in a convenience sample of adult residents who were likely to participate in food self-provisioning activities. Respondents were offered a chance to opt into a raffle to win one of 20 gift cards for $50 to a local grocery store for survey participation. Identifying information was kept separately from analyzed data and stored per Cornell IRB's requirements. This online sample aimed to capture adults who participate in the production and consumption of wild and backyard foods. The survey was conducted online to reduce COVID-19 risks for respondents. The respondent population is non-random and therefore biased, including, for example, towards those who learned of the survey, had online access, and were available and interested to take the survey. We compared survey respondent demographic proportions to the 2020 census numbers to assess the bias introduced.

Survey domains

All respondents answered questions in domains covering demographics and COVID-19 impacts on employment (Table 1) and general food procurement (Table 2) from the National Food Access and COVID-19 Research Team (6, 54). This module asked about 7 types of food assistance and 11 sources of food being used at the time of survey, with a parallel reference period of 'the same time period in 2019'. We also captured COVID-19-related impacts on employment using the same approach. Demographic characteristics included education level, income, gender, race, and ethnicity. Food security was assessed with the U.S. Department of Agriculture's Household Food Security Survey Module: Six-Item Short Form over a 30-day reference period (55) again with the parallel reference period in 2019 (Table 2).

To assess COVID-19 impact on general food procurement and production and consumption of wild and backyard foods, we referred in the survey to the "pre-COVID" period as "2019." This was compared to the period "since the COVID-19 outbreak," defined as the time between March 2020 and late fall 2020 (October–December), when the survey was conducted. General food procurement investigated *purchased food* (such as grocery shopping options, delivery options, restaurant options, local and alternative options) and *food assistance* (including federal programs like the Supplemental Nutrition Assistance Program or SNAP, formerly food stamps and the Special Supplemental Nutrition Program for Women, Infants, and Children or WIC; local programs such as community food closets and food banks; food or money for food from family, friends, or neighbors; and religious community support). Perceived shifts in production effort of wild and backyard foods (Figure 1) were assessed by asking which of six ordinal choices best described their effort in 2020, compared with 2019 (choices: 'first time', 'much more', 'a little more', 'the same amount', 'a little less', and 'a lot less'). Participants were asked where they gardened, reared poultry, foraged, hunted, and fished but these answers are not reported here. Wild and backyard food production effort and consumption were assessed based on the below definitions at the group level. Changes in use of individual types of food within each group were not assessed.

Definitions of production methods in online survey	
Gardening	Vegetables, fruits, and herbs
Backyard poultry rearing	Eggs and meat
Foraging	Berries or other fruit, greens or other vegetables, roots, mushrooms, medicinal plants
Hunting	White tailed deer, waterfowl, turkey, upland birds such as grouse, small game, and other
Fishing	Cold water fish such as salmon or trout, etc. and warm water fish such as bass, catfish, perch, sunfish, walleye, etc.

To assess food consumption changes (Table 3), we used a question developed for the National Food Access and COVID-19 Research Team survey to measure changes in fruit and vegetable and red and processed meat consumption during the COVID-19 pandemic as compared to the previous year (6). We also adapted a food frequency questionnaire to specifically focus on frequency of consumption of fish, game, fruits, vegetables, poultry, and eggs, and identify the source of these foods (e.g., wild or backyard production; from family, friends or neighbors; purchased from a farm; purchased from a store). Among those who produced wild and backyard foods, we asked how their consumption had changed. Perceived shifts in consumption of wild and backyard foods were assessed by asking which of six ordinal choices best described their consumption in 2020, compared with 2019 (choices: 'first time', 'much more', 'a little more', 'the same amount', 'a little less', and 'a lot less').

Respondents who indicated they practiced gardening, backyard poultry, foraging, hunting, and/or fishing were asked questions about their practices, effort, skill levels, and challenges regarding each activity. Respondents were asked to compare 2019 and 2020. As the popular deer hunting season was beginning at the time of our survey (October–December), hunting was addressed by asking about respondents' 2020 hunting plans. For other activities, respondents were asked retrospectively about the recent production season and comparisons to 2019. All respondents answered a set of questions regarding motivations for why they chose to get food they produced or harvested themselves by gardening, raising poultry, foraging, hunting, [or] fishing (Table 1). For more details, see the survey text in Supplemental materials.

1 Syracuse.com

TABLE 1 Respondent demographics overall and by food self-procurement activity during the COVID-19 outbreak.

	All households *n* (%)	Gardening *n* (%)	Poultry *n* (%)	Foraging *n* (%)	Fishing *n* (%)	Hunting *n* (%)
Gender	*n* = 431	*n* = 289	*n* = 40	*n* = 110	*n* = 119	*n* = 136
Male	136 (31.6)	83 (28.7)	10 (25.0)	41 (37.3)	60 (50.4)	76 (55.9)
Female	274 (63.6)	190 (65.7)	28 (70.0)	64 (58.2)	57 (47.9)	54 (39.7)
Prefer not to answer	16 (3.7)	13 (4.5)	1 (2.5)	4 (3.6)	2 (1.7)	6 (4.4)
Self-describe	5 (1.2)	3 (1.0)	1 (2.5)	1 (0.9)	0 (0.0)	0 (0.0)
Income	*n* = 412	*n* = 278	*n* = 40	*n* = 109	*n* = 116	*n* = 130
<$15,000	15 (3.6)	9 (3.2)	1 (2.5)	6 (5.5)	3 (2.6)	2 (1.5)
$15,000 to $24,999	28 (6.8)	18 (6.5)	3 (7.5)	6 (5.5)	4 (3.4)	6 (4.6)
$25,000 to $49,999	78 (18.9)	49 (17.6)	4 (10.0)	17 (15.6)	21 (18.1)	24 (18.5)
$50,000 to $74,999	96 (23.3)	70 (25.2)	10 (25.0)	32 (29.4)	30 (25.9)	34 (26.2)
$75,000 to $149,999	139 (33.7)	93 (33.5)	17 (42.5)	35 (32.1)	42 (36.2)	47 (36.2)
$150,000+	56 (13.6)	39 (14.0)	5 (12.5)	13 (11.9)	16 (13.8)	17 (13.1)
Education	*n* = 431	*n* = 289	*n* = 40	*n* = 110	*n* = 119	*n* = 136
Some high school (no diploma)	1 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
High school graduate (including GED)	22 (5.1)	13 (4.5)	2 (5.0)	5 (4.5)	4 (3.4)	9 (6.6)
Some college (no degree)	63 (14.6)	43 (14.9)	8 (20.0)	24 (21.8)	24 (20.2)	21 (15.4)
Associate degree/technical school/ apprenticeship	77 (17.9)	48 (16.6)	8 (20.0)	21 (19.1)	28 (23.5)	33 (24.3)
Bachelor's degree	131 (30.4)	91 (31.5)	11 (27.5)	31 (28.2)	33 (27.7)	44 (32.4)
Postgraduate (Master's, PhD) or professional degree (JD)	137 (31.8)	94 (32.5)	11 (27.5)	29 (26.4)	30 (25.2)	29 (21.3)
Ethnicity	*n* = 426	*n* = 286	*n* = 40	*n* = 109	*n* = 117	*n* = 134
Not of Hispanic/Latino/Spanish origin	415 (97.4)	278 (97.2)	37 (92.5)	106 (97.2)	112 (95.7)	131 (97.8)
Hispanic—Puerto Rican	6 (1.4)	6 (2.1)	3 (7.5)	3 (2.8)	4 (3.4)	3 (2.2)
Hispanic—Another origin (Self-describe)	5 (1.2)	2 (0.7)	0 (0.0)	0 (0.0)	1 (0.9)	0 (0.0)
Race	*n* = 430	*n* = 289	*n* = 40	*n* = 110	*n* = 119	*n* = 136
American Indian/Alaska Native	7 (1.6)	4 (1.4)	1 (2.5)	3 (2.7)	5 (4.2)	4 (2.9)
Asian/Asian American	6 (1.4)	4 (1.4)	0 (0.0)	1 (0.9)	0 (0.0)	0 (0.0)
Black/African American	5 (1.2)	4 (1.4)	1 (2.5)	1 (0.9)	2 (1.7)	1 (0.7)
Hispanic/Latinx/Spanish origin	9 (2.1)	8 (2.8)	3 (7.5)	3 (2.7)	5 (4.2)	3 (2.2)
Middle Eastern/North African	2 (0.5)	2 (0.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Native Hawaiian/Pacific Islander	3 (0.7)	2 (0.7)	1 (2.5)	1 (0.9)	1 (0.8)	1 (0.7)
White	393 (91.4)	260 (90.0)	37 (92.5)	102 (92.7)	109 (91.6)	124 (91.2)
Prefer not to answer	16 (3.7)	11 (3.8)	0 (0.0)	2 (1.8)	2 (1.7)	4 (2.9)
Self-describe	10 (2.3)	9 (3.1)	1 (2.5)	4 (3.6)	3 (2.5)	7 (5.1)

Data analysis

Quantitative data analysis was conducted using R Studio (version 2022.7.2 + 576 "Spotted Wakerobin"). R packages included tidyr, qualtRics, questionr, ggplot2, and viridis. Responses were retained for analysis if they answered questions regarding food security at the time of the survey and in the same period in 2019, and also answered questions regarding at least one wild or backyard food activity at the time of the survey and in the same period in 2019. Respondent characteristics were summarized using percentages for the total sample, and for each wild or backyard food activity sub-sample separately (respondents could be in multiple sub-samples).

First, food security, food assistance utilization, and use of traditional food sources were summarized for before and during the COVID pandemic, and McNemar's tests performed to test whether percentages were equivalent for reports about 2019 and 2020

TABLE 2 Perceived changes in food security, food assistance utilization, and food sources before and during the COVID-19 pandemic.

	2019 *n* (%)	Since the COVID-19 outbreak *n* (%)	*p*-value
Participation in wild and backyard food production			
Gardening	303 (60.0)	307 (60.8)	0.77
Backyard poultry	48 (9.5)	46 (9.1)	0.86
Foraging	108 (21.4)	121 (24.0)	0.086
Fishing	134 (26.5)	124 (24.6)	0.203
Hunting	142 (28.1)	143 (28.3)	1.0
Food security			
High or marginal food security	398 (93.4)	378 (87.7)	**<0.001**
Low food security	19 (4.5)	38 (8.8)	**<0.001**
Very low food security	9 (2.1)	15 (3.5)	**<0.001**
Food sources			
Grocery store	447 (96.8)	411 (89.0)	**<0.001**
Convenience or corner store	155 (33.5)	140 (30.3)	**0.041**
Specialty food store	181 (39.2)	149 (32.3)	**<0.001**
Grocery delivery (like Amazon or Instacart)	43 (9.3)	154 (33.3)	**<0.001**
Meal-kit delivery (like Home Chef)	32 (6.9)	32 (6.9)	1.0
Meals on Wheels	1 (0.2)	2 (0.4)	1.0
Restaurant to-go	274 (59.3)	370 (80.1)	**<0.001**
Restaurant eat-in	355 (76.8)	154 (33.3)	**<0.001**
Farmers' market	307 (66.5)	218 (47.2)	**<0.001**
Direct from farm (CSA, farm stand pickup/delivery)	128 (27.7)	145 (31.4)	0.065
Other (Self-describe)	21 (4.5)	29 (6.1)	0.061
Food assistance			
SNAP or Food Stamps (including COVID-19-EBT or P-EBT)	24 (7.1)	38 (11.2)	**0.014**
WIC (Women, Infant, and Children's Program)	11 (3.3)	8 (2.4)	0.51
Free or Reduced-price school meals	37 (10.9)	47 (13.9)	0.1003
Food pantry/Food bank	22 (6.5)	51 (15.1)	**<0.001**
Food or money for food from family, friends, or neighbors	14 (4.1)	46 (13.6)	**<0.001**
Food or money for food from a religious community	4 (1.2)	21 (6.2)	**<0.001**
Other food assistance program (e.g., Commodity Supplemental Food program, Meals on Wheels)	4 (1.2)	14 (4.1)	**0.0094**
None used	222 (65.7)	212 (62.7)	**0.024**
Job disruption (*n* = 418)			
Have you or anyone in your household experienced a loss of income or job since the COVID-19 outbreak? (multiple responses across rows and columns possible)	**Happened at all since COVID-19 *n* (%)**	**Still happening today *n* (%)**	
Yes, lost job	41 (9.8)	30 (7.1)	
Yes, reduced hours or income at job	58 (13.9)	54 (12.9)	
Yes, furloughed	35 (8.4)	9 (2.2)	
No, have not had any loss of job or income	274		

p-values in bold show a significant change in participation before and after the pandemic.

(Table 2). Second, we examined how production and consumption of wild/backyard foods shifted during the COVID-19 pandemic (Figure 1). The number of survey respondents who reported each pattern of change ("for the first time this year," "much more this year," "a little more this year," "the same amount as last year," "a little less this year, and "much less this year") in production and

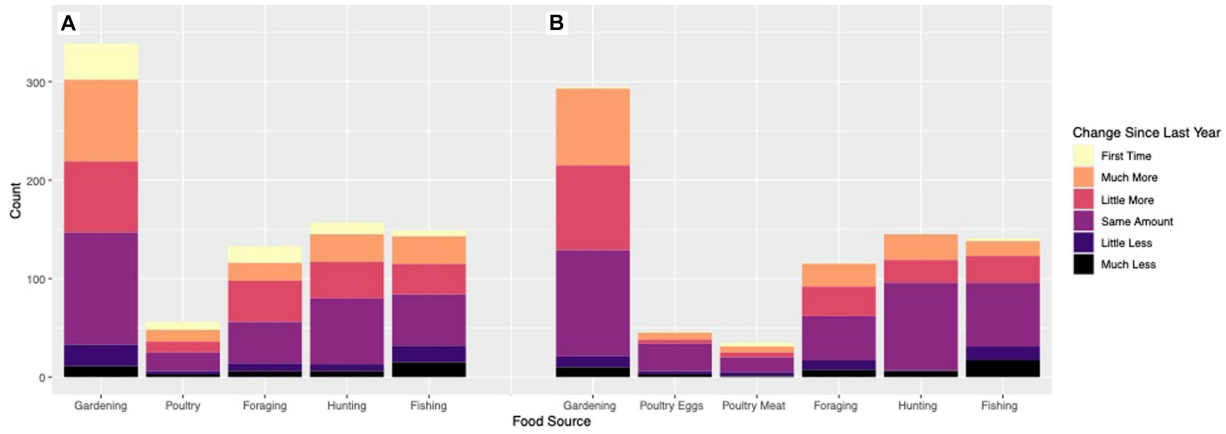

FIGURE 1
Change in **(A)** production and **(B)** consumption of wild and backyard foods.

consumption of each type of wild/backyard food (fruit & vegetables, eggs, poultry, foraged foods, fish or seafood, wild game) was determined. For the total sample and the sub-sample of respondents who reported wild/backyard food production of each food type (e.g., fish for fishers), we described consumption of relevant foods as a percentage of whoever consumed the item from each relevant source and the modal times per month consumed among those who ate it (Table 3). Third, we examined associations between challenges (food insecurity, job loss) or use of food assistance with perceived increase in production or consumption of any wild and backyard foods and tested with Fisher's exact test analysis (Table 4) to accommodate the small sample size for poultry rearers and foragers. All tests were considered statistically significant at 95% confidence. For the Table 4 analyses, we combined those who reported producing or consuming a wild and backyard food "for the first time this year," "much more this year," or "a little more this year" production/consumption into "increased."

Results

Sixty-five percent of respondents gardened, 9.3% raised poultry, 25.5% foraged, 27.6% fished, and 31.6% hunted/planned to hunt in 2020 (Table 1). A small majority of respondents were female (54%). A higher proportion of women than men gardened (65.7% female), reared poultry (70%), and foraged (58.2%), while fishers were nearly balanced between genders (50.4% male and 47.9% female), and the majority of hunters were men (55.9% male and 39.7% female). Survey respondents were highly educated relative to the wider Upstate New York community; a majority of respondents had completed associates, bachelor, or postgraduate degrees (68%). More than three-quarters of respondents were non-Hispanic white (77.5%). People who gardened were relatively more diverse than those who engaged in other activities, in terms of race, income, and education levels. Respondents were relatively high income with 47.3% making more than $75,000, and only 10.3% making less than $25,000. These racial, and gender demographics also differ from the United States 2015 census data of the counties surveyed. Specifically, our survey population skews more white and more female than the census, validating the expectation that the sample would not be representative of central/upstate New York (Table S1, Supplementary material). Instead, it captures a subset of wild and backyard food users who are linked with Cornell Cooperative Extension, New York Department of Environmental Conservation, social media pages aimed at these activities, and who have access to the internet.

About a third of respondents (34.4%) reported that the COVID-19 pandemic had negatively affected their income (Table 2). Compared to 2019, food insecurity significantly increased among survey respondents. Low food security more than doubled to 8.8% and very low food security rose by two-thirds to 3.5% (total food insecurity in 2020 was 12.3%). Respondents' use of food assistance also increased, including significant increases in use of food banks and pantries; food and money from family, friends, neighbors, and religious communities; SNAP or WIC (including COVID-19-EBT or P-EBT); and other food assistance programs. Choices about conventional food sourcing also changed from 2019 to 2020. Grocery delivery and the use of restaurant to-go orders increased while use of grocery stores, specialty food stores, farmer's markets, restaurant eat-in orders, and convenience stores decreased.

Across the wild and backyard food production strategies, 4.0–14.3% of respondents reported engaging for the first time and 39.6–45.7% reported increased production a little or a lot more (Figure 1A). 31.6–42.7% of respondents' production was the same as the previous year. A notable minority of 8.3–21.5% of people, however, reported decreased production (either a little or a lot less) of wild and backyard foods. As there are relatively few people who participated in wild and backyard food use in only 2019 or 2020, there is no significant difference between participation across years (Table 2). More substantial shifts are observed, however, in the intensity of participation in while and backyard food production, and these shifts in engagement were remarkably similar across activities.

Changes in wild and backyard food consumption followed very similar patterns to production (Figure 1B). While few people consumed these foods for the first time, 23.9–55.6% increased their consumption a little or a lot more, with consumption of gardened fruits and vegetables growing most (55.6%). Across food types, 36.6–61.4% of respondents' consumption was the same as the previous year.

TABLE 3 Consumption of wild and backyard foods in total sample and among respondents producing relevant wild and backyard foods.

	All surveyed		Respondents producing wild and backyard foods (e.g., gardeners for fruit/vegetables)	
Over the past 3 months, how many times have you eaten [food] from the following sources?	Ever consumed (%)	Average consumption freq. (times/mo., among those consuming)	Ever consumed (%)	Average consumption frequency (times/mo., among those consuming)
Fruit and vegetables				
Fruit and vegetables from my garden	75.7	13.4	97.6	13.5
Fruit and vegetables grown by friends, family and neighbors	61.3	5.4	63.4	5.2
Fruits and vegetables purchased from a farm or farmers (including CSAs)	76.2	8.8	81.2	9.1
Fruits and vegetables purchased from a store	98.8	16.3	98.6	16.6
Egg consumption				
From poultry that I raised	12.4	16.5	92.7	16.4
From poultry raised by friends, family, and neighbors	23.3	7.2	19.5	12.0
Purchased from a farm or farmers' market	31.0	9.2	14.6	6.7
Purchased in a store	83.4	10.3	34.1	5.1
Poultry consumption				
From poultry that I raised	6.5	6.7	51.2	5.8
From poultry raised by friends, family, and neighbors	8.6	3.2	17.1	2.6
Purchased from a farm or farmers' market	17.8	3.8	9.8	6.0
Purchased in a store	90.7	7.7	78.0	5.3
Foraged foods				
Foods foraged by me	34.0	4.5	93.8	4.6
Foods foraged by friends, family or neighbors	14.8	3.1	30.4	3.4
Foraged foods purchased from a farm or farmers' market	23.1	3.2	29.5	4.2
Fish or seafood				
Fish or seafood that I caught	23.4	3.1	69.7	3.1
Fish or seafood caught by friends, family or neighbors	16.7	2.3	31.1	2.2
Fish or seafood that was purchased	81.0	3.9	83.2	3.9
Wild game				
Wild game that I caught	28.1	4.8	80.1	4.8
Wild game caught by friends, family or neighbors	22.3	3.1	36.8	3.6
Wild game that was purchased	1.9	5.0	2.2	4.7

Again, a notable minority of 4.8–22.0% of people reported decreased consumption (a little or a lot less) of wild and backyard foods.

People producing wild and backyard foods were, as expected, much more likely to report they ever consumed the foods they produced (Table 3). Consumption of gardened fruit and vegetables (97.6%), eggs from backyard poultry (92.7%) and foraged foods (93.8%) was nearly ubiquitous among producers, while a majority also consumed poultry meat (51.2%), fish they caught (69.7%), and wild game they hunted (80.1%). Large proportions of respondents also reported that they consumed wild and backyard foods shared with them by friends, family, and neighbors. These proportions were slightly larger for producers of wild and backyard foods, underscoring these social networks, yet over 60% of all respondents had received shared fruit and vegetables and more than 20% had received eggs and wild game. Among those consuming these foods, consumption frequency was substantial. Average consumption of gardened fruit and

TABLE 4 Associations between pandemic-related challenges and increased wild and backyard food production.

	Food secure (%)	Food insecure (%)	*p*	No food assistance (%)	Any food assistance (%)	*p*	No job/ income loss (%)	Job/ income loss (%)	*p*
Gardening	36.1	52.8	**0.02**	33.8	50.8	**0.05**	34.7	45.8	0.23
Poultry raising	5.3	13.2	0.48	4.4	11.7	1.0	3.8	11.8	**0.04**
Foraging foods	11.2	17.0	0.19	9.6	19.2	0.07	11.0	13.9	0.37
Fishing	11.7	11.3	0.41	10.8	14.2	1.0	11.6	11.8	0.23
Hunting	12.8	13.2	1.0	12.4	14.2	0.41	12.7	13.2	0.10

p-values in bold show a significant association between pandemic-related challenges and production.

vegetables (13.5 times/month) and eggs (16.4 times/month) were very high, while average consumption of poultry meat, foraged foods, fish, and wild game ranged from 3.1 to 5.8 times/month.

There was a significant association between food insecurity and increased gardening effort ($p = 0.02$), use of food assistance and increased gardening effort ($p = 0.05$), and job loss and increased poultry-rearing effort ($p = 0.04$; Table 4). Experiences of hardship (food insecurity, job loss, and food assistance use) were not associated with increased consumption of wild and backyard foods (Table S2, Supplementary material).

The number of respondents motivated to produce food through all strategies to "have more control over food availability" increased between 2019 and 2020 ($p < 0.001$ to <0.05; Table 5). Gardeners were also more likely to report the following motivations in 2020: "have more affordable ways of getting food" ($p < 0.001$), "get outside" ($p < 0.001$), "be active" ($p < 0.001$), "have more control over food quality" ($p < 0.05$), and "keep my kids occupied and learning" ($p < 0.05$). A larger sample size for gardeners ($n = 357$) may have facilitated detection of statistically significant differences in motivations. However, poultry rearers, foragers, fishers, and hunters also saw more people reporting the same motivations in 2020 as compared to 2019, suggesting a wider set of shifting motivations for other wild and backyard food producers as well.

Discussion

During the COVID-19 pandemic, this limited sample of people in upstate New York remade their own food environments by increasing production of wild and backyard foods. This sample of more highly educated, whiter, and relatively wealthy New Yorkers had lower rates of food insecurity than other United States samples [see Niles et al. (6) for comparisons]. Nevertheless, these findings show our sample was motivated to intensify production and consumption of wild and backyard foods to increase the control they had over their food environment during a time of widespread uncertainty.

Across production activities, 39.6–45.7% of respondents increased production (either a little or a lot more) and 4.0–14.3% produced wild and backyard foods for the first time. Further, 23.9–55.6% increased their consumption of the foods they produced. More than half of respondents reported they were motivated to choose home production to control food availability, a key part of food security. Amid increased uncertainty in the conventional food environment, production of wild and backyard foods allowed individuals to exert control over their food environments and particularly to improve access to and control of nutritious, perishable foods.

Recalling the acute impact of the COVID-19 pandemic's outbreak phase is vital to understanding our findings. In the first six-ten months (between pandemic onset in February–March 2020 and the survey in October–December 2020) conventional supply chains faltered nationally and globally, grocery store shelves emptied, and communities faced widespread uncertainty about their food security. Conventional meat production supply chains in the United States were particularly hard hit in 2020 as meat packing facilities struggled with COVID outbreaks and stock outs were common (56). Fresh fruit and vegetable markets initially wobbled, before adapting over time (57). Meanwhile, income loss was common: 34.4% of this study's respondents and 43.5% of respondents in a multi-site United States study faced income loss (6). Between supply chain shifts and income loss, food insecurity rose. In this study sample food insecurity (combined low and very low food security) doubled from 6.6 to 12.3% between 2019 and 2020 (Table 2). A smaller proportion of our respondents was food insecure compared to findings from across the state and nation, which in 2020 ranged from 30.2 to 54.3%. The higher values were observed in communities that were high risk and/or included large numbers of black, indigenous, and other people of color (6).

Adapting to a crisis food environment through shifts in production

Within this larger context and this study's specific sample, gardening production and consumption in upstate New York particularly expanded (of gardeners, 56.6% increased or started new production, 56.3% increased or started new consumption). Most, however, self-reported not as new gardeners, but as increasing compared to previous effort. Those who were "new" may also have been returning to gardening after a period of inactivity. This may represent an intensified application of local knowledge and practices by local communities [as defined by the ICCA Consortium in (58)] that are part of the culture (broadly construed) of Upstate New York. It may also represent activation of local knowledge and practices that respondents already had but were not using.

TABLE 5 Drivers of production of wild and backyard foods from 2019 to 2020.

Motivations as drivers	Garden (n = 357)				Poultry (n = 62)				Forage (n = 139)				Fish (n = 154)				Hunt (n = 163)			
	2019	2020	% dif.	p	2019	2020	% dif.	p	2019	2020	% dif.	p	2019	2020	% dif.	p	2019	2020	% dif.	p
Have more control over food availability	44.0	59.9	16.0	***	40.3	69.4	29.0	***	55.4	67.6	12.2	*	49.4	62.3	13.0	**	50.3	59.5	9.2	*
Have more affordable ways of getting food	49.3	59.4	10.1	***	45.2	56.5	11.3	0.17	59.7	66.2	6.5	0.14	55.2	63.6	8.4	**0.055**	52.1	57.7	5.5	0.16
Get outside	71.4	80.1	8.7	***	64.5	66.1	1.6	1	79.1	83.5	4.3	0.31	76.0	79.2	3.2	0.46	77.3	77.3	0.0	1
Be active	66.4	73.1	6.7	***	58.1	64.5	6.5	0.39	71.9	77.0	5.0	0.25	70.8	74.7	3.9	0.39	74.2	74.8	0.6	1
Have more control over food quality	66.9	72.5	5.6	*	74.2	74.2	0.0	1	79.9	80.6	0.7	1	67.5	72.7	5.2	0.19	68.7	73.6	4.9	0.19
Keep my kids occupied and learning	19.6	23.2	3.6	*	40.3	45.2	4.8	0.55	27.3	32.4	5.0	0.07	25.3	30.5	5.2	0.12	24.5	27.6	3.1	0.27
Build relationships with people with shared interests in producing food	24.9	28.0	3.1	0.11	29.0	25.8	−3.2	0.68	35.3	36.0	0.7	1	29.9	30.5	0.6	1	28.8	28.8	0.0	1
Do something good for the environment	56.3	58.3	2.0	0.36	45.2	45.2	0.0	1	63.3	63.3	0.0	1	53.2	55.2	1.9	0.68	54.6	54.0	−0.6	1
Participate in a cultural tradition	24.9	24.9	0.0	1	29.0	22.6	−6.5	0.29	34.5	33.1	−1.4	0.75	30.5	29.2	−1.3	0.81	31.9	30.7	−1.2	0.81
Other	5.6	5.3	−0.3	1	9.7	8.1	−1.6	1	8.6	7.2	−1.4	0.68	6.5	5.8	−0.6	1	5.5	6.7	1.2	0.62

Non-significant p-values are printed in normal text. Suggestive p-values are in bold text. Significant p-values are marked with *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$.

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The expansion of gardening is consistent with other data showing increased gardening activity in response to the COVID-19 pandemic in the Global North (15, 17, 18). Corresponding to this increased production and consumption, respondents reported moderate decreases in shopping at farmers' markets over the same period (−19.3% pts). Farmers' markets in the United States reported closures or large decreases in sales during COVID-19 lockdowns (59) but our novel data suggest that increases in gardening also may have contributed to reductions in farmers' market shopping.

Increased gardening was associated with food insecurity, while a reliance on food assistance and experiencing job loss were associated with poultry rearing (Table 4). Though we cannot ascertain the directionality of these relationships, the experience of hardship may have motivated increased gardening or poultry effort or allowed more time for these activities. Even as gardening and poultry rearing may be adaptive strategies, additional support from local and regional organizations for these households may be needed.

However, the impact of COVID-19 on wild and backyard food production was not a monolith even within our sample. While most individuals in this study maintained or increased production effort, a notable minority decreased efforts instead. Gardening, poultry rearing, foraging, and hunting saw decreases in 8.3–10.8% of respondents, and 21.5% of fishers decreased their efforts. Time is often a key constraint to fish and wild game harvest, even for people who value it for deeply held reasons (60). While "essential" workers and parents may have had decreased time available, "non-essential" workers who stayed home during 2020's lockdown may have had increased free time, contributing to the variability in our responses. Seasonality may also have influenced these trends. For gardeners planting begins early in the year, which was at the height of pandemic's supply chain bottlenecks, store closures, and reluctance to enter public spaces. Respondents may therefore have been especially motivated to adopt gardening in just the right part of the season for gardening to begin. Likewise, certain hunting and fishing seasons (e.g., turkey season) begin early (April and May) and may have similarly shifted in the immediate aftermath of the pandemic declaration (13, 39). Thus for respondents who were able to continue or increase home production, wild and backyard foods often contributed to diets.

Wild and backyard foods were widely consumed

Backyard food producers (gardeners and backyard poultry rearers) in this sample almost universally consumed the often nutritious and perishable foods they produced. Nearly all gardeners ate fruits and vegetables they grew, with an average frequency of 13.5 times/month. Assuming consumption of average portion sizes, that average frequency provides 17% of the minimum recommended monthly fruit and vegetable consumption [based on dietary guidelines from the (61)]. Our findings are in line with previous studies, which found higher fruit and vegetable intake from any source among other home food producers during the COVID-19 pandemic (52). Similarly, almost all poultry-rearers in our sample (93%) ate the eggs they produced and half (52.3%) ate home-reared meat. The average frequency of consumption for these was high, 16.4 times/month for home-produced eggs and 5.8 times/month for home-produced poultry meat. The US Department of Agriculture (USDA) considers both eggs and poultry as protein foods so, assuming average portion sizes, together this reported average frequency of consumption fulfills approximately 53% of the USDA's monthly recommendation for protein foods (61). Given concerns that diet quality worsened during the early pandemic (62), the contribution of gardening and poultry rearing to meet needs for protein food and fruits and vegetables may have buffered or even reversed negative food environment shifts in access to these foods in upstate New York and similar North American contexts.

Wild foods, or foraged, fished, and hunted foods, were also consumed by strong majorities of producers in this sample. Nearly all foragers (94%), 70% of fishers, and 80% of hunters consumed their own wild foods, though consumption frequencies were relatively lower (4.6 times/month for foraged foods, 3.1 times/month fish; 5.8 times/month wild game). The lower average frequencies of wild foods consumption may be related to the higher investments needed to undertake these activities (e.g., licensing, travel to appropriate sites, etc.) or higher variability of success, compared to gardening and poultry-rearing. Accessing wild foods is qualitatively different from producing backyard foods due to the need to travel to suitable habitats, find and harvest the target species, as well as high levels of safety knowledge required (i.e., species identification, gun safety, and contaminant-related consumption guidelines). It also depends upon some level of chance for actually encountering the desired species.

We also find indications that people in our sample who produced wild and backyard foods were part of a network that affords additional access to wild and backyard foods. Beyond consuming their own foods, about twice as many foragers, fishers, and hunters consumed foraged foods, fish, and wild game harvested from friends, family, or neighbors in comparison to the sample overall. Twice as many poultry rearers ate poultry from food sharing than the sample overall. This suggests that increased access to food sharing also benefits the diets of these home producers. Although we cannot ascertain if this is an increase in sharing, this finding is consistent with other studies from around the world that found an increase in food sharing, trading, or bartering during the COVID-19 pandemic, sometimes as an extension of traditional kin networks and sometimes in broader and even digital communities (63–65). Fish sharing within small-scale fisheries worldwide during the COVID-19 pandemic has also been reported (63, 64) though less is known about sharing of other wild and backyard foods, a gap that our study helps to fill for places similar to our study area.

Control over food availability and affordability motivates food environment shifts

Strong majorities of participants in our sample who produced wild and backyard foods consistently reported they were driven by two types of motivations, (1) to get outside and be active and (2) control food quality, availability, and affordability. However, only one motivation identified by respondents had a statistically significant increase between 2019 and 2020 for gardening, poultry rearing, foraging, fishing, and hunting: have more control over food availability. This seems likely in response to the massive uncertainty the pandemic engendered in food and social systems and illustrates how these households perceived their

use of wild and backyard foods at this time. Several other motivations to garden also increased significantly between 2019 and 2020 including food affordability, control over food quality, and keeping active and outdoors. While poultry rearers, forager, fishers, and hunters increased their identification of these as motivating, the increases were not significant. Given that these production methods had a 2–3 times smaller sample size than gardening, we interpret that lack of significance as less convincing as we would with equal sample sizes. Despite the smaller sample size, affordability as a motive for fishing still had a suggestive value of p ($p = 0.055$), which we interpret as showing the importance of fishing for procuring an affordable protein food. Taken, together, these findings are consistent with prior research identifying food access and cost savings as motivators for COVID gardening across the Global North (20), and provides novel evidence that pandemic-era motivations for poultry-raising, foraging, fishing, and hunting were similar. It is also consistent with recent literature theorizing more broadly about the potential role for wild food provisioning as a support for food security worldwide during crises such as COVID-19 (66, 67), and the role of local knowledge and practices as a buffer and cultural strength recently advocated in human ecology literature (68).

If respondents perceived their use of wild and backyard foods as improving control over food availability and access, or allowing them to practice stress-reducing hobbies, these activities may have been key to reducing pandemic-related stress. Around three-quarters of respondents selected the motivations of "get[ting] outside" and "be[ing] active" consistently between 2019 and 2020. While there was no statistically significant change in identification of these motivations, the high proportion of respondents choosing them may indicate that these behaviors were providing stress reduction. This would be consistent with the widespread literature describing the ways that gardening mitigated pandemic-related stress (19–21, 26, 30–33), and are also consistent with stress reduction associated with pandemic fishing in Europe (46). A study in Vermont found higher stress in hunters and fishers than in gardeners (69). Given demographic differences between hunters and fishers compared to gardeners in our sample, we speculate differences in stress could be related to underlying factors, such as finances or social identity, as opposed to differences in how fishing, hunting, and gardening activities benefit individuals. We found higher proportions of men (20–25% more male identifying fishers and hunters than gardeners), and some studies have found higher levels of untreated stress and mental health problems in men than in women (70).

Shifts seen during the COVID-19 crisis indicate need for ongoing community support

Regional service providers can use our findings to shed light on how wild and backyard food production and consumption intersected with shifting New York food environments. Our research indicates some areas that could be targeted to better support communities as they grapple with the long term fall out of COVID-19, some areas that similar future crises are likely to impact, and some areas that need further clarification. Additionally, it appears that there may be local knowledge and practices active in the communities respondents are part of, which could be linked to future management strategies. This application of local knowledge and practices in a time of crisis would be supportive of calls in the literature for better understanding, respect, use, and integration of local and traditional ecological knowledge (68).

In New York State, the New York Department of Environmental Conservation, Cornell Cooperative Extension offices, and food banks (among others) were forced to create COVID-19 relevant programming on the fly, while dealing with many of the same challenges as the public. For example, to help bridge knowledge barriers to gardening extension programs across the United States often link older, experienced gardeners (e.g., Cornell Cooperative Extension Master Gardeners) with newer gardeners, but the in-person components of these were canceled by New York On Pause. This forced programs to offer remote or online options with very little notice for development or implementation (71). Meanwhile, social distancing reduced space at popular fishing sites (72) and time and access at community gardens (71). Additionally, stock-outs of key materials due to COVID-related supply chain disruptions likely impacted adoption of wild and backyard food production (e.g., seed shortages in early 2020 could have delayed planting or increased costs). Despite these increased barriers, this study found evidence of increases in production effort concurrent with motivations shifting towards improving control over availability and access of wild and backyard foods. This validates the efforts made by service providers like Cornell Cooperative Extension and New York Department of Environmental Conservation and offers encouragement for robust planning to better meet community needs during future crises.

Increases in wild food use in particular also have environmental sustainability implications both positive and negative (73–76). Having more foragers, hunters, and fishers involved or increasingly involved could help address recruitment concerns for hunting and fishing participation, often a key goal of state agencies who rely on these groups to fund state programming for environmental stewardship (77, 78). Yet additional people means additional harvest pressure and more interactions between humans and wildlife. This requires conservation and resource managers to work closely with hunters, fishers, and foragers to facilitate meaningful access while still avoiding negative impacts of heavier use on state or local sustainability and conservation goals. Balancing harvest pressure management with positive outcomes of wild food use has also been a concern in global settings (73, 74). Wild flora can be particularly sensitive to such high harvest pressure. Foraging is also generally outside the purview of community and even regional level programming, perhaps due to the high-level knowledge necessary to safely identify wild mushrooms, herbs, vegetables, and fruits. This means that there are fewer options for building onto to manage higher foraging harvest pressures. These issues are akin to the challenges and solutions explored in discussions of traditional ecological knowledge and environmental management, which attempt to harmonize environmental governance with traditional hunting, fishing, and foraging (68).

Finally, the high levels of wild and backyard food consumption found in this research highlights the importance of education on food safety. The role that agencies like the New York Health Department of Health and the New York Department of Environmental Conservation play in communication of local contamination levels and consumption guidelines is vital, as is biosafety and food safety programing from Cornell Cooperative Extension. While the potential for high nutritional value food access is a clear benefit of wild and backyard food consumption, it must be balanced with risks around food safety and contaminant exposure. Achieving food safety while producing wild and backyard foods requires specific knowledge and skills, identification, potential for

zoonotic disease transmission, safe food processing, preparation, and preservation. Expanding educational efforts in handling and preserving backyard foods (i.e., fruits, veggies, poultry, and eggs) to include food safety in wild food production may be appropriate in the study communities, or others like them [e.g., as in Seneca County Cornell Cooperative Extension's Wild Table programming (79)]. This is all the more critical in a world that has experienced the disruption and tragedy a novel zoonotic infection causes, leading to intensified debate on the consumption of wild foods (e.g., 75, 80).

In addition to food safety, the contamination of soil, water, fish, and game can impact all wild and backyard foods. For example, lead contamination of backyard chicken eggs in (81), urban garden soils (82), and wild game contaminated by "forever chemicals" (83) or lead ammunition (84) are all potential concerns. People eating wild and backyard foods need to be able to contextualize the contamination risks of their whole diet (i.e., how many wild caught fish can be safely eaten if store bought fish, are also being consumed), without being overly intimidated. Concern about risks can reduce levels of consumption below what would provide health benefits, such as the case when pregnant women avoid fish that would be nutritionally beneficial (85–87).

Additionally, any language-based challenges in appropriately interpreting guidelines written in English may compound the difficulty of accurately contextualizing personal risk levels. To effectively strike the delicate balance of writing and sharing guidelines or offering programming that protects diverse communities successfully without discouraging individuals from benefiting from highly nutritious food requires in depth understanding of food environments, cultural practices, local risks. For example, one Western New York organization offers their local fishers state level fish consumption guidelines translated into five locally common languages (88). Robust and consistent future funding can support community outreach to ensure that the necessary knowledge and skills are in fact being used in specific New York communities who practice higher levels of wild and/or backyard food consumption (89).

Study limitations

Our study used an online, convenience sample from upstate New York and our findings cannot be generalized as the sample was not representative of the population. In particular, respondents were disproportionately educated, higher income, and skewed towards non-Hispanic white individuals and women compared to the general population within the counties surveyed. These demographic biases limit this study's ability to assess the impact of cultural and racial diversity, lower incomes, and lower levels of food security on production, consumption, and motivation findings, which is critical to fostering supportive services and systems for all wild and backyard food producers. Of note, global settings where engagement with wild and backyard foods may differ substantially, for example in settings where fishing is more often an occupation (90–92) experienced very different dynamics in response to COVID-19.

As we sought out individuals engaged in wild and backyard food production, we cannot estimate population level participation in these activities more widely from this data. Our survey was conducted in October–December 2020 and captured the early phase of the COVID-19 pandemic. Though we made efforts to minimize recall bias, respondents compared periods before and since the pandemic, likely introducing some recall bias. Because of the seasonality associated with wild and backyard food production, the survey timing also generated different recall periods for different activities (e.g., spring fishing, compared to fall garden harvests). Further, the majority of the first COVID-19-era deer hunting season occurred after our survey was conducted so that activity was reported prospectively. Seasonality of these differing production methods complicates comparisons across seasons. Finally, we did not directly ask about stress reduction as a stand-alone motivation, and so our analysis of the impact of these activities on stress is therefore limited. The timing of the data presented here (collected in 2020) did not provide evidence on whether pandemic-associated behavior change will be sustained in the long term or abandoned.

Conclusion

While COVID-19 presented an acute shock to the food system, it also has had a long shadow. Supply chains have struggled to return to pre-COVID-19 functionality, food prices remain high (93) and have in some cases spiked even higher at times [e.g., egg prices in 2022 in the United States, (94)]. Although COVID-19 restrictions worldwide have largely been removed, the socio-economic impacts of COVID-19 remain widespread and new crises from extreme weather to political upheaval may acutely threaten food systems in the future. Understanding the extent to which and why individuals included wild and backyard food production as part of their food environments will be valuable for planning for and mitigating future crises. Organizations such as New York Department of Environmental Conservation, Cornell Cooperative Extension, and others can use our findings to tailor their current and future support for wild and backyard food production and investigate whether more vulnerable communities are also benefiting as the studied communities did here. For example, the significant relationship between increased gardening effort and food insecurity points to a potential opportunity to further support food insecure households through gardening specific programs. During or after a crisis, wild and backyard food production may support physical and mental health through nutrition, stress relief, and exercise. Producers of these foods have also long been key supporters of environmental sustainability within the woods, waterways, and lands that they use, enabling an even broader contributions their food environments. In a modern world grappling with sustainability, climate change, and socio-political challenges, wild and backyard food production empowers households by letting them exert control over their own food environments and adapt to challenges.

Data availability statement

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

Ethics statement

This study involved humans and was exempted from IRB review by the Cornell Institutional Review Board (Protocol ID#: 2008009765). The study was conducted in accordance with the local legislation and

institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individuals for the publication of any potentially identifiable data included in this article.

Author contributions

JC-S: study design, funding, data collection, early data analysis and synthesis, and writing. NC: data analysis on food security. GM: survey design and administration. LL: early analysis of backyard poultry data. AT: early analysis of hunting and foraging data. ZW: early analysis of fishing data. SY: early analysis of gardening data. AS and KH: study design, analysis, and revisions. KF: advising, study design, coordination, analysis supervision, and writing. 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/fnut.2023.1222610/full#supplementary-material

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Characterizing nutrient patterns of food items in adolescent diet using data from a novel citizen science project and the US National Health and Nutrition Examination Survey (NHANES)

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Introduction: A healthy diet is essential for promoting good health during adolescence and mitigating disease risks in adulthood. This underscores the need for improved nutrition education and increased access to healthier food choices. However, the accuracy of dietary data poses a significant challenge in nutritional research.

Methods: We utilized and analyzed a novel dietary record dataset collected through a high school citizen science project to address this issue. We focused on nutrients rather than food groups to characterize adolescent dietary patterns. The same analyses were performed on the 2019–2021 National Health and Nutrition Examination Survey data for comparison.

Results: Based on the U.S. Food and Drug Administration's recommended daily value (DV) for nutrients, the majority of food items in our citizen science dataset are low (i.e., <5% DV) in lipids, fiber, potassium, calcium, iron, sugar, and cholesterol. Only a minority of items are high (i.e., >20% DV) in macro and micronutrients. The clustering analysis identified nine food clusters with distinct nutrient profiles that vary significantly in size. The analyses on the NHANES data yielded similar findings, but with higher proportions of foods high in energy, lipids, carbohydrates, sugar, iron, and sodium compared with those of the citizen science dataset.

Discussion: This study demonstrates the potential of citizen science projects in gathering valuable dietary data and understanding adolescent nutrient intake. Identifying critical nutrient gaps can guide targeted nutrition education and the provision of accessible healthier food options, leading to positive health outcomes during adolescence and beyond.

KEYWORDS

adolescents, citizen science, nutrients, diet, cluster analysis, schools

1. Introduction

During adolescence, young individuals experience rapid growth and development, making this a crucial period wherein proper nutrition is essential in ensuring optimal wellbeing. Consuming well-balanced meals rich in fruits, vegetables, whole grains, and lean proteins can help maintain a healthy weight while reducing the risk of developing chronic diseases and promoting overall physical health (1). Adopting healthy behaviors, such as adhering to a balanced diet, can also contribute to better mental wellbeing, such as improved mood, reduced stress and anxiety levels, and greater self-esteem (2). A balanced diet not only provides the necessary nutrients but also supplies the energy to support physical activity, psychological health, and academic performance, leading to better concentration and increased productivity. Adolescents who follow such diets may experience better sleep quality, which also positively impacts both their physical and mental health (3).

However, multiple prior studies have indicated a need for improved nutrition education and better access to healthier food choices for adolescents. A meta-analysis of Global School-Based Student Health Surveys conducted in 2018 found that adolescents' diets are composed of an excess of processed foods, sugars, and saturated fat, while showing low intake of fruits, vegetables, and whole grains, with wide variability by subpopulation. This highlights the need for interventions that promote healthy behaviors and reduce the prevalence of health risk behaviors among adolescents, including education on the importance of healthy eating (4). Furthermore, a systematic review examining the relationship between diet and mental health reported evidence of a significant, cross-sectional relationship between unhealthy dietary patterns and poorer mental health in children and adolescents (5). Additionally, poor dietary habits have been linked to various diseases and conditions, including headache (6), diabetes (7), and breast cancer (8). The findings from these studies highlight the need for improved nutrition education and access to healthier food choices among adolescents.

Despite these findings, it has been widely described that self-reported dietary studies may be affected by measurement error (9), potentially leading to a misrepresentation of adolescents' actual dietary habits. To address this issue, multiple dietary assessment methods have been developed, each exhibiting distinct strengths and weaknesses (10). Among these methods, the dietary record approach is one of the standard methods, although it places a relatively significant burden on participants and requires high motivation (11). Food Frequency Questionnaires (FFQ), on the other hand, offer ease of implementation but suffer from low accuracy (12). Another viable option is the twenty-four-hour dietary recall, which generates detailed data with a lower participant burden; however, it requires trained interviewers, making it expensive and time-consuming (13).

In a novel citizen science project, students from the T.C. Williams High School [now Alexandria City High School (ACPS)] in Virginia successfully collected detailed lifestyle data pertaining to their diet, physical activity, and sleep. Collaborating in groups of two to five students, each group selected a specific research focus after receiving clear guidelines on the data collection process. Working closely with both George Washington University faculty and ACPS staff, the students ensured the data quality, accuracy, and reliability. This close working relationship was vital in generating a valuable dataset and yielding valuable insights into adolescent lifestyles. The approach, which involves citizens' participation in scientific projects, can mutually benefit study subjects and researchers. By acting as both the study subject and researcher, data source and data analyst, the students were actively engaged in the study and played a central role in formulating the research questions of interest to them. Citizen science projects have been shown to offer several benefits to the scientific community and the advancement of scientific knowledge. Silvertown (14) describes the emergence and appeal of citizen science as a valuable approach to scientific research. The paper highlights how citizen science can benefit scientific research by augmenting data collection, engaging the public, building community involvement, providing access to data, enabling interdisciplinary collaboration, and improving scientific understanding. The author highlights that citizen science can help overcome limitations in traditional research methods and foster collaboration between scientists and the public (14).

The primary aim of this project was to actively engage students in scientific research and empower them with a deeper understanding of the scientific process. Through their involvement as researchers and citizen scientists, the students gained a sense of ownership over the project. They contributed to a unique data source that provides valuable insights into adolescent diets. Moreover, the inclusive nature of the data collection, which encompassed both school and non-school days, increased the representativeness of the data, making it more reliable and informative.

This study analyzes a dataset of 3,948 food items recorded by citizen scientists and finds that today's U.S. adolescent diet includes a wide range of food items traditionally viewed as "ethnic food." As such, the high schoolers' diet included a diverse collection of items such as "Acheke," "Fried Bami," and "Japchae." However, categorizing these items by broad food groups such as fruits, vegetables, grains, protein, or dairy cannot fully capture their varying nutritional profiles. Therefore, to better represent and characterize the adolescent dietary patterns, we performed a clustering analysis of the food items based on their macronutrients and micronutrients. This approach enabled us to capture a more nuanced understanding of the diet of adolescents. To the best of our knowledge, no previous clustering analysis has been performed on adolescent dietary data, as prior clustering analyses mainly focused on food items and food groups to understand adult dietary patterns (15).

To provide a comparative analysis, we identified the adolescent population (15–17 years old) in the 2019–2021 National Health and Nutrition Examination Survey (NHANES) dataset and repeated the analysis. NHANES utilizes trained dietary interviewers fluent in Spanish and English to conduct 24-h dietary recall interviews (16). To ensure data accuracy, NHANES also performs a follow-up dietary interview via telephone 3–10 days after the initial in-person recall for all participants when possible. Additionally, NHANES utilizes "a complex, multistage, probability sampling design to select participants representative of the civilian, non-institutionalized U.S. population" (17).

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2. Materials and methods

2.1. Datasets

The citizen science project was reported in a prior publication (18). We briefly describe the data collection here. The data was collected from 28 high school students who participated in the study to self-report their healthy lifestyle behaviors and mood. Data collection took place from December 2018 to January 2019. The students who collected data were given detailed instructions by their teacher and the George Washington University researchers throughout a biotechnology course. Participants in the study filled out a one-time questionnaire and a daily mood tracker for 30 days and used fitness trackers to monitor their daily activity, sleep, and steps. The students conducted literature reviews, developed research questions and hypotheses, and collected data on mood, activity levels, sleep, and nutrition using surveys and fitness trackers. The dataset included demographic information, such as age, gender, and race/ethnicity, as well as data on their reported behaviors and mood, perceptions of the project, and its impact on their understanding. The study incorporated principles of citizen science, with students actively participating in the research process and contributing to the design and implementation of the study. By design, the citizen science dataset is a convenient sample.

From the NHANES data, we identified 735 adolescents (15–17 years of age) from 2017 to March 2020. NHANES refers to this dataset as the pre-pandemic data. The NHANES survey follows a multi-year, stratified, clustered four-stage design. The stages included: "(a) primary sampling units (counties, groups of tracts within counties, or combinations of adjacent counties), (b) segments within primary sampling units (census blocks or combinations of blocks), (c) dwelling units (households) within segments, and (d) individuals within households" (19). In addition, during the study period, we selected individuals with the desired age group we were interested in. It is important to note that NHANES incorporated oversampling techniques to ensure adequate representation of minority groups (Hispanic, non-Hispanic black, and non-Hispanic, non-black Asian) as well as low-income individuals (at or below 185% of the federal poverty level).

2.2. Citizen science data preparation

To prepare the data for analysis, we first identified the food items from the dietary record. The citizen science data required significant cleaning, e.g., there were misspellings and concatenations of different food items. We then utilized the nutritional database tables from the United States Department of Agriculture (USDA) (20) as the primary data source for nutrient information for each food item. It is worth noting that the NHANES database also used the USDA to calculate the food energy and nutrient data. We used alternative nutritional data sources such as Nutritionix, Daily Value, and other websites for food items we could not find in USDA. Due to the variation in serving sizes not only by food items but also by brand and data source, we followed the USDA's practice of using 100 g as the standard serving size for all food items.

Finally, to ensure data accuracy, we thoroughly examined the dataset to identify clear errors, missing values, and duplicate records. Examples of errors include instances where a food item contained over 100 g of an individual component in 100 g of food, missing carbohydrate values from a regular pasta product, or identical food items with different names. To correct these errors, we utilized the previously mentioned alternative data sources.

2.3. NHANES data preparation

National Health and Nutrition Examination Survey collects data on each participant's specific food items, along with their corresponding mass and nutrient values. To ensure that our analyses of the NHANES data were consistent with those of the citizen science data, we standardized the nutrient values to a 100 g

TABLE 1 Demographics of study participants in the citizen science and NHANES datasets.

	Citizen science (*N* = 28)		NHANES (*N* = 735)	
	Mean/N	Std/%	Mean/N	Std/%
Age	16.5	0.81	16	0.81
Gender				
Female	18	64.3%	353	48.0%
Male	10	35.7%	382	52.0%
Race				
White American	21	75.0%	227	30.9%
African American	3	10.7%	181	24.6%
Asian	3	10.7%	84	11.4%
Others	1	3.6%	80	10.9%
Ethnicity				
Non-Hispanics	n/a	n/a	572	77.8%
Hispanics	n/a	n/a	163	22.2%

serving size. This enabled us to make meaningful comparisons between the two datasets and draw accurate conclusions.

2.4. Data analysis

To analyze the energy and nutrient content of the food items, we calculated the minimum, mean, maximum, and standard deviation for all food items in the dataset. We also determined the percentage of food items with high and low values based on the Food and Drug Administration (FDA) definition. Please note that the data analyses was carried out on the food items, not patients. There are 3,948 food items in the citizen science dataset and 11,430 in the NHANES dataset.

To identify clusters of similar food items, we chose two widely used methods: K-Means (21) and Gaussian Mixture Modeling (GMM) (22). K-Means is a vector quantization method that assigns a data point to one of the k clusters with the nearest mean (i.e., the cluster center or centroid). The objective function is:

$$J = \sum_{i=1}^{m} \sum_{k=1}^{K} w_{ik} \| x^i - \mu_k \|^2$$

Where: K = number of clusters
x^i = represents data point
m = number of points
w_{ik} = 1 if the data point (x^i) belongs to the cluster (k)
w_{ik} = 0 if the data point (x^i) does not belong to the cluster (k)
μ_k = denotes the centroid of xi's cluster

GMM is a statistical method that assumes all data points are generated from n underlying Gaussian distributions. Both K-Means and GMM require a predefined number of clusters n. K-Means seeks to minimize the within-cluster variance, and GMM seeks to maximize the model's fit (i.e., the probability that the model generates the observed data). The probability distribution function of Gaussian Distribution with d features is defined as:

$$N(\mu, \Sigma) = \frac{1}{(2\pi)^{d/2}\sqrt{|\Sigma|}} exp\left(-\frac{1}{2}(x-\mu)^T \Sigma^{-1} (x-\mu)\right)$$

Where: μ = Mean
Σ = Covariance Matrix of the Gaussian
d = The number of features in our dataset
x = the number of data points

There are several methods for estimating the number of clusters. One of the most widely used methods is the Bayesian Information Criterion (BIC), which balances the model complexity and fit. This BIC is calculated as follows:

$$BIC = kln(n) - 2\ln(\hat{L})$$

Where: $\hat{L}$ = the maximized value of the likelihood function of the model M, i.e., $\hat{L}$, $p(x|\widehat{\theta}, M)$, where $\widehat{\theta}$ are the parameter values that maximize the likelihood function

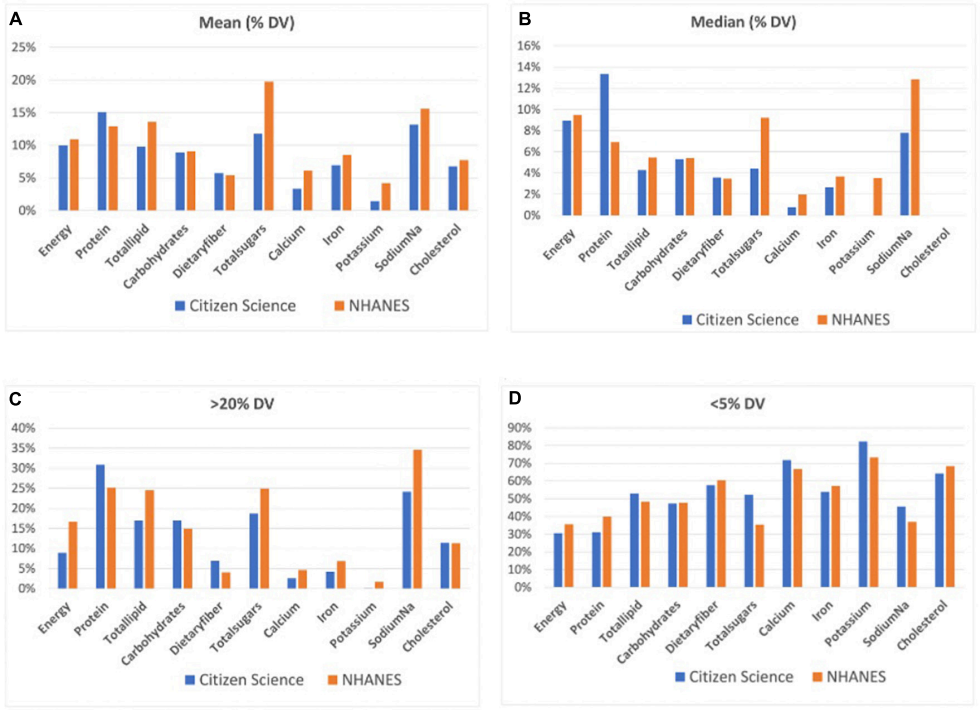

FIGURE 1
The mean **(A)** and median **(B)** energy and nutrients of food items as well as the percentage of food items exceeding the 20% **(C)** and below the 5% **(D)** thresholds in the Citizen Science and NHANES datasets.

TABLE 2 Citizen Science and NHANES energy and nutrients descriptive statistics, including the range, median, and 1*st* and 3*rd* quatiles of the nutrient values which are normalized as the percentage of the FDA DV.

	Energy	Protein	Total lipid	Carbo-hydrates	Dietary fiber	Total sugars	Calcium	Iron	Potassium	Sodium	Cholesterol
Citizen science (Number of food items = 3,948)											
Min.	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1st Qu.	4%	4%	0%	2%	0%	0%	0%	0%	0%	1%	0%
Median	9%	13%	4%	5%	4%	4%	1%	3%	0%	8%	0%
Mean	10%	15%	10%	9%	6%	12%	3%	7%	1%	13%	7%
3rd Qu.	15%	23%	13%	12%	9%	14%	5%	9%	3%	19%	10%
Max.	45%	126%	128%	37%	102%	188%	74%	185%	29%	400%	162%
>20%	9%	31%	17%	17%	7%	19%	3%	4%	0%	24%	11%
<5%	31%	31%	53%	47%	58%	52%	72%	54%	82%	46%	64%
NHANES (number of food items = 11,430)											
Min.	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1st Qu.	3%	2%	0%	0%	2%	0%	3%	1%	1%	2%	1%
Median	9%	7%	5%	5%	3%	9%	2%	4%	4%	13%	0%
Mean	11%	13%	14%	9%	5%	20%	6%	9%	4%	16%	8%
3rd Qu.	17%	20%	20%	14%	8%	20%	8%	9%	5%	24%	9%
Max.	45%	156%	128%	36%	123%	200%	106%	193%	76%	342%	338%
>20%	17%	25%	25%	15%	4%	25%	5%	7%	2%	35%	11%
<5%	36%	40%	48%	48%	60%	35%	67%	57%	73%	37%	68%

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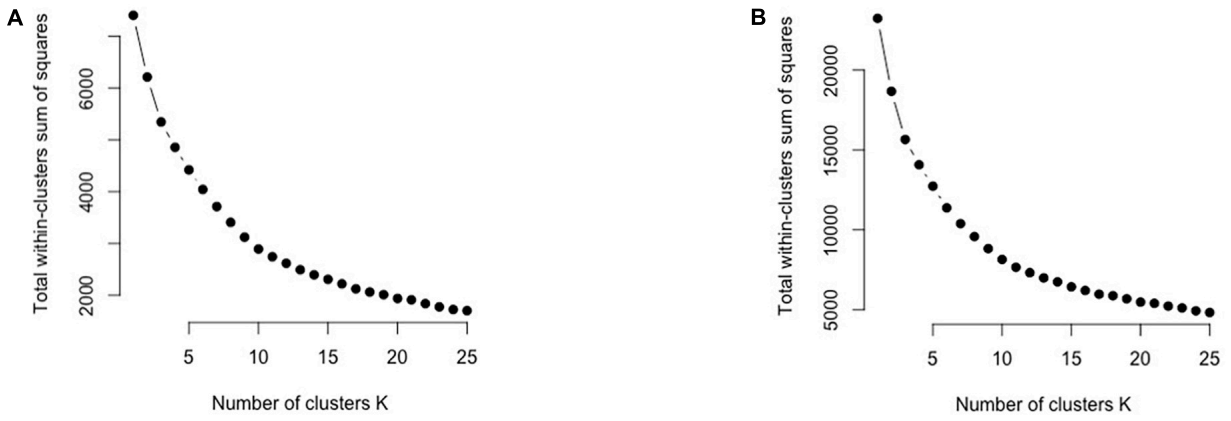

FIGURE 2
The elbow plots for the Citizen Science **(A)** and GMM **(B)** cluster analyses to help determine the number of clusters.

% of DV

	Cluster Size	Energy	Protein	Total Lipid	Carbohydrates	Dietary Fiber	Total Sugars	Calcium	Iron	Potassium	Sodium	Cholesterol
K-Means	43%	2%	2%	0%	4%	1%	10%	1%	1%	3%	1%	0%
	19%	14%	20%	15%	16%	8%	7%	10%	13%	4%	22%	2%
	11%	13%	37%	18%	2%	1%	1%	1%	6%	6%	23%	23%
	9%	20%	7%	12%	26%	4%	84%	2%	7%	2%	9%	0%
	5%	24%	13%	40%	16%	14%	1%	2%	7%	12%	16%	0%
	5%	22%	3%	59%	0%	0%	1%	2%	2%	1%	28%	16%
	4%	5%	2%	0%	10%	2%	43%	1%	2%	5%	40%	0%
	2%	18%	47%	36%	2%	0%	4%	58%	3%	3%	39%	28%
	2%	19%	15%	6%	29%	20%	66%	23%	124%	4%	25%	0%

	Cluster Size	Energy	Protein	Total Lipid	Carbohydrates	Dietary Fiber	Total Sugars	Calcium	Iron	Potassium	Sodium	Cholesterol
GMM	30%	13%	17%	15%	7%	6%	4%	4%	7%	5%	22%	2%
	25%	3%	2%	0%	4%	4%	7%	1%	2%	3%	1%	0%
	14%	19%	9%	15%	22%	5%	65%	3%	7%	3%	11%	0%
	13%	19%	22%	25%	8%	4%	6%	4%	8%	4%	24%	3%
	8%	2%	0%	0%	4%	0%	18%	0%	0%	0%	0%	0%
	4%	3%	7%	2%	2%	0%	10%	10%	0%	3%	2%	3%
	3%	9%	54%	9%	0%	0%	0%	1%	5%	6%	17%	29%
	2%	5%	2%	0%	10%	1%	43%	1%	2%	6%	40%	0%
	1%	34%	2%	96%	0%	0%	1%	1%	1%	0%	28%	14%

FIGURE 3
Nutrient profile of the clusters generated using the ACPS Citizen Science project dataset. The profiles from the K-Means and GMM are not identical but have many similarities.

x = the observed data
n = the number of data points in x, the number of observations, or equivalently, the sample size
k = the number of parameters estimated by the model.

After using the BIC, we confirmed the cluster number using the "Elbow Method," a graph-based method. In the elbow method, the sum of the square distance between points in a cluster and the cluster centroid is plotted against the number of clusters k, forming a curve. Before the elbow point, the slope is much steeper than that after the elbow. We first determined the number of clusters using the unique food items in the citizen science project and then applied it to both the citizen science and NHANES datasets.

Since the range of values varies greatly by nutrient, we scaled the nutritional data before clustering. For the resultant clusters, we calculated the cluster centers/centroids, and the nutrient values of the centers were normalized using the FDA-recommended

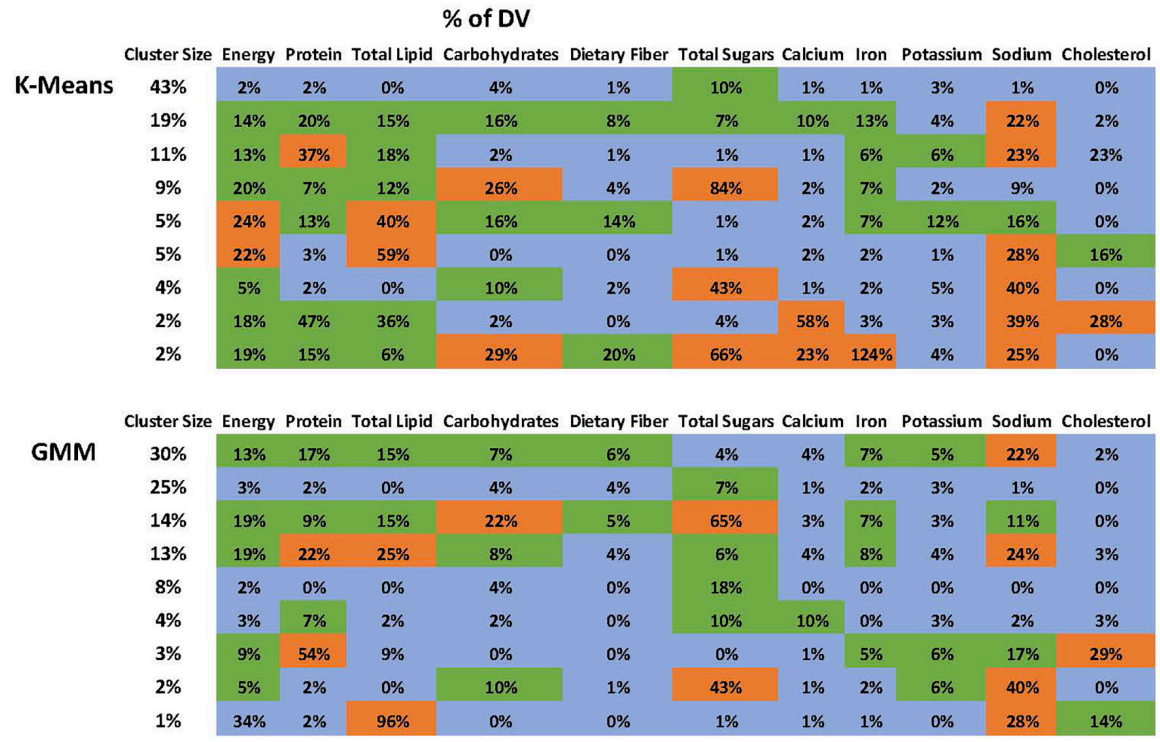

FIGURE 4
Nutrient profile of the clusters generated using the ACPS Citizen Science project dataset. The profiles from the K-Means and GMM are not identical but have many similarities.

daily values. All data analysis in this study was performed using R (23).

3. Results

3.1. Participants characteristics

The citizen science project had a relatively small number of participants with an observation period of over 1 month. In contrast, NHANES had a larger number of patients but a shorter observation period of only 2 days per person (Table 1). It is worth noting that NHANES does not differentiate race for Hispanic participants.

3.2. Descriptive statistics of energy and nutrients

We applied the FDA's rule of classifying food items with less than 5% of Daily Value (DV) of any particular nutrient as low and those with greater than 20% per serving as high. The analysis showed that the citizen science data had low median and mean values of multiple nutrients: Median total lipids, dietary fiber, total sugar, calcium, iron, potassium, and cholesterol, and mean calcium and potassium were low. In the NHANES data, the median dietary fiber, calcium, iron, potassium, cholesterol, and mean potassium were low. None of the means and medians were high (Table 2; Figure 1).

In the citizen science data, the percentages of food items that were categorized as high or low in energy or in nutrients differed. A high percentage (31%) of food items have high protein, while 0% have high potassium. There is a higher percentage of food items with low values on energy and almost all nutrients: 82% have low potassium while 31% have low energy and protein. A similar pattern is observed in the NHANES data. Both datasets have high percentages of food items low in fiber, calcium, potassium, iron, and cholesterol (Table 2; Figure 1).

3.3. Cluster analyses

The optimal number of clusters based on BIC is 9 (Figure 2). Figure 2 demonstrates that "9" is in the "elbow area." The energy and nutrient profiles of the clusters differ somewhat based on the clustering method and dataset (Figures 3, 4). The largest cluster of food items generated from using both K-means and GMM from the citizen science project is low in energy and all nutrients except sugar. There are also several other large clusters, one of which is high in protein and has an amount of sodium in the upper range of normal. Another cluster is high in carbohydrates and normal levels of energy, protein, and iron.

The NHANES analyses also yielded a low-energy cluster that included all nutrients except for sugar. Other large clusters include one high in both protein and sodium, one high only in sodium, and one high in carbohydrates and sugar.

4. Discussion

4.1. Findings

This study analyzed data from a novel citizen science project and a national survey to examine the nutrient content of food items consumed by adolescents in the US. Our results show that the majority of food items in our citizen science dataset are low (i.e., <5% DV) in lipids, fiber, potassium, calcium, iron, sugar, and cholesterol, and only a minority of items are high (i.e., >20% DV) in any macro or micronutrients. The findings from NHANES differ slightly, with most food items low in fiber, potassium, calcium, iron, and cholesterol. Only a minority of items are high in any macro and micronutrients.

The clustering analyses yielded nutrient profiles that provide a new characterization of adolescent dietary patterns in the US. The analyses identified a large cluster low in energy and nutrients, except for the sugar found in both datasets. Each dataset also has a large cluster that is high in protein and high/borderline high in sodium. The citizen science dataset had a large cluster with high carbohydrates, while the NHANES dataset had a cluster with high carbohydrates and sugar.

4.2. Implications

Citizen science is a valuable addition as a new data source and can supplement and complement established data sources like NHANES. Our data analyses showed that the results from the citizen science project and NHANES are similar but not identical. NHANES is highly respected and widely used but has limitations. For example, the NHANES data relies solely on USDA data for nutritional information, which may not capture certain "ethnic" foods or branded products. Working directly with the citizen science data, we can obtain diverse nutritional information on ethnic foods and certain other products from alternative sources when needed.

However, it is important to note that compared to existing dietary collection methods, the citizen science approach may have higher data collection burdens on participants, although their motivation to participate may also be higher. Conversely, the cost of obtaining data from citizen science is lower as participants are not research subjects that require compensation.

It is well known that, on average, US adolescents do not consume enough fruits, vegetables, and whole grains. Some studies have examined trends in specific nutrient intake like sugar, fiber, or potassium along with the associated health outcomes (24, 25). However, few studies have attempted to characterize multi-nutrient patterns through clustering, and none have been carried out in adolescents. As such, our analysis provides new insights into the dietary patterns of US adolescents and can serve as a foundation for further research in this area.

4.3. Limitations

There are several limitations to this study. First, while the citizen science project provided valuable data on adolescent dietary patterns, the sample was relatively small, which may limit the generalizability of our findings. Additionally, the longer observation period per person may have increased the risk of recall bias or other sources of bias. Further research with a larger and more diverse sample size is needed to validate our findings. There is no standard formula for calculating sample size. Some literature suggested that each cluster should have at least 20–30 samples.(26) In this study, the number of unique subjects is modest but the number of food items being analyzed is much larger: $n = 3{,}948$ from citizen science and $n = 11{,}430$ from NHANES. As a result, most clusters had considerably more than 30 samples.

Second, we did not collect serving size information in the citizen science project. This is because participants found it particularly burdensome to estimate the amount of food consumed accurately. This could have affected our ability to accurately assess nutrient intake and make meaningful comparisons with NHANES data. Future studies should consider methods to improve the accuracy of serving size estimation.

Third, citizen scientists are not trained professionals. Despite their strong motivation, their recall is not perfect, and their dietary record had varying degrees of details, e.g., an entry is just "fries" while another is "Wendy's chili cheese fries." While we provided training and guidance, it is possible that some participants struggled to accurately recall and record their dietary intake. More rigorous training and quality control measures for future citizen science projects could improve data quality.

Fourth, clustering analysis results are affected by the chosen method and the number of clusters. While BIC is commonly used, there are alternative methods. We observe that larger clusters are often more stable across different methods and cluster numbers, while smaller ones can be significantly different. Future studies could explore different clustering methods and assess the stability of the resulting clusters.

4.4. Future work

We plan to correlate different nutritional patterns with health outcomes in future studies. We are also interested in exploring the correlation between nutritional patterns, demographic backgrounds, and consumer behavior. By examining these associations, we hope to gain a deeper understanding of the complex interplay between diet and health and identify potential avenues for targeted interventions to improve dietary habits and health outcomes among adolescents.

5. Conclusion

This study analyzed data from both a citizen science project and the NHANES sample to identify nutritional patterns in the diets of US adolescents. Our findings suggest that the majority of food items consumed by this population are low in nutrients, including fiber, potassium, calcium, iron, and cholesterol. The largest cluster of food items is low in energy and nutrients, with the exception of sugar. These results highlight the need for targeted interventions to improve the dietary habits of this population. Lifestyle change can be difficult and slow. While health is part of the standard current curriculum in secondary schools across the US, there is clearly room for improvement.

Furthermore, our study suggests that citizen science data could be a valuable addition to existing datasets, such as NHANES, to provide a more comprehensive understanding of adolescent dietary patterns. By incorporating information on a wider range of foods, including those often excluded from traditional dietary assessments, citizen science data has the potential to enhance our understanding of the complex relationships between diet and health outcomes.

Moving forward, it will be important to continue exploring the link between nutritional patterns, demographic factors, and consumer behaviors in this population to better inform public health interventions aimed at improving dietary quality and reducing chronic disease risk.

Data availability statement

The NHANES dataset is publicly available. The citizen science dataset in the study are not publicly available to protect the privacy of research participants, but aggregated datasets are available from the corresponding author on reasonable requests.

Ethics statement

The studies involving humans were approved by the George Washington University Office of Human Research-Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

QZ and JT: conceptualization and methodology. JT: formal analysis. JU, LZ, AL, and GT: resources. JU and JT: data curation. QZ, JT, and ST: writing—original draft preparation and writing—review and editing. QZ and JT: visualization. QZ and JU: supervision. QZ, LZ, TC, and GT: project administration. QZ, LZ, TC, AL, and GT: funding acquisition. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Psychosocial drivers influencing local food purchasing: beyond availability, the importance of trust in farmers

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Introduction: Although consumers bought more local food during the changing context of pandemic COVID -19, this positive modification may not become a stable habit afterward.

Methods: To understand this change in drivers of consumers' intention to buy local food, we investigated the role of perceptions of various intrinsic and extrinsic attributes of local food, its perceived quality, price and availability, and consumers' trust in local food producers. We also investigated the role of sociodemographic variables as well as the moderating role of consumers' stage of change (i.e., absence, reduction, maintenance, and increase) in the purchase of local food.

Results: Structural equation modeling results on a representative sample of Italian consumers ($N = 511$) showed that local food availability is the main driver of purchase intention ($\beta = 0.20$; $p = 0.001$), especially among consumers who have changed their habits toward buying local food (reduction stage = $\beta = 0.24$; increase stage = 0.30; $p = 0.001$). In addition, trust in local food producers was found to be a key antecedent to consumers' perceptions of local food as environmentally friendly ($\beta = 0.57$; $p = 0.001$), healthy ($\beta = 0.55$; $p = 0.001$), authentic ($\beta = 0.58$; $p = 0.001$), tasty ($\beta = 0.52$; $p = 0.001$), socially sustainable ($\beta = 0.59$; $p = 0.001$), and as a product with a good appearance ($\beta = 0.55$; $p = 0.001$).

Discussion: Overall, these results improve our understanding of which food attributes should be emphasized in communication to promote the purchase of local food.

KEYWORDS

local food, food availability, trust in farmers, food attribute, COVID-19

1. Introduction

Recent crises have brought the vulnerability of global food supply chains to the fore (1) and demonstrated that the availability of several food categories may be at serious risk. These events raise concerns about the resilience of supply chain systems to shocks, i.e., their ability to continuously change and adapt in response to stressors and societal challenges (2). As a result, interest in local and regional food production is increasing significantly and is likely to grow further.

Although there are different definitions of "local food," in most cases, it is defined as food grown near the consumer (3). In the European context, the Joint Research Centre of the European Commission defines local food as food that is produced, processed, and sold in a specific geographical area, for example, within a radius of 20 to 100 km (4). In the present study, we have referred to local food, taking into account not only geographical proximity but also the sustainable production/distribution methods used by local farmers who do not follow the large-scale distribution logic.

Although consumers purchased more locally produced food during the last years of the COVID-19 pandemic (5), these changes may not become a stable shopping habit after the pandemic (6), e.g., because localized and small food supply chains are less cost-efficient than

large retailers and offer less product variety at higher prices (7). A deeper understanding of why many consumers reduced their purchases of local food can be gained by looking at consumers' perceptions of the intrinsic and extrinsic attributes of local food. While intrinsic attributes are the characteristics of the food product itself, such as taste and health, extrinsic attributes are the characteristics that belong to the food product but are not part of it, such as its environmental impact or its expected price availability (8). While there are some studies on pandemic-related changes in consumers' perceptions of the intrinsic and extrinsic qualities of local food (8), there is so far a lack of studies that address what happens afterward.

To fill this gap, the present study aimed to investigate how consumers' perceptions of local food after the COVID-19 pandemic influenced their intention to purchase such food. Specifically, we investigated the role of perceptions of various intrinsic and extrinsic attributes of local food, its perceived quality, price, and availability, and consumers' trust in local food producers. We also investigated the role of sociodemographic variables, as well as the moderating role of consumers' stages of change in the purchase of local food (i.e., absence, reduction, maintenance, and increase).

2. Theoretical background

Researchers from diverse backgrounds have studied how different values, beliefs, and attitudes influence consumer preferences for different food products (9). In the case of local food, these key factors are diverse and relate to both intrinsic and extrinsic food attributes (10). Moreover, most scholars pointed out that price consciousness (11), trust (12), and availability (13) play an important role in consumers' decisions to buy local food. In the following, we summarize the theoretical considerations that led us to formulate our research hypotheses and develop the model that we subsequently tested using structural equation modeling. A summary representation of our model and hypotheses can be found in Supplementary Figure 1.

2.1. Consumer's perception of local food

The overall evaluation of the quality of local food is an important factor in consumers' intention to buy food from local producers (14). If consumers perceive a product to be of high quality, they may have a higher purchase intention. In contrast, a poor quality perception may lead to a lower purchase intention.

> **H1**. Perceived quality of local food increases future intention to buy it.

The overall evaluation of the high quality of local food is shaped by the perception of its intrinsic and extrinsic attributes (15). In terms of intrinsic attributes, consumers tend to perceive local food as a high-quality product due to its sensory appeal, especially in terms of appearance (such as freshness) and taste (16). In addition, local food is perceived as healthier by consumers (10), as their producers often offer information about their production, e.g., what kind of chemicals they use in production (17). Another important characteristic of local food is its perceived authenticity, which is related to aspects such as continuity, credibility, and symbolism of the local agri-food sector (18).

> **H2**. A high perception of local food as a product with a good appearance (**H2a**), tasty (**H2b**), authentic (**H2c**), and healthy (**H2d**) predicts perceiving it as a high-quality product.

The same intrinsic and extrinsic characteristics of local food are likely to directly influence consumers' intention to buy local food as well as their actual purchase. For example, previous research has shown that those who perceive local food as safe, clean, and fresh are more likely to buy it (19).

> **H3**. A high perception of local food as a product with a good appearance (**H3a**), tasty (**H3b**), authentic (**H3c**), and healthy (**H3d**) increases consumers' future intention to buy it.

Consumers buy local food not only for its perceived sensory and health attributes but also because it contributes to sustainable practices for both the environment and society (13, 20, 21). Indeed, some scientists agree that local food supply chains are produced in a non-industrial, non-mass, and environmentally friendly way and can, therefore, have a low impact on the environment. They reduce greenhouse gas emissions associated with food transport and adopt more ecological practices (e.g., crop rotation, creation of field margins as a retreat for native biodiversity, reduction of packaging, or moderate use of fertilizers and chemicals) (22).

> **H4**. A high perception of local food as respectful of the environment (**H4a**) and socially sustainable (**H4b**) increases consumers' perception of the quality of local food **(H5a)** and their future intention to buy it (**H5b**).

Local food purchases are not only influenced by objective price but also by price consciousness (11), i.e., the meaning attributed to objective price and its translation into a more personal or psychological price. Therefore, we expected the perceived price of local food to be influenced by its perceived quality. However, price expectancy is often a barrier to consumers' intention to buy local food (10, 11). When people are very aware of the price of a product, they are generally less likely to choose that product [e.g., (23)].

> **H6**. The perceived quality of local food increases its expected price (**H6a**).

The expectation of a high price for local food predicts a low future intention to buy it (**H6b**).

2.2. Local food availability

To date, few studies have examined contextual and extrinsic factors that act as barriers to local food choices. Among these barriers, availability plays an important role. When a product is highly available, consumers usually have the intention to buy it (24, 25). In turn, lack of availability is the major barrier to consuming local food (13).

H7. The perceived availability of local food predicts consumers' intention to buy it.

2.3. Trust in local food producers

Trust is a complex concept that has attracted the interest of many researchers, so much so that it is now often considered one of the key variables in the consumer decision-making process. In particular, due to numerous food scandals and the ongoing industrialization and globalization of food chains, consumer skepticism about food quality and safety has increased in recent decades (26). Certifications and labeling of products or processes usually solve this problem successfully, even though some relevant properties of food cannot be easily certified because they pass through a short supply chain. The credibility attributed to local food producers is, therefore, often based on the assurance that they have the know-how and skills required for efficient and traceable production. Interestingly, trust provides a solution to situations characterized by increasing complexity and a lack of knowledge, as in the case of consumer trust in food and buyer–seller relationships (12). Moreover, previous studies in the field of correlational studies investigating consumer food purchase intention have shown that consumer trust has both a direct and an indirect influence on food purchase intention (27).

H8. Consumers' trust in local food producers predicts the perception of local food as having a good appearance (**H8a**), being tasty (**H8b**), authentic (**H8c**), healthy (**H8d**), respectful of the environment (**H8e**), and socially sustainable (**H8f**). Moreover, trust in local food producers predicts the perceived quality (**H8g**) and expected price of local food (**H8h**). Finally, trust in local food producers predicts consumers' future intention to buy local foods, both directly and indirectly (**H8i**).

2.4. Sociodemographic variables

Several previous studies have examined the role of some sociodemographic characteristics as important predictors of food consumption [e.g., Winterstein and Habisch (28); Witzling and Shaw (29)], as well as during the COVID-19 pandemic (30, 31). In terms of perceived quality and price consciousness, past researchers have observed the influence of income, age, education, and gender. For example, women and educated consumers with high incomes were found to be more likely to purchase local food (32). In addition, households that lost income reported being more willing to continue the positive changes they had made in their food habits during post-pandemic COVID-19 (31). Based on the above studies, we hypothesized that sociodemographic characteristics would influence beliefs and intentions toward local food. However, we did not develop a specific hypothesis about the relationship between these variables and the psychosocial drivers presented in the sections above, but only two research questions.

RQ1: Do age, sex, and education influence the paths linking the psychosocial antecedents of local food choice and the intention to buy local food?

RQ2: Does the family's economic condition influence the perception of the price and availability of local food and the intention to buy it?

2.5. Stage of change in local food consumption

Some previous studies investigated the impact of perceived local food attributes, price, and quality on its consumption during the COVID-19 lockdown period (21, 33). For example, a study considered the frequency of purchases from short food supply chains during COVID-19 as correlated with diverse psychosocial antecedents, such as environmental perception, perceived food safety, and healthiness (34). However, changes in local food purchasing during the COVID-19 period might also modulate the impact of psychosocial antecedents on future intention to purchase local food. Indeed, a large number of studies have already shown how past behavior and the actual stage of change moderate the effect of multiple predictors of food choices on future intention (35–37). To date, no study has conducted a similar investigation regarding the purchase of local food. In addressing this issue, in the present study, we assumed that the COVID-19 period was an important turning point in consumer behavior, if only in terms of the importance attributed to the issue of health protection. Therefore, we decided to investigate whether the influence of the psychosocial and sociodemographic factors would vary according to what the person did before the COVID-19 pandemic, categorized in terms of absence, reduction, maintenance, or increase compared to pre-pandemic levels.

RQ3: Is the impact of local food perceptions (i.e., extrinsic and intrinsic attributes, quality, price, availability, and trust) on future purchasing intention moderated by the consumer's behavior before the surge of the pandemic?

3. Materials and methods

3.1. Sample and procedure

This study was part of a research project funded by the Catholic University of the Sacred Heart (Milan, Italy) aimed at understanding changes in Italians' behavior after COVID-19. Italy is an exemplary country due to its leading food industry, and sustainable agriculture and is the first in the world for food quality certification (38). The survey data were collected from Italian consumers 1 year after the second wave of COVID-19 closures in March 2021.

The research was conducted according to the rules of the 1975 Declaration of Helsinki, which was revised in 2013. As this research was a non-interventional study (i.e., a survey), we did not require ethical approval. The study was explained to the participants in the online questionnaire. They were informed that they would participate in the survey using their personal computer and that all data would be de-identified and reported only in aggregate form. All participants signed an informed consent form to participate in the study. All participants were fully informed that their anonymity was guaranteed, why the study was being conducted, how their

TABLE 1 Demographics of the study sample.

Main sociodemographic characteristics	Total sample
Gender	
Female	52.7%
Male	47.3%
Age	
18–24 years	8.6%
25–34 years	13.5%
35–44 years	16.0%
45–54 years	21.5%
55–64 years	18.0%
65–74+ years	22.3%
M	49.46
SD	16.52
Education	
Secondary school	38.2%
High school diploma	40.4%
University degree	21.4%
Marital status	
Single	27.8%
Married/cohabiting couple	61.8%
Separated/divorced	7.2%
Not declared	3.3%

data would be used, and that there was no risk associated with their participation.

In June 2021, a nationally representative survey was conducted in Italy using the Computer-Assisted Web Interview (CAWI) method. The survey was conducted by Ipsos, one of the leading market research companies in Italy. The sample consisted of four stratified and random subsamples representative of an Italian consumer panel in terms of gender, geographic residence, age group, educational attainment, and employment status ($N = 511$; age: mean = 49.46, standard deviation = 16.52, range = 18–90; Table 1). The sample was balanced in terms of gender (men = 268, women = 243). Most participants were highly educated: 40.4% of them had completed high school, and 21.4% had higher education. Most participants were married (62.8%), and almost half of them had a job (49.7%). Before data collection, participants gave their written consent.

3.2. Measures

The online questionnaire was organized into diverse sections that covered different areas of Italians' behavior after the surge of the COVID-19 pandemic. Below, we report the measures relevant to the current study.

First, we asked participants to indicate their age, sex level of education, and family's economic condition.

3.2.1. Stage of change

Then, participants were asked to report their local food consumption during the ongoing year by selecting one of the four options: (1) "I never bought local food," (2) "I bought local food less than before the surge of the COVID-19 pandemic," (3) "I bought local food as before the COVID-19,"and (4) "I bought local food more than before the COVID-19." Statement 1 was coded as the absence stage, statement 2 was coded as the reduction stage, statement 3 was coded as the maintenance stage, and statement 4 was coded as the increase stage.

Next, we invited participants to complete a series of scales on a Likert scale aimed at measuring their perceptions about local food.

3.2.2. Local food attributes

Seven items to measure perceptions about the attributes of local foods [adapted from Ghali-Zinoubi (33); Denver et al. (39); Soonsan et al. (40)], defined as foods produced within 70 km from the place of sale by adopting sustainable methods of production and distribution. Specifically, we asked participants to rate local food *appearance* ("Local food looks nice"), *taste* ("Local food is tasty"), *authenticity* ("Local food is authentic"), *healthiness* ("Local food is healthy"), *environment respect* ("Local food is produced in an environmentally friendly way"), *social sustainability* ("Local food is produced in a way that respects workers' rights"), *quality* ("Local food is high-quality"), and *price* ("Local food is expensive").

3.2.3. Local food availability

The consumers' perception of local food availability was measured with three items (e.g., "Local food is easy to find"). $\alpha = 0.87$, composite reliability = 0.92, and AVE = 0.80.

3.2.4. Trust in local food producers

The consumers' trust in local food producers was measured with three items (e.g., "Local food producers work according to strict and controlled standards"). $\alpha = 0.88$, composite reliability = 0.92, AVE = 0.79.

3.2.5. Intention to buy local food

This dimension was measured with three items (e.g., "I intend to buy local food in the near future"). $\alpha = 0.96$, composite reliability = 0.97, and AVE = 0.93.

3.3. Data analysis

We ran all analyses using MPLUS 7. As preliminary analyses, we tested the measurement model with confirmatory factor analysis. We verified the internal consistency among the observed variables using Cronbach's alpha and composite reliability. We then tested the convergent and discriminant validities of our data using average variance extracted (AVE) values.

Then, we verified our hypotheses and research questions by testing the goodness-of-fit of four nested SEM models. We compared the nested models with the chi-squared difference test ($\Delta\chi 2$). Model 1 tested our H1–H4 about the role of local food

attributes. Model 2 tested our H5 by including the paths from local food availability to intention. Model 3 tested our H6 related to the inclusion of trust in local food producers (H5). Model 4 tested our RQ1 and RQ2 related to the inclusion of sociodemographic variables by including age, sex, education, and family economic resources. To verify if local food purchasing after COVID-19 moderated the relationship between antecedents and the future intention to buy local food (RQ3), we conducted a multigroup SEM analysis (41). Then, to disconfirm the invariance of the paths among the study variables across the above groups, we constrained the paths of each group to be invariant in the other groups, and next, we used Wald tests to disconfirm the invariance of the paths.

In all the above analyses, the goodness-of-fit of all models was tested using chi-square and incremental goodness-of-fit indices: root means square error of approximation (RMSEA) < 0.05, comparative fit index (CFI) < 0.90, Tucker–Lewis index (TLI) < 0.90, and standardized root mean squared residual (SRMR) < 0.08 (42).

4. Results

4.1. Preliminary analyses

A confirmatory factor analysis showed that the measurement model fitted the data satisfactorily ($\chi 2$ (103) = 264.21, $p = 0.001$; *RMSEA*= 0.05, *CFI* = 0.98, *TLI* = 0.95, *SRMR* = 0.03). The standardized item loadings of all study variables varied from 0.71 to 0.94. Composite reliability values were all greater than the minimum threshold of 0.60. Thus, we confirmed the reliability of the measurement model. The standardized factor loadings and the AVE values were all above the recommended threshold (43), showing that all constructs had high convergent validity. Finally, all AVEs were higher than correlations between latent constructs, confirming the discriminant validity of the study variables (43). Table 2 reports the means, standard deviations, and correlations between study variables.

Results showed that participants recognized authenticity as the main intrinsic attribute of local food and environmental respect as the main extrinsic attribute. Overall, participants perceived local food as available and reported a medium level of trust in local food producers and an intention to buy local food. Importantly, 24.1% of respondents never bought local foods (i.e., absence stage), 11.7% bought less local food than before the COVID-19 (i.e., reduction stage), 46,4% bought local food as before the COVID-19 (i.e., maintenance stage), and 17,8% bought more local food than before the COVID-19 (i.e., increase stage).

4.2. Model comparisons

The results of the comparisons among the four nested models showed that only Model 4 (i.e., the model including intrinsic and extrinsicα attributes, quality, local food availability, trust in local food producers, intention to buy local food, age, sex, education, and family economic condition) had acceptable goodness-of-fit ($\chi 2 = 13.76$, $p = 0.08$; RMSEA = 0.04; CFI = 0.99; TLI = 0.98; SRMR = 0.01). The comparison between Models 1 and

TABLE 2 Means, standard deviations, and correlations between study variables.

Study variables	*M*	*SD*	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Appearance	4.60	1.29	1											
2. Taste	5.00	1.27	0.63*	1										
3. Authenticity	5.08	1.29	0.54*	0.68*	1									
4. Healthiness	5.00	1.29	0.59*	0.74*	0.76*	1								
5. Environment Respect	5.13	1.23	0.45*	0.58*	0.64*	0.66*	1							
6. Social Sustainability	5.04	1.25	0.51*	0.51*	0.58*	0.57*	0.64*	1						
7. Price	4.56	1.28	0.22*	0.24*	0.16*	0.24*	0.17*	0.17*	1					
8. Quality	4.79	1.37	0.58*	0.74*	0.77*	0.74*	0.63*	0.55*	0.21*	1				
9. Local food availability	5.04	1.25	0.43*	0.47*	0.47*	0.43*	0.38*	0.40*	0.00	0.45*	1			
10. Trust in Local Food Producers	4.58	1.09	0.58*	0.56*	0.61*	0.60*	0.55*	0.63*	0.15*	0.59*	0.53*	1		
11. Stage of change	1.61	1.01	0.21*	0.24*	0.26*	0.27*	0.26*	0.25*	0.00	0.24*	0.35*	0.21*	1	
12. Intention to buy	4.79	1.47	0.37*	0.50*	0.55*	0.55*	0.52*	0.44*	0.02	0.54*	0.47*	0.49*	0.37*	1

M, mean; *SD*, standard deviation. *$p = 0.001$.

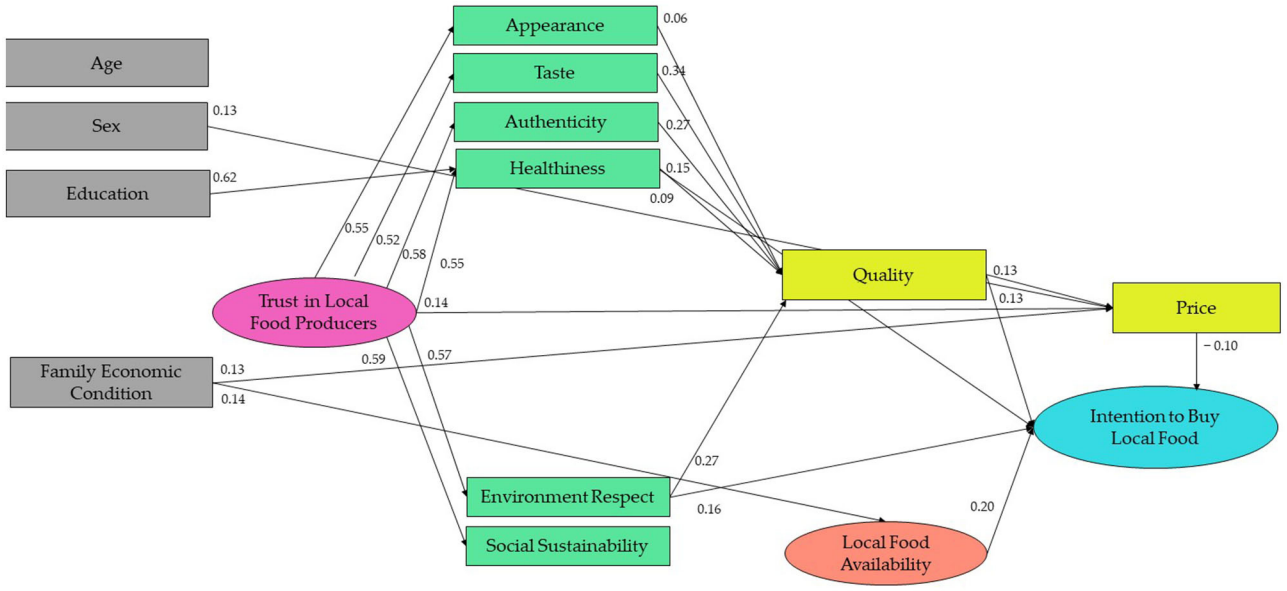

FIGURE 1
Results of the integrated model to explain the consumers' intention to buy local food.

2 supported the addition of local food availability ($\Delta\chi 2$ (9) = 214.45, p = 0.001). The comparison between Models 1 and 3 ($\Delta\chi 2$ (19) = 610.99, p = 0.001) and between Models 2 and 3 ($\Delta\chi 2$ (11) = 396.70, p = 0.001) confirmed the opportunity to include trust in the model. Finally, the comparison between Models 1 and 4, Models 3 and 4, Model 3, and Model 4 supported the inclusion of control variables (age, sex, education, and family economic condition, $\Delta\chi 2$ (46) = 151.83, p = 0.001). As expected, the more comprehensive Model 4 was the model that best predicted participants' intention to buy local food (Figure 1). Supplementary Table 1 shows the goodness-of-fit and the standardized coefficients of each tested model.

The study confirmed H1 and H2 that consumers' perception of local food as a high-quality product positively influenced their intention to buy it and that this perception was largely predicted by healthiness, taste, and authenticity, but not appearance. Healthiness had a direct and indirect effect on intention, while taste and authenticity only had an indirect effect through quality perception. Appearance did not have any significant effect on intention. Thus, we confirmed H3b, H3c, and H3d but not H3a. Then, we confirmed H4a and H5a that environmental respect determined the perceived quality of local food and directly influenced the consumers' intention to buy it. Differently, social sustainability influenced neither quality nor intention, disconfirming our H4b and H5b.

As expected (H6a, H6b), consumers' perceived quality of local food increased their expected price. In turn, the consumers' perception of local food as expensive decreased their future intention to buy it. This effect of price on intention was also indirect through consumers' perception of quality. Interestingly, taste and authenticity had a slightly indirect effect on intention via quality and then price, showing that they predicted consumers' intention to buy local food only when it was considered a high-quality inexpensive product.

As regards the contribution of local food availability, it was the most relevant factor in explaining purchasing intention (H7).

As for trust in local farmers, we confirmed that this variable predicted consumers' perception of intrinsic and extrinsic attributes (H8a–H8f), but not perceived quality. Thus, we disconfirmed H8g. Trust in local food producers only indirectly affected consumer intention through health, environment, and price. Higher trust not only led to the perception of local food as authentic and high-quality but also as expensive, decreasing the intention to buy (partially confirming H6i). Therefore, H6i was partially confirmed.

Analyzing the role of sociodemographic variables (RQ1 and RQ2), we found that females perceived local food as more expensive than males, which reduced their intention to buy it. Low-income individuals perceived local food as less available and thus intended to buy it less. Higher education predicted trust in local food producers, which led to greater environmental respect and the intention to buy local food. Consumers' age and education positively correlated with their intention to buy local foods.

4.3. Comparison of the integrated model across consumers' stages of change related to local food consumption

The multigroup models obtained an acceptable fit ($\chi 2$ = 63.73, df = 32; $\chi 2$ absence stage = 21.62; $\chi 2$ reduction stage = 21.24; $\chi 2$ maintenance stage = 14.10; $\chi 2$ increase stage = 6.70; RMSEA = 0.06; CFI = 0.99; TLI = 0.90; SRMR = 0.02). Supplementary Tables 2, 3 in report the findings of the Wald test

for each comparison used to disconfirm the invariance of the paths among study variables across the four groups of consumers' stages of change. In these analyses, we ran the Wald test only when a path was significant in at least one group.

Compared to those in the reduction stage, people in the absence stage perceived local food as high in quality when also evaluating it as healthy (Supplementary Figure 2). If they trusted local food producers, they perceived local food as tastier and healthier but more expensive. They had a lower future intention of buying local food when they perceived it as expensive. First, compared with those in the maintenance stage, they perceived local foods as tastier, more socially sustainable, and more expensive. Second, women had a greater perception of local foods as environmentally respectful than men. Third, people who had low family economic conditions perceived local food as more expensive. Finally, compared to those who increased local food purchasing after COVID-19, they perceived local food as more expensive when having low family economic conditions, and had lower future intention to buy local food when perceiving it as expensive.

Compared to what we observed in all other stages, people who reduced local food purchasing after COVID-19 perceived it as high in quality, mostly when evaluating local food as authentic (Supplementary Figure 3). Moreover, they intended to buy more local food in the future when they perceived it as healthy. Men strongly perceived local food as more high-quality than women. They also perceived local food as more socially sustainable than those in the increase stage and intended to buy local food more than those in the maintenance stage, when they also perceived local food as a product with a good appearance.

Compared to what we observed in all other stages, in the maintenance stage (Supplementary Figure 4), consumers intended to buy more local foods when they were old. However, they had lower intention when perceiving local food as expensive. Differently from what we observed in the reduction and increase stages, they perceived more local food as healthy and authentic and then evaluated it as higher in quality. In turn, they had a higher intention to buy local food in the future. Interestingly, these effects on future intention were also driven by consumers' trust in local food producers. In addition, when these consumers trusted local food producers, they also perceived local food as tastier and healthier, compared to those who were in the reduction stage.

Differently from what we found in all other stages, a positive evaluation of local food in terms of taste is a strong determinant of the perceived quality in people who increased local food purchasing after the COVID-19 period (Supplementary Figure 5). Moreover, authenticity was not relevant to quality. In addition, they perceived it as more expensive when they had a higher level of education. They also perceived local food as being more available and thus intended to buy local food in this case, when they were old. Compared to those who never bought local food (i.e., the absence stage), they intended to do it in the future when perceiving local food as available. Compared to consumers in the reduction stage, they perceived local food as higher in quality when they also evaluated it as healthy. If these consumers trusted local food producers, they also perceived local food as tastier and healthier. In addition, they expected local food to be more expensive because it is higher quality. This last difference also emerged in the case of the comparison of the increase stage to the maintenance stage.

5. Discussion

The study analyzed the psychosocial drivers that influence Italian consumers' intention to buy local food, considering changes in their behavior due to the COVID-19 pandemic. The study found that consumers' perceptions of intrinsic and extrinsic attributes of local food, their expectations of its quality, price, and availability, and their trust in local food producers predicted their future intention to buy local food. The consumers' sociodemographic characteristics also played a role in the model, given that females perceived local food as more expensive than males, which reduced their intention to buy it. In this regard, it appears that there are varying findings in different studies regarding women's preferences and price sensitivity. For example, some studies suggest that Australian and New Yorker women prioritize price attributes more than men (44, 45), while other research indicates that women are more likely to purchase organic food, suggesting lower price sensitivity (46). These differing results highlight the complexity of consumer behavior and the need for further investigation.

5.1. The major role of local food availability

The most important predictor of future intention to buy local food turned out to be the availability of that food. While studies of consumers' food choices before the COVID-19 pandemic have shown an important, but not as central, role in food availability and perceptions of control over food purchases (24), the present study suggests that the experience of lockdown restrictions increased the perceived importance of this factor. Local food availability in Italy plays a crucial role in shaping consumer behavior and food choices. The country has a rich tradition of local culinary diversity and offers different diverse options for buying local food. For example, farmer's markets and open-air markets are common, offering an array of locally grown produce, artisanal products, and traditional specialties. Moreover, Italy is renowned for its small specialty shops, which often source their products locally. In addition, Community-Supported Agriculture Programs have been gaining popularity in Italy, connecting consumers directly with local farmers (47). Participants in these programs pay in advance for a share of the farm's produce, providing financial support to the farmers while ensuring a steady supply of fresh, locally grown products for the consumers. Furthermore, Italy hosts numerous food festivals and fairs celebrating regional specialties and local produce. With the advancement of technology, many local farmers and producers in Italy have embraced e-commerce platforms to sell their products directly to consumers. This may allow for broader access to local food, even for those who may not have easy physical access to local markets or shops. All these aspects make the availability of local food a determining factor in its consumption.

Despite the abundance of local food options, challenges related to local food availability also exist in Italy. Among them, some local products are available only seasonally, limiting the year-round

availability of certain items. In addition, the accessibility of local food in urban vs. rural areas is different. In urban areas, consumers often have greater access to various food retailers and markets, which may offer a wider selection of local products. However, the prices of local foods in urban settings might be influenced by higher operating costs and increased demand, potentially affecting affordability for some consumers. On the other hand, in rural areas, consumers might have more direct access to local farmers and producers through farmers' markets or farm-to-table initiatives, which can promote the consumption of locally sourced products. However, the variety and availability of local foods in rural settings could be limited compared to urban areas. Considering these factors, policymakers in Italy should continue to explore ways to enhance local food availability and accessibility. Our study showed that the availability of local food is a key factor, not so much when a food habit remains stable, but when people change their habits. Therefore, undertaking large-scale policies aimed at increasing access to and visibility of local food at points of sale, as well as information about its traceability, can be extremely important.

We have also observed that consumers perceive local food as less available when they describe their economic situation as low. This result can be better understood by considering what previous studies have found about the accessibility of healthy food (48). The easy access of high-income individuals to healthy food is linked to their proximity to supermarkets, which tend to stock a variety of healthy foods. In contrast, small independent grocery shops, which are often found in low-income neighborhoods, are less likely to have healthy options. This makes it harder for individuals living in low-income areas, who may also lack convenient transportation, to access healthy food. The same may be true for local food, but further studies are needed to confirm this. Policymakers should focus on understanding the logistical difficulties specific groups face in accessing local food and proposing solutions.

5.2. The effects of the intrinsic and extrinsic attributes of local food

According to previous studies showing the impact of taste on food preferences (10, 49), our study showed that taste is the most important predictor for evaluating the quality of local food, especially for consumers who have increased their consumption of local food. In addition, we found that authenticity was mostly important for people who did not yet buy local food (i.e., people who were in the absence stage). Our study also showed that healthiness and environmental respect were important consumers drivers, especially for those who reduced their consumption compared to that during the pandemic.

Social sustainability did not have a relevant weight in the evaluation of the quality of local food or in the purchase intention. This result is relevant because local and short-chain products can contribute to rural development and a sense of community by benefiting small local businesses beyond the market logic of wholesale (50). However, this prosocial attribute did not appear to influence consumer choice. This result is similar to what was observed in a pre–COVID-19 study, which found a stronger influence of self-centeredness than altruism in the context of local food consumption (10), as well as in a recent Italian study, which argues that local food is preferred by the consumer group that holds individualistic values (32). Considering this finding, the emerging relevance of environmental protection may thus be less related to an altruistic value and more to an interest in protecting the environment to ultimately control its impact on our health. To better investigate this tendency of Italian consumers, future studies could include other variables (such as moral and intrinsic motivations and social dominance orientation (51, 52) to assess how consumers' selfish and altruistic values influence the relevance associated with intrinsic and extrinsic attributes of local food.

Consistent with previous research (10), this study found that price expectations strongly influenced consumers' intention to buy local food. Consumers were less likely to choose local food when they were highly aware of the product's price, and the perception of local food as a high-quality product increased price expectations, which in turn reduced purchase intention. The impact of price expectations on purchase intention varies depending on the stage of consumer change toward buying local food, with price becoming important in both the absence and maintenance phases of the habit.

5.3. The impact of consumers' trust in local food producers

In our study, consumer trust in local food producers indirectly affected future intention to buy local food through perceived health, respect for the environment, and authenticity. In other words, trust in local food producers increased perceptions of local food as healthy, environmentally friendly, and authentic, and thus increased purchase intention. This result suggests that trust in the seller is likely to be related to an interaction with the consumer, which is why it can be called interpersonal trust (53). During a product purchase, the buyer and the seller communicate face-to-face about the production process, value, and concepts underlying the product, and interpersonal trust is thus fostered. Such communication provides consumers with information not only about the food producer but also about the product itself, and this information influences purchase intention (53). This reasoning confirms the importance of farmers' and urban markets, where citizens can engage directly with producers. Our findings also suggest that people with high levels of education trust local food producers more than people with low levels of education. Moreover, among highly educated people, the perception that local food respects the environment mediates the link between trust and the intention to buy local food. This suggests the importance of communication campaigns in the food sector (54) and the need to test the effectiveness of various types of content, especially based on the target audience they are intended for (55, 56).

It should be noted that, beyond the role of trust, price, availability, and quality, other crucial variables influence intention regarding local food. Therefore, any comprehensive analysis of local food consumption should consider these key determinants to gain a more accurate understanding of the factors that guide consumers toward choosing local food options. This is even more relevant when considering that these variables may have a direct effect on behavior beyond mere intention (57, 58). For example,

if the price of local food is significantly higher than non-local options or if local products are not readily available in certain areas, consumers may opt for more affordable and easily accessible alternatives, even if they had the intention to buy local food.

5.4. Limitations

Our study has several limitations. First, given the existing gap between the intention to engage in a certain behavior and its actual execution, the lack of measurement of actual behavior is perhaps the most important limitation. Second, our questionnaire focused on local food in general, without specifying the different typologies of local agriculture and food categories. Third, we did not measure participants' ethnocentrism, which might have influenced their evaluation of local production. Fourth, in Italy, where the study was carried out, there is a specific definition of local food (e.g., zero kilometers and solidarity purchasing groups) and a specific availability of these products on the market (e.g., open-air markets and urban markets). On the one hand, by focusing on the unique aspects of Italian food culture, this study can offer valuable insights into the dynamics of local food consumption during the pandemic in this specific context. On the other hand, this detailed specificity might limit the direct transferability of the study's findings to other countries or regions with different food cultures and market structures. However, our research design paves the way for future research that compares our findings with what might emerge in other European and international contexts.

Finally, it is essential to recognize that our findings only represent the psychosocial perspective in a broader landscape of research on this subject. It is crucial to consider our results as part of a larger body of scientific knowledge that collectively sheds light on consumer behavior regarding local food. Future studies should build upon our research, incorporating multiple perspectives, including important economic factors. Including the evaluation of economic factors allows a better understanding of the impact of cost considerations on local food consumption. Exploring the economies of scale, pricing strategies, and accessibility of local food compared to non-local alternatives can provide a more comprehensive understanding of consumers' decision-making processes.

6. Conclusion

This research explores how consumers' perceptions and expectations of local food influence their intention to buy it, particularly in the context of the COVID-19 pandemic in Italy. The study identified three important factors that influence the intention to buy local food: availability, health, and trust in local food producers. The study suggests that promoting direct sales between producers and consumers could facilitate opportunities for interaction and increase the perception of local food as environmentally friendly, healthy, and authentic, thus promoting its consumption.

Based on our results, several food policy implications can be drawn to foster local food consumption and support sustainable food systems during the post-pandemic period. Given the central role of food availability in influencing consumers' intention to buy local food, policymakers should prioritize initiatives that increase access to and visibility of local food at various points of sale. Supporting farmers' open-air markets and urban markets can be an effective way to promote direct interactions between producers and consumers, fostering trust and facilitating communication about the production process and the value of local products. Encouraging large-scale policy interventions that facilitate the distribution of local food products to supermarkets and grocery stores can further enhance their accessibility. To tackle the issue of perceived low availability among economically disadvantaged consumers, policymakers should focus on understanding the logistical challenges faced by specific groups in accessing local food.

Our study also found that if local products are viewed as more expensive, the intent to purchase goes down. Implementing targeted support programs, such as subsidies or vouchers—especially for low-income individuals—to purchase local food, can help mitigate economic barriers and promote equitable access to locally sourced products. To address the impact of price expectations on local food purchase intention, policymakers can explore strategies to manage price perceptions. For instance, introducing price visibility labels on local food products or implementing price promotion initiatives can influence consumer perceptions of affordability and quality. Additionally, supporting local food producers in adopting cost-effective practices may help maintain competitive prices while preserving product quality.

Policymakers should collaborate with local food producers to emphasize the intrinsic attributes of local food, particularly taste and authenticity, as key drivers of consumer choices. Providing adequate and effective information on health benefits and environmental sustainability can enhance consumer awareness and appreciation of local food quality. In this vein, policymakers can support initiatives that foster trust in local food producers, recognizing the importance of interpersonal trust in influencing consumer behavior. Supporting farmers' markets and facilitating face-to-face interactions between producers and consumers can strengthen trust and establish lasting relationships. Promoting transparency and traceability in food production processes can also bolster consumer confidence in the authenticity and safety of local food products.

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 humans were approved by Ethics Commission of the Catholic University of the Sacred Heart-Milan. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

VC: conceptualization, methodology, visualization, resources, formal analyses, data curation, and writing—original draft. PC: conceptualization, methodology, and writing—original draft, supervision. 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/fnut.2023.1204732/full#supplementary-material

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A novel approach to assess diet diversity: a development of the Nutritional Functional Diversity indicator

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Background and aims: Diversity is a key element of diet quality. The Food Variety Score (FVS) is used to assess diversity, especially in low- and middle-income countries. It sums up the number of foods consumed ignoring their nutrient content. A more suitable index should combine the number of foods consumed and their nutritional composition. We adapted the Nutritional Functional Diversity indicator (NFD), proposed by ecologists, to measure diversity in the human diet. We compared NFD and FVS evaluating subjects' distributions across quartiles of the two diversity indices. To evaluate which one reflected a higher diet quality, we estimated associations between these two diversity indices and diet quality measures, i.e., the Mediterranean Diet Score (MDS) and the Healthy Eating Index-2015 (HEI-2015). Associations were expressed by odds ratios (OR) and corresponding 95% confidence intervals (CI).

Materials and methods: We used the data of controls only derived from an integrated series of hospital-based case-control cancer studies conducted in different Italian areas. The NFD identifies groups of foods based on a set of nutrients according to a cluster analysis. Some steps are required: creating a food-nutrient matrix; clustering of the Euclidean food-food distance matrix to identify groups of foods with nutritional (dis)similarities; and calculating the NFD as the ratio between the sum of branch lengths of the dendrogram belonging to the number of foods consumed by individuals (i.e., subject-specific diversity) and the sum of all branch lengths of the dendrogram (i.e., maximal diversity).

Results: More than one quarter of individuals (28.4%) were differently classified within quartiles of the two diversity indices. For both indices, increasing the diversity level increased the risk for adhering to MDS (OR for NFD = 11.26; 95% CI: 7.88–16.09, and OR for FVS = 6.80; 95% CI: 4.84–9.54) and to HEI-2015 (OR for NDF = 2.86; 95% CI: 2.39–3.42, and OR for FVS = 2.72; 95% CI: 2.27–3.26). Associations were stronger for NFD.

Conclusion: Our findings showed a greater ability of NFD to assess diet quality quantifying the degree of diversity.

KEYWORDS

diet diversity, novel approach, cluster analysis, nutritional composition, diet quality, Mediterranean diet, Healthy Eating Index-2015

1. Introduction

For a long time, public health nutrition guidelines have recommended diversity (or variety) in eating patterns as a key element of an optimal diet (1, 2). The guidelines highlight that no single food or food group ensures an adequate intake of all necessary nutrients.

Several indices have been proposed to assess diversity (3–8). The most commonly used are the Food Variety Score (FVS) (3) and the Dietary Diversity Score (DDS) (4). These indices sum up the number of foods (FVS) or foods groups (DDS) consumed by an individual over a reference period, usually from 1 to 3 days (4, 9), but longer periods have also been considered (10, 11). Nevertheless, FVS would be equal for individuals who eat the same number of foods even if the foods consumed have an intrinsically different nutritional composition. Likewise, the DDS is not able to consider nutrient content of foods consumed within the same food group and between food groups. Due to their simplistic counting approach, FVS and DDS have been especially used in countries with limited food availability (e.g., low-income countries) (12).

Other composite measures of overall diet quality (13) have been suggested for assessing the dietary compliance to nutritional recommendations (14–17) or the adherence to *a priori* determined diets (18, 19). The use of diet quality measures became widespread in populations with more complex dietary patterns such as high-income countries (12). Although these measures provide an overall assessment of diet quality, they do not formally quantify the diversity of an individual's diet.

A trade-off approach to assess diversity as a component of diet quality could consist of combining the information from the number of foods consumed and nutrient composition. Ecologists developed the Functional Diversity indicator to evaluate the impact of biodiversity among species (20). DeClerck and colleagues (21) extended Functional Diversity indicator to describe diversity of nutrients in cropping systems. Since adding of key species belonging to distinct nutritional groups on a farm or household system increases the availability of nutrients, DeClerk et al.'s Nutritional Functional Diversity indicator (NFD) links agrobiodiversity to diet according to the idea that cropping diversity can modify available nutrients for humans (21).

In this study, we adapted the NFD to assess diversity in the human diet. Furthermore, we compared NFD and FVS evaluating their differences in quantifying diet diversity. Finally, to evaluate which one reflected a higher diet quality, we estimated the associations between these two diversity indices and the Mediterranean Diet Score (MDS) and the Healthy Eating Index-2015 (HEI-2015), respectively.

2. Materials and methods

2.1. Subjects

We used the data of an integrated series of hospital-based case-control studies enrolling cancer patients and controls in different Italian areas from 1991 to 2008. These studies shared a similar protocol and a structured questionnaire to collect individual data. For the purposes of the present analysis, we considered only data of controls, for which individuals' behaviors (including dietary ones) are more similar to the general population. Indeed, controls were hospital patients admitted for a wide spectrum of acute diseases or conditions not associated to long-term diet modifications. Trained interviewers administered a structured questionnaire to collect information on sociodemographic characteristics, anthropometric measures, lifestyle (e.g., smoking, physical activity), reproductive factors, use of drugs, personal history of disease, family history of cancer, and dietary habits. Habitual diet (i.e., 1 year prior to the interview) was assessed by a reproducible and validated food frequency questionnaire (FFQ) (22–25). The FFQ included information on weekly intake of foods (or recipes) and beverages according to the following sections: (1) milk, hot beverages and sweeteners; (2) bread, cereals and first courses; (3) second courses (e.g., meat and other main dishes); (4) side dishes (i.e., vegetables); (5) fruits; and (6) sweets, desserts and soft drinks. Serving size was defined either in "natural" units (e.g., 1 cup of milk, 1 coffee spoon of sugar, 1 egg, 1 apple, etc.) or as an Italian average serving (e.g., 80 g of pasta, 100 g of mixed salad, 175 g of potatoes, 150 g of beef, etc.). Each serving size was converted into the corresponding approximated weight or capacity (Supplementary Table S1). Seasonal variation in fruit and vegetable consumption was also considered to account for the fluctuations within the year. Participants were asked to report the weekly consumption and the duration within the year (in months) for seasonal fruit and vegetables; therefore, the weekly consumption were accordingly reproportioned.

Nutrient content of each food (or recipe) and beverages included in the FFQ were computed using an Italian food composition database (26). This database collected energy and nutrients content for 1,037 foods and beverages. The nutrient content was reported per 100 g of edible matter (or 100 mL for beverages) and thus, the FFQ items were weighted to consider the different weight/capacity of the serving size. The nutritional composition of each recipe (e.g., pasta with tomato sauce) was computed using nutrient content of single ingredients. The Italian food composition database was also used to estimate the total energy intake (kcal/day) for each study subject according to his/her usual diet assessed by FFQ.

2.2. Nutritional Functional Diversity indicator (NFD)

We adapted the DeClerk and colleagues' approach (21) to compute NFD for quantifying diversity in the human diet. The NFD is rooted in the cluster analysis, i.e., a multivariate statistical method that gathers objects according to similarity defined through a function on a set of measured variables (27). There are four steps to calculate NFD: (1) creating a food-nutrient matrix; (2) calculating the food-food distance matrix from the food-nutrient matrix; (3) performing a clustering algorithm on the food-food distance matrix to produce a dendrogram; and (4) calculating individual NFD using the dendrogram.

2.2.1. Step 1: creating a food-nutrient matrix

In the food-nutrient matrix, each row represents a food (i.e., the objects of the cluster analysis) and each column represents a nutrient (i.e., the measured variables of the cluster analysis), such that each cell of the matrix expresses a specific nutrient content of a specific food (as in a food composition table). Our food-nutrient matrix included 70 foods (or recipes) and beverages (all items of the FFQ used to assess diet of subjects) as reported in Supplementary Table S1, and 28 selected nutrients as follows: animal and vegetable proteins,

carbohydrates (i.e., water soluble carbohydrates and starch), total fibers, fats (i.e., saturated and monounsaturated fatty acids, linoleic acid, linolenic acid, and other polyunsaturated fatty acids), cholesterol, vitamins (i.e., retinol, thiamine, riboflavin, niacin, vitamin B6, total folate, vitamin C, vitamin D, and vitamin E), minerals (i.e., calcium, iron, potassium, phosphorus, sodium, and zinc), beta carotene equivalent, and lycopene. To account for different scales, nutrients were standardized to have mean of 0 and standard deviation (SD) of 1.

2.2.2. Step 2: calculating the food-food distance matrix from the food-nutrient matrix

The food-food distance matrix contains the pair-wise Euclidean distances between foods, based on their nutrient contents ($K = 28$ nutrients):

$$d_{ij} = \sqrt{(i_1 - j_1)^2 + (i_2 - j_2)^2 + \cdots + (i_K - j_K)^2} \text{ with } k = 1,2,\ldots,K$$

where d_{ij} is the Euclidean distance between foods i and j; i_1 is the standardized content of the first nutrient in food i and j_1 is the standardized content of the first nutrient in food j; i_K and j_K are the standardized contents of the last nutrient in foods i and j respectively.

2.2.3. Step 3: performing a clustering algorithm on the food-food distance matrix to produce a dendrogram

Hierarchical clustering of the distance matrix identifies groups (or clusters) of foods according to nutritional similarity. Clusters are created by an unweighted pair group method with arithmetic mean (UPGMA) that uses the following linking algorithm: (1) identifying the minimum distance between any two foods; (2) combining the two foods previously identified as a single pair; (3) re-calculating the Euclidean distance matrix for this new pair and all other foods; (4) identifying the closest pair in the new distance matrix; (5) and so on, until the last two clusters are joint. Clustering results are used to create a dendrogram, a branching diagram that depicts the hierarchical relationship between clusters of foods. Distances between clusters are depicted by branch lengths: longer branches represent greater nutritional dissimilarities between foods or cluster of foods.

2.2.4. Step 4: calculating individual NFD using the dendrogram

The individual NFD is calculated by summing the branch lengths corresponding to individual's food consumption and dividing by the total branch length of the dendrogram. Thus, NFD is a continuous index defined on the interval $(0,1]$. To illustrate the computation of NFD from the dendrogram, we propose an example from Luckett et al.'s work (28) adapting it to human diet diversity. Consider the following six foods: cabbage, spinach, fish, cheese, steak, and chicken. Foods were clustered according to the dendrogram reported in Figure 1A. The vertical lines represent the branch length (i.e., similarities between foods or food clusters). For example, steak and chicken are more similar in their nutritional composition than cabbage and spinach, as shown by shorter branch lengths. The denominator of NFD is given by summing all branch lengths of the dendrogram (i.e., total branch length); it corresponds to 10 in our example (Figure 1A). Now, consider the habitual diet of two hypothetical individuals named X and Y. Suppose that X consumes cabbage, spinach, fish, and cheese, whereas Y consumes fish, cheese, steak, and chicken. The NFD for X is given by the sum of branch lengths according to his/her food intake over the total branch length, i.e., 8.0/10.0 = 0.8, 80.0% (Figure 1B). Likewise, NFD for Y is 6.5/10.0 = 0.65, 65.0% (Figure 1C). Thus, the diet of X is more diversified than the diet of Y. Furthermore, note that diets of X and Y would be equivalent according to FVS (i.e., a score of 4 for both individuals).

2.3. Assessment of diet quality measures

We used two measures to assess diet quality of study subjects. The first measure was the Mediterranean Diet Score (MDS), developed by Trichopoulou and colleagues (18, 29), which assesses the adherence of individual's diet to the Mediterranean one. Briefly, the MDS includes 9 dietary components: (1) vegetables; (2) fruit; (3) cereals (including bread and potatoes); (4) legumes; (5) monounsaturated to saturated fatty acids ratio (MUFA/SFA), as a proxy of the consumption of olive oil (30); (6) fish; (7) dairy products (including milk); (8) meat (including poultry, red and processed meat) and; (9) alcohol. A value of 0 or 1 is assigned to each of 9 components using fixed or median sex-specific intakes as cut-offs according to the component considered. In particular, for components more frequently consumed in the Mediterranean diet (i.e., vegetables, fruit, cereals, legumes, MUFA/SFA, and fish), a score of 1 is given if the individual intake is greater or equal to the sex-specific median intake, and 0 otherwise; for components less frequently consumed (i.e., dairy products and meat), a score of 1 is given if the individual intake is lower than the sex-specific median intake, and 0 otherwise. For the alcohol component, a score of 1 is given for an individual consumption ranging from 5 to 25 and 10 to 50 g of ethanol/day for women and men, respectively, and 0 if the individual consumption is outside of these ranges. The MDS is obtained adding up the 9 components' score, and therefore, it ranges from 0 (no adherence) to 9 (complete adherence) points.

The second measure of diet quality was the Healthy Eating Index (HEI-2015) (31), which assesses the compliance of individual's diet to the 2015–2020 Dietary Guidelines for Americans (DGA) (32). Briefly, the HEI-2015 includes 13 dietary components: (1) total fruits, (2) whole fruits, (3) total vegetables, (4) greens and beans, (5) whole grains, (6) dairy, (7) total protein foods, (8) seafood and plants proteins, (9) fatty acids, (10) refined grains, (11) sodium, (12) added sugars and, (13) saturated fats. The first 9 components (named adequacy components) represent foods and nutrients that are encouraged to be consumed by the DGA; the remaining 4 components (named moderation components) represent foods and nutrients that are recommended to be limited in the consumption by the DGA. A value from 0 (no compliance) to 10 (complete compliance) is assigned to each of the 13 components using predefined values (named minimum and maximum standards) as cut-offs. Three components consist of two subcategories (i.e., total fruits and whole fruits; total vegetables and greens and beans; and total protein foods and seafood and plant proteins) and each subcategory is assigned a value from 0 to 5. For each component, a proportional score between 0 and 10 (or to 5 for the subcategories) is assigned based on the individual intake ranking in comparison with the standards. As some standards are expressed in cups, we converted the corresponding dietary

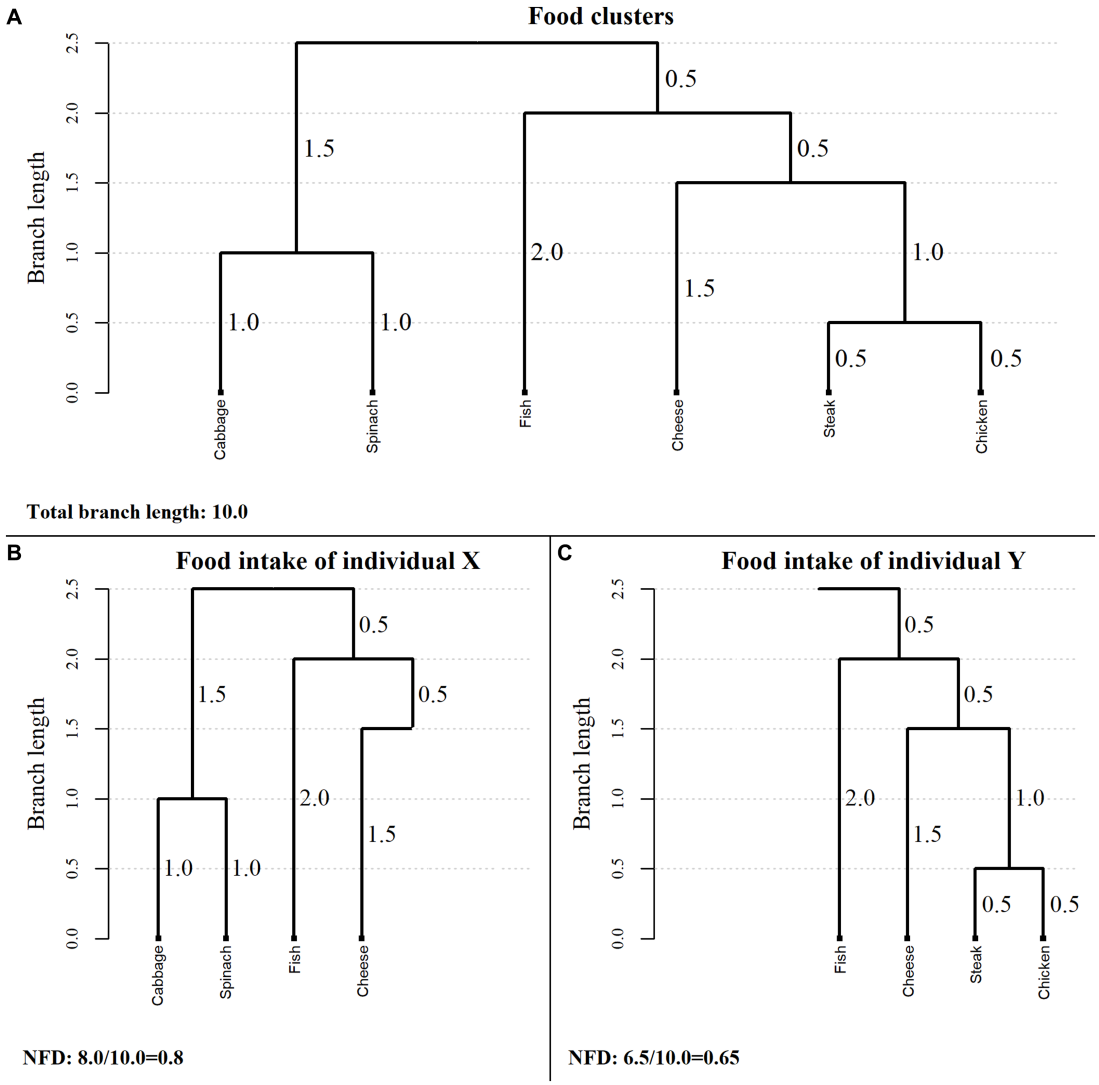

FIGURE 1
Example of a cluster dendrogram and the corresponding values of the Nutritional Functional Diversity indicator for two hypothetical individuals. NFD, Nutritional Functional Diversity indicator.

information from the FFQ (expressed in grams), as reported in our previous application (33). The total score is obtained summing up proportional scores of all components, and therefore, the HEI-2015 is a continuous index ranging from 0 to 100 with higher scores indicating greater compliance to the 2015–2020 DGA.

2.4. Statistical analyses

The FVS was computed summing up the number of foods (or recipes) and beverages consumed over a week. For both NFD and FVS, no consumption was defined when a food (or recipe) and beverages has been consumed less than once per week. We used unweighted and weighted Cohen's kappa statistics (34, 35) to evaluate agreement in study subjects' classification within quartiles of NFD and FVS. To reflect the degree of disagreement, the weighted kappa uses higher weights for large differences between two categorical ordered variables than weights used for small differences. We used linear weights which are proportional to the discrepancy between subjects' classification within quartiles of the two diversity indices. The unweighted kappa treats all disagreement equally. Associations between categories of diversity indices (i.e., NFD and FVS) and categories of diet quality measures (i.e., MDS and HEI-2015) were evaluated by unadjusted and adjusted odds ratios (ORs) and corresponding 95% confidence intervals (CIs), estimated by means of multinomial logistic regression models (36). Adjusted models included potentials confounders, namely sex, age (<55; 55–64; ≥65 years), geographical area (North, Center/South), education (<7, 7–11, ≥12 years), year of enrolment in the study (<1994, 1995–1999, ≥2000), BMI (<25.0, 25.0–<30.0, ≥30.0 kg/m^2), physical activity (very low, low, high, very high), smoking habit (never, former, current <15, ≥15 cigarettes/day), and energy intake (<1842, 1842–2,249, 2,250–2,737, ≥2,738 kcal/day). The distributions of adjustment factors as well as of MDS and HEI-2015 were reported in Table 1. We fitted separate models for each diversity index (covariates) and each diet quality measure (outcomes).

All analyses were conducted using SAS software, version 9.4 (SAS Institute, Inc., Cary, North Carolina, USA).

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TABLE 1 Distribution of 7,948 study subjects according to sociodemographic characteristics, year of enrolment, body mass index, physical activity, smoking habit, energy intake, and the adherence to the Mediterranean diet and to the Healthy Eating Index-2015.

Variable	Study subjects	
	n	(%)
Sex		
Men	3,660	(46.1)
Women	4,288	(53.9)
Age (years)		
<55	2,974	(37.4)
55–64	2,576	(32.4)
≥65	2,398	(30.2)
Geographical area		
North	6,513	(81.9)
Center/South	1,435	(18.1)
Education (years)[a]		
<7	3,906	(49.3)
7–11	2,052	(25.9)
≥12	1,542	(19.5)
Year of enrolment[a]		
<1994	2,886	(36.3)
1995–1999	3,211	(40.4)
≥2000	1,849	(23.3)
BMI (kg/m^2)[a]		
<25.0	3,587	(45.1)
25.0– < 30.0	3,259	(41.0)
≥30.0	1,074	(13.5)
Physical activity[a,b]		
Very low	2,427	(31.2)
Low	2,899	(37.3)
High	1,507	(19.4)
Very high	939	(12.1)
Smoking habit[a]		
Never	3,890	(49.0)
Former	1,963	(24.7)
Current <15 cigarettes/day	946	(11.9)
Current ≥15 cigarettes/day	1,133	(14.3)
Energy intake (kcal/day)		
<1,842	1,987	(25.0)
1,842– < 2,250	1,987	(25.0)
2,250– < 2,738	1,987	(25.0)
≥2,738	1,987	(25.0)
MDS (points)		
0–2	915	(11.5)
3–6	6,162	(77.5)
7–9	871	(11.0)
HEI-2015 (values)		
<63.5	2,647	(33.3)
63.5– < 69.1	2,654	(33.4)
≥69.1	2,647	(33.3)

Italy, 1991–2008. [a]The sum did not add up to the total because of missing values; [b]Combining levels of physical activity at work/home and during the leisure time.
BMI, body mass index; HEI-2015, Healthy Eating Index-2015; MDS, Mediterranean diet score.

3. Results

We excluded individuals in the top and bottom 2.5% of the estimated sex-specific energy intake distributions (252 men and 214 women) to reduce the effect of implausible extreme values. After these exclusions, the present analysis comprised 3,660 men (46.1%) and 4,288 women (53.9%) as reported in Table 1.

The dendrogram reported clusters of foods (or recipes) accounting for a total branch length of 38.56 (Figure 2). In particular, foods with high sugar content (i.e., sweets, sugar, honey, etc.) showed the shortest branch length and were firstly grouped together as reported in the center of the dendrogram. Moving toward the right side of the dendrogram, there were foods rich in starchy carbohydrates. Fruits having high carbohydrate content (i.e., glucose and fructose) were next to the starchy carbohydrate foods and then followed the vegetable cluster. The cluster of foods rich in animal protein located on the right side. To the left side of the dendogram, next to the foods with high sugar content was the cluster of high refined carbohydrates and then next was the dairy food cluster. To the far sides of the dendrogram (both left and right) were residual groups of heterogeneous foods which were grouped to others at the end of clustering process.

The NFD ranged from 0.23 to 0.88 with a mean of 0.50 (SD = 0.09), whereas FVS ranged from 14 to 56 with a mean of 29.3 (SD = 6.7). According to quartiles of NFD and FVS, 2285 (28.4%) study subjects were classified differently by the two diversity indices (unweighted Cohen's kappa = 0.62 and weighted Cohen's kappa = 0.77; Table 2 and Figure 3). In particular, 4.3% of individuals were classified in the 1st quartile of FVS but in a higher quartile of NFD (i.e., 4.1% were classified in the 2nd quartile and the remaining individuals in a higher one); 4.3% of individuals were in the 2nd quartile of FVS and in 1st quartile of NFD, whereas 4.2% of individuals were in the 2nd quartile of FVS and in a higher quartile of NFD; 6.6% were in the 3rd quartile of FVS and in a lower quartile of NFD, whereas 4.2% were in the 3rd quartile of FVS and in the 4th quartile of NFD; and 4.9% were in 4th quartile of FVS but in a lower quartile according to the NFD.

Table 3 reported associations between quartiles of the two diversity indices and categories of MDS (i.e., 0–2, 3–6, and 7–9 points). For both NFD and FVS, increasing diversity strongly increased the "risk" for adhering to the Mediterranean diet. Furthermore, unadjusted and adjusted analyses showed a stronger association between NFD and the adherence to the Mediterranean diet. In particular, individuals who were classified in the 4th quartile of NFD showed an adjusted OR of 11.26 (95%

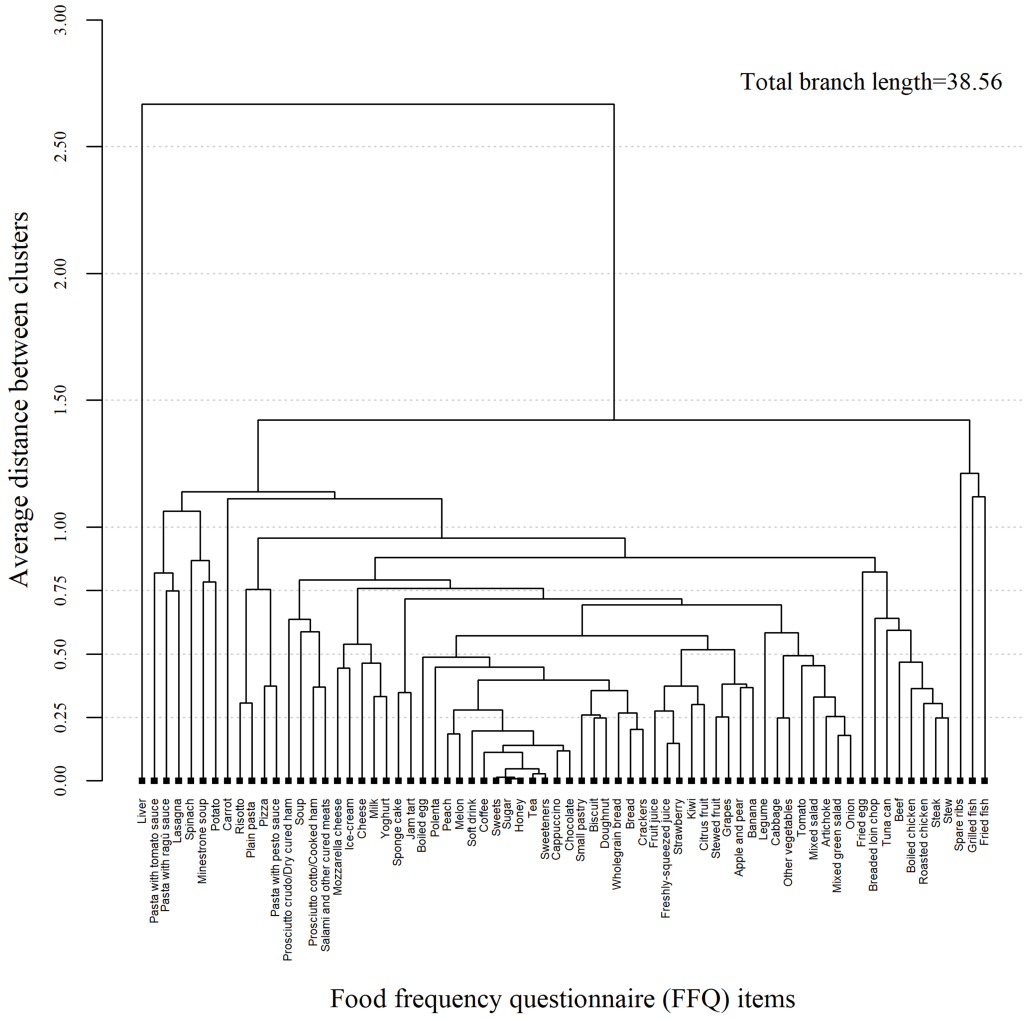

FIGURE 2
Cluster dendrogram of 70 foods (or recipes) and beverages from an Italian food frequency questionnaire.

TABLE 2 Distribution of study subjects according to quartiles of diversity indices.

NFD	FVS				Unweighted Cohen's kappa	Weighted Cohen's kappa
	Q1 (<25)	Q2 (25–28)	Q3 (29–33)	Q4 (≥34)		
	n (%)	*n* (%)	*n* (%)	*n* (%)		
Q1 (<0.43)	1,629 (20.5)	344 (4.3)	14 (0.2)	0 (0.0)		
Q2 (0.43– < 0.49)	323 (4.1)	1,150 (14.5)	506 (6.4)	8 (0.1)		
Q3 (0.49– < 0.56)	14 (0.2)	314 (4.0)	1,275 (16.0)	384 (4.8)		
Q4 (≥0.56)	1 (<0.1)	16 (0.2)	334 (4.2)	1,636 (20.6)	0.62	0.77

Italy, 1991–2008.
df, degree of freedom; FVS, Food Variety Score; NFD, Nutritional Functional Diversity indicator.

CI: 7.88–16.09) which is approximately double than the corresponding OR of 6.80 (95% CI: 4.84–9.54) observed for FVS. A similar pattern was observed for the unadjusted analysis.

Table 4 reported associations between quartiles of the two diversity indices and categories of HEI-2015 (i.e., <63.5, 65.5- < 69.1, ≥69.1). Although less marked, there was an increasing association between quartiles of both diversity indices and the adherence to the HEI-2015. Individuals in the 4th quartile of NFD showed a risk of 2.86 (95% CI: 2.39–3.42) to adhere to the higher category of HEI-2015 which is slightly higher than the corresponding risk observed for FVS (OR = 2.72; 95% CI: 2.27–3.26).

4. Discussion

We adapted the NFD to quantify diversity in the human diet. We firstly evaluated study subjects' distributions across quartiles of NFD and FVS showing that more than one out of four subjects (i.e.,

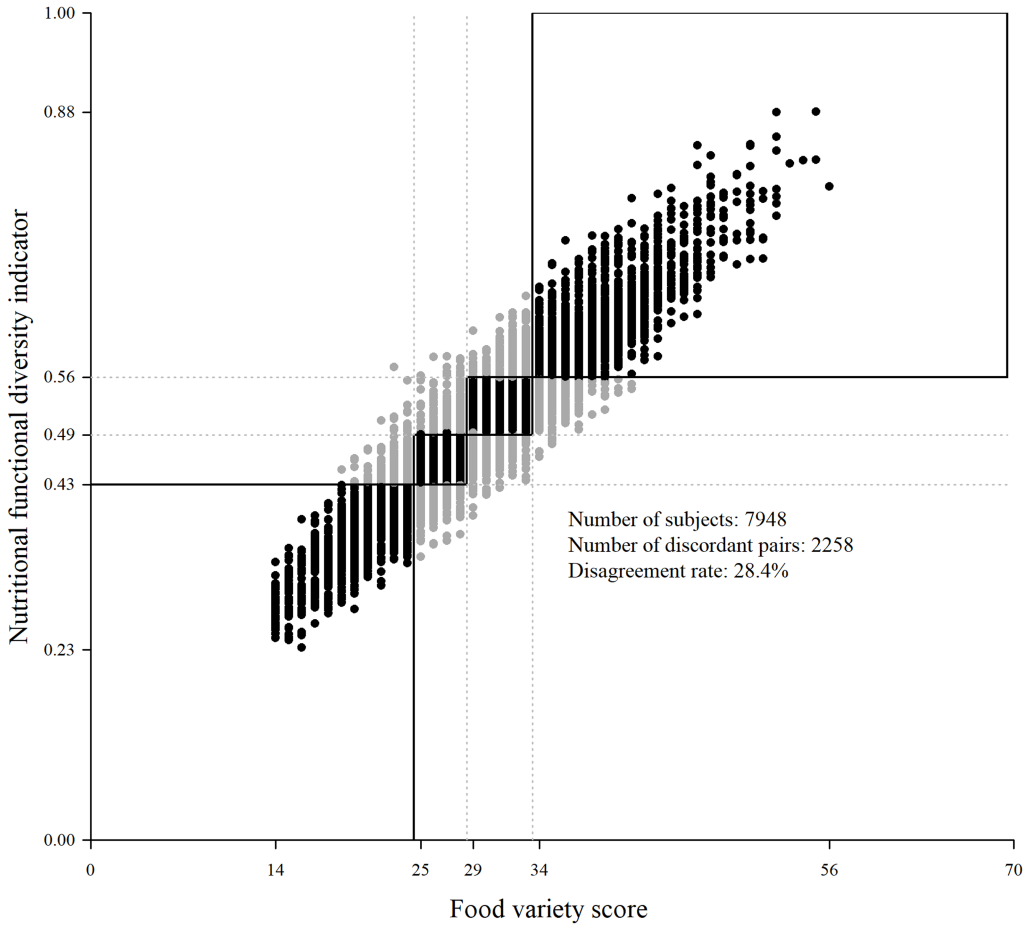

FIGURE 3
Scatter plot of study subjects according to diversity indices. Italy, 1991–2008. Dotted lines represent quartiles for NFD (*y*-axis) and FVS (*x*-axis); the black boxes represent regions with classification agreement according to quartiles of the two indices; the black circles represent subjects' classification agreement and gray circles represent subjects' classification disagreement according to quartiles of the two indices.
NFD, Nutritional Functional Diversity indicator; FVS, Food Variety Score.

TABLE 3 Odds ratios and 95% confidence intervals of the association between diversity indices and the Mediterranean Diet Score.

Diversity index	MDS						
	0–2 points[a]	3–6 points			7–9 points		
	n (%)	*n* (%)	OR (95% CI)[b]	OR (95% CI)[c]	*n* (%)	OR (95% CI)[b]	OR (95% CI)[c]
NFD							
Q1	361 (39.3)	1,527 (24.8)	Ref.	Ref.	99 (11.3)	Ref.	Ref.
Q2	263 (28.6)	1,520 (24.7)	1.37 (1.16–1.63)	1.36 (1.14–1.62)	204 (23.2)	2.68 (2.01–3.58)	2.58 (1.92–3.46)
Q3	201 (21.9)	1,537 (25.0)	1.87 (1.55–2.25)	1.80 (1.47–2.19)	249 (28.3)	4.60 (3.44–6.15)	3.89 (2.87–5.27)
Q4	93 (10.1)	1,567 (25.5)	4.69 (3.65–6.03)	4.25 (3.24–4.57)	327 (37.2)	15.15 (10.90–21.05)	11.26 (7.88–16.09)
FVS							
Q1	342 (37.3)	1,508 (24.5)	Ref.	Ref.	117 (13.3)	Ref.	Ref.
Q2	241 (26.3)	1,404 (22.8)	1.29 (1.08–1.54)	1.29 (1.08–1.55)	179 (20.4)	2.10 (1.58–2.79)	2.01 (1.50–2.69)
Q3	209 (22.8)	1,648 (26.8)	1.92 (1.59–2.31)	1.84 (1.51–2.24)	272 (30.9)	3.89 (2.94–5.15)	3.26 (2.42–4.38)
Q4	126 (13.7)	1,591 (25.9)	3.46 (2.76–4.34)	3.16 (2.45–4.08)	311 (35.4)	9.13 (6.74–12.36)	6.80 (4.84–9.54)

Italy, 1991–2008. [a]Reference category; [b]Unadjusted estimates; [c]Adjusted estimates for sex, age (<55; 55–64; ≥65 years), geographical area (North; Center/South), education (<7; 7–11; ≥12 years), year of enrolment (<1994; 1994–1999; ≥2000), BMI (<25; 25– < 30; ≥30 kg/m^2), physical activity (very low; low; high; very high), smoking habit (never, former, current <15; current ≥15 cigarettes/day); and energy intake (<1,842; 1,842– < 2,240; 2,250– < 2,738; ≥2,738 kcal/day).
BMI, body mass index; CI, confidence interval; FVS, Food Variety Score; MDS, Mediterranean Diet Score; NFD, Nutritional Functional Diversity indicator; OR, odds ratio.

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TABLE 4 Odds ratios and 95% confidence intervals of the association between diversity indices and the Healthy Eating Index-2015.

Diversity index	HEI-2015						
	<63.5[a]	63.5– < 69.1			≥69.1		
	n (%)	*n* (%)	OR (95% CI)[b]	OR (95% CI)[c]	*n* (%)	OR (95% CI)[b]	OR (95% CI)[c]
NFD							
Q1	870 (32.9)	550 (20.7)	Ref.	Ref.	567 (21.4)	Ref.	Ref.
Q2	678 (25.6)	638 (24.0)	1.49 (1.28–1.73)	1.58 (1.35–1.82)	671 (25.3)	1.52 (1.31–1.76)	1.65 (1.41–1.92)
Q3	584 (22.1)	676 (25.5)	1.83 (1.57–2.14)	2.06 (1.75–2.43)	727 (27.5)	1.91 (1.64–2.22)	2.28 (1.93–2.68)
Q4	551 (19.5)	790 (29.8)	2.43 (2.08–2.83)	3.06 (2.57–3.65)	682 (25.8)	2.03 (1.74–2.37)	2.86 (2.39–3.42)
FVS							
Q1	845 (31.9)	567 (21.4)	Ref.	Ref.	555 (21.0)	Ref.	Ref.
Q2	652 (24.6)	556 (20.9)	1.27 (1.09–1.48)	1.35 (1.15–1.58)	616 (23.3)	1.44 (1.23–1.68)	1.56 (1.33–1.83)
Q3	586 (22.1)	753 (28.4)	1.92 (1.65–2.23)	2.19 (1.86–2.57)	790 (29.8)	2.05 (1.76–2.39)	2.51 (2.13–2.96)
Q4	564 (21.3)	778 (29.3)	2.06 (1.77–2.39)	2.67 (2.24–3.19)	686 (25.9)	1.85 (1.59–2.16)	2.72 (2.27–3.26)

Italy, 1991–2008. [a]Reference category; [b]Unadjusted estimates; [c]Adjusted estimates for sex, age (<55; 55–64; ≥65 years), geographical area (North; Center/South), education (<7; 7–11; ≥12 years), year of enrolment (<1994; 1994–1999; ≥2000), BMI (<25; 25– < 30; ≥30 kg/m^2), physical activity (very low; low; high; very high), smoking habit (never, former, current <15; current ≥15 cigarettes/day); and energy intake (<1,842; 1,842– < 2,240; 2,250– < 2,738; ≥2,738 kcal/day).
BMI, body mass index; CI, confidence interval; FVS, Food Variety Score; MDS, Mediterranean Diet Score; NFD, Nutritional Functional Diversity indicator; OR, odds ratio.

28.4%) were differently classified within quartiles of the two diversity indices. To assess which diversity index reflected a higher diet quality, we estimated their associations with MDS and HEI-2015. We observed stronger associations between NFD and both MDS and HEI-2015.

The NFD introduced nutritional (dis)similarity of foods consumed in calculating diversity. This led to a different diversity level of more than 25% of our sample using NFD instead of FVS. The NFD tries to answer the question: "What is the nutritional dissimilarity of the number of different foods consumed?", whereas FVS and other diversity indices based on counting approach answer the question: "What is the number of different foods (or food groups) consumed?". In high-income country populations that are characterized by complex dietary patterns, the simply counting approach could lead to a poor evaluation of diversity and in turn of overall diet quality. Over the time, several composite measures of diet quality have been proposed for these populations (13, 19). Generally, these measures were based on a multidimensional concept of diet quality including: diversity (both across and within food or food groups), adequacy (sufficiency of dietary components consumption compared to recommended energy requirements), moderation (restriction of specific nutrient or food intake to prevent harmful effect on health), and overall balance (the proportionality of macronutrient intake) (12). The stronger associations observed between NFD and both MDS and HEI-2015 may reflect a higher ability of NFD than FVS to assess diet quality, measuring one of its key components: diet diversity. A recent systematic scoping review aimed to provide the link of existing diversity indices and their association to health outcomes in adolescents and adults, concluding that the ability of available diversity indices to reflect diet quality is principally limited. The authors emphasized the inappropriate use of available indices to assess overall diet quality also in low- and middle-income countries (37). Alkerwi previously reviewed the concept of diet quality and concluded that an integrated approach that combines all different dimensions of diet quality is needed to successfully measure it. In addition, the author raised the importance of considering both nutritional characteristics and other facets of diet quality such as food safety, organoleptic properties, and cultural aspects when designing diet quality measures (12).

Although FVS is easy to compute (simply adding up the foods consumed), it fails to discriminate between diets with the same number of foods consumed but with different nutritional compositions. Incorporating the nutritional (dis)similarity of food consumed, NFD reflects a higher diet quality, providing a different diversity level than FVS. Nonetheless, it requires a more complex calculation (i.e., a cluster analysis). In addition, NFD depends on the choice of nutrients included in the cluster analysis. Different nutrients will produce different clusters of foods, as will different values of NFD. We proposed a comprehensive list of essential nutrients which could also be applied in populations with different taste preferences and food availability than the Italian one. However, we do not exclude the possibility of using different sets of nutrients in other specific contexts. Moreover, the choice of foods to include in the cluster analysis may also impact on the calculation of NFD limiting the generalizability of this index. As FVS, the NFD does not consider frequencies of consumption which in turn limits the overall evaluation of diet quality. This could be supported by weaker associations for both diversity indices and HEI-2015 which is designed on density-based amounts. In addition, dietary behaviors may change during time and the long enrolment period of study subjects included in this analysis could have impacted in the assessment of diversity. However, changes in diet may affect to a greater extent the frequency of consumption than the selection of foods themselves. Since frequency of consumption is not accounted for in NFD computation, we expect a limited impact of dietary changing through time on the present results. We evaluated the association between NFD and FVS with two recognized measures of diet quality, it could be interesting to assess the association with other existing diet quality measures. In addition, simulation studies of typical diets could be carried out to assess in a more comprehensive and generalizable way the associations between NFD and other diet quality measures. Furthermore, it would be useful to apply our proposal in other study populations to confirm results of the present study and to validate our methodology in different contexts. Lastly, NDF may have limited application for populations in low-income countries due to lack of individual level

of food consumption data, as well the necessary dietary reference data (e.g., food composition tables). For these populations the use of simple indices could constitute valid and suitable options. However, low- and middle-income countries are increasingly collecting individual level dietary data and therefore application of the NFD method to assess diversity may be more feasible in the future. In addition, NFD could better discriminate subjects' group of high-income countries (who generally consumed a wider range of foods with different nutritional composition) and investigate the relationship between each identified group and the development of disease.

5. Conclusion

Our findings indicate that NFD provided different diversity levels of FVS for more than a quarter of our sample. In addition, NFD was more strongly associated with a higher adherence to the Mediterranean diet and Healthy Eating Index-2015 providing evidence of a greater ability of this tool to assess diet quality evaluating diversity.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: participating hospitals are owners of data. Anonymized patient data are available for use in collaborative studies to researchers upon reasonable request to the corresponding author. Data will be provided following the review and approval of a research proposal (including a statistical analysis plan) and the completion of a data-sharing agreement. Requests to access these datasets should be directed to matteo.dimaso@unimi.it.

Ethics statement

The studies involving humans were approved by Hospitals of participating centres. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MF conceptualized the methodological idea. MDM and FB further developed the methodological idea, performed the analyses, and drafted the manuscript. JP helped in the statistical methodological approach. LP helped with the nutritional issues and interpretations. CLV managed data collection and helped to review the final version of the manuscript. LDM helped to interpret the results. All authors critically reviewed and approved the final version of the manuscript.

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Conflict of interest

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

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2023.1170831/full#supplementary-material

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Construct validity of a dietary protein assessment questionnaire to explore college students' knowledge and attitudes towards dietary protein

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Introduction: Misconceptions about dietary protein may exist due to unscientific information from commonly used sources such as social media. Understanding knowledge and attitudes towards protein is important for developing effective interventions to improve the dietary behaviors of U.S. college students. The objective of this study was to develop a questionnaire to evaluate college students' knowledge and attitudes towards dietary protein.

Methods: The questionnaire had 64 questions, including 8 demographic, 24 knowledge, 14 attitude, and 18 behavior questions. Construct validity of the knowledge questions was assessed by performing known-group comparisons using an independent t-test. Exploratory factor analysis (EFA) with principal axis factoring and a promax rotation was used to evaluate the factor structure of the attitude questions.

Results: Four hundred seventy participants (87.3% female) provided responses for the attitude questions. Fifty-five nutrition and Fifty-one non-nutrition students provided responses for the knowledge questions. Three factors were retained: animal protein sources' relationship with human and environmental health (Factor 1); organic protein sources (Factor 2); and adequacy of the protein recommended dietary allowance (RDA) for weight loss and vegetarian diets (Factor 3). Mean knowledge responses were 66.4±11.5% and 47.6±16.4% for nutrition and non-nutrition students, respectively (t-test p-value for difference <0.001).

Conclusion: Protein attitudes appear multidimensional and correlated. Further testing is needed to confirm the three-factor model and to assess temporal reliability.

KEYWORDS

questionnaire, knowledge-attitude-behavior, dietary protein, factor analysis, statistical approaches, college students

1 Introduction

Protein is a major structural and functional component of the human body, accounting for approximately 14%–16% to the total mass of a lean adult (1, 2). Dietary protein intake recommendations vary by life cycle phase, disease state, and physical activity (2–6). The Recommended Dietary Allowance (RDA) for protein for healthy adult men and women is 0.8 grams per kilogram of body weight per day (g/kg/day), which is based on careful analyses of available nitrogen balance studies (2). Dietary protein recommendations vary across professional organizations, such as the International Society of Sports Nutrition, Academy of Nutrition and Dietetics, and Institute of Medicine, based on physical activity and age (2, 3, 5). The International Society of Sports Nutrition recommends 1.4–2.0 g/kg/day for an athlete who lifts weights or is training for an endurance event (3). The Academy of Nutrition and Dietetics recommends that a protein intake of 1.0–1.6 g/kg/day for older adults >60 years is safe and adequate to meet their needs, while the Institute of Medicine suggests older adults do not have elevated protein needs above 0.8 g/kg/day (2, 5). The Acceptable Macronutrient Distribution Range (AMDR) for protein varies by age and is 10%–35% of total calories for adults >18 years (2). These discrepancies are of consequence for health professionals who provide dietary recommendations for patients and for young adults and athletes who seek recommendations from reputable sources.

The average protein intake in the United States (U.S.) is close to the *Dietary Guidelines for Americans*' recommendations for all age-sex groups; however, the average intake of different protein sources vary in comparison to the recommendations, especially for seafood (7). These dietary behaviors may be due to poor nutrition knowledge, poor attitudes towards food and nutrition, use of unreliable sources, lack of availability and/or accessibility to food sources, and/or unawareness of evidence-based recommendations (8, 9). Dietary behaviors are influenced by many factors including nutrition knowledge and attitudes towards food and nutrition (8–10). Attitudes towards food and nutrition are formed in part by nutrition knowledge. Greater nutrition knowledge has been associated with positive attitudes towards food and nutrition, as well as increased adherence to dietary recommendations (8–10). Unhealthy dietary behaviors among college students, such as high intakes of fast food and low intakes of fruits and vegetables, have been observed (11, 12). Additionally, lack of knowledge about protein has been found among college students, despite common use of protein supplements (13). Low levels of nutrition knowledge, as well as poor attitudes towards protein, may be due to unsubstantiated nutrition information (14).

There is limited research available on protein knowledge and attitudes among U.S. college students; and no validated instrument exists to accurately assess these constructs (9). It is crucial to understand protein knowledge and attitudes to design and implement appropriate education tools, increase awareness, and address misconceptions. Considering these limitations, the Dietary Protein Assessment Questionnaire (DPAQ) is under development to quantify dietary protein knowledge, attitudes, and sources of nutrition information so that researchers can explore the relationships between these constructs and outcomes. The DPAQ will ultimately help professionals create and provide appropriate educational interventions and resources to help improve the health of U.S. college students. This study provides valuable preliminary data on construct validity of the knowledge and attitude questions, which will guide future development of the DPAQ to become the first validated instrument for dietary protein.

Abbreviations: DPAQ, Dietary protein assessment questionnaire; EFA, Exploratory factor analysis; RDA, Recommended dietary allowance (for protein: 0.8 g/kg/day).

2 Materials and methods

2.1 Item generation

The items for the DPAQ were generated using principles from Don Dillman's book on survey development (15). The DPAQ consisted of 64 questions on the knowledge, attitudes, and behaviors towards protein, including 8 demographic questions. The knowledge questions consisted of three answer choices (true, false, unsure) and were created to assess respondents' knowledge about dietary protein sources and requirements for various populations, such as physically active individuals and individuals adhering to a vegetarian diet. The attitude questions included a 5-point Likert scale ranging from "strongly disagree = 1" to "strongly agree = 5" with a neutral midpoint to assess respondents' attitudes towards plant and animal protein sources. The behavior questions consisted of multiple-choice answer options to assess respondents' dietary patterns regarding protein.

Nutritional science researchers reviewed the questionnaire for applicability, structure, reading level, and comprehension. The questionnaire was then updated according to feedback. Cognitive interviews were conducted using individuals with no nutrition background to assess information-processing needs of the questionnaire items (16). Researchers and statisticians reviewed the questionnaire to identify appropriate scaling of answer choices and the questionnaire was updated to create the final version prior to distribution. The DPAQ was then administered using PsychData (PsychData.com, LLC, State College, PA). See Supplementary material for the version of the DPAQ that was administered.

2.2 Sample and recruitment

In the fall 2018, participants were recruited through an open call email sent to students attending Texas Woman's University. The email informed potential participants of the study's purpose, eligibility requirements, and included a link to the DPAQ. Participants were recruited with the help of professors and researchers to voluntarily complete the questionnaire. The online questionnaire link was also posted on social media sites and spread by word of mouth. Eligibility requirements included individuals ≥18 years of age with a reliable Internet source.

Data were collected from nutrition undergraduate students enrolled in a junior-level nutrition class and from non-nutrition undergraduate students enrolled in a junior-level education class as a comparison group for the knowledge section. Students were offered extra credit in their respective classes for successful completion of the questionnaire.

Approval of the study was obtained from Texas Woman's University Institutional Review Board. Informed consent was collected from each participant before participation in the questionnaire. Data were de-identified except for the nutrition and education students used for the knowledge section.

2.3 Validity measures and data analyses

For the attitude questions, participants were randomly partitioned into two analytic samples. One sample was used to identify possible factor structures, while the other was used to re-evaluate the factor structure. The correlation matrix and factor loading scores for both analytic samples were examined, and items were eliminated according to criteria.

Exploratory factor analysis (EFA) with principal axis factoring and a promax rotation was performed on the 14 attitude questions to identify the dimensionality of the attitude constructs for the subjects. The correlation matrix was examined for items exhibiting multicollinearity ($r \geq 0.9$). Factor retention criteria included factors $\geq|0.4|$ and factors comprised of two or more items. Composite scores for the factors were calculated according to their factor loadings. Internal reliability was examined using Cronbach's α. The questionnaire responses were then compared across gender, education, and race/ethnicity using an ANOVA and adjusted for multiple comparisons using the Tukey–Kramer adjustment where necessary.

The knowledge questions were evaluated for construct validity by comparing mean scores between nutrition and non-nutrition majors using independent samples *t*-test. The correct answers were totaled for each student to determine the mean scores. The answers marked "unknown" were given a value of zero and did not contribute to overall mean scores. A $p < 0.05$ was considered statistically significant for all analyses unless otherwise indicated. All data analysis was performed with SAS® software, Version 9.4 Statistical Analysis System (RRID:SCR_008567). Copyright© 2013 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, United States.

3 Results

3.1 Questionnaire participants

Four hundred seventy responses were received and 450 provided complete demographic data. Most participants were female (87.3%), and the mean age was 28.2 ± 11.4y. See Table 1 for complete demographic information.

TABLE 1 Demographic data for questionnaire participants randomized to exploratory factor analysis.

Variable	Total sample (n = 450)	EFA #1 (n = 225)	EFA #2 (n = 225)	p
Age (mean ± SD)	28 ± 11.4	28 ± 11.7	29 ± 11.0	0.37
Sex *n* (%)				
Female	393 (87)	205 (91)	188 (84)	0.02*
Race *n* (%)				
Caucasian	294 (65)	148 (66)	146 (65)	0.92
Hispanic	77 (17)	34 (15)	43 (19)	0.32
African American	55 (12)	28 (12)	27 (12)	1.00
Asian/Pacific Islander	34 (8)	19 (8)	15 (7)	0.59
American Indian	13 (3)	6 (3)	7 (3)	1.00
Other	7 (2)	2 (1)	5 (2)	0.45
Health status *n* (%)				
Healthy	356 (79)	182 (81)	174 (77)	0.42
Overweight/ obese	117 (26)	57 (25)	60 (27)	0.83
Diabetes	7 (2)	3 (1)	4 (2)	1.00
High cholesterol	26 (6)	11 (5)	15 (7)	0.55
CKD	3 (1)	2 (1)	1 (<1)	1.00
High blood pressure	16 (4)	5 (2)	11 (5)	0.20
Education *n* (%)				0.59
High school	57 (13)	31 (14)	26 (12)	
Some college	84 (19)	47 (21)	37 (16)	
Associate degree	66 (15)	29 (13)	37 (16)	
Bachelor's degree	153 (34)	75 (33)	78 (35)	
Graduate degree	90 (20)	43 (19)	47 (21)	

CKD, chronic kidney disease; *$p < 0.05$; group difference for the continuous variable was assessed using the independent *t*-test; group differences for categorical variables were assessed using chi-square test for independence.

3.2 Exploratory factor analysis #1

Two hundred twenty-five participants were randomized to the first EFA; 74.2% provided complete responses for the attitude questions. The data exhibited good sampling adequacy (Kaiser–Meyer–Olkin test = 0.8) and the correlation matrix was suitable for structure detection (Bartlett's test <0.001). There was some evidence of multicollinearity observed within the correlation matrix (determinant = 0.006). A total of five items did not meet inclusion criteria (primary factor loading $\geq|0.4|$) and were removed for the subsequent EFA. The first EFA retained four factors and explained 62.3% of the total variance.

3.3 Exploratory factor analysis #2

Two hundred twenty-five respondents were randomized to the second EFA; 59.1% provided complete responses for the attitude questions. The data demonstrated good sampling adequacy (Kaiser–Meyer–Olkin test = 0.76) and the correlation matrix was suitable for structure detection (Bartlett's test <0.001). The correlation matrix was examined for items exhibiting extreme multicollinearity (determinant = 0.007). There was some evidence of multicollinearity observed among the statements of "meat consumption is unhealthy" and "meat should not be consumed" ($r = -90$). Three factors were retained, which were comprised of the nine items remaining from EFA #1 and explained 73.9% of the total variance. See Table 2 for variance explained by each factor. All items displayed a factor loading $\geq|0.4|$.

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TABLE 2 Exploratory factor analysis pattern and structure matrices with communalities and explained variance by factor ($n = 225$).

Items by factor	Pattern matrix	h^2	Structure matrix	Explained variance
Factor 1: human/ environmental health				44.6%
The impact of climate change can be reduced by consuming less meat, dairy, & eggs	0.74	0.49	0.69	
Meat production is harmful to the environment	0.85	0.63	0.79	
Egg consumption is harmful to human health	−0.54	0.63	−0.61	
Meat consumption is unhealthy	−0.88	0.81	−0.90	
Meat should not be consumed	0.81	0.76	0.87	
Factor 2: organic sources				15.5%
Organic protein sources are better for the environment	0.67	0.59	0.75	
Organic protein sources are healthier	1.01	0.92	0.95	
Factor 3: protein RDA				13.8%
The RDA for protein is adequate for healthy weight loss	0.59	0.33	0.57	
The RDA for protein is adequate for people following a vegetarian diet	0.84	0.72	0.85	

RDA, recommended dietary allowance (for protein: 0.8 g/kg/day); h^2 denotes the communalities.

Factor 1 included five items related to animal protein sources and their relationship with human and environmental health. Factor 2 included two items pertaining to the healthfulness of organic protein sources. Factor 3 included two items describing the adequacy of the RDA for protein with respect to weight loss and adherence to a vegetarian diet. Factor 1 shared a moderate, inverse relationship with Factor 2 ($r = -0.47$), and a weak, positive relationship with Factor 3 ($r = 0.29$). Factor 2 shared a weak, inverse relationship with Factor 3 ($r = -0.19$). Cronbach's α coefficient for Factor 1 ($\alpha = 0.87$) and Factor 2 ($\alpha = 0.83$) displayed evidence of good internal reliability. Satisfactory internal reliability was observed for Factor 3 ($\alpha = 0.65$).

3.4 Knowledge towards protein

Fifty-five nutrition undergraduate students and 51 education undergraduate students' responses were analyzed. The majority of participants were female (95.3%) and the mean age was 27.9 ± 11.2 years. The nutrition students' mean test score was 66.4 ± 11.5% with scores ranging from 42%–92%. The education students' mean test score was 47.6 ± 16.4% with scores ranging from 17%–79%. A significant difference in mean test score values was observed between nutrition and education students (18.8 ± 14.1; $p < 0.001$). Cohen's d indicated a large, standardized difference between nutrition and education mean scores ($d = 1.33$).

4 Discussion

Currently, no validated questionnaires exist that attempt to measure the knowledge and attitude constructs of protein among the college student population (17, 18). As a result, studies that evaluated knowledge and attitudes towards specific macronutrients lacked validated instruments (17–23). This study provided evidence of construct validity for the DPAQ's protein knowledge and attitudes.

The EFA identified a multidimensional structure, and the original 14 attitude items could be shortened by five items without decreasing internal reliability. Five items loaded strongly with human/ environmental health (Factor 1). Items contributing positively to the Factor 1 score included "meat production is harmful to the environment," "meat should not be consumed," and "the impact of climate change can be reduced by consuming less meat, dairy products, and eggs." Items contributing negatively included "meat consumption is unhealthy" and "egg consumption is harmful to human health." The inverse contributions of the items "meat consumption is unhealthy" and "meat should not be consumed" to the overall Factor 1 score suggest that college students' consider environmental health more than human health when determining food items that should and should not be consumed. This could be a misconception among college students due to social media platforms being one of their main sources of nutrition and health information.

Two items loaded strongly with organic sources (Factor 2), which suggests that college students believe that organic protein sources are healthier to consume and better for the environment compared to conventional (non-organic) protein sources. Although the exact extent is unknown, this shows that college students place some value on organic protein sources. Two items also loaded strongly with protein RDA (Factor 3), which shows that college students believe the RDA for protein is adequate in terms of healthy weight loss and people adhering to a vegetarian diet. The factor structure provides evidence that attitude constructs towards protein are multidimensional.

Future development of the DPAQ should further develop the attitude constructs. An analysis of the relationship between nutrition information sources and the attitude constructs would be beneficial to identify strategies to educate college students. Adding more items related to Factors 2 and 3 may help define the factors and may strengthen the correlations observed among the protein attitudes measured.

The significant difference in mean test scores between the undergraduate nutrition and non-nutrition (education) students indicated that the DPAQ instrument had adequate construct validity. The nutrition students' mean test score was greater than the non-nutrition students, which has been observed in previous studies (23–27). The mean test score of nutrition students in the current study was lower than those in previous studies, which may be due to many factors, such as administering the questionnaire without prior notice or wording of knowledge statements (19–22). It is important to note the instruments used in previous studies had content not exclusively on protein, but included content related to general nutrition and salt knowledge among adult and student populations (18–22).

While studies have shown dietary patterns can be influenced by eating motives and the perceived impacts on human health and the environment, more research is needed (18–22, 28). With further development, the DPAQ may be used to identify knowledge and attitudes towards protein on the topics of human/environmental health, organic sources, and adequacy of the RDA, as well as other topics needed to capture the full nature of protein attitudes.

Due to increased popularity of social media platforms, there has been a commensurate rise in the amount of false nutrition information presented to the public (29–31). The lack of "media literacy" may contribute to this wide range of false information. Therefore, it is necessary to create validated instruments to assess protein attitudes and knowledge among the public. Identifying protein knowledge and attitudes will facilitate the design and development of education tools to increase awareness and decrease misconceptions currently associated with protein. Interventions targeting various factors, such as eating motives and reliable nutrition sources, may also lead to improved understanding of evidence-based protein intake.

The strengths of this study include sample sizes, internal consistency of items, and utilizing the evidence-based approach for questionnaire development; however, several limitations exist. Although participants were homogenous in gender, age, and race, results may not be generalizable to other populations. It is important to examine validity in a more diverse population before conducting broader population studies. Just like any self-reported item, this study is also limited by the truthfulness of participants. Satisfactory internal reliability ($\alpha \leq 0.70$) was identified for Factor 3, which may provide evidence of inconsistent answers to attitude questions regarding protein RDA (32). Future studies should focus on increasing internal reliability of the DPAQ by adjusting the number of items, rewording questions, and reformatting the instrument. The instrument's validity should be examined in a more diverse population with a more equal gender distribution to increase generalizability to the college student population, as well as provide more complex measurements to explore the attitude constructs multidimensionality.

5 Conclusion

The results of this study provide preliminary evidence for the knowledge and attitude constructs validity within the DPAQ to be used among the college student population. The instrument, and, in particular, the topic on "protein RDA" requires further development. Attitudes towards protein seem multidimensional and correlated. Additional testing is needed on the DPAQ to confirm the three-factor model and to estimate test-retest reliability. A multidimensional approach seems crucial for future development of the DPAQ, as well as for effective interventions. Future development should focus on increasing internal reliability by adjusting the number of items, rewording questions, and reformatting the instrument. This will allow the DPAQ to be administered to more diverse populations, which will enable researchers to accurately measure protein knowledge and attitudes to create effective nutrition interventions for college students.

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 humans were approved by Texas Woman's University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because this study utilized an online questionnaire, so it was not possible to obtain a signature from participants. Informed consent was obtained from participants by providing the consent form on the first page of the questionnaire. Since this study was an exempt study involving a questionnaire, a complete consent form was not required. The following statement, which was required, appeared on the consent form instead: the completion of this questionnaire constitutes your informed consent to act as a participant in this research.

Author contributions

PG: Visualization, Conceptualization, Formal analysis, Investigation, Visualization, Writing – original draft. CW: Methodology, Resources, Supervision, Visualization, Writing – review & editing. DM: Visualization, Data curation, Conceptualization, Formal analysis, Methodology, Resources, Supervision, Visualization, Writing – review & editing.

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Conflict of interest

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

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Supplementary material

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The interplay of food-related lifestyle and eating behavior in Italian women

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Introduction: Women play a crucial role in food shopping and preparation, and their food choices have significant implications for their health and that of their families. This study aims to provide a perspective on women's eating lifestyle, which has undergone significant changes.

Methods: A factor analysis was conducted to assess the degree of involvement in food choices and the types of food items consumed among a sample of 399 Italian women.

Results: Through cluster analysis, four segments were identified: hedonic food consumers, sustainable- and balanced-diet consumers, food experimenters, and no food fondness consumers. The results reveal a correlation between the degree of food involvement and the type of food consumed.

Discussion: Furthermore, the food lifestyle of the sample is partially dependent on age. Individuals aged 25–28 years show more hedonic food consumption behavior, while the older age group (44–64 years) falls into the sustainable and balanced diet consumer cluster (the largest cluster) and the cluster of those who do not express definable food choices (no food fondness).

KEYWORDS

food-related lifestyle, consumer behavior, women, cluster analysis, factor analysis

1 Introduction

Women represent a highly heterogeneous component of the population due to the strong diversity found regarding formative, work, migration, marital, and reproductive life trajectories (1). In addition, they play a significant role in society when it comes to food choices and food shopping; their influence is shaped by various factors, including cultural norms, gender roles, socioeconomic status, and individual preferences (2–5).

Over the decades, the role of women has changed radically as a result of a series of events that have seen them become more involved in the social and working world which have changed their lifestyles (6). Lifestyle is a social concept (7) shared by a group of individuals who hold comparable views on variables and are profoundly impacted by their concurrent requirements. It was mainly used primarily to assess activities, interests, and attitudes through which marketers have attempted to characterize homogeneous groups of customers and identify market trends (8, 9).

However, even when individuals share the same culture and social class, those affiliated with the same professions may not consistently adopt identical lifestyles. These variations can stem from demographic factors and individual expressions of identity, as well as integration factors such as age, education, income, and gender (10, 11).

The ambiguity of the lifestyle concept has raised concerns among experts over the years (12, 13) who have argued that lifestyles should be limited to certain aspects of life, such as food

behavior (14), considered a complex system that is expressed through desires for self-actualization and representation and can certainly be considered an important component through which to describe the lifestyle.

The initial exploration of the elements constituting food lifestyles was undertaken by Brunsø et al. (15). They posited that a food lifestyle encompasses both declarative and procedural attributes. These attributes not only reflect an individual's values but also indicate the qualities they may prioritize in food selection, providing insights into their food preferences.

Given the notable roles that women fulfill in modern society and the increasing attention they have received in recent studies, it is crucial to acknowledge that, while women may have a prominent influence on food choices, shopping, cooking, and household nourishment (16, 17), individual experiences and preferences can vary significantly (18). Furthermore, the lifestyle of women can exert a significant impact on their food choices and preferences. It is important to recognize that individual choices are subjective and can exhibit considerable variation; however, there are several common factors that contribute to this relationship (19–21). Food-related lifestyle can be viewed as "the system of cognitive categories, scripts and their associations that relate a set of products to a set of values" (22). It is a mental construct that describes the real behavior (23), thus demonstrating how product attributes are connected to the effects of food intake, transcending brands or goods, but that may be class-specific (24). In this respect, individuals vary not only in their level of participation with food (25), but also in the reasons behind their level of involvement with food, such as their desire to experiment with new foods and cooking techniques.

One of the most intriguing aspects is knowledge pertaining to gender variations in food relationships (26). Several studies have demonstrated significant gender differences in the relationship with food (27, 28). Since women are typically the primary food purchasers (29) and are often described as being especially attentive to sustainable and healthy diets (30–32) the main purpose of this study is to assess the eating lifestyle of a sample of Italian women through the correlation between involvement in food choices and the type of food consumed based on consumers' stated preferences (33).

The theoretical framework employed in this study aligns with the model introduced by Brunsø et al. (34), which preserves the foundational principles of the established food-related lifestyle concept. Using their self-reported behaviors related to food engagement and dietary choices as key indicators, this model enabled the researchers to explore the food preferences and consumption patterns of a cohort of Italian women.

The results are intended to support food companies who, by identifying distinct consumer groups that adhere to different dietary patterns, can improve the effectiveness of their public campaigns and marketing strategies (21, 35).

2 Conceptual framework for food-related lifestyle: objective and research questions

A deductive model of food-related lifestyle was created in the late 1990s (22), which is considered more rigorous than the inductive approach prevalent in lifestyle research (36) and enables the description of eating behavior according to self-stated consumption preferences (37, 38).

Initially, the emphasis in food-related lifestyle was on tying innovation to the means–end perspective across several dimensions, such as shopping, meal preparation, and dining, which represents a wider approach compared to the innovation construct.

In several investigations the instrument has been updated, either by lowering the number of items or by tailoring it to the objective of the research, such as by making it more applicable to the kind of meal being evaluated (39, 40). It has been widely developed and successfully applied over the years to different European and non-European food cultures (41–43).

According to the theoretical model (44), food-related lifestyle manifests itself in several life domains, such as purchasing motives, quality aspects, cooking methods, shopping behaviors, and consumption situations, which are characterized by several latent dimensions that can be used to describe consumers' lifestyles. The food-related lifestyle method views lifestyle as a cognitive mediator between life values, i.e., the fundamental end-states that individuals find desirable, and food-related perception and behavior (34). While it aligns more with Western cultures (45), it is widely accepted as a validated tool for international segmentation in the food sector (40). This method uses correlation between sets of psychographic attitudes and observable actions (46) and consists of three core dimensions: food involvement; food innovativeness; and food responsibility (34).

Given that the food-related lifestyle instrument has not previously been used to conduct a gender survey, this study is novel in terms of using a convenience sample of Italian women as the population of interest (47) to analyze the correlations between involvement in food consumption and the types of food they prefer.

Starting from the general hypothesis that eating habits and food lifestyles may coalesce in a survey specifically aiming to understand the behavioral features of female food consumers, the objective is to verify whether there is a relationship between the degree of food involvement and the types of foods consumed, which would enable us to describe the lifestyle of the sample surveyed according to the stated preferences of women consumers. Eating habits and food lifestyles are two related concepts; however, they have distinct meanings (48). Eating habits primarily focus on the specific behaviors and patterns of food consumption, encompassing the types of foods consumed, portion sizes, meal timing, frequency of eating, and preparation methods (49–51). Food lifestyles encompass a broader spectrum of attitudes, values, and practices related to food choices and behaviors (21, 52). Hence, it becomes intriguing to assess the food attitudes and motivations of females, with the aim of segmenting the broader target market into smaller, more homogenous groups or segments based on specific criteria such as environmental concerns, innovative food and cooking methods, healthy dietary preferences, or demographic characteristics.

Based on the above, this paper aims to answer the following research questions (RQs):

> *RQ1*: Do environmental aspects still represent a fundamental motivation for women in their food choices today?
>
> *RQ2*: Are women willing to experiment with innovative food and new culinary methods?

RQ3: Do women exclusively prefer healthy and nutritious foods?

RQ4: What are the most relevant foods in women's diet today?

RQ5: Is it possible to identify homogeneous categories of female consumers to segment the food market?

RQ6: Are socio-demographic characteristics relevant in influencing food-related lifestyles?

3 Materials and methods

3.1 Data collection

An anonymous and structured questionnaire was administered, from March to April 2022, to a convenience sample of 399 Italian women via Google Forms (53–55). After a brief introduction, participants were asked to sign the informed consent form. The ethical review and approval for this study were waived due to the observational nature of the research, whereby consumer data were provided voluntarily. The questionnaire was circulated via major social networks, such as Facebook, WhatsApp, and LinkedIn, to gather data on participants' eating habits and food lifestyles. While the sample size is deemed acceptable for multivariate analysis and model dependability (56), this sampling strategy necessitates that the findings be taken with care due to the reduced likelihood of generalizability. However, convenience sampling is a popular method in the scientific literature since the validity of the data is not compromised (57–60).

The questionnaire, aiming to collect a variety of qualitative and quantitative data on food consumption attitudes and purchase behavior, was divided into six parts: purchasing motives; quality aspects; cooking methods; ways of shopping; consumption situations; and socio-demographic characteristics. Respondents were presented with a series of coded options and asked to select the one that best reflected their opinion or behavior. The queries were structured as multiple-choice responses on a Likert scale with the intent of categorizing the respondents' and their families' attitudes and preferences.

To identify purchasing motives, the 15 items proposed by Brunsø et al. (34) were used, while maintaining the original concept of food-related lifestyle (19). This approach measures three basic dimensions of food-related lifestyle, namely food responsibility, food involvement, and food innovation; for each, the five items that would work best as indicators of the three constructed dimensions were identified. Responses were recorded using a seven-point Likert scale (1 = completely disagree; 7 = completely agree). Thereafter, self-reported eating behavior was analyzed using validated items assessing the frequency of: (a) consuming various sorts of goods; (b) utilizing extended time for cooking and baking; (c) using different types of shops; and (d) eating circumstances (34). Similarly, the survey comprised in part questions previously used in the validation of the food-related lifestyle instrument (19) and in part items created by Brunsø et al. (34) from scratch. In the second section of the questionnaire (quality aspects), respondents were asked how often they consumed items including fruits, vegetables, legumes, pasta, bread, meat, fish, sweets, and alcohol.

Responses were recorded using a seven-point Likert scale (1 = never; 7 = every day). In the third section of the questionnaire (cooking techniques), respondents were asked how often they spend more than one hour in the kitchen, such as during the week or on the weekend. In the fourth section of the questionnaire (shopping methods), respondents were asked how often they purchase food from supermarkets, retail outlets (e.g., greengrocer, fisherman, butcher, bakery), and the Internet. In the fifth section of the questionnaire (consumption situations), respondents were asked how often they eat meals in certain places, such as at home, at work, or at a restaurant.

The final section collected the social and demographic characteristics (Table 1) of the sample considering the following features: age group (18–24 years; 25–28 years; 29–43 years; and 44–64 years); education level; number of household members; and the presence of minors (<18 years old) in the household.

3.2 Data analysis

The survey data were examined using inferential and multivariate statistical methods, including factor analysis and cluster analysis (61). The study first conducted two separate exploratory factor analyses (EFAs) on data blocks. Therefore, the dataset was divided into two subsets to separately summarize different information about the involvement of food consumption (EFA 1) and the type of foods (EFA

TABLE 1 Socio-demographic variables.

	Freq.	%
Age (years)		
18–24	78	19.55
25–28	102	25.56
29–43	106	26.57
44–64	113	28.32
Total	399	100.00
Education		
Primary and middle school certificate	18	4.51
High school diploma	171	42.86
University degree	175	43.86
Postgraduate degree (Master's and/or PhD)	35	8.77
Total	399	100.00
No. of household members		
1	19	4.76
2	68	17.04
3	92	23.06
4	163	40.85
>4	57	14.29
Total	399	100.00
Presence of minors in the household (<18years old)		
No	244	61.15
Yes	155	38.85
Total	399	100.00

2) consumed by the sample examined. Subsequently, a separate EFA was performed on each block to reduce the dimensionality of the data and identify the main factors within each block. A complex or heterogeneous dataset with different blocks of variables may have different relationships or be influenced by different factors. By performing an EFA on each block separately, it was possible to capture the most relevant variations within each block. Following that, to verify the EFA1 model and determine the structure of the factors, confirmatory factor analysis (CFA) was performed. Finally, a cluster analysis was conducted on each block using the factor component scores as input variables to assign observations to clusters.

3.2.1 Exploratory factor analysis

EFA was used to reduce the information contained in the original variables (62) into latent constructs, which were then utilized to identify homogenous consumer groups through cluster analysis.

EFA enables us to examine whether factors can describe the primary aspects of food involvement and consumption, summarizing the phenomenon's description while minimizing information loss in terms of variance explained. This was accomplished by transforming the initial collection of the correlated variables into a new collection of orthogonal variables. Varimax rotation was used to facilitate the understanding of EFA findings and optimize the variance of the sum of square loadings (63). Therefore, factor loadings and explained variance in the results tables will relate to the rotated components.

This statistical technique was conducted separately for blocks of homogeneous variables (64), corresponding to two distinct sections of the questionnaire: the EFA1 to establish the underlying structure of the 15 items proposed by Brunsø et al. (34) pertaining to consumers' food responsibility, food involvement and food innovation; and EFA 2 was conducted on 13 items pertaining to the type of food consumed by the sample. In the factor matrix analysis, we used 0.5 as the minimum value (65).

Kaiser–Meyer–Olkin (KMO) and Bartlett's test, based on partial correlations between the variables, were utilized to validate the validity of the model (66).

The model's fit was evaluated using the Kaiser–Meyer–Olkin (KMO) test, which is based on partial correlations between variables. The scores of the KMO test fall between 0 and 1. Low values indicate that the analysis is insufficient, since the correlation between pairs of variables cannot be explained by the variance shared by the whole collection of variables. Hence, it is advised that KMO test results not fall below 0.5, while findings over 0.7 are regarded as satisfactory (67).

Concerning the evaluation of the model's validity, the Bartlett test is commonly utilized to test the hypothesis that the correlation matrix coincides with the identity matrix (68). When the Bartlett test is insignificant, the identity matrix may coincide with the correlation matrix; therefore, the factorial model may not be suitable.

3.2.2 Confirmatory factor analysis

To validate the model and ascertain the structure of the factors, confirmatory factor analysis (CFA) was conducted. The CFA evaluates the fit of an *a priori* model containing the number of factors and the items that are assigned to them to the data.

The estimation method most frequently employed for CFA is maximum likelihood (ML).

The ML method operates under the assumption of a continuous scale, while the observed data adheres to an ordinal scale. However, Byrne (69) argues that the impact of considering ordinal data as continuous is negligible when there are more than five response categories, and the data are close to a normal distribution. The data utilized in this study satisfy the criteria, and the ML method was deemed a suitable estimation technique.

The evaluation of the fairness of fit was conducted utilizing the χ^2 statistic. Nevertheless, due to the χ^2 statistic's susceptibility to large sample sizes (69) and in accordance with Hair et al. (70)'s rule of thumb, an additional absolute and incremental fit indices were premeditatedly incorporated: Tucker Lewis Index (TFI), Comparative Fit Index (CFI), Root Mean Square Error of approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR). Values exceeding 0.95 are regarded as indicative of a satisfactory fit for TLI and CFI, whereas values falling below 0.08 are indicative of a satisfactory fit for SRMR and RMSEA (71).

3.2.3 Cluster analysis

To identify homogenous consumer groups, a cluster analysis using the k-means technique on factor scores derived from the EFA1 and CFA was conducted (72, 73). The k-means method is a nonhierarchical classification technique that permits the construction of clusters using an iterative procedure that minimizes Euclidean distances between centroids (74).

Using the pairwise distance matrix, the silhouette statistic was then calculated to determine the location of instances inside the clusters (75, 76). Comparing, for each example, the average distance from other cases in the cluster in which the case is placed to the average distance from the closest cluster yields silhouette width as a measure of cluster adequacy. A silhouette width less than 0 suggests a case that is a poor match with its cluster, while clusters are appropriately differentiated when this number is closer to 1.

Finally, to analyze how eating behavior varies within clusters by age group, a chi-square test was performed (77).

4 Results

4.1 Exploratory factor analysis (EFA) results

EFA 1 was carried out on 15 items related to consumer involvement in food consumption; the summary statistics of the variables used in the factor analysis are reported in Table 2. This yielded three different factors: environmentally friendly awareness; experimental orientation; and food indulgence.

The first factor draws information about consumer perceptions of environmental externalities due both to food production and consumption. This factor measures the weight that information related to, for example sustainable food production (0.9015) and environmental impacts (0.9007), have on food purchasing behavior. In view of the variables expressed, this factor was named "responsibility."

The food attitudes of environmentally friendly consumers, also known as sustainable consumers, are characterized by a strong emphasis on the environmental impact of food choices. These individuals prioritize sustainability, ethical considerations, and the overall ecological footprint of the food they consume. The second factor tends to emphasize the aptitude to try new foods and recipes related to different culinary traditions. This factor explains a

TABLE 2 Summary statistics for consumer involvement in food consumption.

Item	Mean	Std. dev.	Min.	Max.
I just love good food	5.93	1.62	1	7
Eating and drinking are a continuous source of joy for me.	5.40	1.77	1	7
Decisions on what to eat and drink are very important for me.	5.32	1.70	1	7
Food and drink are an important part of my life.	5.03	1.85	1	7
Eating and food are an important part of my social life.	4.64	1.90	1	7
I like to try new foods that I have never tasted before.	4.84	1.95	1	7
I love to try recipes from different countries.	4.71	1.97	1	7
Recipes and articles on food from other culinary traditions encourage me to experiment in the kitchen.	4.32	2.00	1	7
I like to try out new recipes.	5.15	1.81	1	7
I look for ways to prepare unusual meals.	4.12	1.94	1	7
I try to choose food produced with minimal impact on the environment.	4.21	1.90	1	7
I am concerned about the conditions under which the food I buy is produced.	4.63	1.87	1	7
It is important to understand the environmental impact of our eating habits.	5.16	1.79	1	7
I try to choose food that is produced in a sustainable way.	4.51	1.89	1	7
I try to buy organically produced foods if possible.	4.24	1.88	1	7

*Items measured on a seven-point Likert scale (1 = completely disagree; 7 = completely agree).

TABLE 3 Summary statistics related to the type of food consumed.

Item	Mean	Std. dev.	Min.	Max.
Eat bread	5.74	1.51	1	7
Eat fish	4.51	1.20	1	7
Eat buttery/creamy sauces	3.17	1.56	1	7
Eat legumes	6.08	1.20	1	7
Eat vegetables	4.67	1.13	1	7
Eat salad	5.64	1.39	1	7
Eat fruit	5.96	1.42	1	7
Eat red meat	4.51	1.29	1	7
Eat pizza	4.45	0.88	1	7
Eat sweets, desserts, cakes	4.78	1.33	1	7
Drink wine	3.39	1.94	1	7
Drink beer	2.92	1.75	1	7
Drink milk	4.41	2.46	1	7

*Items measured on a seven-point Likert scale (1 = never; 7 = every day).

particular consumption pattern related to the willingness to try new foods. Consumers in this group show openness to new culinary experiences and trying new recipes in the kitchen (0.8369) from different countries (0.8592). In view of the variables expressed, this factor was named "innovation." This factor includes consumers who are experimenting with new foods and can be described as adventurous eaters or culinary explorers. These individuals are open to trying unfamiliar or unconventional dishes, ingredients, or cuisines, actively seeking out novel culinary experiences. They may enjoy exploring different flavors, textures, and cultural influences, and often embrace the opportunity to expand their palate and discover new taste sensations. Experimenting with new foods can involve trying exotic dishes, experimenting with innovative cooking techniques, or exploring alternative dietary choices. This reflects their openness to stepping outside of their comfort zone and engaging in gastronomic exploration.

The third factor is characterized by information regarding the degree of involvement in food consumption. This factor emphasizes the importance of food as a source of joy (0.8225) and as an important aspect of life (0.8494). In view of the variables expressed, this factor was named "involvement." This factor describes a consumer attitude characterized by a strong preference for pleasurable and indulgent food experiences.

EFA 2 was performed on 13 items related to the type of food consumed; the summary statistics of the variables used in the factor analysis are shown in Table 3. Consequently, the following four factors were identified: vegetable-based diet; carbohydrate-based diet; likes alcohol; and meat- and fish-based diet (Table 4).

The first factor contains information about the consumption of fruits (0.7396), vegetables (0.7940), salad (0.7332), and legumes (0.5022), which explains a particular propensity to eat more vegetables. In view of this, the factor was named "vegetable-based diet."

The second factor describes a particular consumption toward fancier foods, such as bread (0.5764), buttery and creamy sauce (0.5522), pizza (0.7338), and sweets, desserts, and cakes (0.7585), which explains a particular propensity to consume foods higher in carbohydrates (and fat). For this reason, this factor was named "carbohydrate-based diet."

The third factor explains 13.2% of the variance and describes a particular propensity to consume alcoholic beverages, such as wine (0.9061) and beer (0.9139). Therefore, this factor was named "likes alcohol."

Finally, the fourth factor describes higher consumption of red meat (0.8267) and fish (0.6937). Accordingly, this factor was named "meat and fish-based diet."

Regarding the goodness of fit of the model, for both the factor analyses the values of the KMO test, 0.9149 in EFA 1 and 0.6645 in EFA 2 indicate that the variables are appropriate for factor analysis,

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TABLE 4 Exploratory factor analysis (EFA 2) related to the type of food consumed.

	Vegetable-based diet	Carbohydrate-based diet	Likes alcohol	Meat and fish-based diet	KMO
Eat bread		0.5764			0.8030
Eat fish				0.6937	0.6320
Eat buttery/creamy sauces		0.5522			0.7003
Eat legumes	0.5022				0.6845
Eat vegetables	0.7940				0.7304
Eat salad	0.7332				0.6970
Eat fruit	0.7396				0.7643
Eat red meat				0.8267	0.5509
Eat pizza		0.7338			0.7354
Eat sweets, desserts, cakes		0.7585			0.6639
Drink wine			0.9061		0.5521
Drink beer			0.9139		0.5401
Drink milk					0.7854
Overall					0.6645
Bartlett test					0.000

*Blank cells represent abs(loading) < 0.5.

TABLE 5 Exploratory factor analysis (EFA 1) on consumer involvement in food consumption.

	Responsibility	Innovation	Involvement	KMO
I just love good food			0.7530	0.9309
Eating and drinking are a continuous source of joy for me.			0.8225	0.9365
Decisions on what to eat and drink are very important for me.			0.7565	0.9473
Food and drink are an important part of my life.			0.8494	0.9073
Eating and food are an important part of my social life.			0.7411	0.9494
I like to try new foods that I have never tasted before.		0.8178		0.8852
I love to try recipes from different countries.		0.8592		0.8626
Recipes and articles on food from other culinary traditions encourage me to experiment in the kitchen.		0.8369		0.9184
I like to try out new recipes.		0.7045		0.9414
I look for ways to prepare unusual meals.		0.7772		0.9384
I try to choose food produced with minimal impact on the environment.	0.9007			0.8400
I am concerned about the conditions under which the food I buy is produced.	0.7740			0.9576
It is important to understand the environmental impact of our eating habits.	0.7694			0.9496
I try to choose food that is produced in a sustainable way.	0.9015			0.9468
I try to buy organically produced foods if possible.	0.8972			0.8413
Overall				0.9149
Bartlett test				0.000

*Blank cells represent abs(loading) < 0.5.

which makes the model plausible for application. The high significance of Bertlett's test result (0.000) in both EFAs also indicates that the variables contain a high amount of common information showing strong correlation between the variables, thus justifying factor analysis (Table 5).

For this reason, the applied models and tests seem to be appropriate for analyzing the results (72, 73).

4.2 Confirmatory factor analysis (CFA) results

The EFA1 was subjected to a confirmatory factor analysis (CFA) to reproduce the 15-item three-factor model. Based on the findings of EFA1 and as suggested by Brunsø et al. (34), it was postulated that items 11, 12, 13, 14, and 15 were associated with

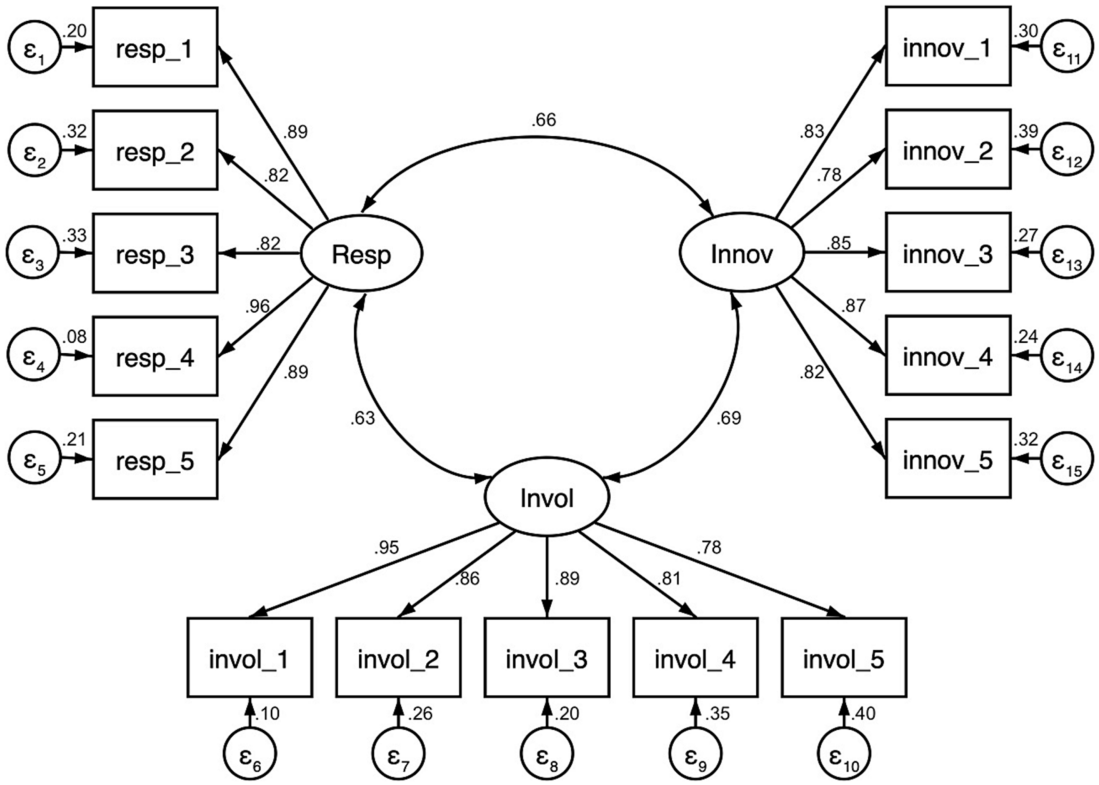

FIGURE 1
Measurement model for 15 items with standardized estimates.

factor 1, while items 6, 7, 8, 9, 10, 11 were associated with factor 2, and items 1, 2, 3, 4, and 5 were associated with factor 3. According to the model's results, each item and its corresponding factor produced statistically significant results. Indeed, the model appears to be exceptionally well-fitting overall, as indicated by the following indices: TLI = 0.987, CFI = 0.995, RMSEA = 0.047, and SRMR = 0.032. As an illustration, a strong positive correlation was observed between the factorial scores of EFA1 and CFA (responsibility = 0.90; involvement = 0.77; innovation = 0.80). In conclusion, the statistical analysis is corroborated by the constructs identified by Brunsø et al. (34). Consequently, the products serve as effective indicators for elucidating food responsibility, food involvement, and food innovation. Figure 1 illustrates the diagram representing the final measurement model incorporating the standardized estimates.

4.3 Cluster analysis results

This section presents the main results of the application of cluster analysis to the seven factors, the results of which led to the identification of four homogeneous clusters. The main characteristics of these clusters are shown in Table 6, in which the factorial scores in the centroids obtained by the k-means method are shown.

Four clusters emerged from the clustering results, carried out using the scores from CFA and EFA 2. All factors present themselves as significant in explaining the clusters, except for "likes alcohol," which does not present itself as significant (Table 6).

The first cluster was labeled "hedonic food consumers" ($n = 69$), encompassing consumers who have a strong preference for hedonic foods, especially those rich in carbohydrates, such as bread and pizza. They have a particular affinity for sugary treats and tend to favor buttery and creamy sauces, as well as sweet desserts and cakes. This group includes individuals who derive pleasure and satisfaction from their food choices and eating experiences. They prioritize the sensory and emotional aspects of food, seeking pleasure, indulgence, and gratification through their food consumption.

The second cluster was identified as "sustainable- and balanced-diet consumers" ($n = 99$), referring to conscientious individuals who pay special attention to ecological aspects and follow a lifestyle related to a higher consumption of plant-based foods. This group includes consumers who prioritize both the health and environmental aspects of their food choices. They are mindful of how their food consumption affects their own well-being as well as the planet. These consumers strive to make choices that promote personal health and sustainability. Their focus is on maintaining a balanced diet that includes a variety of nutritious foods from different food groups, such as fruits, vegetables, whole grains, lean proteins, and healthy fats. They aim to meet their nutritional needs while ensuring a well-rounded intake of macronutrients and micronutrients.

The third cluster was defined as "food experimenters" ($n = 150$), representing consumers who have a penchant for culinary exploration and pay less attention to sustainable consumption practices. This group enjoys experimenting with new food recipes and cooking techniques and has a greater inclination toward trying novel and gourmet foods.

TABLE 6 Results of cluster analysis using the k-means method.

	Cluster 1 (Hedonic food consumers) (n = 69)	Cluster 2 (Sustainable- and balanced-diet consumers) (n = 99)	Cluster 3 (Food experimenters) (n = 150)	Cluster 4 (No food fondness) (n = 81)	Chi-square	p-value
Responsibility	−1.3732	0.5082	1.4177	−2.0773	8.16	0.043**
Innovation	−0.6249	0.2166	1.3723	−2.2738	22.14	0.000***
Involvement	0.3961	0.0450	1.1618	−2.5440	40.41	0.000***
Vegetable-based diet	−0.6639	0.1661	0.2756	−0.1480	18.86	0.000***
Carbohydrate-based diet	0.4102	0.1258	−0.1122	−0.2955	13.82	0.003**
Likes alcohol	0.0690	−0.5220	0.3771	−0.1190	4.02	0.259
Meat- and fish-based diet	0.2096	0.0951	−0.1725	0.0247	10.92	0.012**

*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$.

TABLE 7 Results of the chi-square test by age.

Age (years)	Cluster 1 (Hedonic food consumers) (n = 69)	Cluster 2 (Sustainable- and balanced-diet consumers) (n = 99)	Cluster 3 (Food experimenters) (n = 150)	Cluster 4 (No food fondness) (n = 81)	Total
18–24	15	20	27	16	78
	21.74%	20.20%	18.00%	19.75%	19.55%
25–28	26	25	36	15	102
	37.68%	25.25%	24.00%	18.52%	25.56%
29–43	21	26	47	19	106
	30.43%	26.26%	**31.33%**	23.46%	26.57%
44–64	7	28	40	31	113
	10.14%	**28.28%**	26.67%	**38.27%**	28.32%
Total	69	99	150	81	399
	100.00%	100.00%	100.00%	100.00%	100.00%

*Pearson chi-square = 18.1089 (p-value < 0.034).

The fourth cluster was named "no food fondness" (n = 81), indicating consumers who have no preferences and are not particularly involved in their food choices. This class consists of individuals who do not have a strong preference or fondness for any specific types of food.

They may not derive great pleasure or satisfaction from eating and view food from a more practical standpoint, considering it primarily as a means to fulfill their nutritional needs rather than a source of enjoyment or excitement. They may not experience strong cravings or desires for specific foods and may be content with simple or basic meals.

In terms of socio-demographic characteristics (Table 7), only age seems to be significant, i.e., there seems to be variability in dietary lifestyle among the age groups. The first cluster (hedonic food consumers) consists largely of women who aged 25–28 years (37.68%). The second cluster (sustainable- and balanced-diet consumers) is largely composed of individuals aged 44–64 years (28.28%). In the third cluster (food experimenters), consumers aged 29–43 years seem to prevail (31.33%). Finally, in the fourth cluster (no food fondness), there is a slight prevalence of female consumers aged 44–64 years (38.27%). The choices of the lowest age group (18–24) do not seem to be as indicative in food choices compared to the other three age groups.

5 Discussion

This section discusses the results concerning the eating habits and food lifestyles of women based on Brunsø et al. (34) model to understand the behavioral features of female food consumers. Considering the intricate nature of the factors that shape women's identities and subsequently influence their choices, we have made an effort to provide a comprehensive analysis of all the results, starting from the factor analyses and concluding with the outcomes obtained from the clusters.

As regards the overall objective, we can confirm that there is a strong relationship between the degree of involvement in food choices and the type of foods consumed according to stated preferences, which enables us to describe the food lifestyle of the sample of Italian women. A person's lifestyle, which encompasses various aspects of their daily routines, activities, and values, can significantly influence the types of foods they prefer; in this context,

we found keyways in which lifestyle and women's food preferences are related.

In response to RQ1, regarding the predisposition toward consciously consuming in a manner that respects environmental balance, the environmental awareness of our sample (with all its associated impacts) emerges, which appears to be highly consistent with the environmental sensitivity of the Italian female population (78, 79). Consequently, women who prioritize sustainability and environmental concerns in their lifestyle may have food preferences that reflect those values. This result appears to be strongly consistent with previous studies since women are more inclined to choose locally sourced, organic, or ethically produced foods, which may reduce the environmental impacts (80, 81).

Regarding RQ2, less widespread but no less relevant is the trend toward experimenting with new foods and recipes, both in the kitchen and at the table. The interest in innovative food options may be related to various aspects, such as convenience and sustainability, as well as to recipes or concepts specifically targeted toward women's needs. This inclination, which has been widely found in the literature, reflects the high interest in innovative food by a certain proportion of women. Several authors have referred to the high interest in novel and innovative food products, such as irradiated or functional foods, foods with added functional ingredients, and foods with specific health benefits to support women's well-being (82–84).

In response to RQ3, regarding whether women exclusively prefer healthy foods, a noticeable inclination among women toward consuming carbohydrate-rich and sweetened foods can be observed. Specifically, although hedonism is a more pronounced characteristic among men, while women usually make healthier dietary food choices (2, 85, 86), our study evidences that women, albeit to a limited extent, also appear to be attracted to the pleasure of good cuisine and dining, thus also preferring unhealthy food. This appears to be quite consistent with some previous studies, wherein a certain proportion of women tend to make unhealthier food choices; in particular, women with lower educational attainment tend to have an unbalanced diets and have lower food involvement (87, 88).

In response to RQ4, regarding the types of food consumed, four distinct eating patterns emerged: vegetable-based diet; carbohydrate-based diet; likes alcohol; and meat- and fish-based diet. The first pattern (vegetable-based diet) encompasses individuals who follow a vegetarian lifestyle. This finding aligns with existing literature, as it has been widely reported that some women opt for a vegetarian or vegan lifestyle, avoiding animal products in their diets. Additionally, prior studies have often associated females with a higher intake of vegetables and fruits (80). These individuals may prioritize plant-based foods, such as fruits, vegetables, legumes, whole grains, and plant-based protein sources, being prosocially motivated to follow such a diet (4).

The second factor shows the importance of the carbohydrate-based diet factor. This result is in line with previous research that considers high-carbohydrate foods, such as bread and pasta, tasty and able to provide useful nutrients for human nutrition (50, 89). However, this factor also includes unhealthy foods, such as desserts and cakes. The consumption of such products, that consumers believe to be unhealthy (87), is consolidated and the overconsumption of highly sugary foods still represents a widespread model even among women (90–93).

Equally important is the animal-derived protein consumption pattern (meat- and fish-based diet). Despite the recent growing interest in plant-based protein, the consumption of animal-derived protein remains prevalent in many parts of the world: animal-derived protein sources, such as meat, poultry, fish, eggs, and dairy products, are still traditional sources of protein in human diets (94–96).

Finally, women's inclination to consume alcoholic beverages did not show statistical significance. However, even though women generally consume fewer alcoholic beverages than men (97), a bias toward beer and wine was found among female respondents. This result is in line with previous studies on female consumers' preferences for beer and wine (98–100).

Regarding RQ5, when considering food preferences, it is challenging to categorize women into specific clusters as individuals have diverse tastes and preferences. However, the survey aimed to explore potential homogeneous market segments, revealing certain broad patterns and clusters of food preferences among women already found in previous FRL applications (20, 34, 40, 101). In this regard, it was observed that four main consumer groups emerged: hedonic food consumers; sustainable- and balanced-diet consumers; food experimenters; and no food fondness consumers. This implies that generalizable categories can be found even for the complex feminine universe.

First, a strong tendency to be high-intensity sustainable consumers emerged; women are often more conscious of the environmental impact of their consumption habits and strive to make choices that align with their values. This is strongly consistent with what prior literature has evidenced, namely that women may prioritize sustainable food products (79, 102, 103).

The emergence of the identified cluster validates findings from prior Food-Related Lifestyle (FRL) applications, which also identified segments of rational consumers (34, 40). These segments are characterized by a heightened interest in health and product information, a preference for shopping at specialized shops and markets, a tendency to consume organic food, meticulous scrutiny of product labels, and a prioritization of taste and healthiness over convenience and brand (104).

As regards the hedonistic groups, our study evidenced how some women may prefer comfort foods or indulge in specific treats or high-carbohydrate foods on occasion. These preferences may include sugar-sweetened desserts or sweets, or pizza or grain-based foods (that are high in calories), which certainly provide emotional satisfaction. In this context, food indulgence can be induced by specific emotional states, such as nostalgia or anxiety (3, 105). This group of consumers seems to be characterized by being highly indulgent in relation to unhealthy food.

Previous FRL applications (20, 40, 101, 106) identified consumer segments inclining toward hedonism, or the pursuit of delight and enjoyment, which are corroborated by the formation of this cluster (20).

As regards experimental behaviors in foods, we included all those respondents willing to try new and unfamiliar foods, ingredients, or cooking techniques. This group is characterized by curiosity and openness toward exploring different culinary experiences and expanding one's food preferences. People with experimental behaviors in food enjoy seeking out novel and unique food experiences, and they may actively seek opportunities to try new dishes, cuisines, or food combinations. This behavior is often associated with a sense of enjoyment in discovering new tastes and textures. Experimental behaviors in food can contribute to a diverse and varied food

repertoire, as individuals continuously explore and expand their culinary horizons. Although these attitudes, differentiated by gender, are not so common in the literature, our study is consistent with the findings of prior studies providing specific insights into women's tendency to experiment with novel food (84, 107, 108).

Previous FRL applications have identified adventurous consumer segments (34, 40, 106) that exhibit the following characteristics: a penchant for social and self-validating food, an inclination toward quality, pleasure derived from preparing meals and products that are novel, and a demand for innovation (34, 40, 106) in terms of products and meals.

Finally, as regards the last group (individuals with no fondness for food), these individuals can be described as consumers having a relatively neutral or indifferent attitude toward food (52). They may not derive much pleasure or interest from different tastes or culinary experiences. For them, food is primarily seen as fulfilling their basic nutritional needs rather than being a source of enjoyment. They seem not invest much time or effort in culinary experiences or experimenting with different types of cuisine. This low food involvement has been previously detected in the literature concerning women who focus on practicality and efficiency rather than indulgence or variety, as well as among those not prioritizing eating a well-balanced diet, which is common among women with a low educational level (80, 109).

The cluster in question has been characterized in prior FRL applications through the identification of segments of uninvolved consumers (34, 40, 52, 106, 110) and careless consumers (40, 104): the former refers to individuals who are less inclined to shop in specialized shops or at the market, disregard organic food labels, cook infrequently, and do not adhere to a strict food regimen. The latter cohort consists primarily of snack and convenience food consumers.

Finally, in response to RQ6, regarding the socio-demographic characteristics of the sample, although education and the number of household members were not found to be relevant in influencing food-related lifestyles, it is noteworthy that food preferences have different directions by age group. Our results confirm previous findings in numerous studies showing that older individuals are more likely to make healthier and more sustainable food choices, while younger consumers are inclined to experiment more and are less inclined to make more conscious environmental food choices (111–115).

6 Conclusion

6.1 Main results and implications

Women are often considered the primary food shoppers in many households. They are frequently responsible for planning meals, creating shopping lists, and purchasing groceries for the family. This role places them at the forefront of decision-making regarding food choices. Within this context, and given the significant influence that women have on food choices and preferences in modern society, the present work aimed to explore the eating lifestyle of Italian women by assessing the degree of association between involvement and eating habits.

Summarizing the main findings of this study, conducted through factor analyses and a subsequent cluster analysis, a direct relationship emerges between the degree of involvement and women's food preferences. Drawing inspiration from factor analysis, the extreme importance of environmental awareness (conscious choice), a strong inclination toward food experimentation, and a certain relevance of hedonism leading to food choices that are not always necessarily healthy can be observed.

Regarding the cluster analysis results, which generated four different groups, the three patterns obtained from the factor analysis are confirmed, with the addition of a completely disinterested category that seems to have little inclination toward choices determined by taste, preferences, or food-related lifestyles.

The results of this study thus add incremental knowledge related to marketing to women, as they provide further insights into the role women play in directing the diets of family members and shaping society's food preferences based on food lifestyle theory.

In addition, there are also social implications related to female food consumers. Specifically, our study shows that, as well as many women being involved in consuming sustainable food and interested in balanced diet, there are any female consumer segments attracted by unhealthy foods or even totally disinterested in what they eat.

In this regard, these results may have implications for public health nutritional initiatives that could be formulated to enhance the well-being of women.

To design strategies to encourage young women to adopt healthy eating habits, social marketing can, in fact, assist policymakers in comprehending the target audience and customizing messages for distinct segments.

In accordance with their needs, beliefs, and intentions, segmentation thus determines which groups are most susceptible to persuasion regarding the adoption of the desired behavior.

6.2 Limitations and future research

One potential limitation pertains to the utilization of a convenience sample, which calls for caution when generalizing the findings to the broader population. However, considering this study as an initial exploratory analysis, the chosen sample can be considered suitable for examining the food-related lifestyle of Italian women.

Another aspect is that the present study may appear inconsistent with modern gender theories, which challenge strict categorizations and recognize blurred distinctions between genders, acknowledging intermediate stages. These theories call for a nuanced understanding of gender differences, including in food preferences shaped by diverse social and cultural influences. However, we argue that it is still meaningful to discuss gender differences in food preferences and choices, even in light of these new theories. This is because food preferences and choices result from a complex interplay of biological, social, cultural, and experiential factors, including those associated with gender.

Additional studies could be carried out by including different countries of EU to detect differences and contact points among European women.

In addition, it could be interesting to add psychometric constructs to identify more, and more complex, clusters. Specifically, these clusters are not exhaustive, and individual preferences can vary widely.

Finally, it is important to note that food preferences could change over time due to factors such as personal experiences, health concerns, environmental influences, and evolving dietary knowledge.

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 approval was not required for the studies involving humans because for this type of study, our university does not require approval from the ethics committee but only the informed consent of the participants is necessary. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MH: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. MD'A: Conceptualization, Funding acquisition, Supervision, Validation, Writing – review & editing. DS: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. GLV: Supervision, Validation, Writing – review & editing. GDV: Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

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

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Centering context when characterizing food environments: the potential of participatory mapping to inform food environment research

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Food environments are a critical place within the food system to implement interventions aimed at enabling sustainable diets. In this perspective article, we argue for the need for food environment research to more comprehensively examine the different types of food environments that people access within their communities to ensure that interventions and programs are better aligned with people's lived experiences. We highlight the potential ways in which participatory mapping (PM) can be leveraged to better design food environment research by: (1) identifying the different food environment types that are accessed within a given community; (2) providing insight into the timing for data collection; (3) informing the prioritization of where to conduct food environment assessments; and (4) highlighting the dynamism of food environments over time (e.g., across a given day or across seasons). We provide a case study example of the application of PM and the lessons learned from it in Cambodia. By conceptualizing food environments in a more comprehensive way, from the perspective of the people living within a given community, we will be able to measure food environments in a way that more closely aligns with people's lived experiences.

KEYWORDS

food environment, participatory mapping, Mekong River, Tonle sap lake, focus group discussion

Introduction

Food environments are a critical place within the food system to implement interventions aimed at enabling healthy and sustainable diets. While several definitions (1–4) for the food environment exist, we define the food environment as "*the consumer interface with the food system that encompasses the availability, affordability, convenience, promotion and quality, and sustainability of foods*" (5). Food environments in low- and middle-income countries (LMICs) are much more multifaceted than what we typically observe in high-income countries (HICs). While in HICs we often characterize food environments as the built food environments that people have access to (6), in LMICs many people access diverse food environments (5). This includes wild, cultivated, built (formal and informal) environments (5), as well as kin and community and supplemental food assistance (7) (see **Box 1**). These different food environment types subsequently influence the foods that are acquired, purchased, and consumed from them which has implications for diet and nutrition outcomes, as well as interventions aimed at improving those outcomes.

Access to different food environment types has been found to be associated with differences in food security (8), dietary intakes (1), and nutrition outcomes (9). In most LMIC contexts, foods are procured by interacting with natural food environments through means of hunting, fishing, and foraging in wild settings, and growing foods in cultivated settings (5, 10). This can also be true in HIC, particularly within indigenous communities (11, 12). However, the majority of food environment research in HICs focuses on the built environment with little recognition of food access from the natural environment. While we focus this article on the need to recognize and incorporate the heterogenous food environment types (especially the natural food environment) into food environment research in LMICs, this holistic approach has implications for HIC settings as well. For example, there has been a recent resurgence of growing food for household consumption in HICs, partly related to the COVID-19 pandemic (13). Thus, it is important that food environment research in both HICs and LMICs examine the variety of food access points of populations of interest.

While access to the natural food environment has been attributed to increased access to nutrient-rich foods and dietary diversity, access to modern retail has been shown to have more mixed influences on diets and nutrition (14). In the Solomon Islands, having access to wild, cultivated, and kin and community environments was found to be associated with improved fruit and vegetable acquisition, whereas access to formal retail environments was associated with acquisition of less fruit and vegetable yet more ultra-processed foods (7). In urban informal settlements in Kenya, a majority of kiosks and hawkers have been characterized as predominantly selling fried starches and sweets/confectionary, respectively (15). Other evidence from Central Province, Kenya, reveals acquiring foods at a supermarket vs. any other retailers (self-service stores and kiosks) was associated with a higher body mass index (BMI) and probability of overweight among adults (16). In children, supermarket food purchases were associated with improvements in child growth, without any contributions to obesity (17), demonstrating both positive and negative impacts that formal retailers can have on diets and nutrition.

There is a growing recognition of the need to better measure food environments in order to inform the design and implementation of interventions to promote healthy and sustainable diets that are more closely tailored to their context. In this perspective article, we argue for the need to include the natural environment, as well as any other food access points [e.g., kin and community (7)] in food environment assessments conducted in LMICs in particular, but even in HIC contexts where food environments may be diverse [e.g., indigenous communities (10)]. Often, the heterogeneity of food access points might not always be immediately apparent. As such, we further highlight the potential of leveraging participatory mapping (PM) as a methodology to better, and inclusively, design studies that aim to characterize food environments in a more comprehensive way. We provide a case study example of its application and the lessons learned from it in Cambodia.

Integrating participatory mapping into food environment studies

Participatory mapping

Participatory mapping is a focused ethnographic method that encourages participants to collaborate in drawing a map of their local community and discussing the importance of the different landmarks and assets depicted within it (18). It is a relatively quick method, taking approximately 90 min to employ, and can be conducted as part of focus group discussions (FGD). The goal of PM is "to make visible the relationship between a place and local communities" by creating a visual representation of how members of a given community perceive it (19). PM can include various tools including sketch mapping, transect mapping, Geographical Information Systems (GIS) mapping, remote sensing images, among others (19, 20). It has historically been used to map community assets such as schools, health centers, and other key landmarks to inform development initiatives. In the context of food environment research, PM can be used to generate a map of the food access points within a given community, by those living within it. By working together as a group to map food access points, and to discuss their importance for the community, the FGDs conducted as part of the PM allow for community members to work together to establish a common understanding of their community food environments. It empowers individuals to contribute their knowledge and perspectives to the mapping process based on interactions with their own surroundings and to discuss the community's experiences related to food availability, affordability, quality, etc. The PM can be used as part of a broader participatory research approach or could be used as a standalone participatory method. While the maps produced as part of the PM process can vary in terms of quality, they can be used as an important starting point for guiding discussion among the group of participants and generating key contextual information about the community's food environment that "fills in the gaps" of traditional GIS mapping techniques.

BOX 1 Overview of food environment types [Adapted from: (5), (7)].

Natural food environments: Natural food environments include both wild (e.g., water bodies, wetlands, forests, jungles, etc.) and cultivated (e.g., fields, gardens, pastures, etc.) environments where people access food for own consumption.

Built food environments: The built environment includes both informal and formal food market food environments. Informal market food environments include wet markets, mobile vendors, kiosks, etc., whereas formal markets include supermarkets, restaurants, and other formal retailers. The same vendor types (e.g., street vendors) could be informal or formal, depending on the context. Formal vendors are regulated in some way, whereas informal vendors are not.

Kin and community: Kin and community (or social networks within communities) includes gift or exchange of food from friends, neighbors, or other community members, food assistance provided by charities, food obtained from social or cultural gatherings as well as food remittances.

Supplemental food assistance and aid: Supplemental food assistance and aid is food provided through government or non-governmental food provision systems.

Application of participatory mapping to food environment research

Participatory mapping can make a unique and important contribution to the design of food environment research, including: (1) identifying the different food environment types that are accessed within a given community by centering the community's lived experience; (2) providing insight into the timing for data collection within the informal sector in particular; (3) informing sampling for food environment assessments; and (4) highlighting the dynamism of food environments over time (e.g., across a given day or across seasons).

Food environment access points

First, PM allows for the identification of the different food access points—the places and spaces where people access food—consumers in a given community acquire food from. It has been used by members of our team in Myanmar, Kenya, and Cambodia (21, 22). When trying to characterize food environments, understanding all the food access points is critical, particularly in countries that are experiencing food environment transitions (23) and for communities that heavily rely on natural food environments for their livelihoods, food security, sociocultural traditions, and nutrition (24, 25). Characterizing participants' perceptions of personal and external food environment dimensions (e.g., food availability/accessibility, food prices/affordability, convenience, promotion and quality, and sustainability) (**Box 2**) in the different food access points that they interface with is also critical. These dimensions apply to all food environment types, with the exception of food prices/affordability which are not directly captured in wild and cultivated environments. In the FGDs, participants first identify the different spaces where they access food and subsequently discuss how they access those spaces (see **Supplementary material A** to review an example FGD guide). While the built and wild food environments tend to be communal spaces, the cultivated food environment often includes individual spaces such as home gardens or household plots of land. In these cases, the discussion focuses on the community experience with cultivated food access points rather than individual plots of land, gardens, etc.

Timing of data collection

Informal markets and vendors often vary in terms of where, when, and how much they sell food. As such, the ways in which consumers interface with this informal food environment may also vary. For this reason, it is important that food environment data collection be informed by consumers' knowledge about how the informal sector operates in their given community. Moreover, mobile vendors are difficult to capture in food environment research and could be easily missed depending on the timing of data collection. Since the COVID-19 pandemic, mobile vendors have emerged as being critical in terms of increasing food access in some communities in LMICs (26, 27). PM can provide researchers with insights into the hours of operation of informal markets and the reliance on mobile vendors in a given community, which can subsequently inform their approach to data collection. PM can also inform the timing of food environment data collection based on local festivals or holidays (28) or how consumers strategize the purchase of different foods (29) which can influence food availability and prices, among other food environment dimensions.

Prioritization of where to conduct food environment assessments

Participatory mapping can help to identify which food access points should be prioritized for conducting food environment assessments as well as the food outlets within them (for built environment) that should be targeted. For example, open-air traditional markets have historically played an important role in providing fresh, nutritious, foods to rural and urban populations alike (30–32). However, there have been shifts in their importance in some settings in the aftermath of economic, COVID-19, and conflict shocks in some settings (33). The PM can help inform whether it makes sense to conduct food environment assessments in open-air markets, and which markets to focus data collection on based on participants' discussion of the role of those markets in terms of their food access. Conducting PM can also provide insight into where to capture data to characterize different food environment dimensions (e.g., food prices/affordability). For example, food price data should be collected from the types of food outlets people primarily purchase their food from vs. outlets that may appear to be the dominant access points in the community. This may not be intuitive given that consumers make many trade-offs (e.g., convenience of purchasing near to home with higher food prices or purchasing food via digital apps rather than physically going to stores to purchase food) when deciding what food to acquire and from where.

Highlighting the dynamism of food environments over time (e.g., across a given day or across seasons)

Seasonal changes to food environments are evident in LMICs and HICs alike. For example, availability, accessibility, and affordability of foods acquired in rural and urban Malawi (34), urban India (35), and urban areas in the United States (36) is

BOX 2 Defining food environment dimensions captured in participatory mapping [adapted from: Downs et al. (5) and Turner et al. (4)].

Availability/accessibility: Availability refers to whether a food item is present within a given physical range (external food environment) and accessibility refers to physical distance, mobility, mode of transport, and individual activity spaces (personal food environment).

Food prices/Affordability: The prices of food items relative to other foods or to a defined income standard (e.g., % of median income or % of poverty line).

Convenience: Time cost of obtaining, preparing, and consuming a food item.

Promotion: How a food item is presented, marketed, promoted, and front-of-pack labeling which is designed to influence the desirability of food.

Quality: External characteristics of food including its freshness, integrity, safety, nutrient and phytochemical profiles, and objective sensory attributes.

Sustainability: The environmental and social impact associated with the food item.

significantly impacted by seasons. Seasonality can also influence access to vendor types with certain vendors not being accessible during certain seasons, such as wet and dry (36, 37). However, much of the food environment literature has failed to take into account seasonal changes in food environments (4). PM can be practical in terms of gaining consumers' perceptions of how their food environments shift across seasons in terms of the types of food environments they access and the dimensions with them. It can also help determine which food environment assessment, if any, should be conducted in different seasons (wet or dry season) to account for seasonal variation. This can help to optimize resources for food environment research.

In the next section, we provide a case study that demonstrates how PM can be leveraged to streamline food environment data collection in Cambodia.

Case study: application of participatory mapping in Cambodia

As part of a larger project—A River in Transition: understanding the health and environmental sustainability of consumer food choice, local food environments and diets in riverine communities of the Lower Mekong Basin (LMB) —we conducted eight PM FGDs in four provinces (2 communes per province) along the Mekong River and the Tonle Sap Lake in Cambodia. Each focus group included 6–8 women consumers (total n = 59) living in the communes (administrative divisions of Cambodia are divided into province, district, commune, and village), given that they were the primary food shoppers in the study communities. The PM was designed to inform the food environment data collection approach in each of the communes for the project. Ethical approvals were obtained from the National Ethics Committee for Health Research in Cambodia and the Johns Hopkins University Homewood and Rutgers University Institutional Review Boards in the United States.

FGDs were conducted between February and March 2023 and were moderated by a senior researcher, with the help of an assistant. The FGD guide for the PM can be found in **Supplementary Material A**. In short, the FGD included the following topics: where people go to access food, foods purchased and from where, most commonly and infrequently used vendors, changes in access to markets/vendors over time, foods grown and foraged and from where, foods acquired and exchanged with neighbors and who consumes grown and foraged foods. Within each FGD, participants drew a map of their food environment (see **Supplementary Material B** for an example). The FGD took an average of 85 min to complete and were conducted in Khmer. As part of the FGD, the participants created maps of their communes with the different food environment types that they accessed. **Table 1** provides a description of the participant characteristics. The FGDs were audio-recorded and subsequently translated to English and transcribed verbatim.

We used open coding to analyze the FGD transcripts using NVivo software [release 14.23.0 (13)]. Open codes were subsequently organized by key themes for each of the communes separately. We also examined key themes that cut across different communes. We present findings related to the ways in which leveraging PM in this study helped inform the food access points,

TABLE 1 Study participant characteristics (N = 59)*.

Sample characteristics	% (n)
Age	
19–24 years	11.9 (7)
25–34 years	33.9 (20)
35–44 years	23.7 (14)
45–55 years	15.3 (9)
>55 years	15.3 (9)
Education	
None	10.2 (6)
Primary, not completed	22.0 (13)
Primary, completed	22.0 (13)
Secondary, not completed	10.2 (6)
Secondary completed	30.5 (18)
Some higher education, no degree	5.1 (3)
Primary occupation	
Homemaker	64.5 (41)
Small business owner	6.8 (4)
Daily/casual labor	6.8 (4)
Full-time salaried worker	17.0 (10)
Marital status	
Single	6.8 (4)
Married	88.1 (52)
Widowed	5.1 (3)
Divorced/separated	0

*Eight focus group discussions were conducted with 6–8 participants in each discussion.

the timing of data collection, the sampling for food environment assessments, and seasonal changes in food environments.

Key findings related to food environment research implementation from participatory mapping

Food access points

The PM provided important insights into the places people in the 8 communes accessed food. Key themes related to food access points included: the importance of mobile vendors and "*family retail*" (e.g., small stores selling food often attached to people's homes) for daily food purchases, the minor role of markets for food purchases in most communes, and the critical role of wild and cultivated food environments, as well as kin and community, for providing a safety net to ensure food security. These populations reported a heavy reliance on the wild and cultivated environment for their food. As one participant stated: "*We grow vegetables to just feed our household, avoiding dependence on the market*." In addition, community members in 7 of the 8 communes also shared that they sell, trade and/or share food with other people in their communities. In one commune, a community member stated "*sometimes, I plant the vegetables that the other houses don't, so we exchange*" indicating that cultivation of certain foods is at times strategically planned among households. These social networks were viewed as creating camaraderie among villagers: "*It is an easy life in our village. Some villages are not. Villagers here are kind. We love one another*." Thus, if researchers were to solely capture dimensions of the built food environment in this context, they would miss critical food access points that provide access to nutrient-rich foods such as animal-source foods, leafy greens and other vegetables, as well as fruit.

Another key learning from the PM related to food access points was the shift away from accessing open-air markets and a heavy reliance on mobile vendors in several communities. More specifically, we found that in 6 of the 8 communes, the community members indicated that they rarely go to the nearest local markets to purchase foods. In most cases, these communities "*only buy from the family retail or the motorbike groceries*" selling a wide variety of food to meet their household's needs. Lastly, while this project was being conducted in Cambodia, one of the study communes was situated near the border with Vietnam. In that community, focus group participants reported often accessing a nearby market in Vietnam.

Timing of data collection

The PM helped to inform the timing of data collection in the study communes. This was important given that some markets within the larger landscape of the built food environment changed significantly over the course of the day. In some cases, the early hours of the morning were when the market was in full operation, whereas in other markets it was in the evening. FGD participants described these as "*waxing*" markets, where their size varied with the time of the day. As one FGD participant stated: "*They only sell in the morning. . .if you are late, there is nothing else*."

Prioritization of where to conduct food environment assessments

The findings from the PM related to identifying food access points also helped to inform which markets and vendors should be prioritized for the food environment assessments in each commune. For example, in communes where people reported not regularly accessing the nearest local markets, we did not conduct any food environment assessments at those markets. Instead, we focused on the food access points that consumers indicated that they purchased food from such as local small groceries and mobile vendors, allowing us to characterize the food environment with which the community most frequently interacts with. In some cases, these were brick and mortar food outlets, and in other cases, these were completely informal vendors.

Highlighting seasonal changes in food environments

The PM exercise also helped to inform the changes that consumers observe in their food environments across seasons. Key themes related to seasonal changes included variation in the number, and mode of travel (e.g., shifting from motorbike to boat) of mobile vendors, changes in food access from wild and cultivated environments, and the increase in the time and economic cost of accessing markets in the wet season. For example, in one of the communes included in our sample, the wet season changes the village landscape to a partially, or fully, floating village depending on the year (see **Figure 1**). This has important implications in terms of where and how people access food. For example, some of the mobile vendors that sell food by motorbike during the dry season shift toward selling food by boat during the wet season. However, the degree to which this occurs depends on the degree of flooding in the community each year. Moreover, in all the FGDs where community members noted the importance of mobile vendors, they indicated a decline in their availability in the wet season.

Other important aspects related to seasonal changes in food environment relate to the natural environment. In all the FGDs, participants mentioned substantial differences in the foods that they have access to during the dry as compared to the wet season. In particular, many of them also described the influence of more extreme temperatures, seasons shifting to different months, and a change in the availability and abundance of foods from the natural environment across seasons.

Discussion

In this perspective, we highlight the role of using PM to provide insights into consumers' food environments in a way that better informs approaches to food environment data collection. This case study from Cambodia helps to provide an example of its application to food environment work in a LMIC. However, we anticipate that PM can also be used to help inform food environment research in HICs as well, given that populations in HICs also access wild and cultivated spaces as evidenced by the paper by Coffin-Schmitt et al. included in this Research Topic (13).

While we argue that including PM as a formative, exploratory step to inform food environment data collection approaches can strengthen food environment research, there is a clear need for

FIGURE 1
An example of a floating small grocery store in wet season.

methods and data collection tools that are tailored to these diverse and dynamic food environments (5). There are several groups of researchers who are currently working toward designing food environment assessment tools that are more relevant to the food environments that consumers interface with in LMICs. PM can then help to identify which methods and tools would be most appropriate for measuring the food environment in a given context.

One of the key learnings of understanding food environments from the perspective of consumers using PM is their dynamism, which has implications for measuring them. For example, in the case of market mapping assessments, such as the assessment included in the USAID Advancing Nutrition Guidelines for Market-based Food Environment Assessments (38), the timing of the assessment would need to be aligned with the peak market days, and times within those days. Moreover, it is likely that conducting assessments across different seasons might be necessary in some settings to capture cross seasonal variation in food environment dimensions.

Participatory mapping can also be leveraged to identify which markets you might prioritize measurement of. For example, we found in the PM that we conducted in Cambodia that consumers were crossing the border to access food from a major market in Vietnam. Ideally, we would then conduct market mapping at that market as part of the food environment research; however, this requires additional research permits, IRB approvals and buy-in from the community, which can create additional barriers to data collection. Food environment research is often conducted within pre-defined geographical boundaries; however, these boundaries do not always align with the spaces where people access food (39). Nevertheless, PM allows prioritization of food environment assessments to spaces that consumers most frequently engage thus is likely to yield more meaningful results in terms of characterizing food environment dimensions that directly influence communities' food acquisition and purchase.

Another key learning from the PM that can help inform food environment research is just how important the natural and kin and community food environments (e.g., social networks) are in some settings. For example, if you were to solely conduct food environment assessments of the built environment, the researcher might be vastly misrepresenting the food that people have access to. In this Cambodia case study, this also would be true if mobile vendors were not included in the assessments given that they were one of the main sources of fresh food in several of the communes included in the study. Furthermore, the supplemental food acquired by sharing and exchange among community members would be missed, although found to be common practice among this study's participants. For this reason, food environment research needs to include these food environment types. While measuring food accessed through the kin and community might be best done using surveys with consumers given that it would be difficult to observe these exchanges via food environment observations, observational assessments could be used to assess the food environment dimensions among mobile vendors. Findings from PM also offer the added value of interpreting the findings from food environment assessments conducted as well as consumer surveys.

By conceptualizing food environments in a more comprehensive way, from the perspective of the people living within a given community, we will be able to measure food

environments in a way that more closely aligns with people's lived experiences. PM provides a useful, easy to implement tool for conducting this with the view to better designing food environment research. This will be particularly important for communities that access different food environment types, such as those living in LMICs and indigenous communities. Aligning food environment assessments with people's lived experiences can help to better characterize gaps in the availability, affordability, convenience, promotion and quality, or sustainability of food; however, there is a clear need for better methods and tools to measure these environments. By improving our ways of measuring food environments, we will be able to design better interventions that are more aligned to the needs of a given community.

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 humans were approved by the Ethical approvals were obtained from the National Ethics Committee for Health Research in Cambodia and the Johns Hopkins University Homewood Institutional Review Board in the United States. The studies were conducted in accordance with the local legislation and institutional requirements.

Author contributions

SD: Conceptualization, Data curation, Methodology, Supervision, Writing – original draft, Writing – review and editing. SM: Conceptualization, Data curation, Methodology, Supervision, Writing – original draft, Writing – review and editing. WS: Formal Analysis, Writing – review and editing. CK: Data curation, Writing – review and editing. SoS: Data curation, Methodology, Writing – review and editing. NC: Methodology, Writing – review and editing. JF: Conceptualization, Writing – review and editing. SeS: Conceptualization, Methodology, Supervision, Writing – review and editing.

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Conflict of interest

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

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2024.1324102/full#supplementary-material

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Adapting food environment frameworks to recognize a wild-cultivated continuum

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Food environments, or interfaces between consumers and their food systems, are a useful lens for assessing global dietary change. Growing inclusivity of nature-dependent societies in lower-and middle-income countries is driving recent developments in food environment frameworks. Downs et al. (2020) propose a food environment typology that includes: wild, cultivated, informal and formal market environments, where wild and cultivated are "natural food environments." Drawing from transdisciplinary perspectives, this paper argues that wild and cultivated food environments are not dichotomous, but rather exist across diverse landscapes under varying levels of human management and alteration. The adapted typology is applied to a case study of Indigenous Pgaz K'Nyau food environments in San Din Daeng village, Thailand, using the Gallup Poll's Thailand-adapted Diet Quality Questionnaire with additional food source questions. Wild-cultivated food environments, as classified by local participants, were the source of more food items than any other type of food environment (37% of reported food items). The case of Indigenous Pgaz K'Nyau food environments demonstrates the importance of understanding natural food environments along a continuum from wild to cultivated.

KEYWORDS

natural food environment, diet quality, dietary diversity, indigenous, wild foods, niche construction theory, diet, Swidden

1 Introduction

Globalization is rapidly transforming diets and food choices (2, 3). An ongoing 'nutrition transition' toward calorie-dense and nutrient-poor 'Western' diets is exacerbating global burdens of disease (4), garnering much attention in the global public health literature. Changes to food environments are driving global dietary transitions (1). Often understood as the interface between the consumer and the food system (1, 5), food environments include physical environments where people acquire food (including built environments, such as homes, restaurants, schools, supermarkets; and natural environments, such as forests, home gardens and crop fields) with measurable characteristics that influence food decision-making (referred to as aspects or dimensions of the food environment, such as availability, access, affordability, convenience and desirability) (5–7).

Over the last few decades, food environment research has played a pivotal role in drawing attention to the structural factors shaping food access and choice (8, 9). Application of most food environment frameworks, however, remains limited to predominately high-income country and urban contexts with some notable exceptions (8, 9). The rest of the world (who still need to procure

food and make dietary choices daily) are all-too-often overlooked. A recent systematic review of food environment research found no studies conducted in low-income countries (10). Since this systematic scoping review, a nascent food environment literature in low-income countries is emerging (11–15).

Geographic bias in the food environment literature toward high-income countries and urban contexts is responsible for an underrepresentation of some populations. The majority of the world's Indigenous Peoples reside in low-and middle-income countries (LMICs). Indigenous communities are experiencing particularly stark agricultural and dietary transformations (16–18), associated with higher burdens of chronic disease (19). Indigenous food environments are shifting from wild and cultivated environments toward built food environments with reduced dependency on forest foods and increased market purchases (16, 20–22). Food environment frameworks designed for urban studies in high-income countries have not translated well to Indigenous and low-income country contexts, in which wild and cultivated landscapes and informal markets often provide important contributions to diet quality (1, 9, 15).

More inclusive frameworks for LMICs and Indigenous societies are beginning to garner attention (1, 12). Downs et al.'s typology of natural and built food environments is more inclusive of Indigenous and rural food environments, including those transitioning rapidly. Their framework fills a notable gap in the food environment literature for LMICs, where agricultural, pastoral, forested and aquatic natural environments provide affordable and healthy food sources in economically marginal contexts. Particularly commendable is the inclusion of wild foods. Though wild foods contribute substantially to the global food basket (23, 24), wild foods remain a key research gap in the food environment literature (5). Food environment research tends to underrepresent the contributions of wild foods and other non-market food sources in favor of the built market environment (6, 9).

New frameworks effective at drawing attention to the dietary significance of wild and cultivated natural food environments could further benefit from transdisciplinary perspectives. By leveraging findings from diverse disciplines, this paper reevaluates the wild-cultivated and nature-built dichotomies that permeate current food environment frameworks. Proposed is an adapted food environment typology that dissolves wild-cultivated boundaries in favor of a continuum. The adapted typology is applied to a case study of Indigenous Pgaz K'Nyau food environments in San Din Daeng village, Thailand, using the Gallup Poll's Thailand-adapted Diet Quality Questionnaire (DQ-Q) (25). The Pgaz K'Nyau case study showcases the dietary importance of the previously overlooked wild-cultivated type of food environment in a semi-subsistence Indigenous community.

2 What is wild?

Current conceptualizations of the natural food environment designate 'wild' and 'cultivated' as separate spheres (1). Growing consensus in wild foods literature, however, contends that wild and cultivated environments vary along a 'wild-cultivated continuum' (23), by domestication stage (23), adaptive niches (26) and management intensity (27).

Wild-cultivated boundary-bending is the norm in many of the world's natural food environments. Natural food environments, such as swidden fallows and home gardens, act as 'boundary elements' that traverse a wild-cultivated divide. Wild-cultivated crossovers include orchards or forests with lightly managed wild fruit trees (i.e., pruning, mulching and watering). Other wild-cultivated food environments include cultivation zones with wild terrestrial or aquatic foods, such as: (i) home gardens with wild transplants, spontaneous edible plants and bushmeat, (ii) rice paddies with wild plants, shellfish and amphibians, and (iii) swidden fallows with spontaneous vegetables and forest species (see Figure 1). Home gardens, for instance, have been described as the "closest mimics of natural forests yet attained," signaling a status that is not purely cultivated nor fully wild (28). Swidden fields provide another liminal space traversing the wild-cultivated divide. Swidden forest-farmers modify landscapes with fire to create successional patch mosaics of croplands and secondary forests that provide ecological niches for a spectrum of wild-cultivated foods (29–31).

Niche construction theory (applied in human-environment geography, archeology, anthropology, ethnobotany, human ecology, among others fields) provides a theoretical explanation for the range of edible species' adaptive niches that span a wild-cultivated continuum (26). Niche construction theory posits that originally 'wild' organisms adapt to environmental niches formed through human management and landscape modification. Commonalities in organism and landscape modification strategies derived from global case studies include: (i) modifying plant communities, (ii) broadcasting wild annuals, (iii) transplanting edible tree and root crops, (iv) light management of perennials (e.g., mulching and pruning), and (v) landscape modification for enhanced food procurement (32).

At the landscape-scale, following niche construction theory, alterations through fire or other disturbances, create niches for edible wild species to adapt. Human-landscape interactions, according to anthropologist, Paul Roscoe, complicate: (33).

> "…what constitutes "wild." The very presence of consuming humans on a landscape affects food resources, blurring the lines between wild and domesticated and, hence, between hunting and pastoralism and between gathering and cultivation (e.g., 34, 35)."

'Natural' landscapes, as noted by Roscoe, tend to be products of human modification. Iconic 'wildernesses', such as Yosemite Valley (36), the Amazon rain forest (37, 38), African savannahs (39) and Australia's arid deserts (40, 41) have long-standing histories of anthropogenic manipulation for enhanced food acquisition. Forest-dwelling peoples around the world have long modified surrounding landscapes for hunting and foraging (30, 32). Artificial forest islands have transformed Southwest Amazonia (42) and African savannahs (39). Even remote jungles of the Amazon Basin rain forest are shaped by over 13,000 years of human-environment interactions (43), including shifting horticulture and tree planting since 4,000 years ago (~2,050 BC) (43), soil fertility enhancement (44–46) and 'large-scale forest transformations' (47). Amazonia and its jungles have even been referred to as a 'domesticated landscape' (48). Paleoethnobotanical explorations of ancient landscape management and agroecosystems have unearthed the co-existence of both wild and cultivated species in overlapping spaces (49). Findings from around the world demonstrate millennia of human-environment co-evolution that overturn wild-cultivated dichotomies (38, 42).

At the scale of organisms, classifying plants and animals as either wild or cultivated is similarly difficult, given the expanse of semi-cultivated states (23). Sago (*Metroxylon sagu* Rottboell), for instance,

is situated along a management gradient from remote sago forest stands (with no or minimal management) to cultivated sago patches in villages (50). Sago users of Nuaulu ethnicity do not differentiate between wild and cultivated sago (50). Ethnobiologist, Roy Ellen, while working with the Nuaulu concluded that "there is a continuum," because "the distinction between cultivated and non-cultivated becomes a difficult one to make" (50).

Scholars from diverse disciplines continue to grapple with the perplexing question of what 'wild' or 'wilderness' is (23, 50, 51). Food environment literature is beginning to engage with wild foods and wild natural environments (1), but not yet with the subtleties of bounding 'wild', 'wildness' and 'wilderness' that is highly contested in other fields.

3 An adapted food environment typology integrating a wild-cultivated continuum

The proposed conceptual approach leverages transdisciplinary perspectives on complex wild-cultivated dynamics to build upon Downs et al.'s natural (wild and cultivated) and built (formal and informal market) food environment typology to integrate a wild-cultivated continuum (1) (see Figure 1).

The adapted typology recognizes the oftentimes porous boundaries and complex crossovers and migrations of foods between different types of food environments (depicted with a dashed line in Figure 1). Some food items, such as fish, may be sourced from multiple different food environments, regardless of their original source. An artisanal fisherperson consuming their own wild-caught fish would be interacting with a wild natural food environment. Consumers purchasing wild-caught or aquaculture farmed fish in a supermarket would be interacting with a formal market environment.

We apply the adapted food environment typology to quantify the dietary contributions from different types of food environments in the Pgaz K'Nyau community of San Din Daeng village, Thailand.

4 Case study of indigenous Pgaz K'Nyau food environments in Thailand

Pgaz K'Nyau Peoples (a Karen ethnic subgroup) traditionally practice rotational farming, a type of shifting cultivation with 6–12 year fallows that support agrobiodiversity and dietary diversity (52). Forest conservation policies and market integration pressures are driving conversions toward monoculture, agrochemicals and market reliance. Simultaneously, highland infrastructure projects (e.g., roads,

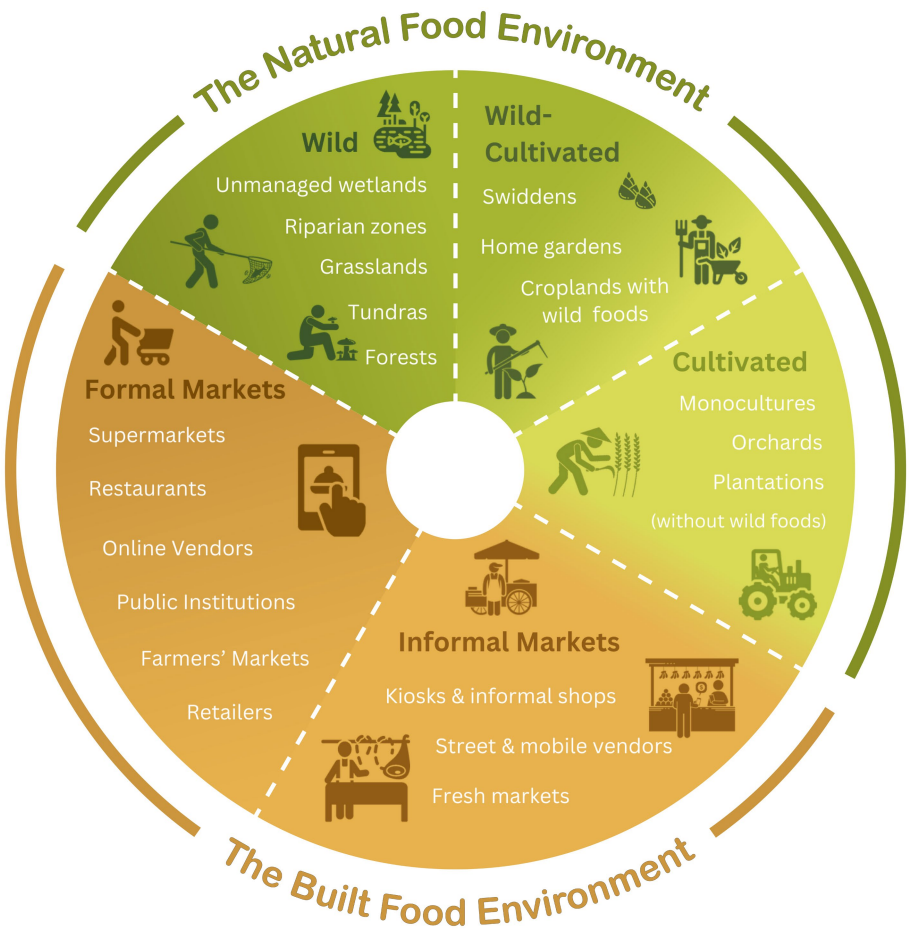

FIGURE 1
An adapted food environment typology with an integrated wild-cultivated continuum.

electricity) are increasing market access and altering local diets, resulting in Pgaz K'Nyau food environment transitions (1).

Dietary diversity from different food environment types was assessed in San Din Daeng village, Chiang Mai province, Thailand. Emic local classifications of types of food environments were discussed in focus groups ($n=6$ women). Focus group participants classified food sources under the following types of food environments: (i) Cultivated: monoculture animal feed corn fields (indirect dietary pathway via income generation reinvested in market food purchases), (ii) Wild: forests (though forests are sites of animal husbandry, participants considered forests mostly 'wild'), (iii) Wild-Cultivated: home gardens, swiddens, agricultural streams, and rice paddies (rice paddies were included due to the presence of aquatic wild foods), (iv) Informal Market: fresh markets, kiosks, street vendors, informal shops and restaurants, and (v) Formal Market: supermarkets (e.g., Tesco Lotus, Big C and Macro) and convenience stores (e.g., 7-11) located in Chom Thong town.

The Gallup Poll's Thailand-adapted Diet Quality Questionnaire (DQ-Q) (25) was administered to one adult woman (>18 years old) per household ($n=31$; 94% of households) in late rainy season (late September – October, 2023). Sources of food items consumed the previous day were also recorded (e.g., Cultivated: monoculture non-swidden crop field; Wild-Cultivated: home garden, swidden, rice paddy, agricultural pond or stream; Wild: forest or forest stream; Informal Market: fresh market, village kiosk, informal shop, informal restaurant, street vendor; and Formal Market: convenience store or supermarket) (see Supplementary Information for survey questions).

The average Dietary Diversity Score was 5.4 (ranging from 3 to 9) with 68% of respondents exceeding the Women's Minimum Dietary Diversity Score of 5 (21 out of 31 women). Wild-cultivated environments were the most frequented type of food environments with respondents reporting daily visits on average (compared to 4 times per week for informal markets, once a month for wild environments, and less than once a month for cultivated and formal market environments).

More food items were consumed from wild-cultivated environments than any other type of food environment (37% or 88 out of 240 food items reported in the DQ-Q; see Figure 2). Wild-cultivated food environments were the main source of micronutrient-rich food groups (vitamin A-rich fruits and vegetables, dark green leafy vegetables, other vegetables and

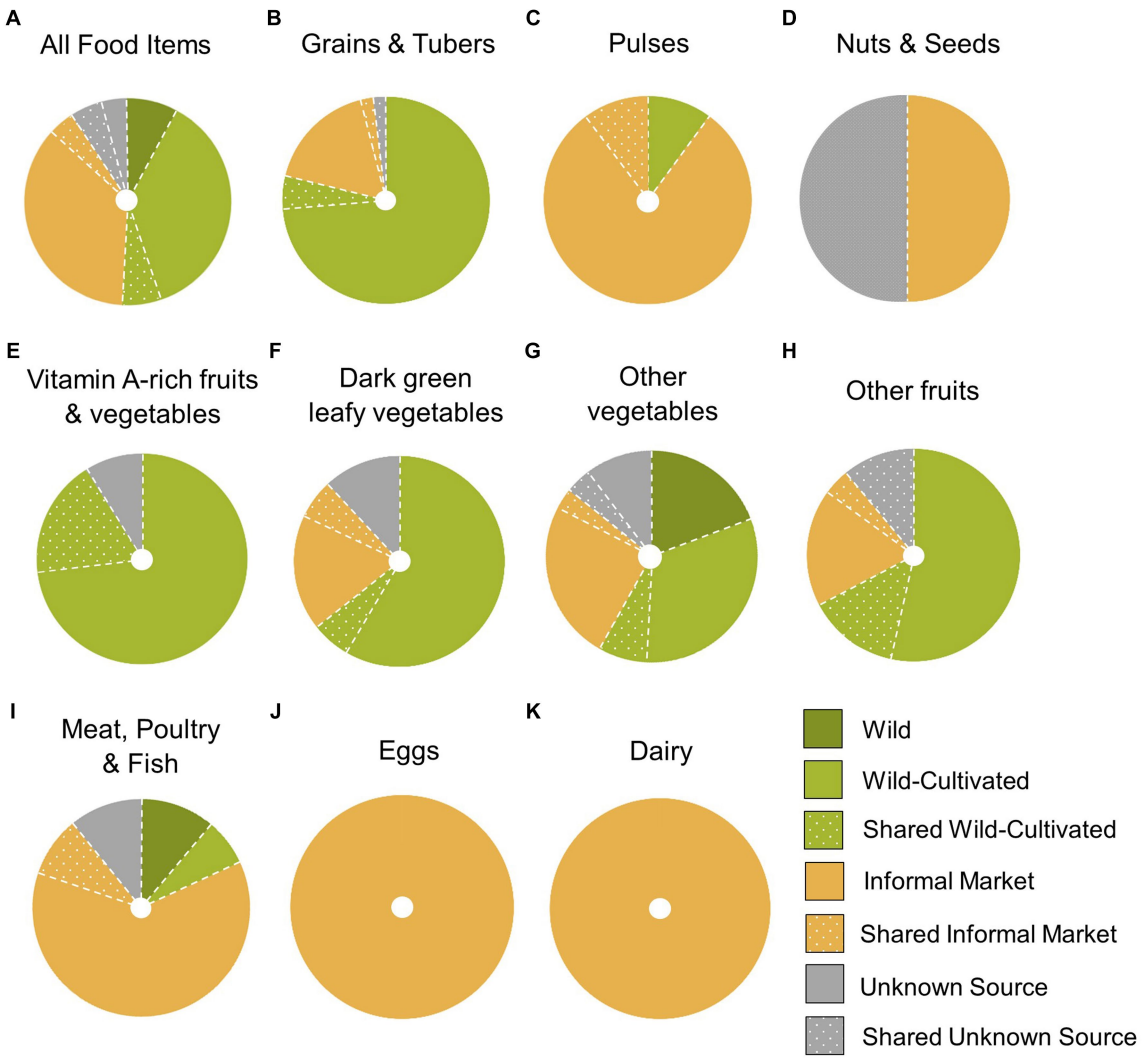

FIGURE 2
Proportions of food items acquired from each type of food environment per dietary diversity group **(A-K)**, reported in a diet quality questionnaire in San Din Daeng village, Thailand ($n=31$; 240 food items). 'Shared' refers to food items acquired from food sharing. E.g. 'Shared wild-cultivated' refers to food items acquired via food sharing from a wild-cultivated food source.

other fruit) consumed the previous day. The majority of vitamin-A rich fruits and vegetables were obtained from home garden and swidden wild-cultivated environments (91%, or 8 out of 11 food items with an additional 2 shared food items). Wild-cultivated environments provided 65% of dark green leafy vegetables (10 out of 17 reported food items, and 1 shared food item), 68% of other fruits (15 out of 28 food items with an additional 4 shared items), and 39% of other vegetables (21 out of 67 food items with an additional 5 shared items) (see Supplementary Table S1 in Supplementary Information). Animal-sourced foods, such as meat, fish and eggs, were predominately obtained from informal markets. Carbohydrate staples, such as rice, were mostly acquired from wild-cultivated swiddens and rice paddies (31 out of 37 reported grain food items, or 84%).

Despite rapid social-ecological change, San Din Daeng residents continue to rely heavily on natural food environments and particularly wild-cultivated environments. The formal market environment that has dominated food environment research is only marginal in this semi-subsistence setting (none of the food items reported in the DQ-Q were acquired from formal markets). The case of the Pgaz K'Nyau food environment of San Din Daeng village demonstrates that the previously overlooked wild-cultivated food environment can contribute substantially to local diets.

5 Discussion

Most food environment frameworks have underrepresented marginalized communities in LMICs, for whom the natural food environment presents a vital, affordable and healthy food source (1, 5, 53). With growing evidence on the nutritional importance of wild foods (54–57), the significance of natural food environments in LMICs is becoming more apparent (1, 5, 53). Though research on natural food environments is still embryonic, other disciplines have long engaged with forest-and nature-dependent peoples. Anthropologists, ethnobiologists, geographers, landscape ecologists, among others, have compiled an extensive body of knowledge on diverse food acquisition strategies, globally (41, 50, 55, 58). Greater emphasis on cross-disciplinary discussions is bringing decades of debates on wild-cultivated dynamics, plant-people interactions, traditional ecological and Indigenous knowledge, and nature-based ontologies into conversation with budding conceptual developments of natural food environments. Capitalizing on transdisciplinary theories, perspectives and bodies of knowledge can catalyze the development of effective food environment measurement tools that best capture the nuanced complexity of natural food environments.

Data availability statement

The datasets presented in this article are not readily available because data is only made available upon request at the authors' discretion. Requests to access the datasets should be directed to lmz5288@psu.edu.

Ethics statement

The studies involving humans were approved by the Pennsylvania State University Institutional Review Board (STUDY00019694). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin because some participants can not read or write. Participants signed or checked their names on a consent form. Formal written consent was obtained from the village leader.

Author contributions

LZ: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing. SD: Methodology, Supervision, Visualization, Writing – review & editing. BP: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Visualization, Writing – review & editing.

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Conflict of interest

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

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2024.1343021/full#supplementary-material

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Measuring and shaping the nutritional environment via food sales logs: case studies of campus-wide food choice and a call to action

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Although diets influence health and the environment, measuring and changing nutrition is challenging. Traditional measurement methods face challenges, and designing and conducting behavior-changing interventions is conceptually and logistically complicated. Situated local communities such as university campuses offer unique opportunities to shape the nutritional environment and promote health and sustainability. The present study investigates how passively sensed food purchase logs typically collected as part of regular business operations can be used to monitor and measure on-campus food consumption and understand food choice determinants. First, based on 38 million sales logs collected on a large university campus over eight years, we perform statistical analyses to quantify spatio-temporal determinants of food choice and characterize harmful patterns in dietary behaviors, in a case study of food purchasing at EPFL campus. We identify spatial proximity, food item pairing, and academic schedules (yearly and daily) as important determinants driving the on-campus food choice. The case studies demonstrate the potential of food sales logs for measuring nutrition and highlight the breadth and depth of future possibilities to study individual food-choice determinants. We describe how these insights provide an opportunity for stakeholders, such as campus offices responsible for managing food services, to shape the nutritional environment and improve health and sustainability by designing policies and behavioral interventions. Finally, based on the insights derived through the case study of food purchases at EPFL campus, we identify five future opportunities and offer a call to action for the nutrition research community to contribute to ensuring the health and sustainability of on-campus populations—the very communities to which many researchers belong.

KEYWORDS

food choice, measurement, monitoring, determinants, digital traces, health, sustainability, policy

1 Introduction

The concept of a modern campus evolved to be more than a collection of buildings and grounds that belong to an institution. A modern campus is a complete local community. In such a situated context, people spend significant parts of their time working, educating, or being educated, but also socializing, learning, doing sports, or entertaining themselves.

People also consume food regularly and globally, in university, corporate, medical, industrial, and other types of campuses. The food consumed on campuses has broad implications for the people on campus and the general population, impacting health and the environment (1, 2). Given the need to actively address the challenges of climate change (3), stakeholders have a growing interest in reducing their campuses' environmental impact.

Social issues, including health and environmental issues, as well as situated socialized contexts such as campus environments, have been areas of interest in nutrition research. The nutrition research community is well-positioned to help campus communities, universities, corporate stakeholders, and policymakers promote these values. To be able to take action toward the goals of ensuring on-campus health and sustainability, it is important to know, to begin with, what foods are consumed on campus and in what context.

However, answering this question poses two major challenges. First, it is challenging to provide good measurements. Traditional methods such as surveys rely on self-reporting, face limitations such as under-reporting of undesired behaviors (4–6) and cannot capture temporal dynamics accurately. Researchers have begun to explore digital traces, e.g., from social media (7), search engines (8–10), or food-tracking applications (11, 12), however, it remains unclear to what extent such distant proxies reflect real food consumption (13–15). Second, measurements from a single campus do not necessarily generalize to other campuses since behaviors are observed at different times, locations, and food landscapes. The worldwide campuses are fundamentally incomparable isolated eco-systems. Hence, much about fundamental campus dietary behaviors with implications for health and the environment—such as meat vs. meat-free meal consumption and consumption of caffeinated or alcoholic drinks—remains unknown. New measurement methods are needed to overcome these challenges and collect dynamic, fine-grained, and generalizable data about the diet of campus populations.

In the present work, we investigate how passively sensed[1] food purchase logs can be used to shape the nutritional environment, and argue that nutrition researchers are well-positioned to contribute to improving the nutritional environment at their institutions. To that end, we introduce case studies of an anonymized dataset of passively collected logs of food purchases made on a large university campus and perform statistical analyses of purchasing behaviors with policy implications. The present work studies purchasing behaviors on a university campus, however, the notion of campus, the insights, opportunities, and challenges refer to similar, more or less closed environments.

In this work, we present the following contributions. First, through a case study of purchases at one campus, we report quantitative empirical analyses of passively sensed food purchases. In doing so, we aim to characterize the determinants of food consumption and demonstrate how studies relying on passively sensed purchase logs have the potential to support the stakeholders in their efforts to understand food choice and consumption. We demonstrate the utility of measurement and monitoring via large-scale digital traces through case studies leveraging real-world passively collected food sales logs. In particular, aiming to understand why people on campus purchase the foods they do, we identify spatial proximity, food item pairing, and academic schedules (yearly and daily) as important determinants.

We then formulate a set of further research questions that showcase the breadth of insights that can be sourced from the purchase logs, beyond the specific campus studied here. We aim to make a case for re-purposing such data, which are often available by default and can serve as a valuable source of information to harness in campus environments to monitor and measure nutrition. Finally, we conclude by offering future opportunities and a call to action for the nutrition research community to contribute to ensuring the health and sustainability of the institutions researchers are part of. We argue that it is crucial for researchers to understand the values embedded in the existing food systems at campuses, the existing data collection and analysis practices, and the values and priorities of the individuals impacted by the food offering and food consumption.

2 Materials and methods

2.1 Dataset: food purchase logs

We leverage an anonymized complete dataset of food purchases made on the École Polytechnique Fédérale de Lausanne (EPFL) university campus. The data spans eight years, from 2010 to 2018, and contains about 38 million transactions, of which about 18 million were made with a badge that allows linking to an anonymized person's ID.

The statistical analyses are based on the seven-year period from Jan 1 2012 to Dec 31 2018 with menu data available. The data includes 38.7 k users, who, on median, are observed for a time period spanning 578 days and make 188 transactions. The analyses include all the transactions within that period, unless otherwise noted. Each transaction is attributed with the time it took place, information about the sale location, the purchased items, their quantity, and price. Sold food items are mainly ready to consume and are associated with unstructured textual descriptions (e.g., "coffee", "croissant", "Coca-Cola can").

The data covers all the food outlets permanently located on campus, including restaurants, cafes, and vending machines. During the entirety of the studied period, there were twelve major catered shops located throughout the campus,[2] and a number of self-service vending machines. The shops typically open Monday through Friday, opening at 07:00 and closing at 20:00, while vending machines are available 24/7. The shops generally are not open during the weekend. All shops offer lunch, while breakfast and dinner offerings vary across shops. Note that student halls in the vicinity of the campus do not have associated dining halls. Hence, the catered shops are the main campus-provided food option for students. In the close proximity of the campus, there are several

1 Contrary to traditional data sources—e.g., surveys—digital data is passively collected in order to support regular campus operations, meaning that the act of data collection does not impact or interfere with people's behaviors and the measurements do not rely on self-reporting.

2 Except for one restaurant, which closed in 2016 and re-opened later in the same year.

non-affiliated food providers, including two seated restaurants (an Italian restaurant and a fast food outlet), two grocery stores, a cafe, and temporarily located food trucks.

In addition to anonymized on-campus purchase logs, we also analyze a smaller-size enriched dataset gathered during a three-week campus-wide sustainability challenge in November 2018, during which 1,031 consenting and volunteering participants formed 278 teams to compete in taking sustainable actions (e.g., taking the stairs instead of the elevator, or consuming a vegetarian meal). For this subset of individuals, we leverage demographic information and identify all of their transactions present in the purchase logs. This results in a subset of 585,812 transactions annotated with demographic information.

The unstructured food item textual descriptions were additionally mapped to categorical labels such as "sandwich" or "dessert" by a research assistant who labeled the 500 most frequently purchased items, which account for 95.4% of the total volume of item purchases observed in the dataset. Further supplementary information about the dataset are outlined in the Supplementary material.

2.2 Ethical considerations

Nutrition is a potentially sensitive personal behavior. To protect user privacy, the log data used here was accessed exclusively by the personnel involved in this project, and stored and processed exclusively on internal servers. The data was obtained with approval from Data Protection Officer[3] and was anonymized before it was made available to the researchers for analysis.

In the data collection and analysis process, we worked directly with campus food-providing administration and transaction system managers who exported and anonymized the data, to understand the information about the food items and restaurants encoded in the dataset. Finally, we note that our work leveraging purchase logs was conducted retrospectively on data that had been collected passively in order to support campus operations. Thus, our analysis did not influence users in any way. Purchases executed by sustainability challenge participants were analyzed retrospectively as well, without influencing them in any way.

3 Results

Motivated by the existing knowledge about human dietary behaviors, we perform descriptive statistical analyses of food-purchasing behaviors in order to characterize prominent on-campus food choice determinants. Since human dietary behaviors and choices are known to exhibit spatio-temporal regularity (16) and recurrent routine-like patterns (17, 18), we analyze dimensions along which purchasing behaviors vary, including temporal, spatial, and choice regularities (Section 3.1). We then analyze the known issues that campus food consumption faces, including ensuring sustainability and health, and tackling the impacts of regular campus operations (Section 3.2). In what follows, we describe our findings and discuss how these insights can inform on-campus policy-making.

3.1 Spatio-temporal and choice determinants of food purchases

3.1.1 Temporal determinants: the heartbeat of the campus

During a year, the academic calendar dictates life on campus. The three important periods in the academic calendar of the studied campus—semesters, exam sessions, and breaks—are marked in Figure 1. We find that the number of transactions peaks during the spring and fall semesters when students are attending lectures, drops during the exam sessions, and reaches the minimum during the winter and summer breaks. During the course of a day (Figure 2), the transactions peak in the morning, during the time of lunch, and during the afternoon or evening snack time.

3.1.2 Spatial determinants: migration patterns between shops

After temporal, we describe spatial determinants in the purchasing behaviors. We are interested in understanding the regularities in visits to shops. To that end, we perform an association rule analysis. Across all individuals, we consider the shops where a given individual has executed transactions during a week. We then apply the Apriori algorithm (19), an algorithm for the discovery of association rules between shops. Association rules describe regularities between items in transaction data. For example, a rule $\{X\} \rightarrow \{Y\}$ found in the transaction logs would indicate that if a person visited shop X, they are likely to also visit shop Y during the same week. In Figure 3, the graph depicts the confidence of the association rules found using the Apriori algorithm, defined as the percentage of all transactions satisfying X that also satisfy Y. This approach lets us monitor shop migration patterns (Figure 3). Rules with confidence greater than the 0.2 threshold are displayed with an edge.

For instance, a thick arrow from node *Shop 10* to node *Shop 4* means that there is a high probability that an individual who went to *Shop 10* also went to *Shop 4* during the same week (shop names are anonymized). *Shop 9* is the on-campus bar that also serves food, while the other shops are on-campus cafeterias that serve meals, beverages, and snacks.

Overall, we find that the distribution of the edges is linked to the geographic locations of the shops. For instance, *Shop 4* is the central place in the graph as there are many arrows with high confidence coming to it, and this cafeteria is indeed at the geographical center of the campus. Moreover, the nearby cafeterias on the campus, frequently visited by students, form a cluster in the shop co-occurrence graph. *Shop 8*, *Shop 11*, *Shop 1*, *Shop 9* and *Shop 2* are near-by cafeterias on the campus, frequently visited by students, and we observe that they form a cluster in the shop co-occurrence graph.

3 The university-appointed Data Protection Officer monitors compliance with data protection laws, informs and advises the university community of their obligations under the law, and assists with issues related to personal data protection.

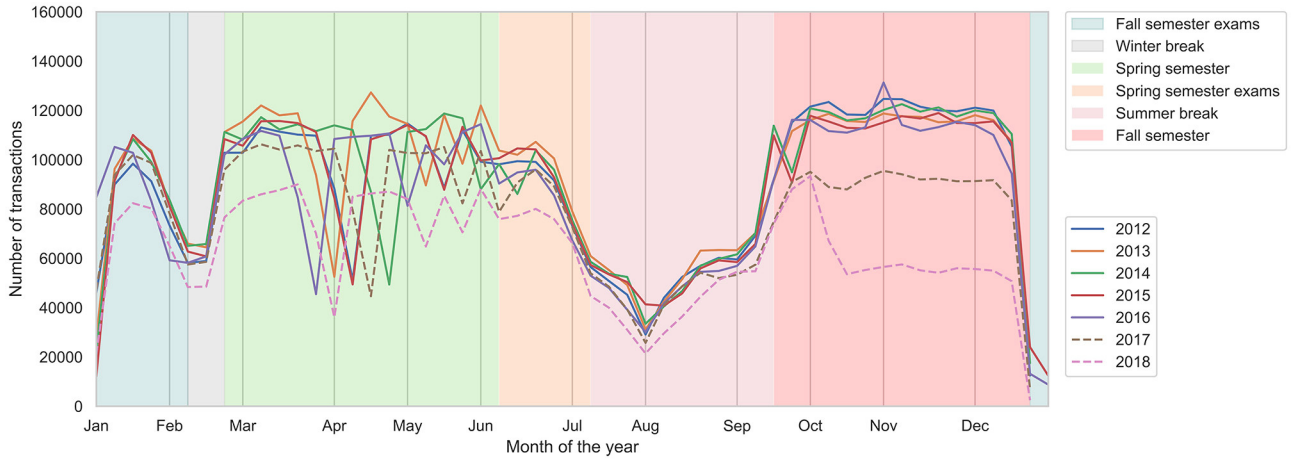

FIGURE 1
Across the month of the year (on the x-axis), the number of executed transactions (on the y-axis), across the years. Background color marks the yearly academic schedule. Note that in 2017 and 2018, the number of transactions during the semester decreased (dashed lines), likely due to the opening of shops close to campus that do not support purchases with the identifying badge.

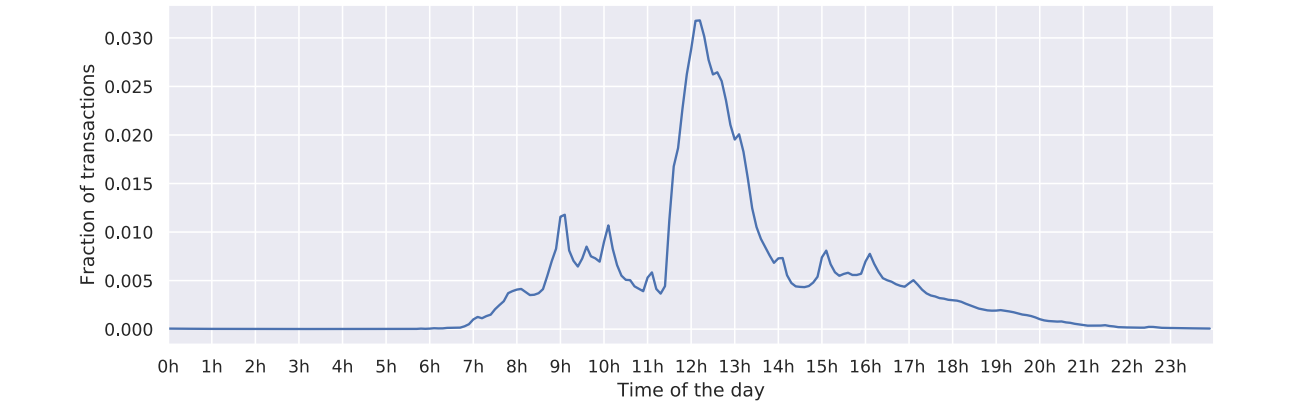

FIGURE 2
The histogram of the transactions by the time of the day. The shops typically open at 07:00 and close at 20:00, while vending machines are available 24/7.

3.1.3 Food-choice regularities and routines: co-purchasing patterns

Next, we study the regularities in purchases of specific foods, performing association analysis, as explained above. We consider purchases composed of food items belonging to different categories, i.e., for each purchase, the food categories a person has purchased. In Figure 4, we show the lifts of the association rules found using the Apriori algorithm, defined as the ratio of how frequently the rule appears in the dataset to that expected if X and Y were independent. Note that the lift is a symmetric measure; therefore, the graph is not directed. We obtain a graph where neighbor nodes are food categories that tend to be purchased together, e.g., *Salty Pastry* and *Pastry*. *Soup*, *fruit*, and *salad* are often co-purchased. Note that the *Non-Food* category contains only products linked to beer, such as glasses on deposit at the on-campus bar.

3.1.4 Implications for policies

To summarize, we reveal regularities in how persons on-campus transition between cafeterias during a week and how food items belonging to different food categories are combined. Since the transitions between cafeterias are governed by geographical proximity (Section 3.1), our analyses imply that the decisions about offering at cafeterias should not be taken in isolation, but should account for such spatial migration patterns. Similarly (cf. Section 3.1), the offer should take into account the frequent item pairings because it is not enough to consider foods in isolation (e.g., a sandwich can have good nutritional properties, but if often purchased together with a beverage with high sugar content, promoting it might not be optimal). Analyses of purchase logs can detect these issues and inform measures taken to improve the experiences around food on campus.

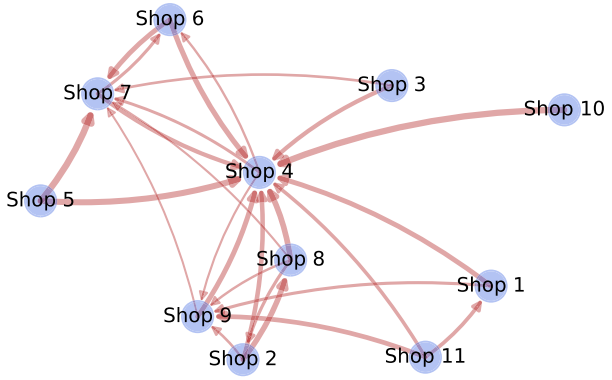

FIGURE 3
The directed weighted graph representing association rules between different shops. Nodes represent shops, and the edges represent association rules. The edge thickness is proportional to the confidence of the rule.

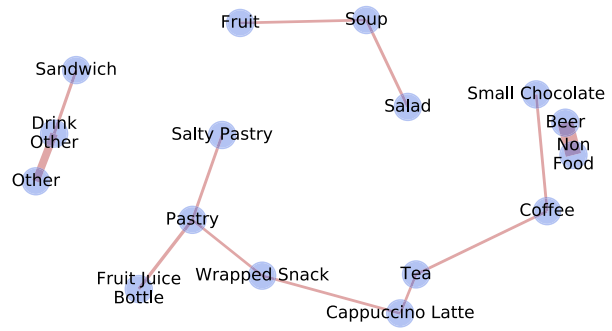

FIGURE 4
The weighted graph representing association rules between different food categories. Nodes represent food categories and the edges represent rules. The edge thickness is proportional to the lift of the rule.

3.2 Specific dietary behaviors: sustainability, health, and the academic schedule

3.2.1 Food sustainability: vegetarian meals

We now turn to analyze specific dietary behaviors relevant to sustainability and health on campus. We first analyze vegetarian meal purchases since the consumption and production of meat have a negative impact on the environment (20). Considering the frequency at which vegetarian meals are purchased out of all purchased meals, we find that, on average, across individuals, 5.3% of purchased meals are vegetarian. Vegetarian meals are the most popular among Ph.D. students (11.2%), followed by undergraduate and master students (8.3%), staff (5.9%), and other statuses (e.g., interns and visitors; 2.4%). Vegetarian meals are the most popular among 21–30-year-olds vs. other age groups (16– 20-year-olds and over 30-year-old) and among women vs. men (8.5% vs. 7.2%). We also note that the proportion of vegetarian meals is monotonically increasing over time, rising from less than 3.98% in 2012 to close to 7.96% in 2018. This rise is likely due to the rise in awareness regarding the effect of meat production and consumption on the environment and health, but also due to the university adapting its offering to cater to these trends. The complete distribution is presented in the Supplementary material.

3.2.2 Potentially harmful dietary behaviors

We next analyze purchases of four types of products that could potentially imply harmful effects on health, albeit to a varying extent depending on the number of daily servings and the specific context (including specific nutritional values, ingredients, and ways of preparation, and added sugar content). We focus on (1) beer, (2) energy drinks, (3) coffee, and (4) vending machine items. We measure the fraction of transactions including such products, out of all purchased products, across subpopulations of status, gender, and age.

First, regarding beers, we find that, on average, across individuals, 2.9% of transactions contain a beer. Beer purchases are the most prevalent among "other" statuses, students, Ph.D. students, 21-to-30-year-olds, and men (3.7% men vs. 1.9% women). Monitoring beer purchases is important since consumption of alcoholic beverages in excessive amounts is not recommended (21). Second, on average, across individuals, 0.15% of transactions contain an energy drink. Energy drinks are the most prevalent among students and Ph.D. students, 26-to-30-year-olds, and men (0.1% men vs. 0.041% women). Monitoring energy drinks is pressing since excessive consumption of caffeinated energy drinks have been reported in association with adverse health effects (22). Third, monitoring coffee purchases, on average, across individuals, we find that 15.4% of transactions contain a coffee. Coffee is the most prevalent among women, staff members, and older subpopulations (31-year-olds and older). We note that the question of the effects of drinking coffee on health is nuanced and multifaceted (23). Lastly, monitoring vending machine purchases, on average, across individuals, we find that 6.2% of transactions contain a vending machine item. Vending machine items are the most prevalent among students and 21 to 25-year-olds. Food products available in vending machines often have a high amount of sugar, and vending machines tend to be nutritionally poor (24), highlighting the importance of minitoring such purchases. The complete distribution is presented in the Supplementary material.

3.2.3 Implications for policies

We observe significant differences between subpopulations. Overall, we find that purchases reflecting potentially harmful dietary behaviors are relatively prevalent, especially vending machine purchases (overall, 6.2% or 1 in 16 transactions a person makes contains a vending machine item). Students, Ph.D. students, younger subpopulations, and men are the most susceptible to purchasing potentially harmful items, while vegetarian meals are most popular among Ph.D. students, people between 21 and 30 years of age, and women. These insights can help stakeholders design targeted interventions and campaigns. For instance, campaigns aiming to promote purchases of healthier alternatives might be located and phrased such that they

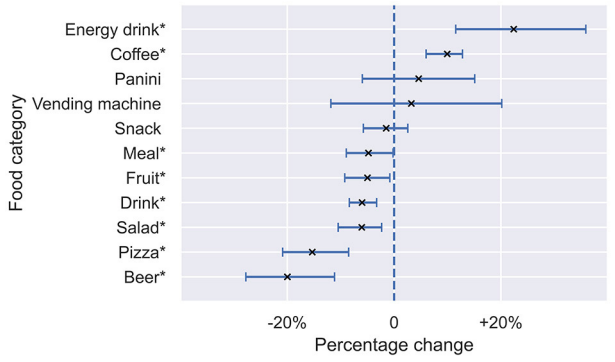

FIGURE 5
For different food categories (on the y-axis), the percentage change (on the x-axis) in the fraction of all purchases that contain the food item during exam weeks, compared to lecture weeks. Positive values mark categories with increased purchases during exam weeks and negative values mark categories with decreased purchases during exam weeks, compared to lecture weeks. Error-bars mark bootstrapped 95% confidence intervals obtained by resampling respective weeks. Stars mark food categories with percentage change significantly different from zero.

are geared toward students and younger subpopulations who are the most susceptible to purchasing potentially harmful items. Communicating attractiveness and health of food options through tailored advertisements (25), visual cues (26), and plate graphics (27) might be effective too, as can sustainability challenges. Similarly, interventions providing discounts on healthy food items outside of regular opening hours could be effective in reducing purchases of potentially unhealthy items. Finally, more research is needed to systematically identify social gatherings and events on campus that increase the risk of repeated unhealthy behaviors, and design interventions to address them.

3.2.4 Yearly and daily academic schedules determine on-campus food choice

Finally, we aim to understand how campus operations determine purchasing behaviors. First, to understand how purchasing behavior changes during the exam session, we compare the differences in purchases between semesters and exam sessions. Monitoring weeks of the entire studied period, in Figure 5, we find that, during the exam weeks, compared to semester weeks, there is a significant increase in the relative frequency of purchases of energy drinks (+22.4%), coffee (+9.9%), and a decrease in the relative purchasing frequency of beer (-20.0%), pizza (-15.3%), drinks (-6.0%), and fruit (-5.0%). For instance, the fraction of purchased energy drinks, which has the greatest change between exam weeks and semester weeks, peaks during the fall semester exams (peak occurs on the last week of the year when 1% or 1 in 100 purchased items is an energy drink). As expected, these effects are stronger among students than among staff members, who are less affected by the academic calendar (Supplementary Figures S5, S6).

During the fall and spring semesters, each class begins after the first quarter of each hour and ends at the end of the hour, with a break of 15 minutes between two classes. Investigating the impact of the academic calendar on purchasing behaviors within an hour (Figure 6), we observe different behavior depending on the individual's status and whether the transactions are made during the semesters or not. During the spring and fall semesters, students' transactions peek at the 8th minute in the hour, during the 15-minute break, and consequently drop (Figure 6, top). Transactions executed by the staff members do not exhibit such a pattern. Ph.D. students are in between staff and students. These differences between staff members and students disappear during the exam sessions and breaks when there are no 15-min breaks (Figure 6, bottom), implying that hourly patterns are indeed linked with the academic calendar since students tend to take advantage of the 15-min break to buy drink or food.

3.2.5 Implications for policies

To summarize, we find that academic schedules determine food consumption on campus, both at the yearly level (lecture season vs. exam season) and the daily level (lectures vs. breaks). On the yearly level, exam sessions are associated with surges in the consumption of both coffee and energy drinks (Figure 5), while on a daily level, the 15-min break between lectures drives food consumption, particularly among students and during lecture weeks. Exams are associated with increases in purchases of potentially unhealthy products, likely due to stress and performance desires. These insights highlight the need for policy-makers to do more to promote student well-being as stress and anxiety levels are elevated among university and college students (28, 29). Modifying the food offer and making exam sessions a better experience for students by encouraging socialization might be promising directions, as socialization might be reduced during exams since beer and pizza purchases decrease, cf. Figure 5. Such community-setting food environment interventions targeting young adults are typically associated with improvements in diets and nutrition outcomes (30). Similarly, insights regarding the 15-min break imply that purchase line congestion might occur. Interventions mitigating the surge in purchases and modifying the offering might be effective, for instance, by opening additional dedicated checkouts with modified healthy snack offerings.

4 Discussion

4.1 Summary of main findings

The presented results imply that approaches leveraging passively sensed anonymized data should be an essential component in efforts to monitor the evolution of food consumption on campus while being aware of complex spatio-temporal determinants and differences between subpopulations. For instance, the finding that the academic schedules determine food consumption on the studied campus at the yearly and daily level, and the fact that exams are associated with significant increases in purchases of potentially unhealthy products, highlight the need for policy-makers to do more to promote student well-being.

These findings have direct implications for developing new methods for population nutrition monitoring, encouraging better eating practices, and optimizing food offerings. By capturing

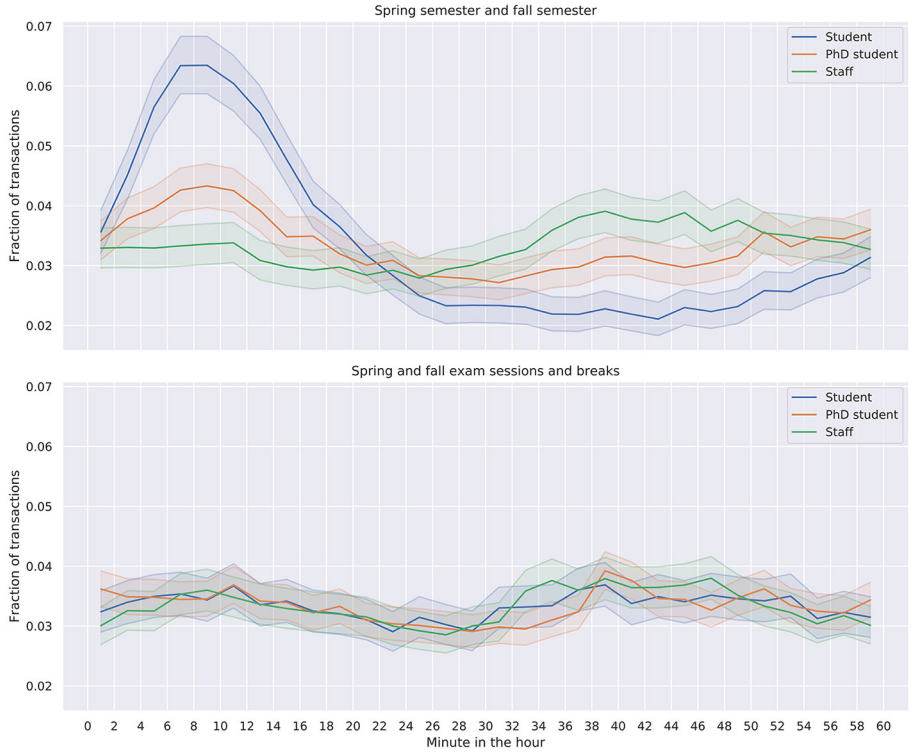

FIGURE 6
By the minutes of the hour (on the x-axis), the fraction of executed transactions during the minute, separately during the semesters **(top)** vs. during the exams sessions and breaks **(bottom)**, and separately by status. Error-bars mark bootstrapped 95% confidence intervals.

nearly all on-campus food consumption, the purchase log analysis approach complements survey-based methodologies, which likely under-report (5, 6) stigmatized consumption of unhealthy items.

4.1.1 Limitations

Certain limitations should be kept in mind when interpreting our results. First, the presented case study is limited to a single campus. Behaviors on the studied campus can fundamentally differ from behaviors on other campuses. External validity and generalization are not guaranteed. Future work should determine to what extent behaviors measured on campus reflect behaviors in other on-campus settings, which might differ in their location, climate, the characteristics of the population, and other environmental properties. We also note that self-selected sustainability challenge participants are not a representative sample of the entire campus population (Supplementary material, Section 1.2). Second, on the studied campus, the unstructured food item labels and the information derived from them are incomplete. For instance, cash transactions cannot be mapped to individuals (46.92% of transactions could be mapped to a specific user). Further information about the difference between the entire dataset, non-identifiable cash or card transactions, and identifiable transactions executed with the badge are listed in Supplementary Table S1. Overall the distributions are similar across the datasets, although systematic differences exist. Similarly, he vegetarian tag was deduced from the name and type of the product and is, therefore, not necessarily always correct. Third, the log data does not directly capture food consumption but provides indirect proxies via purchasing. We also note that the described analyses do not necessarily establish causality. It is reasonable to assume that students and staff indeed consume the food that they purchase. However, one cannot eliminate the possibility of persons borrowing the card, or paying for items consumed by other people.

Future work should determine to what extent behaviors measured on campus reflect consumption of food purchased outside of the campus and off-campus behaviors. For example, people who primarily eat home-cooked or delivered food might present a skewed representation of their diet in the studied cafeteria purchase logs, and the fact that individuals might consume delivered or home-cooked food introduces unobserved variables into our analyses. Meals consumed at restaurants nearby but outside of campus are similarly not captured, while opening and closing of shops close to campus can impact on-campus behaviors. Furthermore, cultural factors and dietary preferences might play a role in determining whether students and staff choose to rely on food options provided on campus to begin with (31, 32). Related to cultural background, we note that the number of unique users in the dataset grew as the staff and student body expanded (by around 40%, from 12.5 k unique users in 2012 to 17.5 k unique users in 2018). This increase coincides with a recorded growth in the international student population (33), highlighting the importance of campus stakeholders adapting food offerings to various cultures and cuisines.

4.1.2 Further research questions

The insights from the statistical analyses inform a wide range of research questions that can be addressed leveraging anonymized passively sensed purchase logs, potentially in conjunction with other data sources. For instance, future work should understand how food choice is determined by the availability of options, and how the lack of food offerings at late hours might be linked with potentially unhealthy patterns, including vending machine purchases. How does food choice evolve over the course of a day and a week? Do people tend to consume healthier foods at the beginning of the day or the week? To what extent is food choice determined by geographical proximity to options? How much work would people be willing to put in to reach better options? How does the opening of unaffiliated premises near campus affect on-campus meal consumption? Similarly, how does weather affect food purchases? Could random variation in weather be leveraged to study spatial proximity? Additional opportunities to tackle potentially harmful dietary behaviors include understanding their onset. Can on-campus alcohol drinking and energy drink consumption be predicted? How does eating with others impact on-campus food choice, and can social challenges lead to more sustainable on-campus behavior?

4.1.3 Further background and scope

We now turn to situate our findings with respect to the existing literature on monitoring and measuring nutrition with digital traces in a campus-wide setting. A rich body of previous work examined the factors that represent barriers and enablers to healthy eating in campus environments (34). The dominant factors include price, value for money, healthfulness, and taste (35, 36). Previous work has studied the specific, potentially harmful, dietary behaviors in on-campus setting, including the consumption of energy drinks (37, 38), alcohol (39, 40), vending machine foods (24, 41), and a failure to reach the nutritional recommendations (42). On-campus dietary interventions that aim to improve food availability, accessibility, prices, and promotions through policies received considerable attention from researchers (35, 43–45). Accessibility and price are important factors on the studied campus, too. For instance, during the studied period, the average price of a purchased meal was monotonically increasing, and grew by 30.31% between 2012 to 2019 (from 7.62CHF to 9.93CHF). Similarly, the price of a non-meal item grew from 2.54CHF in 2012 to 3.85CHF in 2019, further highlighting the role of affordability of both on- and off-campus options.

However, understanding all the determinants of food consumption and identifying intervention effectiveness is challenging since the key factors, such as availability and attitudes, change over time, interact, and do not necessarily generalize across campuses. Moving forward, there is a need for unified frameworks to better monitor and understand food consumption in campus environments worldwide.

Studying diets through digital traces has been an active area of research (10, 46, 47). Large-scale passively sensed signals have been harnessed in university campus environments to measure factors of well-being (29) and performance (48), pointing toward the feasibility of leveraging behavioral traces for campus-centric applications (49–51).

Nonetheless, while large-scale digital traces are promising for monitoring and modeling nutrition, little is known about how food sales log signals could be used for understanding and shaping on-campus nutritional environments.

4.2 Opportunities and implications: a call to action

Moving forward, we identify knowledge gaps and outline sketches of themes for analyses to be done at other institutions and other campuses to shape the nutritional environments. We identify five specific areas where we call on the nutrition research community to apply their expertise. Below we propose a research agenda and specify how different research paradigms can answer this call to action to improve nutritional environments.

(1) Deriving generalizable insights about on-campus dietary behaviors. Each campus is an independent eco-system, which makes it challenging to derive findings that hold between campuses. Estimates are typically produced at different times and different locations. Furthermore, cultural factors can, in important ways, alter behaviors—for instance, due to varying susceptibility to stress. What behaviors can generalize across campuses around the world? What behaviors are shared between various types of campuses (e.g., educational vs. industrial vs. corporate vs. medical)?

Future efforts might include creating a network of partner institutions that would enable researchers to replicate the same set of analyses and then perform meta-analyses to discover universal behavioral patterns. We envision developing a system to enable processing the anonymized purchase logs (in a pre-determined format) and obtaining and sharing aggregated high-level insights with other campuses. An a priori-designed meta-analysis would then be performed across a cohort of campuses via "megastudies" (52). A unified client-side analysis framework could be built to process the anonymized logs, following templates of studies that can be conducted worldwide in order to answer pre-agreed research questions.

(2) Collecting more detailed on-campus food offering and consumption data. A major challenge of the efforts to study on-campus food consumption is the lack of transparency regarding food offer and consumption. On campuses, complex sets of factors beyond the knowledge and reach of individuals who consume food often determine the availability of options, the nature of collected data and its usage, resulting in a lack of transparency regarding food. Moving forward, there is a clear need for more robust and open policies. This is an opportunity for nutrition researchers to influence local stakeholders at their respective institutions in order to reject the lack of transparency regarding food offering and consumption, and advocate for sustainable and resilient supply chains (53).

Since institutions are responsible for the health of everyone on campus, there is a pressing need to collect more data about offered food at institutions and campuses globally. Future efforts should involve advocating for and collecting rich information

about the food items and communicating it to the public. This information includes but is not limited to foods' origin, distance of the food source from the campus (i.e., whether it originates from local farms), ingredients, nutrients, calories, nutritional scores, sustainability metrics (e.g., carbon footprint), preparation methods, and food waste statistics.

(3) Establishing on-campus digital cohorts. Another potential solution addressing the concern about the incompleteness of purchase logs is setting up digital cohorts where students and staff could share their food consumption and other health-related data for research purposes. In particular, the individuals could share information about their dietary intake, calorie intake, and health outcomes (for instance, through electronic health records or well-being surveys). That would allow studying specific conditions closely linked with dietary habits (e.g., diabetes and heart diseases), and behaviors assumed to be linked with food consumption but not well understood. The latter could include, for instance, information about major life events, daily habits, social media usage and web browsing, menstrual cycle, and mental health. Active data collection efforts are required to answer such ambitious research questions with implications for the health of the general population. Such an effort would be a way to address the incomplete nature of purchase logs by capturing dietary intake and health outcomes more completely.

(4) Discovering needs and priorities regarding the nutritional environment. Since campuses worldwide face a lack of unified effort toward health and sustainability, there is a need for a closer examination of structural processes of power at the campuses and a need for a better understanding of factors that slow down current efforts toward health and sustainability. In addition, there is no principled and systematic understanding of what individuals on campuses worldwide want and need, as well as the difficulties and challenges they face. Future efforts should explore experiences and perspectives from marginalized and underrepresented subpopulations including essential campus service staff who consume food but traditionally do not play a role in the decision-making.

To tackle the challenges mentioned above, new qualitative and participatory approaches are needed. A major lesson learned through our case studies is that the researcher analyzing the logs cannot assume the role of a friendly outsider. The researcher needs to talk to stakeholders, understand the events and schedule of the campus, and engage with both food providers and consumers. In our study, we benefited from having the respective information by being embedded into campus. Similarly, there is a need to acknowledge that food offering, the collected data, and the derived insights embody and reproduce the values of those who designed the food offering systems and data collection mechanisms, to begin with (54). However, the values of individuals who are part of the campus should be discovered, not assumed (55), while enabling individuals on campuses to identify their own priorities and make decisions about the food system and about the future use of digital traces they contribute. In the process, the goal is to give a voice to all stakeholders and enable everyone involved to answer questions such as "How is our data being collected? Will the findings be of benefit to us?" (56).

(5) Developing new principles and practices around ethics and privacy. Since behavioral data can be misused and purchases can reveal potentially sensitive information about individuals (57), it is necessary to balance the potential to do good with the potential to harm. At present, corresponding institutional approvals are needed to perform analyses within one campus, guiding researchers through ethical and privacy concerns. However, new challenges emerge when there is a need to replicate the same analyses across several campuses so as to derive generalizable insights about dietary behaviors. Having all the data, which is potentially sensitive, at a single central point is a risk and a liability.

Future efforts can involve designing an application that would allow locally running purchase log analysis scripts with embedded privacy mechanisms. If there is an agreement about data formats, universal processing scripts can be run locally. Previously, decentralized data processing across silos has been deployed in settings where silos corresponded to hospitals processing medical datasets (58), consistent with the paradigm of federated learning, a privacy-enhancing technique that allows institutions to keep control of the data. Furthermore, federated learning can be used with other privacy-enhancing technologies, such as differential privacy (DP), which ensures that one cannot infer additional information about the original data from the aggregated results (59, 60). To facilitate collaboration over sensitive data, an alternative approach is to take a sensitive dataset as input and generate a structurally and statistically similar synthetic dataset with strong privacy guarantees (61, 62). Finally, secure multi-party computation (63) and trusted environments (64) enable parties to jointly compute a function over their inputs while keeping those inputs private from each other, or from the main processor of the central server. A key barrier toward that goal is determining whether other institutions are willing to provide data to their own researchers to begin with, and whether researchers could share aggregated insights with researchers at other institutions.

4.3 Conclusion

On-campus food offer and consumption broadly affect health, performance, and the environment. We make a case for shaping such nutritional environments by leveraging passively sensed food sales logs, typically available by default. Through case studies of food choice determinants in a large university campus, we demonstrate how analyses of such logs can potentially inform policy-making and argue that nutrition researchers are well-positioned to apply the expertise necessary to contribute to improving food offer and consumption across institutions.

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.

Ethics statement

The studies involving humans were approved by EPFL Data Protection Officer (the university-appointed Data Protection Officer monitors compliance with data protection laws, informs and advises the university community of their obligations under the law, and assists with issues related to personal data protection). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

KG and RZ contributed to data curation, formal analysis, and writing – original draft. AC, EK, RWh, EH, and RWe contributed to conceptualization and methodology. All authors contributed to writing – review and editing.

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Conflict of interest

EK, RWh, and EH were employed by Microsoft Research.

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Supplementary material

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Strategies associated with improved healthiness of consumer purchasing in supermarket interventions: a systematic overview of reviews and evaluation of primary articles

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Background: Growing evidence suggests that it is possible to change the retail food environment to enable healthier choices via in-store interventions. It has been difficult to draw clear conclusions as to which interventions are most effective in positively influencing consumer purchasing behaviour given the significant heterogeneity within the food retail research literature. The aim of this study was to (1) summarise current high-quality systematic, scoping, and/or narrative reviews (Part I: overview of reviews); and (2) synthesise high-quality original research, to understand the range, types and effectiveness of strategies implemented in food retail settings (Part II: evaluation of primary studies).

Methods: To identify reviews describing the effects of intervention strategies aiming to improve the healthiness of consumer purchasing in supermarkets, a systematic search across seven electronic databases was completed in April 2023. The methodological quality of reviews was assessed using the risk of bias in systematic reviews for systematic and scoping reviews, and the Scale for the Assessment of Narrative Review Articles for narrative reviews. High-quality reviews were further inspected and synthesised narratively (Part I). Next, to understand strategies associated with improved healthiness of consumer purchasing high-quality, primary articles from high-quality reviews identified in Part I were retrieved, and the strategies implemented within these interventions were summarised (Part II).

Results: Thirty-eight reviews met the inclusion criteria for Part I; two-thirds ($n = 25$, 66%) were rated as high-quality (66%). These reviews indicated that pricing strategies had the greatest proportion of reported positive or promising effects on outcomes ($n = 8$ of 11 reviews, 73%). Twenty reviews met the inclusion criteria for Part II and the 771 primary articles from these reviews were screened with 23 high-quality primary articles included in analysis. Findings indicated that promotional strategies in combination with another strategy appeared to be most successful among regular shoppers (the general population), whereas pricing was most successful in low socio-economic status and rural sub-groups.

Conclusion: Promotion, pricing and prompting were the most commonly tested strategies across the overview of reviews and review of primary articles. Promotion, in combination with other strategies, and pricing appear to be most promising, but the effectiveness of pricing strategies may vary by sub-groups of the population. How pricing and promotion in combination with other

strategies can be implemented responsibly and sustainably to change purchase habits towards healthier items should be explored further.

Systematic Review registration: OSF, https://osf.io/jyg73/.

KEYWORDS

supermarket, retail food environment, public health, health promotion, review

1 Introduction

Poor dietary intake, characterised by lower intakes of whole grains, fruits, nuts and seeds, higher intakes of red meat and sugar-sweetened beverages, is a leading driver of morbidity and premature mortality, globally (1). Dietary intake is influenced by a range of individual, social, environmental and system level factors (2–4). Supermarkets, as one actor in the food system, influence population diets through the creation of retail environments that shape food purchases, and ultimately consumption, through manipulating layout, availability, price, and promotion (5, 6).

In developed countries, households purchase nearly all their food within a retail setting (7). In Australia, two-thirds of all food purchased is from supermarkets (8), with similar figures in the US (9) and United Kingdom (10). Previous research has shown that individuals living in areas with greater availability of supermarkets have a lower body mass index (11). Living near healthier food stores is also associated with better diet quality (12). Supermarket purchase behaviour can be habitual, but is not often planned in detail (13), meaning consumers' purchasing behaviour could be shifted by changing the in-store retail food environment to be more health enabling (14).

Currently, supermarkets actively attempt to influence purchasing through techniques typically grouped into the 'four Ps of marketing'—product, price, placement, and promotion (5, 6). Published literature provides examples of enabling strategies within each 'P' such as reducing/replacing unhealthy foods (product); using price reductions to increase acceptability of unfamiliar healthier foods (price); placing multiple healthy checkout aisles in stores to shift the healthy/unhealthy balance (placement); and highlighting healthy options by displays, labels and samples to taste (promotion) (6). The effectiveness of interventions using such strategies is mixed (15–18). It has been difficult to draw clear conclusions as to which of the four P strategies, or combination thereof, is most effective in positively influencing consumer purchasing behaviour given the significant heterogeneity within the food retail research literature in terms of the effectiveness of such interventions, as well as the types of populations and settings included.

Several reviews (6, 19–26), and updates of reviews (27, 28) investigating the effectiveness of interventions on improving the healthfulness of the retail food environment have been published over the past two decades. These have been undertaken across a broad range of food retail outlets including convenience stores, vending machines, quick-service restaurants, and school or workplace cafeterias, and few have focused exclusively on supermarket settings. This is important, since these other settings have attributes distinct from supermarkets, and account for a much lower portion of individuals' food and beverage purchases (13). Existing reviews also include studies conducted in mock (simulated) supermarkets, or laboratory settings, which is less ecologically valid and likely less reflective of natural behaviour (29). Given the central role of supermarkets in shaping population diets, the supermarket food environment should be given focussed consideration as an avenue to improve eating habits.

The objective of this study was to review the available evidence on the effectiveness of real-world supermarket-based interventions on the healthiness of consumer purchases and consumption. Given the existing high volume of literature on this topic, an overview of reviews was considered appropriate to synthesise existing findings and provide a rapid synthesis of high-quality evidence. Overviews of reviews (also known as 'umbrella' reviews) are common practice and integrate the findings of multiple previously published reviews, allowing rapid assessment of the evidence base on a topic area (30, 31). Therefore, the first aim was to summarise the current body of high-quality evidence obtained from systematic, scoping, and narrative reviews (Part I). The second aim was to interrogate this high-quality secondary research to better understand the range and effectiveness of strategies evaluated in food retail settings (Part II).

2 Methods

2.1 Overview

The first stage of this research was to use a systematic process to synthesise current evidence through an umbrella review (Part I). To understand what strategies are most likely to be effective in changing purchase patterns of consumers in supermarkets, we then undertook a comprehensive review of high-quality primary research studies, identified from high-quality review articles (Part II). This synthesis aimed to provide a deeper understanding of the strategies implemented within supermarket-based studies, and key learnings about their relative success and failure in improving the healthiness of consumer purchasing. Figure 1 provides an overview of the two parts of this review.

2.2 Information sources and search strategy

This review was guided by recommendations for the conduct of overviews of reviews from the Cochrane Handbook (32) and findings of reviews are reported based on suggestions in the Preferred Reporting Items for Overviews of Reviews (PRIOR; (33)) guidelines. The study objective, search strategy, selection criteria and synthesis plan were specified *a priori* (see study protocol in Appendix A) and uploaded to Open Science Framework,[1] retrospectively.

1 https://osf.io/jyg73/

A literature search was conducted in March–April 2023 across seven databases: PubMed, Web of Science (core collection), Scopus, ProQuest, EconLit, Cochrane Central and Google Scholar (retrieving the first 200 results). The search strategy was developed by the authors in conjunction with an expert librarian using a modified PI(E)COCS framework (Population, Intervention/Exposure, Comparison, Outcome, Context, and Study Design; Table 1) (34). Briefly, reviews that reported on the effectiveness of strategies implemented in supermarkets or grocery stores that aimed to improve the healthiness of food and/or beverages purchased or consumed by consumers were included. Accreditation schemes are a type of promotion and a potentially important lever for influencing consumer behaviour but occur at a system level. Furthermore, in light of a recent review focused specifically on the effectiveness of outlet-level healthy food and beverage accreditation schemes (35), these strategies were considered beyond the scope of this review.

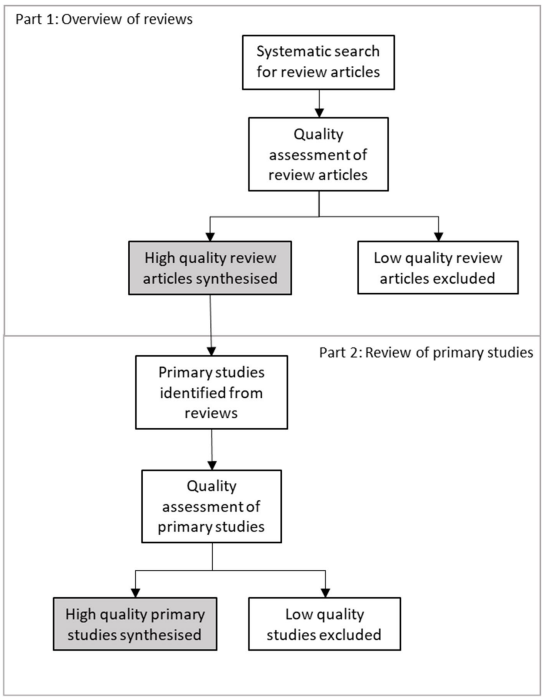

FIGURE 1
Summary of the methodological approach to sourcing and including articles in the two parts of this review: Part 1, Overview of reviews; and Part 2, Review of primary studies.

A combination of MeSH (medical subject headings) terms and free-text keywords were used to search for relevant interventions (e.g., 'product availability', 'choice architecture', 'price', or 'promotion') and the outcomes of interest (e.g., 'healthy eating', 'diet quality', 'sales data' or 'customer satisfaction'). The detailed search strategy is available in Appendix B. The reference lists of included reviews and relevant review articles were searched to capture any citations missed by electronic searches ('backward search'). Search parameters were limited to review articles published in the English language (the native language of the authors). No date restrictions were applied; the search included review articles published from database inception through to 4 April 2023.

2.3 Review selection

Citations and abstracts of all retrieved records were imported to EndNote (X9) (36). Duplicate records were identified and removed, and the remaining citations imported to Covidence (37). Records were assessed for eligibility against the PI(E)COCS criteria (Table 1), initially screened based on their title and abstract; any records that

TABLE 1 PI(E)COCS criteria.

Criteria	Inclusion	Exclusion
Population	Supermarket shoppers	Children or persons who do not make food purchases independently
Intervention/Exposure	Interventions that aimed to improve the healthiness of food purchased by consumers by altering factors such as product, price, promotion, placement	Interventions that focused on new stores Interventions related to government taxation or money subsides Interventions operating at the manufacturer, rather than retailer, level (e.g., product reformulation, food labelling) Accreditation schemes
Comparator	No restrictions	
Outcome	Food/beverage purchasing information – can be objective (e.g., sales data, shopper receipts) or self-reported (purchase behaviour); or Dietary consumption (e.g., food recall); or Health outcomes (e.g., weight change)	Alcoholic drink sales/consumption Hypothetical choice/purchase intentions Economic evaluation Shelf-space or availability of products
Context	Real-world, physical or online supermarket or grocery stores* where there is an exchange of money for food and beverage products to be consumed elsewhere	Other food retail environments such as farmers markets, food pantries, convenience stores, corner stores, cafeterias/restaurants, vending machines, school/workplace canteens, sporting venues# Simulation or laboratory studies
Study design (Part I)	Review articles (scoping, systematic, literature, umbrella)	Primary research articles
Study design (Part II)	Primary research articles, no restrictions were placed on study design	Reviews, conference abstracts, study protocols

*The retail literature does not use the terms 'grocery store' and 'supermarket' interchangeably, so we accepted each term as presented by the author (s) (27); #Reviews that included mixed settings were eligible if at least one of the settings contained supermarket or grocery stores (e.g., reviews of supermarkets and convenience stores).

were potentially eligible were advanced to full-text review. Study selection was performed by two reviewers (PB and CH), independently. Conflicts in the selection process were resolved by discussion until a consensus was reached.

2.4 Quality appraisal of reviews

The search retrieved all review types, including systematic, scoping, and narrative reviews. To identify high-quality reviews, assessments were conducted using published quality appraisal tools specific to each review type. Currently, there are no internationally established standards for critically appraising or determining risk of bias in scoping reviews (38), therefore, the Risk of Bias In Systematic Reviews (ROBIS) (39) was used to appraise both scoping and systematic reviews. To assess the quality of narrative reviews, the Scale for the Assessment of Narrative Review Articles (SANRA) was used (40).

As per instructions, the ROBIS tool was completed in two phases: (i) identify bias with the review process, and (ii) judge the overall risk of bias in the review. In phase one, the risk of bias was assessed across four domains: study eligibility criteria; identification and selection of studies; data collection and study appraisal; and synthesis and findings. The level of risk of bias associated within any of the domains in phase 1 was graded to categorise the overall risk of bias (referred to as study quality hereafter) as *low*, *high*, or *unclear* (phase 2).

The SANRA tool assesses the quality of narrative reviews across six domains: explanation of the review's importance; statement of the aims; description of the literature search; referencing; scientific reasoning; and presentation of relevant and appropriate endpoint data. Each domain is scored out of 2, and summed to give a total score out of 12; a score of 4 or below indicates very poor quality (40). The SANRA tool does not provide a cut-off score to indicate whether a review can be considered 'high-quality'. For this study, two investigators (PB and CH) agreed on 'critical' domains and a subsequent scoring system to assess the overall quality of reviews. Articles were considered high-quality if they scored two (maximum score) for each critical domain and did not score poorly (zero) in more than one other domain (Appendix C). The quality assessment was performed in duplicate by two independent reviewers (PB and CH). Disagreements were resolved by consensus between the two reviewers.

2.5 Primary article selection

Where a quality assessment was completed within high-quality reviews, primary articles deemed to be high-quality (based on criteria established by the original review authors) were retrieved. Where reviews used a risk of bias tool that do not provide an overall quality rating of primary articles, two authors (PB and CH) decided on critical domains from each quality assessment tool and used the review authors scoring on these domains to categorise primary articles as high-quality, or not (Appendix D). There is no standard approach to deal with overlap in primary articles across reviews (41). Therefore, when primary articles were included in more than one high-quality review, the quality rating from the most recently published and highest quality review was chosen; an approach suggested by Lunny and colleagues (42, 43). The retrieved primary research articles were examined for eligibility against PI(E)COCS criteria (Table 1).

2.6 Data extraction and synthesis

A standardised data extraction template was created in Microsoft Excel® (Version 2022), and used to collect the following information from the included reviews and primary articles: (i) Publication Details: first author's family name, year of publication; (ii) Review/Study Characteristics: primary objective, inclusion criteria and search restrictions (reviews only), study design (primary studies only), and retail setting(s); (iii) Intervention Characteristics: details regarding intervention and control treatments; (iv) Outcomes: methods used to assess outcomes, and outcome results; and (v) Study Conclusions: main conclusions as reported by authors. Data from each review and primary study were extracted by one author (PB or CH) and checked by a second investigator (CH or PB). Data were synthesised narratively. The type of in-store intervention described in articles was categorised according to the framework by Kraak et al. (44), and adapted for use in grocery store settings by Slapø et al. (13) (Table 2). The framework was adapted further to include '*product availability*', and '*combined*' strategies. Outcome effects were coded using ratings proposed by Chan et al. (46). Outcome effect ratings included: (i) 'positive', where there was a positive effect on the primary outcomes as intended; (ii) 'promising', positive effect potentially with change in power, dose, exposure, or analysis; (iii) 'mixed due to intervention', mixed outcomes due to different treatment arms having different effects; (iv) 'mixed due to outcomes', positive findings for some outcomes, negative, or no effect for other outcomes; (v) 'no effect', no effect on any outcome; (vi) 'negative', effect in opposite direction as intended; or (vii) 'unclear', inappropriate analysis or insufficient evidence to support outcome. Where a review or primary study reported separate syntheses of the effects of different intervention strategies, information describing the effects of each synthesis was extracted. If multiple time points were reported, only the end of the intervention point and final follow-up were used. Where information was missing from the published manuscripts, authors were contacted twice over a two-week period to provide the additional information.

2.7 Deviations from the pre-registered study protocol

Some changes to the methods outlined in the pre-registered protocol were necessary. Overviews of reviews were planned for inclusion to capture all available (consolidated) evidence in the research area. Following execution of the search strategy and study screening, umbrella reviews were excluded from further analysis. We did, however, examine the reference lists of eligible umbrella reviews (Gupta et al. (47), Roberts et al. (48) and Wolfenden et al. (49)) to cross-check for the inclusion of relevant review articles.

Reviews that focused on interventions related to food labelling or taxation/money subsidies were pre-planned exclusion criteria. After examining the search results, it became apparent that these broad terms encompassed strategies deemed eligible for inclusion in the review. For example, 'food labelling' may include promotion of products via

TABLE 2 Strategies to promote healthy food and beverage environments in grocery stores.

Strategy	Description
Portioning	Reduce and/or standardise the portion size of food and beverage products that meet recommended nutrient targets to influence customers' expectations about single servings and appropriate portions to support healthy dietary guidelines
Place	Changing the internal setting (e.g., lighting, smell, music and branding of stores) that impact the ambience or atmospherics to highlight healthy food and beverage products.
Proximity	Placing healthier products at eye level or physically closer to customers at point-of-choice and point-of-purchase (e.g., placing healthier options at the entry or exit of store and giving healthy options better placement in the shelf).
Promotion	Use of marketing practices inside store that support healthier diets (i.e., products samples, taste-testing, in-store demonstrations, inside store audio public service announcements and education sessions inside store to promote healthy products).
Healthy Default Picks	Use of environmental cues that are convenient, accepted and expected to socially normalise healthy defaults choices (e.g., introducing swaps that offer customers the opportunity to replace their usual food with healthier alternatives).
Pricing	Use of pricing strategies to increase sales of products that meet recommend nutrient targets to support healthy dietary guidelines (e.g., changes in price per unit, coupons and cash-back).
Prompting	Use of information on products to help customers make healthier choices at point-of choice and point-of-purchase (e.g., guiding star labelling system, nutrition labels and traffic-light labels).
Profile	Change in the product's nutritional profile, quality, smell, taste, texture, flavour of food or beverage products that make meeting nutritional targets according to dietary guidelines.
Product Availability	Increasing, decreasing, or changing the range or number of product options available to customers [as defined by Hollands et al. (45)].
Combined*	Reviews that included a high-level narrative synthesis of either (i) multiple single-component strategies or (ii) both single-and multi-component strategies that were synthesised together, and thus the results could not be attributed to a particular strategy.

Adapted from "Efficiency of In-Store Interventions to Impact Customers to Purchase Healthier Food and Beverage Products in Real-Life Grocery Stores: A Systematic Review and Meta-Analysis," by H. Slapø, 2021, foods, 10 (922). *applicable for Part I only; Reviews that only synthesised studies examining the effects of 'Portioning' and 'Profile' strategies were not included in this review.

shelf-tags (included), not just front-of-pack labelling (excluded), and taxation/money subsidies may include pricing discounts in-store (included), not just government taxation initiatives such as 'sugar tax' (excluded).

3 Results

3.1 Part I—overview of reviews

The literature search resulted in a total of 1,406 records. After the removal of duplicates ($n = 331$), a total of 1,075 abstracts were initially screened by title and abstract. Eighty-two abstracts were eligible for full-text review. A total of 38 review articles met the eligibility criteria and were included in this overview of reviews (Figure 2).

3.1.1 Quality assessment of included reviews

The quality of the review articles was assessed using the ROBIS or SANRA tools. Appendix C shows the full quality appraisal, including how the reviews scored on each domain. Twenty-five (66%) were rated as high-quality (low risk of bias), and the remainder were rated as low-quality (high risk of bias; $n = 4$), or the quality was unclear ($n = 9$).

The focus of this overview of reviews was on high-quality reviews. Therefore, results will be presented only for high-quality reviews. Characteristics of low-quality reviews, or those where the quality was unclear, can be found in Appendix E.

3.1.2 Review characteristics

The characteristics of the 25 high-quality reviews are presented in Table 3. Reviews were published between 2014 (19) and 2023 (60). Most were systematic reviews, and included between eight (62) and 107 (52) primary articles. About a third of the reviews ($n = 9$ of 25, 36%) also searched grey literature (45, 52–55, 60, 61, 67, 68).

Of the 25 reviews, most ($n = 19$, 76%) included a range of food retail settings, such as supermarkets, convenience stores, cafeterias, farmers markets, vending machines and canteens. Only six reviews (24%) focused exclusively on primary studies conducted in supermarkets and/or grocery stores; two of which were conducted solely in physical brick and mortar supermarkets (57, 62) while the other four were conducted in a combination of real-world physical stores, real-world online stores or simulated supermarket environments (13, 53, 60, 65) (Appendix F).

Reviews mostly focused on 'regular shoppers' as the population of interest ($n = 17$ of 25, 68%); one focused on people or stores from middle-income and high-income countries (56). Seven reviews did not specifically state the eligible population(s) as part of their PICO framework (14, 51–53, 55, 63, 66).

The most assessed strategies in reviews were pricing ($n = 9$ of 25, 36%), promotion ($n = 8$, 32%) and availability ($n = 8$, 32%). Other strategies less commonly evaluated in reviews included proximity ($n = 7$, 28%), prompting ($n = 6$, 24%), place ($n = 2$, 8%) and healthy default picks ($n = 1$, 4%). Seven of the reviews (28%) focused on a single intervention strategy—four solely on prompting strategies (54, 63, 66, 67); two solely on pricing strategies (50, 56); and one on promotion strategies (62). Almost half the reviews ($n = 11$ of 25, 44%) evaluated 'combined' intervention strategies.

Reviews needed to report outcomes related to purchase/sales, consumption, or health outcomes to be included. Most reviews ($n = 21$ of 25, 84%) (13, 14, 19, 27, 28, 45, 50, 51, 53–60, 62–66, 68) assessed the effects of intervention strategies on objective (e.g., sales data, customer receipts) or subjective (e.g., survey self-reported purchases, intent to

purchase, or direct in-store observation) purchase-related outcomes (Appendix F). Sixteen reviews (64%) (19, 27, 28, 45, 50, 51, 53–56, 58, 61–64, 67) assessed the effects of intervention strategies on consumption as the primary outcome, and three reviews considered consumption as a secondary outcome (14, 45, 59). Seven reviews (19, 27, 50, 53, 63, 64, 67) assessed the effects of intervention strategies on health outcomes (e.g., body weight/composition, BMI, metabolic risk factors or clinical endpoints); and two included this as a secondary outcome (19, 50).

In addition to outcomes forming inclusion criteria for the current study, reviews reported outcomes such as business-related outcomes (e.g., retailer/customer perceptions, commercial viability, community outcomes, storeowner attitudes), industry responses (e.g., changes in formulations or availabilities of products) (52, 55, 56, 63, 68), or consumer knowledge, beliefs, preferences or intentions, nutrient content of baskets, or cost-effectiveness (health-care savings) (19, 54, 58, 60, 62, 65, 67, 68).

3.1.3 Review findings

Prompting was the most common single component strategy across the 25 included reviews. Of the 12 reviews that evaluated prompting as a strategy, five (42%) reported positive/promising effects on the outcomes measured, while seven (58%) reported mixed/unclear effects. As a single component strategy, pricing was most successful with the greatest proportion of reviews reporting positive or promising effects on outcomes ($n = 8$ of 11 reviews, 73%). A total of 14 reviews reported combined strategies, half of which reported positive/promising effects. Pricing plus another strategy was common among the reported multi-component strategies. A summary of the review findings by strategy type are illustrated in Figure 3.

3.1.4 Quality assessment of primary articles included in reviews

Three of the 25 high-quality reviews (12%) did not appraise the quality/bias of the primary articles the included in their review (27, 65, 66). The appraisal tools used to assess primary articles varied among the remaining 22 high-quality reviews, but two common tools were the Cochrane Collaboration Risk of Bias tool or an adapted version (13, 14, 28, 45, 54, 59, 67, 68) ($n = 8$ of 22, 36%), and the Effective Public Health Practice Project Quality Assessment Tool for Quantitative Studies ($n = 5$ of 22, 23%) (19, 51, 53, 55, 58) (Appendix F).

3.2 Part II—review of primary research articles

The scope and objectives of the review articles varied, and as a result the intervention types and settings of the primary studies within the reviews also varied greatly. Given this heterogeneity, it was difficult to conduct a quantitative synthesis from the reviews on strategies, and their effectiveness when implemented in supermarkets or grocery stores. Therefore, to achieve this level of granularity, high-quality primary studies conducted in supermarkets or grocery stores were identified from the 25 high-quality review articles.

Five high-quality reviews were excluded from further inspection because they did not include a quality assessment of the primary research ($n = 3$) (27, 65, 66); did not report the results of their quality appraisal of primary research articles in text (and did provide the requested material when contacted; $n = 1$) (28); or presented aggregated results, so the quality of individual articles could not be evaluated ($n = 1$) (56). Finally, primary research articles from 20 high-quality reviews were sourced and screened (Figure 4).

Seven-hundred and seventy-one primary research articles were reported across the 20 reviews. After removal of duplicates ($n = 148$), articles conducted in the wrong setting/population type/reporting the wrong outcomes ($n = 471$) and articles of low-quality ($n = 72$), moderate-quality ($n = 51$) or an unclear risk of bias ($n = 6$) were excluded, resulting in the inclusion of 23 primary research articles (studies) that implemented an in-store intervention designed to improve the healthiness of consumer purchasing or consumption (Figure 4).

3.2.1 Study characteristics

Characteristics of the 23 primary studies included are presented in Appendix G. The studies were published between 1974 and 2022; about two thirds ($n = 15$ of 23, 65%) were published in or after 2000. Most ($n = 14$, 61%) were conducted in North America (69–82), six in the Pacific region (83–88), and three in Europe (89–91).

The number of stores included in primary studies ranged from one to 372. Most studies ($n = 21$ of 23, 91%) were conducted in physical ('brick and mortar') supermarket or grocery stores, and two studies used online supermarkets as the setting for their intervention. Regular shoppers (that is, no specific subgroup) were the target population for most studies ($n = 16$, 70%), five studies targeted low-income or food insecure individuals or communities, and two studies targeted minority groups including individuals living in regional or rural areas.

There were 46 initiatives (categorised within five broad strategies) tested across the 23 studies (Figure 5). About half of the studies ($n = 12$, 52%) tested a single strategy, and the remaining studies ($n = 11$, 48%) tested multiple single strategies, or a combination of strategies (Appendix G). In-store promotion was the most frequently assessed intervention strategy ($n = 13$ of 23, 56%). Common promotion strategies included providing education to customers about the health benefits of selected products, offering samples of products and giving food demonstrations. Use of prompting was assessed in nine studies (39%), most commonly through in-store signage such as shelf labels and banners to identify healthier products. Pricing strategies were assessed in eight studies (35%), which included at the point of sale, via redeemable coupons or price reductions on target products, or after purchase via rebates. Use of proximity was assessed in three studies, and healthy default picks in two studies. No studies assessed place strategies, and, by design (i.e., per study eligibility criteria), no studies used profile, or portioning strategies. The duration of the interventions ranged between 2 h and 2 years. Just over a third of the studies ($n = 9$ of 23, 39%) included a follow-up period to ascertain the extent to which intervention effects were maintained after the intervention ended.

Customer purchasing behaviour was measured using either sales data, customer receipts, customer surveys, researcher observation, or a combination of these. Sales data were presented as total sales, sales/market share of target products, or expressed as healthiness of food purchases, such as energy density of foods purchased. In addition to consumer purchasing behaviour, four studies reported consumption of target products (via consumption questionnaires), and one study

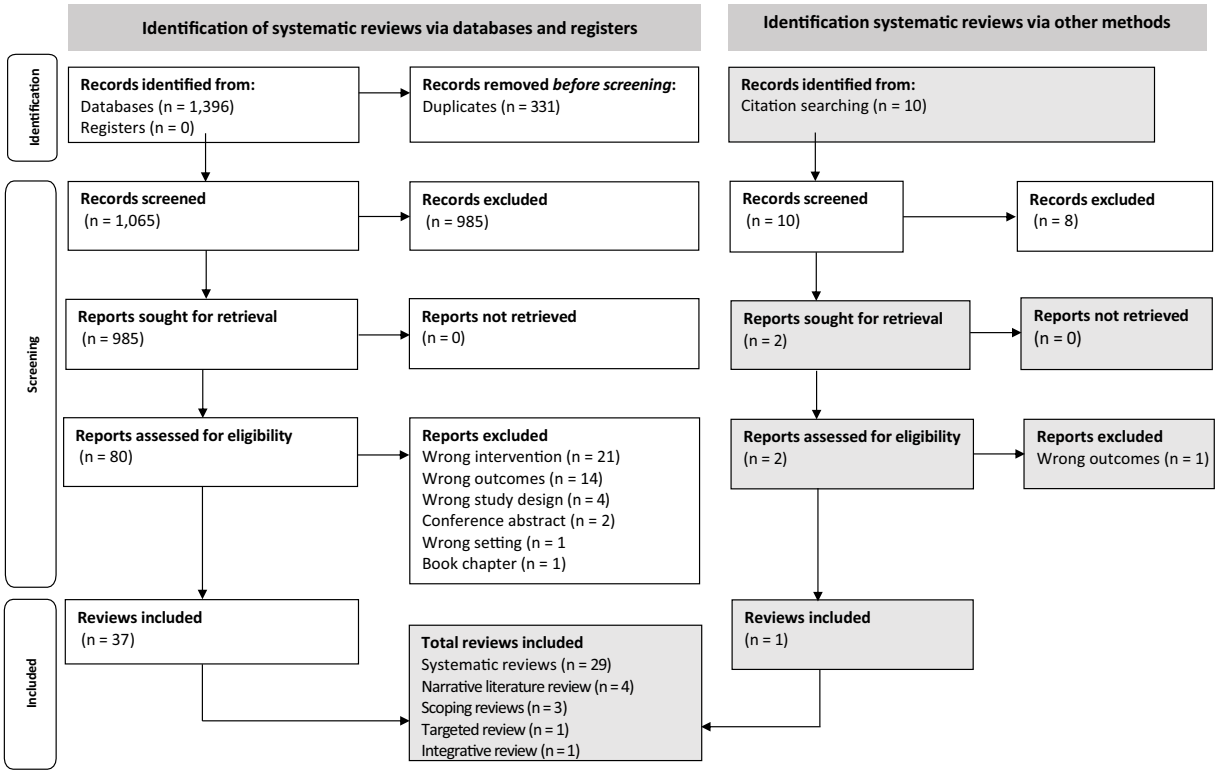

FIGURE 2
Preferred reporting items for overviews of reviews (PRIOR) flowchart for study selection.

used a survey to collect information on skills and behaviours, such as food preparation practices and reading food labels.

3.2.2 Study findings

Results from the primary studies are presented in Appendix H. All studies aimed to improve the healthiness of consumers' purchases, and characterised products as healthy or unhealthy/less healthy. There is no consensus on the definitions of the terms healthy foods and unhealthy foods (92). In this review, the categorisation of foods and beverages into 'healthy' and 'unhealthy/less healthy' was taken from the description in the primary studies. In most studies ($n = 21$ of 23, 91%), the goal was to increase sales of healthy products, most commonly fruit and vegetables, or products with a higher nutritional ranking. Some of these studies ($n = 6$ of 21, 29%) also examined the effect on the sales of unhealthy/less healthy products (70, 71, 74, 84, 85, 87). Only two studies (9%) stated an intent to reduce sales of unhealthy/less healthy products (86, 90).

The effectiveness of intervention strategies on changing consumer purchasing of healthy and unhealthy products is summarised in Figure 6A. Studies considered as having 'mixed' findings were due to differences in the effectiveness of the intervention reported against multiple outcomes. For example, a significant effect may have been reported for purchase of fruit, but not vegetables. To aid interpretation, these mixed studies were separated into 'more' or 'less' promising, with the former representing cases where half or more of the categories assessed showed promise, or effects were not maintained over a longer period and vice versa for the latter (i.e., less promising). Given the purpose of the current synthesis was to inform strategies for targeting food purchasing among the general population, those studies that focussed on specific groups (low SES or regional) were separated from the synthesis of results and discussed independently.

3.2.3 Characteristics of intervention strategies for decreasing purchasing of less healthy foods among the general population

Only three out of 10 initiatives (30%) were effective in decreasing sales of less healthy foods among the general population (Figure 6B). Two of these effective initiatives achieved their intended aim of decreasing sales of less healthy foods (86, 90), and the other decreased sales of less healthy foods as a consequence of the intervention aimed at promoting sales of healthier products. That is, 100% of studies ($n = 2$) that purposely aimed to reduce sales of unhealthy/less healthy products were effective.

Huang et al. (86) used *healthy default picks* to reduce sales of commonly purchased foods higher in saturated fat, particularly higher-fat dairy products, in an online supermarket setting. Customers were recommended different like-for-like product 'swaps', which were lower in saturated fat than the product they selected and were given the option to either retain the chosen product, or swap to the alternative. The amount of saturated fat (per cent of food) purchased by consumers in the intervention group decreased and lower-fat dairy products were the most common items 'swapped'.

Proximity when applied at the checkout, that is, having "healthy checkouts" whereby unhealthy items such as sweets and chocolate were replaced with healthier options such as dried fruit, nuts, juices,

TABLE 3 Characteristics of high-quality reviews included in the overview of reviews.

Reference (author, year)	Review type	Review eligibility criteria			Search strategy		No. of included primary studies
		Research design	Population and setting	Intervention strategy	No. of databases	Search period	
Adam & Jensen, 2016 (14)^	Systematic review	Intervention studies	Population: NR Setting: Physical retail food stores (grocery stores, supermarkets, and convenience stores)	Affordability (price), information and access/availability	3	2003 to 2015 (inclusive)	42
Afshin et al., 2017 (50)^	Systematic review + meta-analysis	RCTs and non-RCTs; prospective observational	Population: Adults and children Setting: Supermarkets, restaurants, schools, workplace, fast food, cafeterias	Change in the price of foods or beverages (i.e., taxation, subsides, or other factors)	7	NR (1992 to 2014)[§]	30
Alston et al., 2020 (51)^	Systematic review	NR	Population: NR Setting: Food retail environment in a rural, non-urban, remote, regional, or non-metropolitan area in any country	Food retail environment initiatives	3	1 Jan 2000 to 31 May 2020	21
Blake et al., 2019 (52)^	Systematic scoping review	NR	Population: NR Setting: Grocery and convenience stores, supermarkets, fresh food markets, bakeries, and specialty food stores; Restaurants and Other Eating Places including cafeterias and cafes; vending machine merchandisers, sale of products related to food and beverages	4Ps (product, place, price, promotion) or any combination of these	8 + grey literature searched	Jan 1997 to Jul 2017	107
Cameron et al., 2016 (53)^	Systematic review	Intervention studies (investigator led or natural experiment)	Population: NR Setting: Supermarkets, grocery stores and online stores	Changed the in-store environment to influence consumer nutrition/diet (i.e., product, promotion, or place)	5 + grey literature searched	No date limits	50
Crockett et al., 2018 (54)^	Systematic review (Cochrane)	RCTs, Q-RCTs, cluster-randomised studies, ITS and CBA	Population: Adults or children Setting: Any retail outlet (grocery stores, food stores, vending machines, cafeterias, and both fast and non-fast-food restaurants); real-world or laboratory	Nutritional labelling of a food or non-alcoholic drink product	13 + grey literature searched	Database inception to 26 Apr 2017.	28
Fergus et al., 2021 (55)^	Systematic review	NR	Population: NR Setting: Rural and urban low-income retail food stores	Retail nutrition intervention besides interventions offering solely financial incentives	5 + grey literature searched	Oct 2010 to Oct 2019	46
Gittelsohn et al., 2017 (56)^	Systematic review	Experimental studies (RCTs, quasi-experimental, natural experiments)	Population & setting: Population studies of people or stores in middle-income and high-income countries (real-world)	Pricing incentive and disincentive strategies (alone or combined with health behaviour interventions or as part of multi-level strategies)	6	Jan 2000 to Dec 2016	30
Golding et al., 2022 (57)^	Systematic review	RCTs and non-RCTs	Population: In-store shoppers Setting: Physical supermarkets	Any intervention aimed at influencing shoppers' food and non-alcoholic drink purchasing behaviour	11	Database inception to Jan/Feb 2017	46

(Continued)

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TABLE 3 (Continued)

Reference (author, year)	Review type	Review eligibility criteria			Search strategy		No. of included primary studies
		Research design	Population and setting	Intervention strategy	No. of databases	Search period	
Harbers et al., 2020 (58)^	Systematic review	NR	Population: Adults Setting: Real-life food purchasing environments where food or meal purchases can be made on a regular basis	Nudging (i.e., availability, position, functionality, presentation, size, information)	3	Database inception to 31 Jan 2018	75
Hartmann-Boyce et al., 2018 (59)^	Systematic review	RCTs	Population: No restrictions Setting: Physical, online, or simulated grocery store	Interventions designed to change the purchase of any foods, non-alcoholic drinks, nutrients, energy, or products belonging to a defined dietary pattern or with defined dietary scores	13	NR (Search performed 2 Jun 2017)	35
Hodges et al., 2023 (60)^	Systematic review	Intervention, observational or qualitative studies	Population: Consumers Setting: Online grocery shopping platform (real-world or laboratory)	Retail marketing strategies (product suggestions, promotions, price etc.)	6 + grey literature searched	1 Jan 2015 to May/Jun 2022	18
Hollands et al., 2019 (46)^	Systematic review (Cochrane)	RCTs or cluster-RCTs with between-participants (parallel group) or within-participants (cross-over) designs	Population: Adults and children Setting: Restaurants, workplaces, schools, homes, bars, pubs, supermarkets, or shops (real-world or laboratory)	Availability and proximity interventions	8 + grey literature searched	Inception Database inception to 23 Jul 2018	24
Karpyn et al., 2020 (28)^	Systematic review	Intervention, pilot, or experimental studies	Population: Customers Setting: Food retail environment (i.e., supermarket, grocery store, corner store, bodega, retail environment)	4Ps (product, place, price, promotion); either single or multi-component interventions	9	2010 to 2019	64
Liberato et al., 2014 (19)^	Systematic review	RCTs, CBA studies or ITS designs and analyses.	Population: General population and/or organisations Setting: Supermarket, grocery store and/or vending machine	Nutrition interventions at the point-of-sale aiming to (i) impact availability, affordability and/or ability to choose healthier foods and drinks, (ii) to influence food and drink purchases (including, infrastructure or monetary incentives as well as marketing strategies including promotion and placement strategies), or (iii) any combination of these	3	No date limits	32
Mah et al., 2019 (27)^	Systematic review	Quantitative, qualitative, or mixed methods	Population: General population Setting: Real-world grocery stores, supermarkets, convenience stores, and gas stations	Altering the availability or mix of retailers in a geographic area (community food environment) or the 4Ps (product, pricing, placement, or promotion) in-store	3	Database inception to Nov 2018	86

(Continued)

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TABLE 3 (Continued)

Reference (author, year)	Review type	Review eligibility criteria			Search strategy		No. of included primary studies
		Research design	Population and setting	Intervention strategy	No. of databases	Search period	
Nikniaz et al., 2020 (61)^	Systematic review	RCTs or quasi-experimental studies	Population: All population groups Setting: NR	Community-based interventions aimed at increasing dairy/calcium consumption	6 + grey literature searched	2000 to 2019	25
Nikolaus et al., 2016 (62)^	Systematic review	No restrictions	Population: No restrictions Setting: Grocery stores, supermarkets	Supermarket/grocery store tours	2	Jan 1984 to Apr 2015	8
Shangguan et al., 2019 (63)^	Systematic review + meta-analysis	RCTs and non-RCTs	Population: NR Setting: Restaurants, supermarkets, grocery stores, cafeterias, food retail/self-service establishments, and vending machines	Food labelling	10	Database inception to 28 Feb 2014	60
Shaw et al., 2020 (64)^	Systematic review	Intervention and observational studies	Population: Individuals >18 years Setting: Supermarkets, convenience stores	Positioning or availability of food/beverage items	9	Jan 2005 to Feb 2019	38
Slapø et al., 2021 (13)^	Systematic review + meta-analysis	RCTs, CBA or ITS	Population: No restrictions Setting: Grocery stores (real physical or real online)	Choice architecture interventions (portioning, place, proximity, promotion, healthy default picks, pricing, prompting, profile)	6	NR (Search performed on 24 Apr 2020)	36
Valencic et al., 2022 (65)^	Scoping review	NR	Population: Adults Setting: Online grocery stores or supermarkets	Interventions using a digital nudging approach (manipulated the user-interface)	8	Database inception to Feb 2022	15
Volkova et al. 2015 (66)*	Narrative literature review	Experimental and real-life designs	Population: NR Setting: Retail settings	Nutrition labels and point-of-purchase information	NR	2011 to 2014	30
von Philipsborn et al., 2019 (67)^	Systematic review (Cochrane)	RCTs, non-RCTs, CBA, RMS, or ITS	Population: Any (adults, adolescents, or children) Setting: Real-world settings	Environmental interventions (i.e., labelling, nutrition standards, economic tools, advertisement regulation, whole food supply, retail and food service, action across sectors)	11 + grey literature searched	Database inception to 24 Jan 2018	58
Wyse et al., 2021 (68)^	Systematic review + meta-analysis	RCTs, cluster-RCTs, stepped-wedge RCTs, factorial RCTs, multiple baseline RCTs, randomised controlled crossover trials, quasi-randomised controlled trials, or CCTs	Population: Generally healthy participants Setting: Online supermarkets and grocery stores, online restaurants, cafes, and canteens; and online food and meal delivery services	Dietary interventions delivered via online food ordering systems	8 + grey literature searched	Database inception to 1 Oct 2020	11

^indicates study quality was assessed using the ROBIS tool; *indicates study quality was assessed using the SANRA tool; (44); $extrapolated from results. CBA, controlled before and after; CCT, clinical controlled trial; ITS, interrupted time series; NR, not reported; Q-RCT, quasi-randomised controlled trial; RCT, randomised controlled trial; RMS, repeated measures studies.

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and water was effective in reducing sales of less healthy foods (90). More explicit strategies such as promotion, pricing and prompting seemed to either be ineffective ($n = 5$ initiatives, 50%) or had negative effects (increase in sales of these products; $n = 2$ initiatives, 20%). There was, however, one exception based on a simple labelling system (71) that decreased sales of less healthy options, but was not effective at increasing sale of nutritious food, following implementation of a nutrition rating system on store shelves rating products with no-, one-, two-, or three-stars (Guiding Stars). In contrast, the labelling system that had a negative effect (increased sales of less healthy products) on sales was also the most complicated (70).

3.2.4 Characteristics of intervention strategies for increasing healthy foods among the general population

Four out of 22 initiatives (18%) were effective in increasing sales of healthy foods among the general population, 13 (59%) were promising ($n = 10$ more promising, $n = 3$ less promising), four (18%) were ineffective and one (5%) reported negative effects (decreased sales of healthy products; Figure 6B). Promotion was the most common strategy assessed, followed by prompting, then pricing.

Supermarket nutrition education tours were the most effective *promotional* initiative in changing sales of healthy products (82). Following a 2-h dietitian-led supermarket tour where participants received advice about how to make sound nutrition choices (aimed at increasing intake of fibre and decreasing intakes of fat and salt,) participants reported that they purchased more healthier food options. However, overall, promotion alone appeared to have no or less promising effects. Three of the five (60%) *promotional* initiatives to improve consumer purchasing were ineffective (84, 87) or less promising (73). All studies included an educational component to support purchase of healthier products.

The combination of promotion with other strategies (*'promotion plus'*) appeared to be the most favourable of the strategies considered, with five out of six studies (83%) using this approach either showing promise (78, 81, 84) or being effective (75, 87) at changing purchase of healthy items. Of these, three used a combination of *promotion and price*—with a price discount of between 10 and 50% (78, 84, 87), and two used *promotion and prompting* (75, 81). The promotional component of the interventions was similar, offering education to consumers about the nutritional content of foods via supermarket tours or provision of educational materials in the form of brochures and newsletters.

Prompting initiatives included the use of shelf-labels to support consumers to identify 'better' food choices across a range of products. Two of the five studies that used *prompting* as their intervention strategy were considered effective (77) or promising (76). One study reported an increase in purchase of healthier products across all eight categories of products tested, following the implementation of a nutrition scoring shelf-label system (NuVal) at the point-of-sale (77). Mixed findings were reported in a study that included a range of different products, whereby sales of some healthy products increased, or sales of less healthy products decreased, but others did not change (76). Prompting also resulted in two negative outcomes in the same study (70), namely a decrease in the sales of an item (popcorn) overall, but coupled with an increase in sales of the less healthy version of this same item. In other studies, there was no effect on the sale of fresh fruit and vegetables (69) or nutritious foods across a range of categories (71). Overall, prompting did not appear to be an effective strategy in the majority of studies conducted to date.

Curhan and colleagues (72) reported the effectiveness of two different *proximity* initiatives on increasing the sales of selected fruits and vegetables. 'Bonus' display space, that is, space allocation of at least 200% of the space usually allocated to products, increased the sales for all categories of fruits and vegetables (i.e., was effective). However, 'location quality', that is, high-traffic positions, increased the sales of some categories of fruits and vegetables (hard fruit and cooking vegetables), but not others (soft fruit or salad vegetables; i.e., was promising).

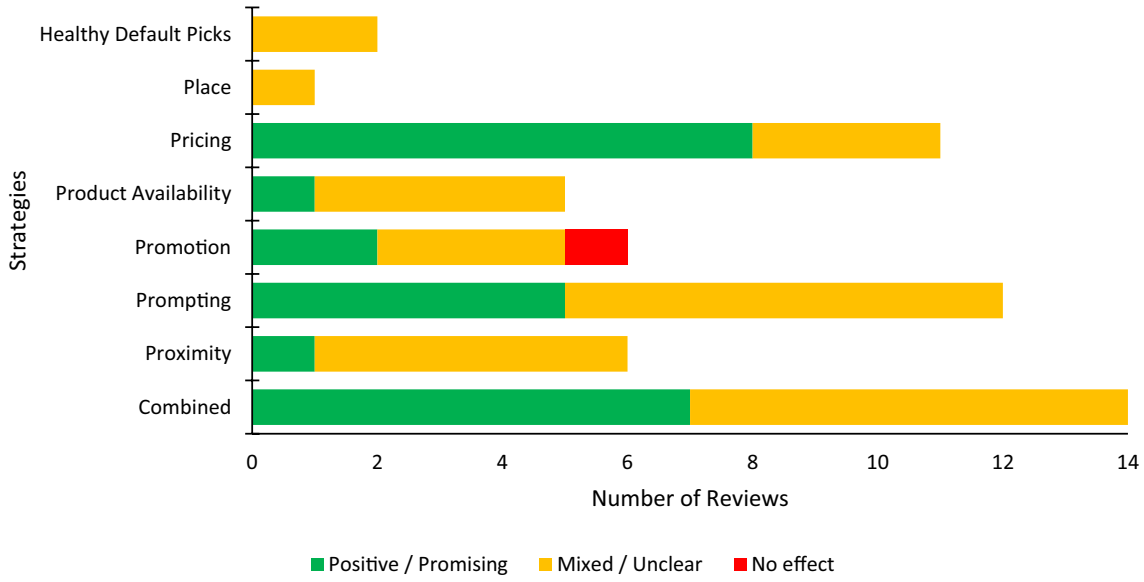

FIGURE 3
Summary of the findings of the included reviews investigating the effectiveness of changing consumer purchases by strategy type.

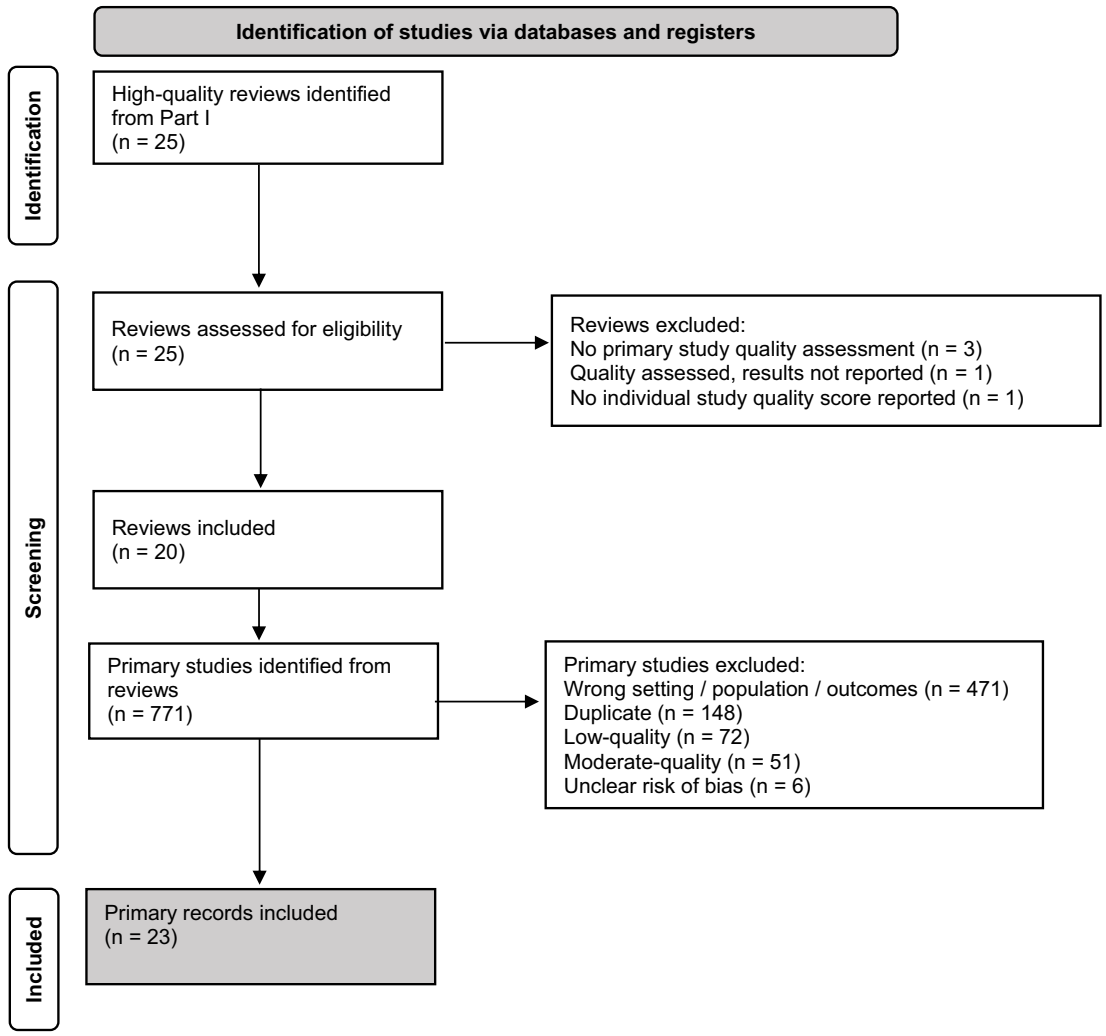

FIGURE 4
Preferred reporting items for systematic reviews (PRISMA) flow diagram for study selection.

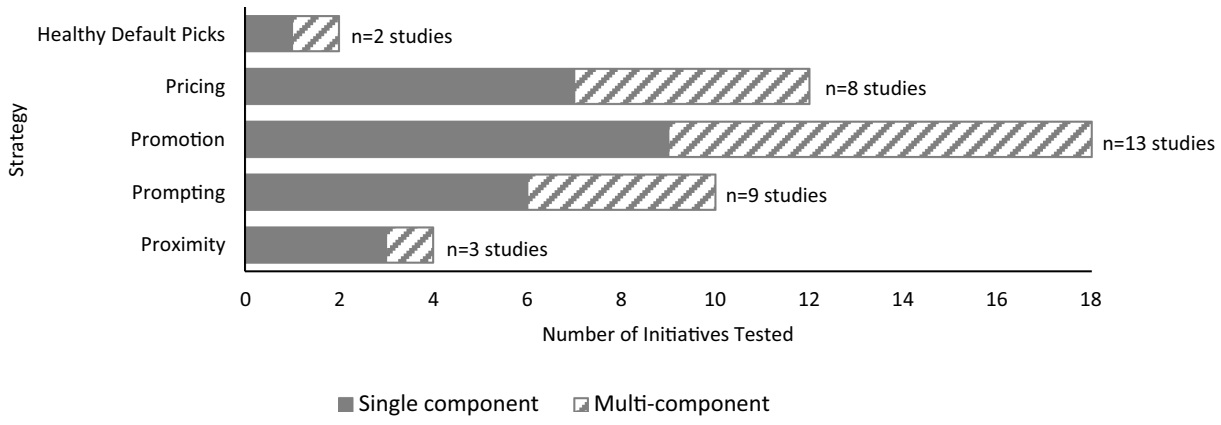

FIGURE 5
Distribution of strategies tested across the 23 primary studies. Studies may have included multiple intervention arms, therefore the number of initiatives presented in the graph may exceed the total number of primary studies included in the review.

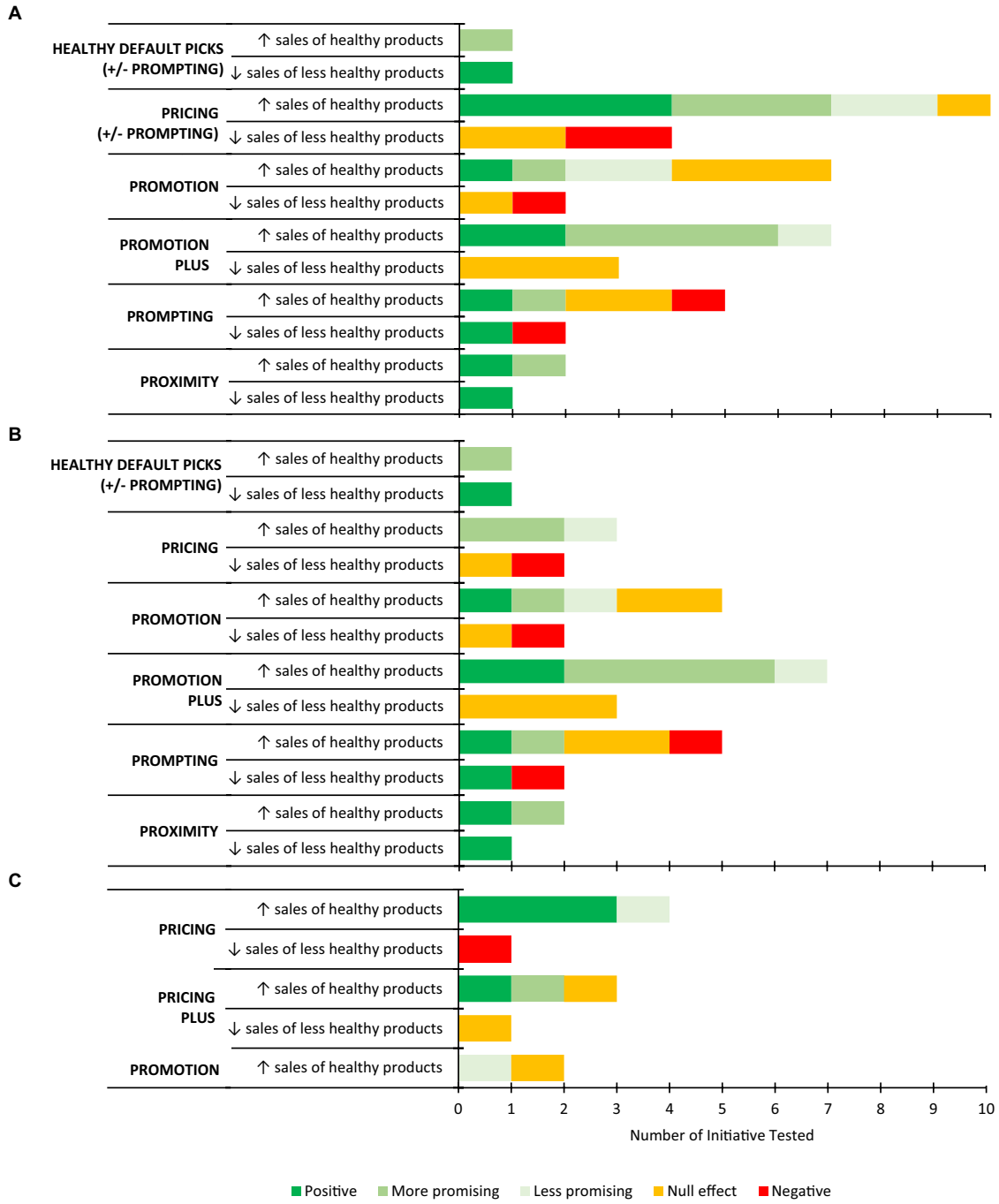

FIGURE 6
Summary of the effectiveness of primary studies included in the review at increasing the sales of healthy food products or decreasing the sales of less healthy food products, by strategy type among **(A)** the whole sample; **(B)** the general population; and **(C)** low SES or regional sub-groups. *Note:* Studies may have included multiple intervention arms with different initiatives or strategies/combinations of strategies, therefore the number of initiatives presented may exceed the total number of primary studies included in the review.

Another study in an online supermarket used *promotion and healthy default picks* centred around promoting images of healthier 'like-for-like' products on selected webpages (in-aisle banners and recipe bundles) (89). There was an increase in purchase of some healthier products, but not others.

Pricing had largely mixed effects across the three studies (72, 84, 87). Pricing initiatives reported improvements in selected discounted foods, but not others; however the food products and their effectiveness was inconsistent across studies.

3.2.5 Characteristics of intervention strategies among low SES or regional subgroups

The effectiveness of intervention strategies on changing consumer purchasing of healthy and unhealthy products for

population sub-groups are summarised in Figure 6C. Among low SES or regional sub-groups, *pricing* strategies were most assessed (4 out of 7 studies, 57%). Three studies reported effective *pricing* strategies and used discounts between 20 and 50% on selected food and drinks. Brimblecombe and colleagues (85) reported sales of healthy, and less healthy food and drinks, following a 24-week intervention which offered customers a 20% price reduction. The other two studies offered a 50% price reduction on fruit and vegetables at the point of sale via coupons (79) or after purchase, via rebates (91). Discounting had a negative effect on reducing less healthy foods, increasing purchases of sugar sweetened beverages (85). One study used three groups to compare pricing, promotion and the combination of both strategies in a group of low SES shoppers in the Netherlands (91). This study reported positive effects for price and price combined with promotion, but not promotion alone, which reported some, albeit less promising, changes in purchasing. Prompting was only considered in combination with promotion in this group of consumers from rural communities, with minimal effects on purchasing behaviour (80).

4 Discussion

Supermarkets have unprecedented and disproportionate power in the food system, influencing population diets through the products they have for sale, their price, store layouts and other marketing activities (93). In view of this, the World Health Organization advises governments worldwide to "develop policy measures that engage food retailers and caterers to improve the availability, affordability, and acceptability of healthier food products" (94). This review examined the effectiveness of strategies used in supermarket interventions to understand which strategies have shown promise in improving the healthfulness of consumer purchasing. Overall, the body of evidence reviewed shows that implementation of health promoting supermarket interventions are more likely to be successful if they include a substantial pricing initiative (particularly for some population sub-groups), or the inclusion of promotion in combination with another strategy.

Retailers need to consider their 'bottom-line' during implementation of any new initiative (95). Therefore, focusing on strategies to increase consumer purchasing would be more likely to be accepted and implemented by retailers. There were more interventions aimed at increasing sales (of healthy products) compared to decreasing sales (of less healthy products) in this review. There was also a higher success rate of interventions that aimed to decrease sales of less healthy products (100% were effective) than those that aimed to increase sales of healthy products (18% were effective). However, only two studies intentionally aimed to reduce sales of less healthy products, so there was not enough high-quality evidence to guide strategies to decrease purchase of less healthy food. The relative success or failure of initiatives may also be related to the type of product(s) selected as targets for intervention. In fact, retailers have previously identified lack of perceived consumer demand for healthy food, and a fear of profit loss as challenges (47). Findings from this review do not indicate a particular healthier food category was more successful than others. Some studies reported increased fruit but not vegetables, others increase in certain types of vegetable but not others, some increased low-fat dairy and others increased healthier tinned goods. Therefore, thought needs to be given not only to the strategies but also to the foods and beverages targeted.

Promotion was a popular strategy amongst papers reviewed, perhaps because of its relative influence in shaping consumer decisions in retail stores (96). Findings from this review highlight that, when used alone, the evidence for promotional initiatives is mixed. In contrast, when promotional initiatives are used in combination with another strategy, they produced favourable effects. Most promotional initiatives used in these studies focused on educating consumers about their food choices via provision of materials in the form of brochures and newsletters, or in-store demonstrations including taste-tests and supermarket tours. Nutrition education and knowledge has been shown to influence consumers ability to identify healthy foods (97), but this does not necessarily alter intentions or behaviour (98). In fact, findings from an umbrella review of food choice and nutrition support the findings of this review, suggesting that combining strategies appears to be the most effective way to achieve healthier food choices (98). It was not possible to determine which combination with promotion was most effective, mainly due to the small number of studies. Promotion and price were used together in three studies and promotion and prompting in two studies, and in both combinations one study reported positive outcomes.

Of the strategies evaluated here, pricing, whether combined with another strategy or tested on its own, appeared to be the most promising strategy at increasing sales of healthy products. The relative success of a pricing initiative does not appear to be strongly influenced by the magnitude of the discount. Discounts applied in successful pricing initiatives ranged between 20 and 50%, and 10 to 50% for unsuccessful initiatives. This is in contrast to economic research that suggests that consumers do not change their intentions to buy unless the promotional discount is above a threshold level (99). Pricing initiatives were more successful among studies that included shoppers in rural or remote areas, or those from low-income households, which is consistent with our understanding that greater affordability/access leads to increased consumption of discounted products, particularly among food insecure groups (100). More research is needed to understand whether all segments of the population benefit from pricing initiatives, the magnitude of the change in price needed to influence consumer purchasing, if there is a saturation point above which, the effect of discounts is minimal, and if such substantial discounts reported in the literature are sustainable for retailers in the long-term.

There was a modest proportion of negative findings (i.e., results going in the opposite direction to that intended) reported among studies reviewed that aimed to increase sales of healthy products (3 out of 6, 50%). Compensatory purchasing can be a problematic side effect of pricing initiatives (101). For example, when discounting healthy food, savings may be used to buy more less healthy products, as observed in two studies in the review (84, 85). Similarly, promoting healthy items next to unhealthy items may also have unintended effects (e.g., water and sugar-sweetened beverages). The implementation of a 'swap' message for popcorn was also associated with an unintended outcome in one of the studies included; while the intervention resulted in less popcorn being sold overall, it was also associated with a shift towards consumption of less healthy popcorn varieties, at the expense of the healthier alternatives (70). These findings highlight the importance considering and evaluating the unintended consequences for retailers, consumers, and the broader community, when implementing new initiatives in a supermarket setting. This includes measuring sales of all products purchased, not just of targeted products, and measuring outcomes beyond sales. Blake and colleagues (52) use a scoping review to summarise the

types of business outcomes used in healthy food and beverage retail strategies, including outcomes that may affect retailers' likelihood of implementing and sustaining a healthy food retail strategy—namely, commercial viability, customer and retailer perspectives, and community outcomes. In general, the selection of business outcomes and measurement tools could be chosen in consultation with the retailer, considering feasibility, and the marginal cost and value of adjusting nutrition data collection methods (e.g., including questions on customer level of satisfaction in a survey focusing on changes in consumption). Consideration of the types of business outcomes that are most relevant to different strategies and settings may allow for more tailored data collection in future studies.

Interventions in supermarkets are often implemented over a short period and/or in a single store, with little attention placed on the long-term sustainability or scalability of the interventions. Less than half of the studies in this review included a follow-up period (range 4 weeks to 104 weeks, average ~ 6 months) to ascertain the extent to which intervention effects were maintained after the intervention ended. Of those that included a follow-up period, about half found that some effects were maintained after removal of the support. For population dietary change that is sustainable in the longer-term, initiatives in supermarkets need to be both feasible for retailers, and acceptable to consumers. In their overview of reviews investigating the factors that influence the implementation, sustainability and scalability of healthy food retail interventions, Gupta and colleagues (47) emphasise the importance of considering how contextual barriers, such as food store structure, low consumer demand and reduced sales or profitability, may be linked to retailers' perceptions, to increase the likelihood of sustained implementation and for potential scale up.

4.1 Strengths and limitations

Strengths of this study include a comprehensive search strategy that was developed (in collaboration with an experienced librarian) and adapted for seven databases to best capture all available evidence. The study also observed PRIOR/PRISMA guidelines with the protocol pre-registered on OSF and deviations disclosed. Screening processes and the risk of bias appraisal were conducted by two reviewers independently. Well-defined study selection criteria and independent coding of the findings make this review process rigorous and robust. Another strength of this study is the inclusion of studies with greater external validity – only those conducted in real-world physical or online supermarket settings and excluded simulation or laboratory studies. Only two studies included were conducted in online supermarkets, so little is known about the effectiveness of initiatives in this emerging food retail setting. The novel approach to identify strong primary studies from strong reviews also meant that a large amount of literature could be assessed without losing detail about what strategies show promise.

Some limitations to this study must also be acknowledged. Firstly, findings from the overview of reviews were restricted to the analyses reported in the included reviews. There was some duplication of primary studies across the reviews, which may have led to some heterogeneity in the findings within the individual reviews, as well as in the overview of reviews (Part I). Secondly, primary studies evaluated in the review (Part II) were identified from the overview of reviews. As such, there may be gaps in the evidence base for some intervention strategies due to study selection, rather than an absence of primary studies. This also means current, primary studies were overlooked because they have not yet been included in reviews. The decision to include only high-quality primary studies meant a higher degree of confidence in study findings, but it could also be considered a limitation. Across the reviews, a range of tools were used by the original review authors to appraise the quality of primary studies, resulting in conflicting quality ratings of studies, potentially due to differences in aspects covered in the tools. These reviews were rated high-quality by the current process, so it was assumed their evaluations of other studies would be also be acceptable. Furthermore, some studies that scored low in the methodological quality may have other strengths not accounted for by the respective scoring systems. Thirdly, publication bias cannot be excluded; ineffective interventions are less likely to be published, and only articles published in English language were included, which may have led to exclusion of relevant reviews and primary studies. Finally, most studies included in this review only measured sales of products, with few studies measuring both sales and consumption. Although sales can be considered a proxy for consumption, it cannot be concluded that increasing sales of selected products led to greater consumption.

5 Conclusion

Food retailers are a key influence of population diets. Stakeholder engagement and use of the right incentives are essential to the success of the interventions and their sustainability longer-term. Therefore, it is critical to optimise the potential and power of supermarket retailers by working with them to make sustainable and scalable changes that help consumers to make purchases that preference healthier foods, without significantly impacting their bottom line. The current study identifies a range of initiatives to improve consumer purchasing behaviour. Owing to the heterogeneous nature of the study exposures, interventions, and outcomes, it is difficult to draw definitive conclusions from the available, published evidence, and few studies included a follow-up period, so even less is known about the longer-term sustainability of these initiatives. Promotional strategies paired with another strategy appear promising for increasing sales of healthy foods. Pricing strategies also have promise, however, the amount price needs to change to influence consumer purchasing and to produce meaningful changes in measures related to public health, and their effectiveness outside of particular sub-groups, should be explored further.

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

PB: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Writing – original draft,

Writing – review & editing. CH: Conceptualization, Data curation, Formal analysis, Methodology, Writing – review & editing. EB: Conceptualization, Formal analysis, Methodology, Writing – review & editing. GH: Conceptualization, Formal analysis, Funding acquisition, Methodology, Writing – review & editing.

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Conflict of interest

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

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1334324/full#supplementary-material

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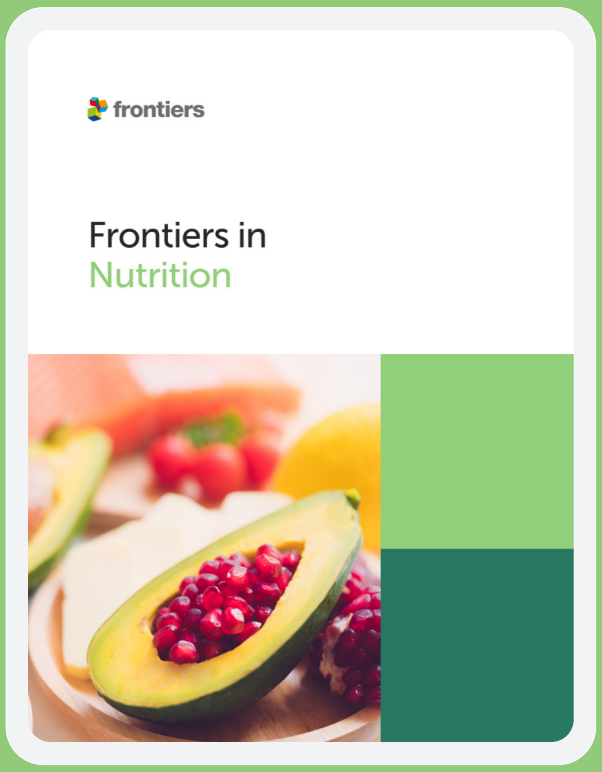

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