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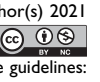
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Vegetables for Healthy Diets in Low- and Middle-Income Countries: A Scoping Review of the Food Systems Literature

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Abstract

Background: Vegetables are an essential element in healthy diets, but intakes are low around the world and there is a lack of systematic knowledge on how to improve diets through food system approaches.
Methods: This scoping review assessed how studies of food systems for healthy diets have addressed the role of vegetables in low- and middle-income countries. We apply the PRISMA guidelines for scoping reviews to narratively map the literature to an accepted food systems framework and identify research gaps.
Results: We found 1383 relevant articles, with increasing numbers over 20 years. Only 6% of articles looked at low-income countries, and 93% looked at single-country contexts. Over half of articles assessed vegetables as a food group, without looking at diversity within the food group. 15% looked at traditional vegetables. Issues of physical access to food were among the least studied food system topics in our review (7% of articles). Only 15% of articles used a comprehensive food system lens across multiple dimensions. There is also a research gap on the impacts of different policy and practice interventions (13% of articles) to enable greater vegetable consumption.
Conclusions: Food system studies necessarily drew on multiple disciplines, methods and metrics to describe, analyze, and diagnose parts of the system. More work is needed across disciplines, across

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contexts, and across the food system, including understanding interventions and trade-offs, and impacts and change for diets particularly of marginalized population groups. Filling these gaps in knowledge is necessary in order to work toward healthy vegetable-rich diets for everyone everywhere.

Keywords
nutrition, agriculture, nutrition-sensitive agriculture, bibliometric, consumption

Introduction

Vegetables are an essential and irreplaceable part of healthy diets. Low vegetable consumption is associated with poorer health, and diets low in vegetables are associated with 1.5 million deaths globally per year through cardiovascular diseases alone, with impacts felt particularly in low- and middle-income countries (LMICs).[1] The World Health Organisation (WHO) has for two decades recommended that people eat at least 400 g of fruit and vegetables per day,[2] and global guidelines have generally recommended five portions of fruit and vegetables a day, of which three should be vegetables.[3,4] More recently, specific recommendations for daily vegetable intake have emerged with a mean vegetable intake of 300 g a day recommended for balancing human and planetary health[5] and 360 g to reduce the global burden of disease.[1] Despite their importance in diets, most people around the world consume far fewer vegetables than recommended, and particularly in low-income countries: average global intake is estimated at around 190 g per person per day, and subregional averages are less than 50 g/day in Micronesia, Polynesia, and Eastern Africa.[4,6,7]

Global vegetable production is insufficient to meet the WHO dietary recommendations, and food loss and waste means much of what is produced is not consumed.[8] Where vegetables are available, they are unaffordable for many, with three billion people unable to afford healthy diets.[9] Fruits and vegetables, along with animal-source foods, are the most expensive element of a healthy diet by many metrics[10,11] comprising around 40% of the cost of a healthy diet.[9] Even if vegetables are available and affordable, most people still do not consume large enough quantities,[12] particularly if they are not considered as an acceptable or desirable food choice, for instance due to food safety or contamination concerns, taste preferences, or cultural appropriateness.[13-15]

The place of vegetables in diets is therefore determined by multiple factors across different food systems, and there is a recognized need to understand how food systems can make vegetables in particular more available, accessible, and desirable for healthy diets in LMICs. This research is important to identify entry points to inform intervention and policy decisions, particularly as there is increased international dialogue and commitment to healthy diets including through the Second International Conference on Nutrition (ICN2), UN Food Systems Summit, and the UN International Year of Fruits and Vegetables in 2021.

Methods

This study is a scoping literature review[16] of research addressing vegetable food systems for healthy diets, focusing on LMICs. We map the research focus and the methods and locations of the totality of this literature, and illustrate research and evidence gaps for future work to fill, applying the PRISMA guidelines extension for scoping reviews[17] with the following exclusions of nonessential aspects: (1) A protocol registration was not undertaken for this review because the approach of the scoping review was designed to be reflexive, drawing on the diversity of experience and methodological competence in the review and advisory team and shaping the search and screening strategy in an iterative manner over the course of the review as new concepts came to light. (2) Critical appraisal within or among evidence sources was not undertaken because we aimed to identify the scope but not the quality

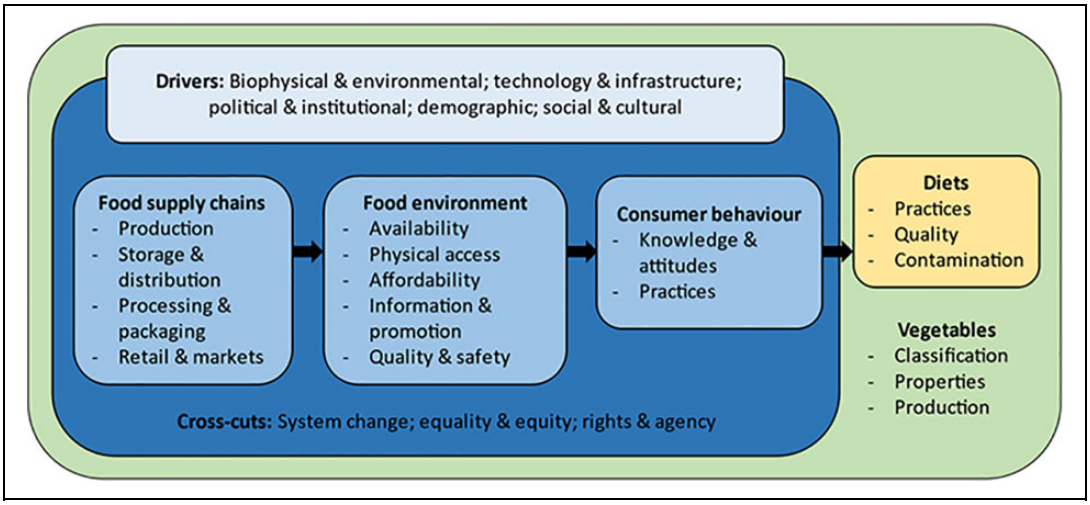

Figure 1. Study framework. Source: Adapted by the authors from HLPE 2017, 2020.[18,21]

of available research on the broad topic across a range of disciplines whose quality criteria differ. See Annex 1 for the PRISMA checklist.

Conceptual Framework

There are several theoretical conceptualizations of different dimensions of the food system, but the most complete framework that has gained most traction for work in LMICs is the UN Committee on Food Security High Level Panel of Experts (HLPE) food systems framework.[18] It describes the "core" food system from food supply chains through food environments and consumer choice; a range of food system drivers, from the biophysical and technological to the political, economic, social, and demographic; and food system outcomes such as diets, livelihoods, and the environment.

Building on this framework, we added additional elements important to our review. These are (1) overlaying cross-cutting aspects onto the framework, including system change and transformation,[19] equality and equity in the system,[20] and issues of rights and agency that were the subject of a newer iteration of the framework.[21] (2) Expanding the construct of "diets" to include dietary practices, diet quality, and diet contamination. We have been careful not to settle on a single definition of "diet" or "healthy diet" given the range of evidence types and disciplines included in the review; rather we allow the reviewed papers to use their own definitions, and we use these to classify whether papers wrote about the topic of healthy diets on their own terms. (3) Focusing on the topic of vegetables, to understand how these have been classified in research (ie, as a general category, combined with fruits, or as specific vegetables); their relevant properties (ie, provision of nutrients, diversity, or health protection); and their associated production and processing systems. As with diets, we have been careful not to define "vegetables" ourselves, or to offer a description of difference from fruits, as in practice different botanical, cultural, and other definitions can be used; as we included a range of papers focusing on different sociocultural contexts and from different disciplines, we chose to let the included papers define whether they were studying fruits, vegetables, or both. The review (search terms, inclusion criteria, mapping, and assessment of gaps) was based on this adapted framework (Figure 1).

Search Process

In this review, we searched for peer-reviewed articles in MEDLINE, SCOPUS, and Web of Science, as databases indexing research across the biomedical sciences, applied life sciences, and

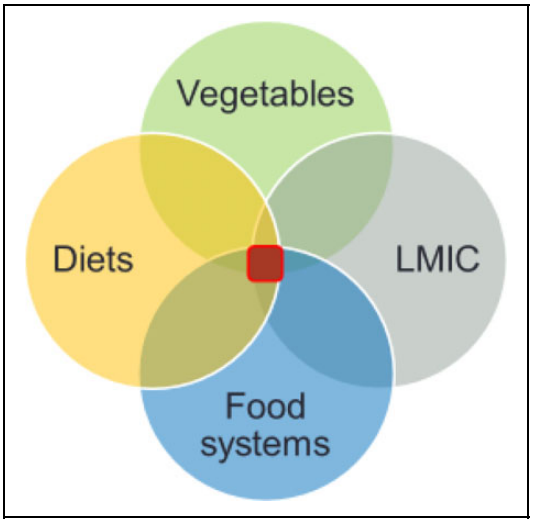

Figure 2. Venn diagram of review focus.

social and political sciences. The databases were searched on April 17, 2020. The searches were carried out on titles, abstracts, and keywords, on the assumption that information core to the study would be captured here. Search terms used were adapted according to subject heading and syntax requirements of each database (see Annex 2 for the search term design). For SCOPUS and Web of Science, further selection filters were placed according to topic classification of the citations by the databases.

Searches were designed to capture articles explicitly incorporating vegetables (we allowed papers to define this for themselves, as plant foods understood through a broad combination of nutritional, botanical, and cultural understandings of what vegetables are); a clear component of a food systems approach (defined in the HLPE framework); and an aspect of diets as a nutrition outcome (defined as foods that are ingested by people, rather than obtained by households; Figure 2). Each of these issues had to be included in the core analysis of the research through the methods applied; it was not sufficient for inclusion if these issues were only mentioned in the rationale for the research or as policy conclusions, because we were looking for direct evidence on food systems.

We searched for articles published from January 2000 to April 2020 to capture work done by the WHO in the early 2000s that informed its 400 g/day fruit and vegetable recommendation. We searched for qualitative and quantitative articles using any research approach, and in any language that was indexed in the databases searched and would be captured with English-language search terms. The review was limited to studies relating to LMICs based on country income classifications in 2020.[22]

Screening and Mapping Process

Records including titles, abstracts, and bibliographic information for all articles identified through the search process were downloaded and exported to a bibliographic database (EndNote version X9) for deduplication and screening. Screening of abstracts for eligibility according to the inclusion and exclusion criteria in Annex 3 was undertaken by one author (WT). To be included, the articles had to contain in their main analysis at least one dimension of food systems according to the conceptual framework, as well as an aspect of diets and of vegetables. Full-texts were downloaded and screened where abstracts required clarification for inclusion. Articles where inclusion remained uncertain were resolved by consensus after discussion between WT and JH.

All articles deemed eligible for inclusion after this initial screening were included in an Excel file for a mapping process undertaken by WT and JH. The conceptual framework in Figure 1 was used to create a classification sheet that contained 7 pieces of core bibliographic and methodological information, 21 dimensions of the food system, 10 aspects of diets, and 8 aspects of vegetables. The descriptions of the mapping criteria are provided in Annex 4. All authors provided expert input to decide the final mapping criteria and their descriptions. To undertake the mapping, the abstract of each article was read in detail, and the information used to complete the classification sheet (one row per article). Relevant aspects of studies were marked on the classification sheet if they were addressed in the article abstract, or left unmarked if not. All eligible articles therefore went through this second layer of screening during the mapping process for

final inclusion in the review, and where this more detailed reading revealed that a study could not be mapped to the classification sheet it was excluded at this stage. The final Excel mapping database and Endnote library of included studies are available as supplementary information for researchers to use in their own studies, on writing to the lead author.

Analysis and Synthesis Process

From the completed mapping database, several approaches were taken to analyze and synthesize findings: We created charts to describe different dimensions of the included articles. These included (a) number of articles published over time; (b) study locations (by income level and geographic region); (c) methodological features of the studies (by study type, approach, and method); (d) dimensions of the food system covered; (e) aspects of diets covered; and (f) characteristics of vegetables covered. From this multidimensional mapping, we looked for patterns in different types of articles. These included (a) whether articles published at different times, in different places, or using different methods looked at different aspects of food systems, diets, or vegetables and (b) whether clear subsets of articles by topic used different methods or were undertaken in different places.

In order to communicate these patterns more clearly, we describe archetypes of how different articles looked at food systems, and at different aspects of diets or characteristics of vegetables. We define the "core" food system as the central parts of the HLPE framework: food supply chains, food environments, and consumer behavior. These may or may not be supported by work looking at established food system drivers, or cross-cutting food system issues. We use combinations of these different food system aspects to create archetypes of food systems research and map them against our outcomes of interest. These archetypes included (a) articles looking only within one dimension of the core food system (supply chains, food environments, or consumer behavior); (b) articles looking across these 3 core dimensions of the food system; (c) articles looking only at the broader drivers or cross-cutting food system issues; and (d) articles looking at cross-cuts or drivers and the core food system. Exemplar articles were then used to illustrate how these archetypes looked at aspects of diets and characteristics of vegetables.

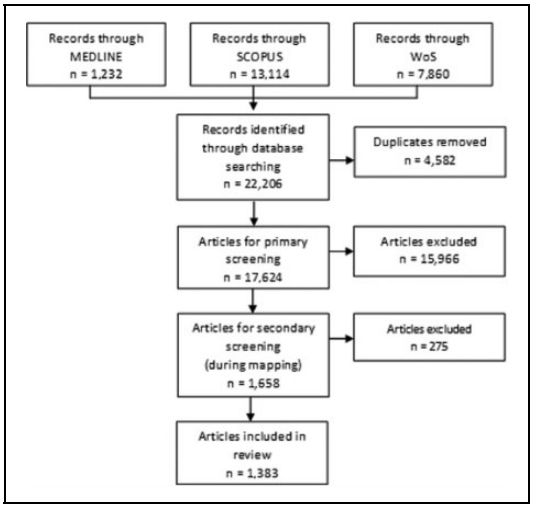

Figure 3. PRISMA flow diagram.

Findings

Search Results

Through searches of the 3 databases, 22 206 potentially relevant records were found, reduced to 17 624 after removing duplicates. A further 15 966 citations did not meet inclusion criteria on initial reading of abstracts and titles, leaving 1658 articles that went forward to the mapping stage. A further 275 studies were excluded at this second reading of the abstract during the mapping (not fitting the classification sheet) for a total of 1383 studies included in the review (Figure 3).

Features of Included Articles

The number of studies that fit our study criteria steadily increased from 8 articles in 2000 to 188 articles in 2019 (83 articles published to April 2020 are not included in this chart as the year was incomplete; Figure 4).

Of the 1383 articles included, a majority collected primary data (90%), used quantitative

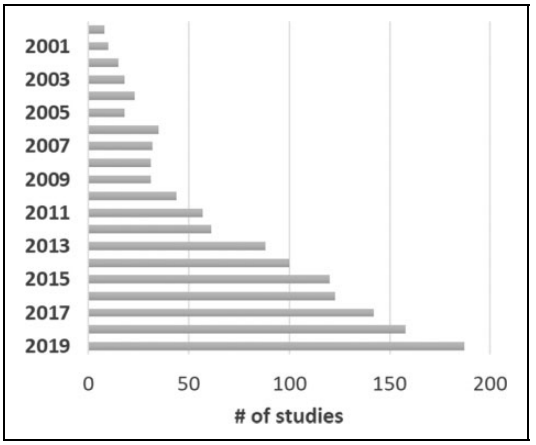

Figure 4. Number of included articles published per year.

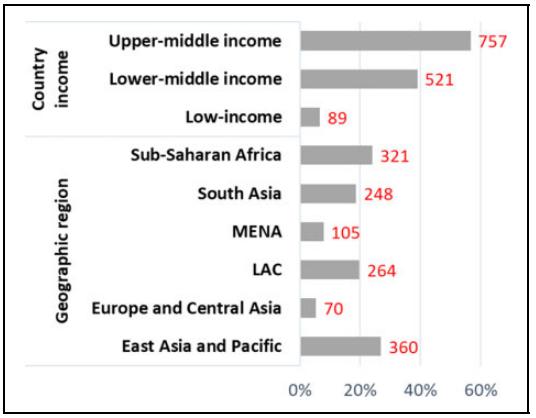

Figure 5. Region and income level of countries studied.

methods (77%), and were observational in nature (85%; Figure 5). Far fewer used qualitative research methods (12%) or mixed-methods (9%), or used secondary data (9%). There were only 24 review articles and 27 conceptual or theoretical articles. Of the included articles, 13% studied interventions. Of these 12% studied interventions in the food environment, 9% in consumer behavior, 6% in food supply chains, and 2% in food system drivers (of which about half looked at political or institutional drivers).

About half of included articles studied upper-middle income country contexts (55%), while 38% studied lower-middle income country contexts, and just 6% studied low-income country

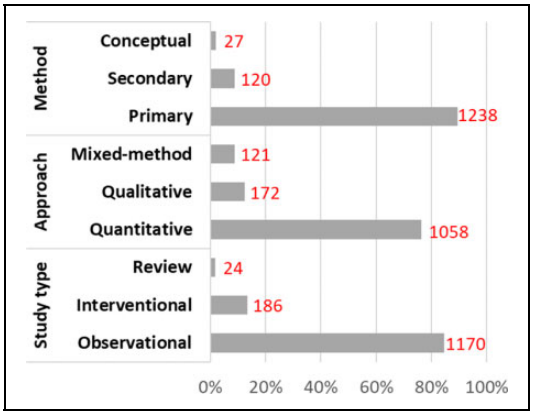

Figure 6. Methods and approaches used in included articles.

contexts (Figure 6). Most articles (93%) were specific to a single country, while 3% looked explicitly across two or more countries, and 1% looked at regional (n = 13) or global (n = 8) levels. Around a quarter of articles (26%) looked at countries in East Asia and the Pacific (n = 360) though only 10 of these were specific to the Pacific region, 23% at sub-Saharan Africa, 20% at Latin America and the Caribbean, and 18% at South Asia. Several articles were not about a particular region or country because they looked across multiple locations or were theoretically based.

There were no clear patterns in the focus of articles over time, location, or method, with all aspects of the food system, diets, and vegetables studied across the different years and places and using a range of methods.

Figure 7 shows an overview of the mapping results across the food systems, diets, and vegetables mapping criteria. There was a large difference in the number (or proportion) of articles addressing different issues: Over 80% of articles looked very broadly at "what people eat" (covering what, whether, how, why or when people eat vegetables, a category that emerged as necessarily broad due to the broad range of disciplines included in the review, which rather than focusing on a specific metric, instead gathers a set of ideas on eating and diets that emerged from different papers in different ways); over 60% looked at vegetables as a general category (again

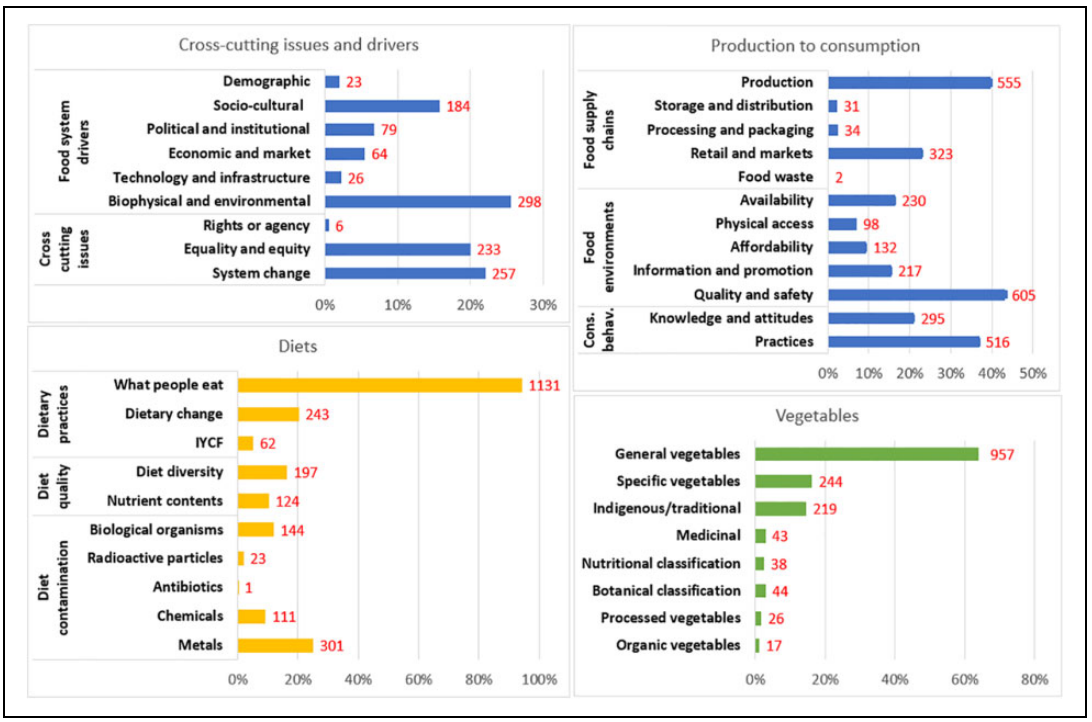

Figure 7. Overview of mapping results across food systems, diets, and vegetables. For each of the charts throughout the article, the bars show the percentage of these 1383 articles that cover a particular topic or use a particular method, and the numbers at the ends of the bars show the number of articles. Note that not all totals will add up to 1383 or 100%, as many articles look at multiple issues or locations.

categorized by the papers we reviewed, depending on the botanical, nutritional, or sociocultural context being researched); and over 30% looked at aspects of vegetable production, food quality and safety, or consumer behavior practices (classified according to definitions in the HLPE framework). Conversely, many aspects of food systems, diets, and vegetables were addressed in only a very small number of articles. We highlight key findings and patterns in this literature.

Classification of Vegetables

A majority of articles (69%) classified vegetables as a food group (or sometimes as "fruit and vegetables") without specifying particular vegetables or vegetable attributes. These either looked at (fruits and) vegetables as a singular food group, or as a food group among other food groups as part of the overall diet. A set of articles (n = 244) went beyond the food group and classified vegetables using a common name or Latin name (eg, broccoli) or a crop family (eg, brassicas) or another grouping that the authors deemed relevant (such as "green vegetables"). Many of these (n = 212) were studies quantifying the contamination of vegetables where specific vegetables were assessed.

A clear set of articles looked specifically at vegetables classed as "indigenous or traditional" (n = 219); these may have specified particular traditional vegetables or used this term for a group of vegetables. In general (but not in every case), studies of traditional vegetables tended to look across multiple parts of the food system and its drivers, but tended to classify diets very broadly looking at aspects of "what people eat" (n = 207) rather than specifically at metrics of dietary quality (n = 54) or dietary change (n = 26). A majority of articles looking at

traditional vegetables were observational studies, describing their current situation in food systems and with relation to diets, though 9 were interventional and 5 were reviews of existing literature. Ethnobotanical studies comprised 31 of the included studies and most of these spanned the full "core" food system as well as drivers such as sociocultural drivers, documenting the production, procurement, classification, and use of plant foods by different population groups; many of these looked at traditional, medicinal, or wild foods and their general consumption.

Aspects of Diet

Of the included articles, 84% looked at dietary practices with 82% studying broadly "what people eat" (such as whether, how, why or when people eat different vegetables). Of these, 70% were observational studies, describing aspects of what people eat generally, usually, or at a specific time or context, including studies about food consumption patterns at population level. Only 10% of all articles tested an intervention, and 20 articles were reviews. Most articles on "what people eat" looked at a specific context in a single country, with 32 looking across more than one country, 8 looking at a geographic region, and 6 looking globally.

A much smaller number of articles looked at change in dietary practices (n = 243) over different temporal or spatial scales. A majority of these articles used quantitative methods (n = 172) based on primary data (n = 195), though 38 articles were qualitative in nature and 28 were mixed methods approaches, and 37 used secondary data while 7 were theoretical articles.

Beyond dietary practices, 21% of articles (n = 284) looked at diet quality. Of these, 197 looked at dietary diversity (between food groups or within the vegetable food group), and 124 looked at specific content of one or more nutrients (36 articles looked at both). Most studies were quantitative (n = 200) and observational (n = 214) in nature, though 39 used mixed methods and 31 qualitative methods, and 65 were interventional studies and 6 reviews.

A large number of articles (41%) looked at the contamination of vegetables (n = 576) and the implications for dietary intake of contaminants, particularly heavy metals (n = 301) and biological contaminants (n = 144). Articles on contaminants through vegetable consumption in diets featured in every year from 2000; a majority (n = 554) were primary quantitative observational studies, describing the levels of contaminants and analyzing implications through consumption in the diet, with 15 interventional studies and 7 reviews. Contamination articles were largely looking at single locations in single countries, with 3 multicountry articles and one global; most were undertaken in middle-income countries with 19 studies undertaken in low-income settings; and most (n = 224) were undertaken in East Asia and the Pacific (largely China) followed by South Asia (n = 104) and Sub-Saharan Africa (n = 91).

Food Systems Research Archetypes and Exemplars

Archetype 1: Articles looking at drivers or cross-cuts only. Cross-cutting issues appear in 33% of articles, and food system drivers in 40%, but the numbers of articles looking only at these aspects of the food system (without any of the core food system aspects, but with relevance to them) are far fewer, with 29 articles looking at cross-cuts only, 8 at drivers only, and 11 at both together.

Of those looking at cross-cutting issues, 31 focused on equity and equality issues, including wealth,[a] social status,[b] ethnicity,[c] and rural-urban location.[d] Five articles looked at "system change" in terms of seasonality,[e] or broader transformation.[f] Of those looking at food system drivers, 6 looked at sociocultural drivers such as religion[g] and cultural or community acceptability.[h] Six looked at political and institutional drivers, all of which covered price, income, or social support policies.[i] Four covered economic drivers, either incomes[j] or structural economic change or crisis.[k] Three articles looked at biophysical drivers, largely biodiversity and environmental boundaries,[l] and 3 at demographic issues including rural–urban location and migration.[m]

Of all 48 articles looking at cross-cutting issues and/or food system drivers, 44 looked broadly at "what people eat" while 19 looked at

dietary change and 17 at some metric of diet quality; and 45 looked at vegetables as a general food group or category.

Archetype 2: Articles looking at one or two aspects of the "core" food system. Food environments, appearing in 77% of articles, were the most studied part of the food system in articles looking at vegetables and diets (n = 1072) either alone (n = 117) or in combination with supply chains (n = 187) or with consumer behavior (n = 78) or as part of the full "core" food system across all 3 areas (n = 205) or in some other combination. Food supply chains are represented in 57% of articles (n = 789), particularly in combination with food environments (n = 187) or as part of the full "core" food system (n = 205). Consumer behavior is studied in 43% of articles (n = 595) either alone (n = 50) or in combination with food environments (n = 78) or supply chains (n = 21).

Of articles looking at vegetable supply, most looked at production (n = 555). Of these, 276 looked at the production aspects of contaminants in the diet, such as production systems, irrigation methods, pesticide and antibiotic use, and soil contamination including from local industry.[n] Retail and markets were assessed in 324 of the supply-chain articles. Supply chain articles predominantly looked at vegetables as a food group (n = 499), specific vegetables (n = 191), or traditional or indigenous vegetables (n = 127).

Of articles looking at food environments, most looked at food quality and safety (n = 608) of which 575 were contamination articles. Food availability was analyzed in 230 of the food environment articles; information and promotion in 217; affordability in 132; and physical access in 98. Many of the articles looking at information and promotion under food environments also looked at knowledge and attitudes under consumer behavior (n = 107) as a step in the pathway to diets, but of the food environment articles only 391 looked at consumer behavior at all.

Of articles looking at consumer behavior, 516 looked at consumer practices and 295 looked at consumer knowledge or attitudes. Most of these articles looked at vegetables as a broad food group (n = 387) or at traditional vegetables (n = 198); and at diets in terms of what people eat (n = 527), dietary change (n = 148) or diet quality (n = 168).

Archetype 3: Articles looking across the "core" food system without drivers or cross-cuts. Of the 205 articles looking across all 3 areas of the "core" food system, 56 do so without analyzing the role of any drivers or cross-cutting issues. These articles look largely at production (n = 21), retail markets (n = 42), availability of food (n = 29), and consumer practices (n = 51). Most look very broadly at "what people eat," with 18 looking at any metric of diet quality; and most look at vegetables as a general food group (n = 33) though some look at traditional vegetables (n = 13).

Archetype 4: Articles looking across the "core" food system with drivers and/or cross-cuts. Of the 205 articles looking at the full "core" food system, 113 look at cross cutting issues, largely system change (n = 38) through changing cultivation or acquisition practices,[o] changing food knowledge or norms,[p] changing socioeconomic or environmental contexts,[q] or changing institutional procurement[r]; and equity and equality (n = 41), including through gender,[s] occupation,[t] and socioeconomic status.[u] Of the "core" food system articles, 86 looked at food system drivers, largely sociocultural[v] (n = 42), biophysical[w] (n = 29, with 9 of these being contamination articles), and political and institutional[x] (n = 27).

Of articles looking more specifically at dietary quality, 73 looked at the full "core" food system from supply chains to food environments and consumer behavior, with 46 of these also looking at cross-cutting issues (largely system change) and 27 looking at food system drivers (largely sociocultural and economic drivers). Many of these "dietary quality plus core food system" studies were interventional in nature (n = 25), aiming to understand the effects of system-based interventions on diets.[y] Of 57 "core" food system articles (with or without drivers and cross-cuts) looking at dietary change, 38 linked this

explicitly to food system change, largely through the nutrition transition[z] concept, or system interventions such as home gardens.[aa]

Discussion

Study Strengths and Limitations

This scoping review used existing theoretical frameworks to systematically find and map 1383 articles that studied the role of vegetables in food systems for healthy diets. As far as we are aware, this is the first review to systematically synthesize this particular set of literature, and to do it so comprehensively. We explicitly included research from multiple disciplines, given that different food system questions require a range of different methods or approaches. This has provided a fuller view of food system evidence, from the economic and epidemiological to the anthropological and political, which is a clear strength—but it also made synthesizing the evidence more difficult and necessarily narrative. The categories and archetypes identified provide a useful overview of the field, showing the broad range of studies that feed into food system research, even on the narrow topic of vegetables.

The included studies can also form a basis to identify research gaps for researchers going forward. Scoping reviews by their nature generate a large volume of material, and our engagement with abstracts only was based on the rationale that articles with an inherent focus on the review topics would mention these in the abstract—but this approach would miss articles which do analyze these issues but do not mention them clearly in the abstract. We recommend that authors ensure that key words and key information is mentioned clearly in abstracts. Each of our core review topics—food systems, vegetables, and diets—to some extent lack entirely clear consensus on definitions. We based our own definitions on the most up-to-date frameworks and explanations, and allowed papers to define for themselves what they were researching, but there is further legitimate debate to be had, particularly on what constitutes food system research and where boundaries should be drawn.

Summary Findings

The section below compares the findings of our review to our conceptual food systems framework (Figure 1) in order to identify the studies that would be expected given our conceptual understanding of food systems, to identify key gaps for future research.

We did not find clear changes in topics researched or ways of researching over time, but we did find that the topic area has been growing consistently over the past 20 years. The increasing number of studies is heartening for those wanting to understand and improve food systems, but we also note that the number of studies explicitly connecting food system issues and diets in the context of vegetables is low compared to the total number of food systems studies of which we are aware (a Google Scholar search for "food system" returned 848 000 hits, for example). We therefore call for more work in the specific areas highlighted below, identified as gaps in the literature through this review, given the importance of vegetables in healthy diets.

Disciplines, methods, and metrics. While the number of conceptual articles found in the review was low, we do not find a lack of theory or ideas in this field. The field of food systems research for healthy diets is relatively new in international development, building on previous ideas of nutrition-sensitive agriculture,[23] nutrition-sensitive value chains,[24] and agriculture-to-nutrition pathways.[25] While we could not in our review explicitly identify disciplines contributing to included articles, it is clear that included articles had their base in multiple disciplines from ethnobotany to economics to epidemiology and beyond, and future food systems research can apply existing concepts and ideas from any discipline to this more specific topic.

In studying vegetables, most articles classified these as a food group rather than looking at specific types or categories of vegetables. Similarly, the most common dietary metric was broadly "what people eat" or whether they eat the vegetable food group. From a food system and a diet perspective, we argue that there is a need for more nuance in classifying vegetables and vegetable-

related dietary outcomes, particularly through looking at the diversity of vegetables *within* this food group (noting that some diversity metrics do break these down a little). While it might be important to continue to understand which vitamins, minerals, macronutrients, and phytonutrients are contained in different vegetables, it is the diversity of compounds within vegetables that makes them such an important food group, and it is consuming a diversity of different vegetables that provides for their role in healthy diets.[26] Diversity of vegetables in food systems and in diets should be assessed therefore, just as dietary diversity *across* food groups is recommended in quantitative metrics studying diets more generally.[27,28]

One clear category of vegetables that was studied in 15% of articles was traditional or indigenous vegetables, many of which are wild or semi-wild plants that are used in traditional cuisine but less likely to be commercial commodities[29] as opposed to "exotic" vegetables that are the focus of major global breeding initiatives.[30] In general, we know a lot about a small fraction of vegetables in the world, and very little about the rest,[31] and our review makes clear that these are neglected in food systems research for healthy diets too, even though increasingly there is global recognition of the importance of these in food and nutrition security.[32]

Additionally, in our review it was clear that traditional vegetables tend to be studied differently to articles looking at vegetables in general, with more of a focus on consumer behavior and the sociocultural drivers for traditional vegetables; rather than a focus on production, affordability, and markets as seen with studies of vegetables in general. We cannot say from our data whether this difference is because of genuine distinctions in how traditional vegetables are produced or sold; we would however argue that both cultural and behavioral drivers, and supply systems and food environments, are important to study for all types of vegetables in food systems research.[21,33]

In our review, only 86 studies looked at low-income country food systems. Yet these are the countries where healthy diets, and particularly fruits and vegetables, are furthest out of reach for a majority of the population[8,9] and where much of the burden of poor diets and the lowest vegetable consumptions falls.[7] They are also most likely to be economically isolated or to be affected by disruptions to food systems (such as conflict, climate change, and forced migration) where there is scope and need to look at the impacts of these on vegetable food systems and healthy diets.[7,34-37] Our review also found very few studies looking explicitly across country contexts. Comparison across different contexts is an important method for understanding the generalizability of food system findings or policy prescriptions that is relatively common in work on policy and governance drivers of global issues[38] but less applied to other areas of the food system, in particular on the more globalized aspects of food systems.[18]

Parts of the food system. Very few articles in our review looked at vegetable processing in relation to diets. This is surprising given that the availability of vegetables is much affected by their seasonal and perishable nature[39] and vegetable losses and waste are usually high.[40] Only 2 articles in this review looked at food loss or waste as it relates to vegetables reaching individual diets; though there is more work on food loss and waste further up the food system, there is clearly a need for more work linking this to effects on diets.[8,40] Conversely, a large proportion of the articles found through this review (41%) concerned contamination of vegetables and implications for diets, a reflection that food safety issues are a major concern for vegetables. There is a need to join these dots into vegetable food system research, and understand solutions to food safety, seasonality, and food loss and waste beyond continuing to describe the problem in different contexts.

Issues of physical access to food were among the least studied food system topics in our review (7% of articles) despite long acknowledgment that physical access to vegetables is limited in so-called "food deserts" in contexts where most food is purchased[41] and that seasonality or other issues with production limit access to vegetables where a major part of the diet is self-produced.[42] Issues of affordability of healthy diets are now

relatively well covered globally[9,43] and some articles have looked at this in relation to vegetables specifically (132 articles in our review), though there is still work to do in understanding how affordability relates to upstream and downstream food system issues (in our review, 81 of the affordability articles linked downstream to consumer behavior and 78 upstream to supply chains).

Several articles (205 in our review) look across the full "core" food system from vegetable supply chains to food environments to consumer behavior, and all the way through to diets. This relatively low proportion of all articles is consistent with previous reviews of food systems beyond vegetables, which find that few food systems studies look explicitly at dietary outcomes.[44] In essence, this leads to upstream/downstream siloes of food systems work, with "downstream" articles linking consumer behavior and diet (598 articles looked at consumer behavior in this review) but "upstream" articles in areas such as vegetable breeding and seed systems not making an explicit connection to diets: In this review, only 26 articles that looked at "technology and infrastructure" drivers of vegetables in food systems went as far as including analysis of implications for diets; and similarly 54 articles looking at storage, distribution, processing or packaging of vegetables did. We do not explicitly look at trade-offs with other food systems outcomes in this review (such as food system livelihoods or environmental impacts) which these studies may consider, so we can't look at how studies deal with trade-offs among these different valid outcomes[45]—but we argue that most if not all food systems research should consider the impacts of what is produced on what is eaten, as the ultimate function of food systems is to provide food to eat.

Beyond the "core" food system, we find that fewer than half of the articles (562 in this review) assessed any of the conceptual drivers of food systems. In particular, demographic drivers of vegetables in diets (such as urbanization and migration) are only assessed in 23 articles in this review, despite decades of work understanding the nutrition transition, and growing realization of the food system vectors of dietary change.[46,47] Similarly, systematic understanding of policy and governance drivers of food systems, including how policy is made and how different groups engage to shape these systems, was only assessed in 6% of studies in our review despite literature highlighting the importance of political economy in food and agriculture policy for healthy diets.[48,49] More work is needed to understand how key drivers shape the food system to enable or disable different groups of people to include vegetables in their diets.

For this review, we built on the HLPE food systems framework[18] as the framing with the most consensus for work in low-income countries—but the framework did not specify the boundaries of what constitutes "food systems research" (must it look across all dimensions of the food system or can it look at just one dimension or something in-between?). We used the heuristic of "food systems archetypes" to classify the extent to which studies engaged with the full food system shown in this framework or with parts of it—and we present as an open debate to the research community the discussion of what constitutes food systems research.

Research Gaps

We need more "systems" studies, therefore, that look across the food system from start to finish: From drivers to consumers, and from production to diets. There are various guidelines on how to undertake such a study[33,50-52] and not all studies will look at every dimension of food systems, but systems approaches are needed to understand how these complex arrangements fit together in practice.[53] These studies may be descriptive, using data to observe aspects of food systems in different contexts, as was the case for 85% of the studies in this review; a lack of complete data sets on food systems makes more comprehensive quantitative analysis across the food system difficult, leading more detailed studies to narrow down to a smaller piece of the food system.[54] Qualitative research (used in 21% of studies in this review) is necessary to understand many of the issues that are relevant to vegetable food systems for healthy diets, particularly around the beliefs and behaviors of

food system actors from policymakers to farmers to consumers.

Beyond observing food systems, we also need to understand the impacts of different policy and practice interventions (13% of studies in this review assessed an intervention), from micro-level gardening programs to population-level behavior change nudges to macro-level trade and agriculture policy changes, on food systems that enable vegetable-rich diets. Each of these systems studies needs to understand the differential impacts on different population groups in including vegetables in their diets, as equity theory and empirical studies tell us that it is often the most marginalized groups who are least able to access healthy diets.[55,56] Understanding these issues is all the more necessary given the way that shocks—such as the COVID-19 pandemic and its associated lockdowns and policy responses—can disrupt aspects of food systems, particularly for perishable items such as vegetables.[34]

Conclusions

We know that vegetables are important in diets, for immediate and long-term nutrition and health, and we know that they are often missing in diets, and particularly in marginalized contexts and for marginalized groups. We have described the state of research currently on vegetable food systems for healthy diets in LMICs. Using systematic methods and comparing to an accepted global food systems framework, our review shows several gaps in the literature which we now call on the global food systems research community—from all disciplinary perspectives—to work to fill.

These include the need for more work on specific vegetables (such as traditional and underutilized vegetables) and on specific parts of the food system (such as issues and solutions for food loss and waste, and contamination and food safety). More work needs to be undertaken in low-income contexts and in under-represented regions, with more comparative work for mutual learning across contexts, and with better metrics and methods to capture the diversity of vegetables in food systems and in diets. Crucially, it includes the need for more work taking a systems focus and connecting upstream and downstream dimensions of vegetable food systems, and work to understand and address food system drivers for potentially sustainable change. Researching such systems can only be undertaken with an inclusive approach across disciplines that offer different ways of describing and analyzing complexity.

The 2021 UN International Year of Fruits and Vegetables, and global agendas for healthy and sustainable diets, recognize the need for greater attention to the role of food systems in making vegetables available, affordable, and desirable for healthy and sustainable diets. This review can inform research and action agendas in pursuit of this goal.

Authors' Note

JH conceived and designed the study, led the design of study tools and methods, and led the manuscript writing. WT undertook all database searching, and JH and WT undertook the screening of records and the mapping of included articles. All authors gave expert input through multiple rounds of designing search terms and inclusion criteria and interpreting results, and were active contributors in writing the manuscript.

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Supplemental Material

Supplemental material for this article is available online.

Notes

a. Eg, Angeles-Agdeppa, et al. (2019). The impact of wealth status on food intake patterns in Filipino school-aged children and adolescents.
b. Eg, Bojorquez, et al. (2015). The social distribution of dietary patterns. Traditional, modern and healthy eating among women in a Latin American city.
c. Eg, Imran Kabir, et al. (2013). Plant items consumed by various tribal groups in Bangladesh during times of food scarcity.
d. Eg, Blagovestova. (2016). The difference of food consumption in Russia's regions.
e. Eg, Broaddus-Shea, et al. (2018). Seasonality of consumption of nonstaple nutritious foods among young children from Nepal's 3 agroecological zones.
f. Eg, Yin, et al. (2020). Diet shift: considering environment, health and food culture.
g. Eg, Tan, et al. (2016). Religiosity, dietary habit, intake of fruit and vegetable, and vegetarian status among Seventh-Day Adventists in West Malaysia.
h. Eg, Chaudhary and Krishna. (2019). Country-specific sustainable diets using optimization algorithm.
i. Eg, Chen, et al. (2019). Impacts of nutrition subsidies on diet diversity and nutritional outcomes of primary school students in rural northwestern China—do policy targets and incentives matter?
j. Eg, Arroyo P and Méndez O. (2007). Energy density, diversity of diets and family income in rural and urban households of Mexico (1992-2002). *Gaceta Medica de Mexico*. 143(4): 301-307.
k. Eg, Hartini, et al. (2003). Food patterns during an economic crisis among pregnant women in Purworejo District, Central Java, Indonesia.
l. Eg, Termote, et al. (2012). A biodiverse rich environment does not contribute to a better diet: a case study from DR Congo.
m. Eg, Bansal, et al. (2010). Effects of migration on food consumption patterns in a sample of Indian factory workers and their families.
n. Eg, Aghili, et al. (2009). Health risks of heavy metals through consumption of greenhouse vegetables grown in central Iran.
o. Eg, Alemu, et al. (2019). Impact of permagarden intervention on improving fruit and vegetable intake among vulnerable groups in an urban setting of Ethiopia: a quasi-experimental study.
p. Eg, Baliki, et al. (2019). Long-term behavioural impact of an integrated home garden intervention: evidence from Bangladesh.
q. Eg, Gandhi and Zhou. (2014). Food demand and the food security challenge with rapid economic growth in the emerging economies of India and China.
r. Eg, Bandoni, et al. (2010). The influence of the availability of fruits and vegetables in the workplace on the consumption of workers.
s. Eg, Herscovici, et al. (2013). Gender differences and a school-based obesity prevention program in Argentina: a randomized trial.
t. Eg, Hamann. (2018). Agro-industrialisation and food security: dietary diversity and food access of workers in Cameroon's palm oil sector.
u. Eg, Ugur, et al. (2014). Impact of socio-cultural and economic factors on vegetable consumption behaviours: case of Giresun Province, Turkey.
v. Eg, Frazier, (2018). Grow what you eat, eat what you grow: urban agriculture as middle class intervention in India.
w. Eg, Cruz-Garcia and Price. (2014). Gathering of wild food plants in anthropogenic environments across the seasons: implications for poor and vulnerable farm households.
x. Eg, Johns and Eyzaguirre. (2006). Linking biodiversity, diet and health in policy and practice.
y. Eg, Schreinemachers, et al. (2017). Impact of school gardens in Nepal: a cluster randomised controlled trial.
z. Eg, Kelly, et al. (2014). Thailand's food retail transition: supermarket and fresh market effects on diet quality and health.
aa. Eg, Jones, et al. (2005). Nutrition knowledge and practices, and consumption of vitamin A-rich plants by rural Nepali participants and nonparticipants in a kitchen-garden program.

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