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Review

Forests support people's food and nutrition security through multiple pathways in low- and middle-income countries

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SUMMARY

Achieving food and nutrition security for the world's population while at the same time reversing and minimizing damage to the natural environment is a grand societal challenge. A growing body of evidence has shown that access to forests can support food security in some settings, but the linkages between forests and people's diets are not well understood. The goal of this review is to provide an overview of the explanations behind observed associations between forests and food and nutrition security. We found that 77% of publications show that forests contribute positively to food and nutrition security. The two main explanations are (1) the direct provision of forest foods and (2) indirect effects from forest-based ecosystem services on surrounding agriculture. Our findings suggest that it is pertinent to rethink the dichotomy between agriculture and nature and move toward more integrated nutrition-sensitive landscapes.

INTRODUCTION

Within the last few years, the total number of people suffering from food and nutrition insecurity has increased globally.[1] While undernourishment is a key focus of policymakers and international institutions, less focus is given to the estimated two billion people who suffer from "hidden hunger" due to micronutrient deficiencies.[2] The dominant discourse within the global agenda on food security has historically been characterized by the notion that undernourishment should be addressed by increased food production through agricultural intensification.[3–5] Feeding a future population of approximately nine billion people in 2050 still appears to be approached by a "production-at-all-costs" narrative, in which croplands need to expand at the cost of forests and pasture lands.[6] Today, agriculture is the leading driver of deforestation, accounting for 27% of global forest loss.[7] Agricultural intensification has not only proved to be damaging environmentally, but also has socio-economic downsides, and has failed to achieve adequate nutrition for millions of people around the world, particularly the rural poor.[8,9] For example, recent studies show how expansion of market-oriented agriculture tends to worsen local food security if it happens at the cost of wild food resources.[10–12] Meanwhile, forests are increasingly acknowledged as essential to poverty alleviation and improved human well-being, as well as important contributors to global food security and nutrition.[13–17] Over the last decade, a growing body of scientific literature has found a positive relationship between living in (and having access to) forest landscapes and improved food and nutrition security.[18–22] These publications are often based on large-scale analyses of international datasets, such as the Demographic and Health Survey or the World Bank's Living Standards Measurement Study. While such studies can provide statistical evidence on the relationship between people's food consumption and forests, they tend to be limited in terms of explaining the mechanisms that drive this relationship. Other studies have used finer-scale data to examine the linkages between local people's food security and their surrounding landscapes.[23–27] Such studies tend to provide detailed explanations on the various ways that forests can contribute to local food and nutrition security. However, the results from these local case studies are often highly site-specific and less useful for large-scale extrapolation. Consequently, there is a need to strengthen the evidence base behind the assumed explanatory linkages between forests and food and nutrition security.

The main goal of this review is to synthesize evidence on how forests affect food and nutrition security in low- and middle-income countries. Although the topic has received increased scientific attention over the past few years (Figure 1), it is still a comparatively small body of literature. It is nonetheless important and timely to synthesize and learn from its emerging findings. We analyzed the results of 65 scientific publications that examine the linkages between proximity to or use of forests and different types of food and nutrition security measures in low- and middle-income countries (see Tables S1–S3 for more information on each article included). Because the reviewed publications span from local case-studies to large-scale analyses, we synthesized across spatial scales to provide a comprehensive overview of existing literature. We grouped the food security and nutrition metrics into four categories: (1) dietary diversity scores, (2) health metrics (e.g., prevalence of stunting and wasting), (3) dietary adequacy (e.g., macro- and micronutrient intake and adequacy), and (4) food security measures (e.g., Household Food Insecurity Access Scale, Days Without Food), excluding measures of dietary diversity and adequacy

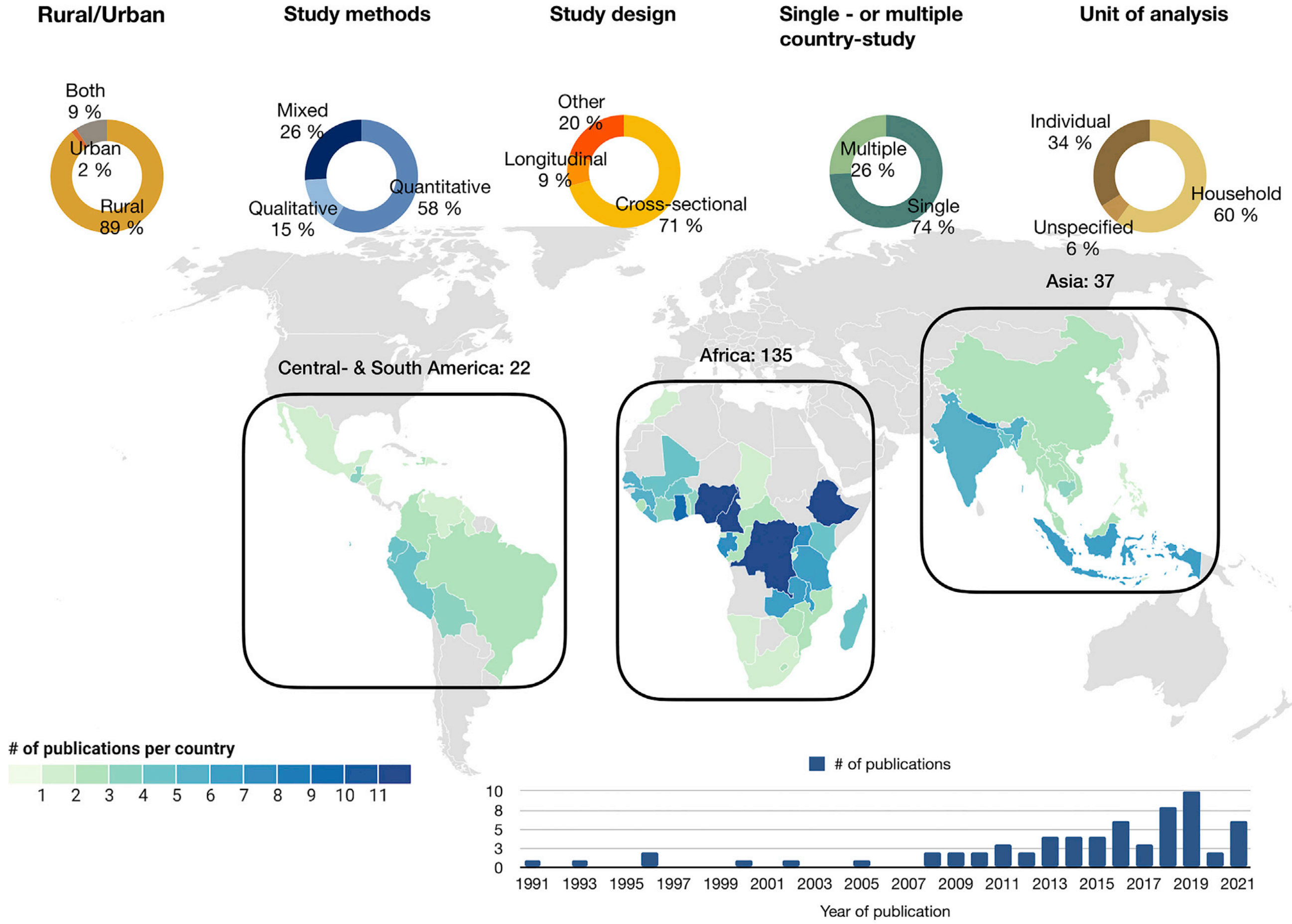

Figure 1. Overview of publications included in the review (n = 65)
Note that 16 of the 65 publications included multiple countries/regions, resulting in 194 different study areas across 62 different countries. Percentages are given for key study characteristics (urban versus rural location, methods used, study design, and unit of analysis).

(see Table S6 for more information on the four outcome categories). Following Gergel et al.,[28] we grouped the potential pathways linking forests and diets into four broad categories: (1) a "direct contribution pathway," (2) an "agroecological pathway," (3) a "fuelwood-energy pathway," and (4) an "income pathway." This categorization is not new,[28,29] but to our knowledge the evidence base behind each explanatory pathway has not yet been analyzed quantitatively.

We used the term "food and nutrition security" as an umbrella term to cover all of the various measures of food security and nutrition used in the literature, such as dietary diversity, dietary adequacy (e.g., micronutrient intake and adequacy), and health (e.g., prevalence of stunting) (see experimental procedures for more details). It should be noted that we do not make any claims about whether the assessed households are food secure or insecure. For example, high vitamin A intake or low presence of stunting are not interpreted as food security. Instead, we examined whether people's proximity to or use of forests affects the various indicators of food and nutrition security in a positive or negative direction. The results of this review illustrate how forests contribute positively to food and nutrition security in multiple direct and indirect ways. Yet, the results also show how more scientific attention needs to be given to how agriculture might benefit from surrounding forests and how that in turn affects dietary quality outcomes. Based on our findings, we suggest integrating the role of forests into food and nutrition security policies and upscaling co-benefits between agriculture and forest-based ecosystem services beyond the forest edge and across larger landscapes.

STUDIES ON FORESTS AND FOOD AND NUTRITION SECURITY

The first article on the linkages between forests and food and nutrition security was published in 1991 (Figure 1), but more than half of the articles within the field have been published since 2015, indicating a renewed scientific interest in the topic.

The 65 articles included in the review covered 62 different countries (Figure 1), although some of the articles covering multiple countries did not present results disaggregated by country.[20,22,30,31] Seventy-four percent of the articles were based on single-country studies, while the remaining included data from multiple countries. We found that most studies were based on data from Sub-Saharan countries, with Cameroon, Democratic Republic of the Congo, Ethiopia, and Nigeria having ten or more studies each. Eighty-nine percent of the articles focused on rural areas, while only 2% focused on urban areas, and the remainder looked at both rural and urban areas. Fifty-eight percent of the articles were based on quantitative methods, 26% on mixed methods, and 15% on qualitative methods. Most of the studies (71%) used a cross-sectional design, while only 9% applied a longitudinal design. The remainder used other types of research designs. More than half of the articles (60%) used data at the household level, while 34% focused on individuals, and the remainder did not specify unit of analysis (Figure 1). No relationship was found between the methodological features of the reviewed studies and the likelihood of observed outcomes (see Table S5).

FOUR WAYS FORESTS IMPROVE FOOD SECURITY

The majority of publications (77%) found positive relationships between forests and food and nutrition security. These positive relationships were predominantly explained by (1) a direct contribution pathway, which describes the direct provision of forest foods, such as the collection of fruits and vegetables in and around forests; (2) an agroecological pathway, which describes the indirect effects from forest-based ecosystem services on surrounding agriculture, such as water provision and improved soil fertility; (3) an income pathway, which describes improved income opportunities from the forest, such as the sale of timber and non-timber forest products (NTFP); and (4) a fuelwood-energy pathway, where improved food and nutrition security is explained by better access to fuelwood for cooking (Figure 2).

Forests can contribute directly to food security

Among those publications that documented positive associations between forests and food and nutrition security, we found that the most frequently observed explanatory pathway was the direct contribution pathway. Forty-eight (74%) of the publications attended to this pathway. These articles differed in terms of their research scope and applied methods, but they all found evidence to suggest that people living in close proximity to forests (or with higher levels of forest use) had improved food and nutrition security through consumption of forest foods. Some articles emphasized the importance of wild animal products from the forest as a key source of protein and certain micronutrients,[32,33] while other studies focused on the role of nutrient-rich plant foods, particularly dark green leafy vegetables.[25,34] Some studies highlighted that people were using wild foods from landscapes surrounding forests such as agricultural fields, fallows, wetlands, and rivers,[25,35] rather than from the forest directly. This could be in part due to changes in the regulation of global forest estates, which increasingly restrict local communities' access to wild forest foods.[36]

A repeated notion in the literature was that wild forest foods rarely make up the majority of the diet. Instead, wild foods supplement what is available from agricultural production and markets.[31,37] Their consumption can increase overall dietary quality because forest foods tend to be micronutrient dense.[31] While most studies alluded to this argument, only nine studies actually quantified nutrient intake[34,38–43] (Figure 2). While forest foods did not appear to be a major source of calories, several studies emphasized the role of forest foods as a safety net during times of food shortage.[65] The consumption of forest foods was often found to be highest in cases of crop failures, economic shocks, and during preharvest seasons.[44] Moreover, studies that included socially differentiated factors of the respondents (e.g., wealth level and education) generally found that the poorest households were the most frequent users of forest foods.[45,46]

Forests can contribute indirectly to food security

Another frequently observed explanatory pathway between forests and food and nutrition security was the beneficial effects of forests on local agricultural production. These benefits include forest-based ecosystem services (e.g., pest control, nutrient cycling, biomass, fodder, and water regulation), which all support agricultural production leading to better and/or more diverse agricultural systems in surrounding landscapes,[23] which in turn can improve food and nutrition security. Thirty-four (52%) out of our 65 articles attended to this pathway. The studies with direct assessment of forest-food linkages (inner circle of the tree crown) were significantly ($p < 0.001$) more likely to attend to the agroecological pathway (Table S4). This signifies the importance of such indirect benefits from forests.

For example, a study from the Yunnan Province in China found that forests were highly valued and protected by local farmers in order to hold and secure water provision over the year—a quality essential to the local terrace rice production.[26] Another study from Cameroon found a negative association between forest depletion and food security, due to a reduction in precipitation.[46] A study from southern Ethiopia described how farmers sourced fodder from the forest, allowing them to keep larger livestock herds compared with farms further away from the forest. The larger herds increased the availability of manure leading to better and more diverse agricultural production in home gardens and surrounding fields, which in turn was associated with higher dietary diversity scores (6.58 ± 1.21 in near-forest zone compared with 4.41 ± 0.77 in distal zone).[23] Another publication described how extensive forest restoration initiatives along the inner Niger Delta in Mali proved to (1) increase visits by migratory birds leading to larger fish stocks due to more fish feed from bird droppings, (2) increase dairy milk consumption among children due to improved access to tree fodder, (3) improve agricultural yields due to better soil fertility (also from bird droppings), and (4) improve people's diets due to higher diversity of crop production.[47] Finally, restricted access to forest resources might also have negative effects on local food and nutrition security. A study from Nepal found that stricter enforcement of protective policies in four mountainous districts contributed to reductions in household livestock holdings by 34% for goats, 30% for cattle, and 27% for buffalo, leading to negative impacts on local food and nutrition security.[48]

Forests can contribute to food security through income

The income pathway was less apparent in the literature, with 23 (35%) of the articles attending to this pathway. For those studies that did examine the income pathway, the positive relationship between forests and food and nutrition security was explained by better income opportunities through (1) collection and sale of forest products[49,50] and (2) labor income (e.g., from plantations, timber industries, or tourism).[24]

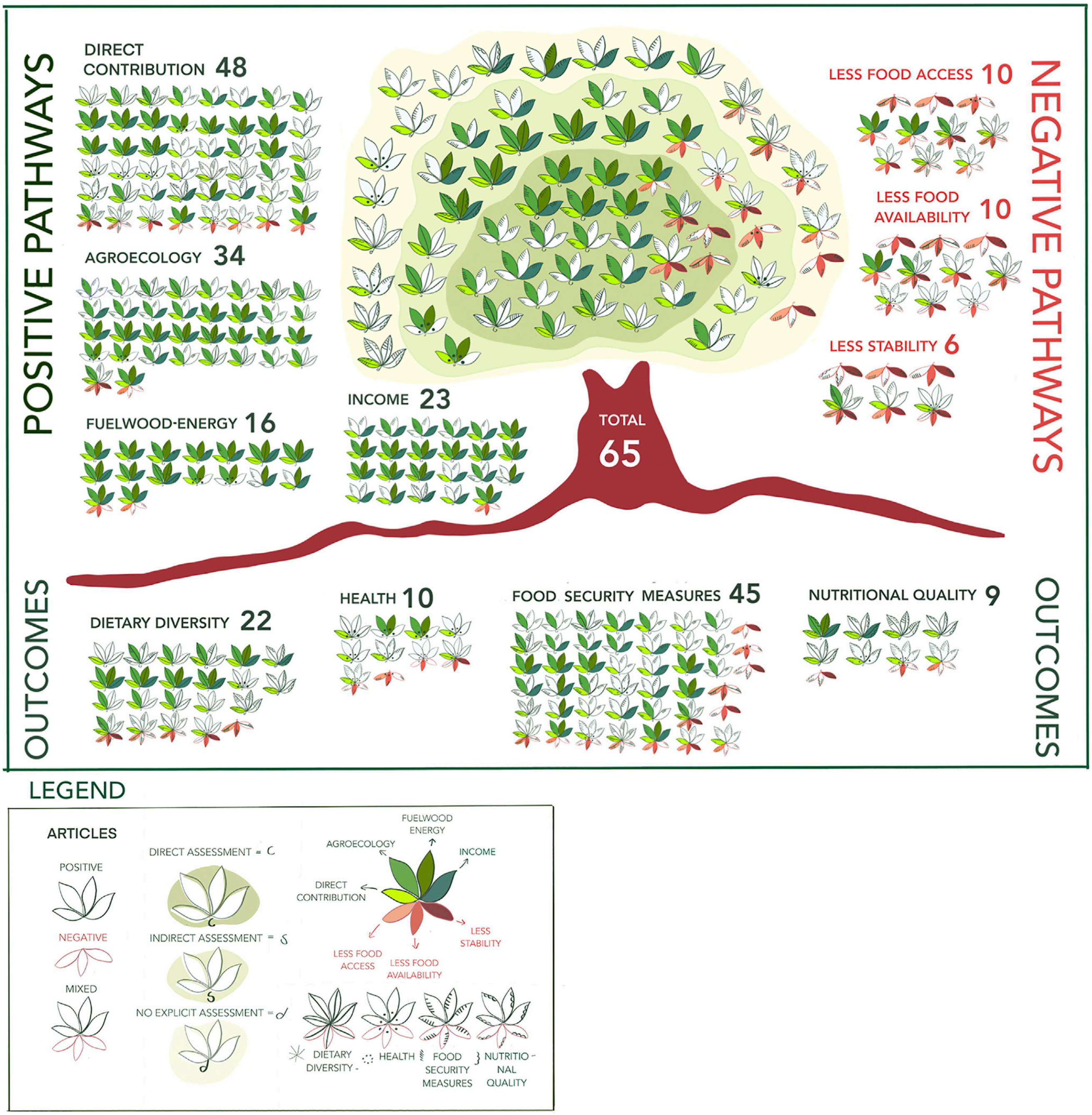

Figure 2. Explanatory pathways between forests and food and nutrition security

Each leaf represents a scientific publication that examined linkages between forests and food and nutrition security. The four green leaflets represent the four positive pathways between forests and food and nutrition security, while the three red leaflets represent the negative pathways. Some leaves have both green and red leaflets, meaning that these publications found positive and negative pathways between forests and food and nutrition security. The patterns inside the leaves represent the four different outcome categories of food and nutrition security. The three layers in the crown represent the type of assessment carried out in each publication. The publications in the inner circle of the crown assessed linkages between forests and food and nutrition security directly, the publications in the middle circle assessed the linkages indirectly (e.g., by examining associations between distance to forests and dietary diversity but without directly examining the explanatory pathways), and the publications in the outer part of the tree crown did not make any explicit assessments of forests but examined the relations between other factors (e.g., consumption of forest foods, use of NTFP) and food and nutrition security.

Yet, some studies found a negative association between income levels and distance to and/or use of forests. A case-study from Lao PDR found that income levels among villagers located further away from the forest were higher compared with those living in close proximity to the forest. The villages further away from the forest were characterized by better market access and a higher degree of commercialization of agriculture with widespread monocultures of maize exported to China and

Vietnam for feed.[35] This is in line with Baudron et al.,[29] who tested and quantified the relative contribution of the three pathways (direct contribution, agroecological, and income) to local diets in seven different countries. The study found no evidence of the income pathway in any of the countries. Instead, they found that higher forest cover was associated with less integration to the cash economy among the households in three landscapes in Cameroon, Ethiopia, and Nicaragua.

In general, higher incomes did not appear to improve food and nutrition security in cases where the higher income was associated with a decrease in wild resources and crop diversity. For example, households in the Peruvian Amazon consumed fewer food groups when commercialization of agricultural production happened in tandem with deforestation and higher reliance on purchased market products.[11,51] The same tendency has been found in multiple other countries,[52] thus questioning the role of purchased (and often processed) foods as sufficient replacements of forest foods.

Forests can provide access to fuelwood energy

Research on the fuelwood-energy pathway was limited, with only 16 studies (25%) describing this pathway. This is surprising, since the Food and Agricultural Organization of United Nations estimates that, globally, 2.4 billion people depend on fuelwood for cooking, and access to forests is expected to affect people's ability to prepare foods.[53] Also, the fuelwood-energy pathway is not a new concept within the scientific literature. A case study from the 1980s in Nepal found a direct negative relationship between deforestation and the time spent (especially among women) on agricultural production, cooking, and breastfeeding, due to the increased time spent on collecting fuelwood.[54] More recently, another case study from Nepal compared and analyzed the four explanatory pathways between forests and food security and found that the fuelwood-energy pathway was a key factor in securing local food security, as up to 88% of households relied on fuelwood as their primary source of energy. The study also highlighted that this pathway is often overlooked by policy makers.[24] The limited attention given to both the income and fuelwood-energy pathways does not necessarily mean that these explanations are less valid. It could instead be that they have been subject to less scientific focus.

Negative associations between forests and food security

It is important to note that forests are not always beneficial for food and nutrition security. For example, we found that 15 publications (23%) showed mixed or negative relationships. Within this group of publications, we identified three overarching explanatory pathways; (1) less food access, as some remote forest communities had less physical access to external food products and/or had less purchasing power to buy food products from the market; (2) less food availability, whereby the local food production close to forest landscapes was characterized by lower yields and/or less diverse outputs; and (3) less stability, whereby forest-dependent communities experienced a higher degree of food volatility between seasons.

In terms of the "less food access" pathway, this group of publications provided examples of non-linear relationships between forests and food and nutrition security. For example, a comparison of dietary differences during intermediate stages of deforestation and market integration in the agriculture-forest frontier of Cross River State, Nigeria, showed how forest edge communities were more food secure, even though they were less engaged in foraging activities compared with communities in the interior part of the forest.[55] The authors suggest that better market access enables communities to capitalize on their forest resources, which results in higher income and better diets. The authors also suggest that forest proximity is more valuable when combined with market access and lower forest density. In other words, forests should not be perceived to have a continuously positive linear effect on food and nutrition security. Communities living in isolated and dense forest landscapes are not necessarily better off in terms of food and nutrition security compared with those communities that experience a higher degree of market integration, or what the authors term "the best of both worlds."[55]

The "less food availability" pathway includes articles demonstrating how agricultural production in or around forests was not always more productive compared with other landscapes. One article found negative associations between forest cover and crop and livestock production in three countries (Cameroon, Indonesia, and Zambia),[29] and another article suggested that deforestation was associated with expansion of farmlands, leading to a positive effect on nutrient intake among children, and ultimately decreased child mortality.[56]

Finally, a number of articles showed how populations living in close proximity to forests were more vulnerable to food fluctuations over the year. A study from Cameroon showed how wild forest foods were more uncertain food sources compared with staples like cassava and maize. The study concluded that the studied populations were expected to move toward a higher reliance on staples in the future due to the volatility of wild forest foods.[57]

MAJOR GAPS OF KNOWLEDGE AND FUTURE RESEARCH

Our review of the existing literature on forests and food and nutrition security has highlighted a number of knowledge gaps. Firstly, there is a need to explore the multiple indirect effects from forests on food and nutrition security. Secondly, there is little scientific evidence on how forests contribute to dietary quality in terms of nutrient adequacy of diets. Thirdly, more emphasis should be placed on the spatiotemporal scales of studies (Figure 3).

Better understanding of indirect linkages

Given that most existing studies focused on the direct contribution pathway, there is a need to better understand the multiple indirect ways that forests can improve food and nutrition security. Some studies highlighted the critical importance of access to fuelwood for cooking and how women's time spent on collecting fuelwood negatively affects their time for childcare, including breastfeeding.[24,58,59] Despite the potential importance of the fuelwood-energy pathway for nutrition (particularly for children), the linkages between forests, fuelwood, and food security are not fully explored. Similarly, despite a relatively large number

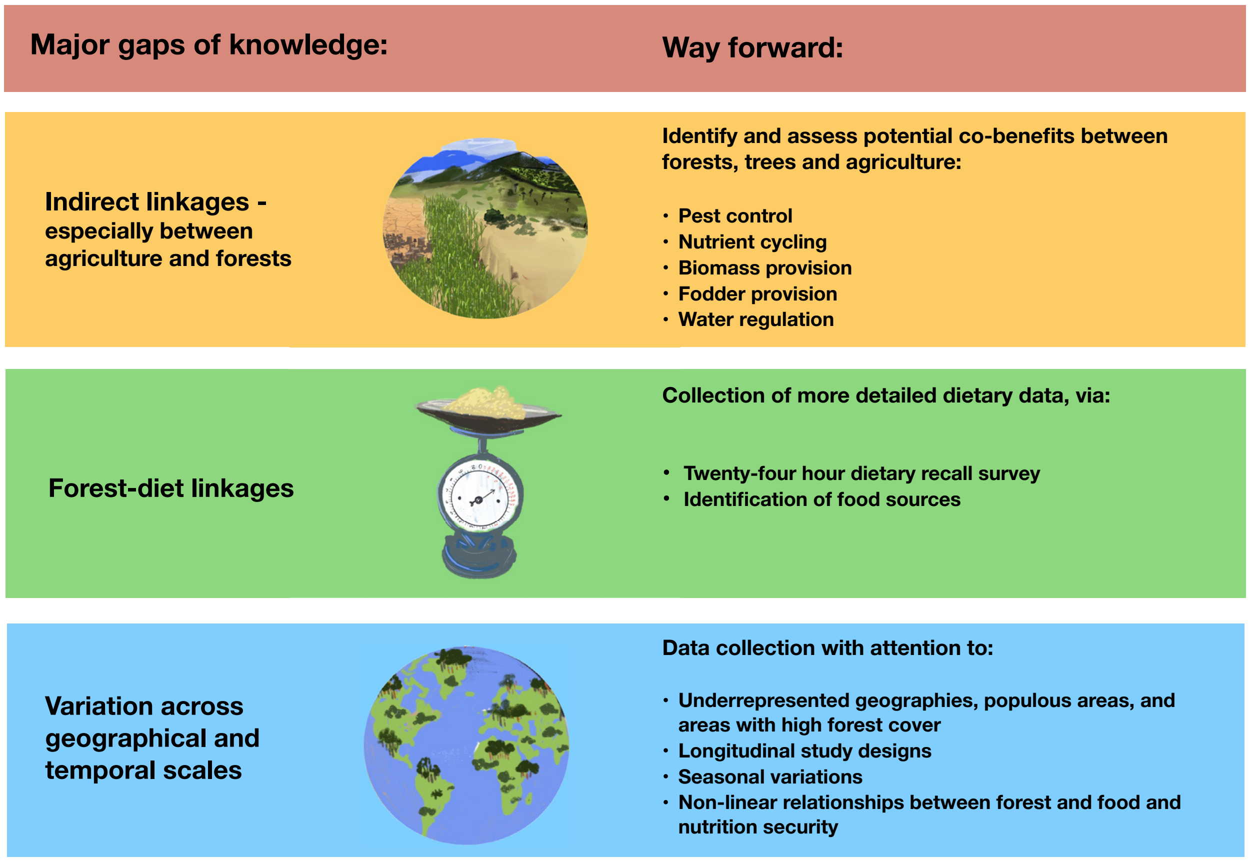

Figure 3. Knowledge gaps and ways for future research

Three knowledge gaps identified from the review of 65 publications on linkages between forests and food and nutrition security—and suggestions for future directions of research to fill these gaps.

of studies attending to the agroecological pathway, the mechanisms are not yet fully understood. As previously mentioned, the agroecological linkages are numerous (e.g., pest control, nutrient cycling, biomass, fodder, and water regulation), and include multiple explanatory pathways, as they are largely dependent on the local agroecological conditions that characterize the specific study area. Future research should place greater emphasis on the co-benefits that can be achieved when different types of agriculture are mixed with different types of forest-based ecosystems.

Better understanding of forests-diet linkages

Our review found that the majority of studies used dietary diversity scores and/or broad measures, such as "days without food," in order to measure food and nutrition security. A small number of studies used anthropometrics such as prevalence of stunting and wasting, and fewer still looked at people's nutrient intake/adequacy. Given that micronutrient deficiencies are widespread in low-income countries (particularly in poor, rural households), it is essential to understand how forests can contribute to dietary quality in terms of nutrient intake. Wild forest foods tend to be rich in micronutrients, particularly those that are commonly deficient in low-income countries. For example, wild animal foods (such as bushmeat and insects) are generally high in bioavailable iron, vitamin B_{12}, and zinc, while wild fruits and vegetables tend to be good sources of vitamin A.[37,60]

While there is clearly a need to better understand the role of forests in improving people's dietary quality, future studies face considerable challenges in doing so. Assessing dietary quality (e.g., in terms of nutrient adequacy) requires detailed food consumption data, ideally collected at the individual level. The most accurate and comprehensive method of collecting data on people's food consumption is via individual dietary recall surveys over a 24-h period, carried out by highly trained enumerators.[61] However, these are time- and cost-intensive and, as a result, are normally carried out at small spatial scales and are often not nationally representative. Likewise, these surveys rarely include questions about the sources of the foods consumed, which is critical to accurately quantify the contribution of forest foods. Alternatively, household consumption and expenditure surveys often collect data on food consumption at the household level, usually over large geographical areas and sometimes over several years (i.e., panel surveys). While useful, food consumption data in these large-scale surveys are often crude and subject to several forms of bias.[61] Ultimately, what is missing are detailed food consumption data collected at broad geographical and temporal scales that also specify whether the food consumed comes from the forest. Compilation efforts to combine disparate datasets will be particularly useful to understand the relative effects of various factors (such as changes in food availability in the market).

A greater emphasis on geographical and temporal scales

Our synthesis shows that 71% of the studies applied a cross-sectional study design, where data from different study sites were compared at a single point in time. Only 9% applied a longitudinal study design, where changes were measured over different time periods spanning from 6 months[37] to 21 years.[24] Moreover, variations in food consumption patterns between seasons were mostly left unexamined. This is critical, since access to and availability of most food and agricultural products in many rural areas in low- and middle-income countries exhibit significant seasonality and are prone to yearly fluctuations. For example, case studies among rural communities in Amazonia, Tanzania, and Ethiopia found that food access would crash seasonally.[62–64]

Our synthesis found a skewed global representation of studies toward rural areas in Sub-Saharan Africa. This signifies an interest in how forests can potentially alleviate the high rates of undernourishment in this part of the world. In 2019, the prevalence of undernourishment in Sub-Saharan Africa was 22% compared with 7.4% in South America and 8.3% in Asia.[1] While it is clear that understanding the role of forests for food and nutrition security in Africa is important, other regions should not be overlooked. For example, the prevalence of severe food insecurity was nearly as high in Southern Asia in 2019 (17.8%) as it was in Sub-Saharan Africa (21.3%) and included a higher total number of people (343 and 228 million people, respectively). Within Southern Asia, we observed an overrepresentation of studies from Nepal. It would be useful to have more studies from other highly populous countries in the region, such as Bangladesh, India, and Pakistan, as these three countries host 94% of the 255 million people suffering from undernourishment in Southern Asia.[1] At the same time, 122 million rural people lived within 5 km of a forest in 2012 in these three countries.[65]

Seventy-two percent of the publications were based on local case studies, with a high degree of site-specific findings (e.g., identification and analysis of available wild resources). While local case studies have advanced our knowledge on how forests are connected to food and nutrition security, they often provide limited options for extrapolation. Larger sample sizes or country-level studies might provide additional insights to local case study analyses. In addition, the spatial organization of the forest might be as or perhaps even more important for people's dietary quality than the total amount of forest.[21] In other words, we need to move beyond the linear thinking that more forest leads to greater benefits for dietary quality. Ultimately, it is important that future studies test whether the observed relationships between forests and food security hold across other regions and landscape types.

POLICY IMPLICATIONS

Our synthesis has two key findings that have implications for policy makers. Firstly, we call for increased attention toward the positive contributions that forests can provide to food and nutrition security. Secondly, we suggest that the observed co-benefits between agriculture and forest-based ecosystem services are upscaled beyond forest edges and into multi-functional landscapes.

The role of forests in food security policies

We found that 77% of the articles described a positive association between forests and food and nutrition security, thereby contributing to the increased call for integrating perspectives on conservation of wild landscapes into the global food and nutrition security agenda. This notion was also addressed in the High Level Panel of Experts (HLPE) report on "sustainable forestry for food security and nutrition," in which the authors emphasized the need to acknowledge forest systems as key to achieving more balanced, healthy, and sustainable diets for the future. The report recommends to move beyond discussions of land sparing versus land sharing and instead focus on how forests and trees can support nutrition-sensitive landscapes[14]—that is, landscapes that provide a diverse range of nutritious foods instead of the traditional focus on producing calorie-dense staple crops. Our review provides further support of this argument by showing that the majority (77%) of studies find that forests contribute positively to food and nutrition security. In other words, forests need to be acknowledged as a key component in healthy landscapes that can sustain local access to nutritious foods.

Given that the EAT-Lancet commission recently stated that the global consumption of fruits, nuts, and vegetables will have to double by 2050 to achieve health and environmental benefits,[66] it is concerning that very few forestry policies mention nutrition, and very few nutrition policies mention forests. For example, the most recent 2020 report from the Committee on World Food Security discussed forests in the context of sustainability but did not attend to the role of forests in improving people's livelihoods and nutrition.[67] Similarly, in the Committee's report from 2019 on "agroecological and other innovative approaches for sustainable agriculture and food systems," forests were only mentioned in the context of agroforestry but no mention was made of their importance for food security.[68] Furthermore, when the EAT-Lancet commission called for a "Great Food Transformation" in 2019—which seeks to achieve an environmentally sustainable and healthy diet for the world's people by 2050—no attention was given to the role of forests.

Reliance on direct monetary measures of land use tends to favor commodity production over wild resources.[69] We argue that when indirect benefits are taken into account, the final valuation will, in many cases, tip toward conservation and integration of forests in coherence with other types of land uses[70–72] (e.g., agriculture[73] and urban settlements[74]). This is in line with a recent report from the International Union of Forest Research Organizations (IUFRO) that stresses the need to actively use forests and tree-based systems as means to alleviate poverty and improve human well-being.[75] The report also highlights how higher incomes often fail to improve dietary diversity in rural areas in low- and middle-income countries if they happen at the cost of wild resources. Likewise, our study results question the notion that improved market access, higher incomes, and increased reliance on purchased food items can replace traditional forest-based food systems sufficiently.

Upscale co-benefits between agriculture and forests

This review highlights the multiple positive agroecological linkages, thereby emphasizing the need to rethink the dichotomy between agriculture and nature and move toward more integrated agriculture-forest landscapes.[76–78] For example, a recent comparison of different types of agricultural zones in Ethiopia demonstrated how zones with high tree cover were more productive in terms of crops, feed, and fuel, and that agricultural productivity decreased when distance to the forest increased.[79,80] While our review demonstrates how forests can benefit food and nutrition security (i.e., through provision of fodder for livestock, protecting the soil from erosion, fixing nitrogen, storing water, and improving pollination), these benefits only appeared within a certain distance to the forest edge.[20,23] A first step for policy makers could be to focus on those (smaller) landscapes where the benefits from forest ecosystem services to agricultural production are more obvious. In the longer term, the focus could be extended to how co-benefits from forests, biodiversity, and agriculture can be upscaled beyond the forest edge across larger landscapes, either through promotion of more small forest blocks or by supporting agroforestry systems. However, this requires site-specific knowledge on how to integrate trees and forests into agricultural landscapes to optimize benefits, such as fodder provision, water regulation, or pollination.

The literature on pathways between agriculture and local food and nutrition security often emphasizes the dichotomy between subsistence production and market-oriented cash crop production. Some studies find that better market access is the strongest predictor of improved diets,[81,82] while other studies argue that diversity of subsistence crops is more important.[12,51] These diverging results have led to conceptual frameworks on linkages between agriculture and nutrition that either show a "market-based pathway" or an "own production pathway."[83] We find evidence to suggest a more nuanced picture than that of food and nutrition security being solely linked to agricultural production. Specifically, we suggest that food and nutrition security strategies should attend to better access to forests and tree-based ecosystem services (beyond the individual farm level) and place more emphasis on agroecological synergies in larger integrated landscapes. These are important lessons that policymakers can respond to in terms of moderating expectations of agricultural expansion outcomes and striving for improved and alternative practices.

Forests are not a panacea to food security

Our findings are, in combination with other studies, suggesting that conservation of forests and trees within and around agricultural production may play a key role in achieving increased food and nutrition security. However, our results should not be interpreted as a definitive endorsement of integrated agriculture-forest landscapes as a panacea to food and nutrition security. Firstly, the limited number of studies included in the synthesis restricts the inferences that can be made. Secondly, our synthesis also exposed how forests in some cases are associated with lower degrees of food and nutrition security. While the majority of the reviewed articles found positive impacts from forests, we also need to acknowledge that households living in close proximity to forests are not always better off compared with households with a higher degree of market integration. For example, studies from Malawi showed how dietary diversity depended more on market access compared with farm diversity or wild food access,[81,84] and a global study showed how less than 10% of the included households would use forest resources as a coping strategy during times of hardships, thus questioning the "safety-net" argument.[85] If we dismiss these difficulties that shape and characterize the daily life of people living in close proximity to forests, we will most likely fail to discover suitable solutions to local food and nutrition security.[86,87] The challenge is to find appropriate balances in multi-functional landscapes to ensure co-benefits between diversified food systems, biodiversity, and income opportunities.

In conclusion, this review highlights the multiple ways that forests contribute to food and nutrition security in low- and middle-income countries. To uncover the full potential of forest-diet linkages, future scientific attention needs to be given to (1) co-benefits between having forests, trees, and agricultural systems within a relatively limited geographical area and how that, in turn, affects dietary outcomes; (2) more detailed nutrition outcomes of living near to forests and/or using forest products; and (3) countries with high forest cover that have received comparatively limited attention in the past (e.g., India and Bangladesh, both countries with more than 15% forest cover).

EXPERIMENTAL PROCEDURES

Resource availability

Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the corresponding author, Rasmus Skov Olesen (rso@ign.ku.dk).

Materials availability

This work did not generate new unique materials.

Data availability

The dataset generated from the literature review is deposited in the FAIR aligned ZENODO repository: https://doi.org/10.5281/zenodo.7330085.

Categorization of publications

We synthesized existing scientific knowledge on the linkages between forests and food and nutrition security. We examined (1) the extent to which forests contribute to food and nutrition security in low- and middle-income countries, (2) the different explanatory pathways linking forests to food and nutrition security, and (3) the potential knowledge gaps in the existing literature.

Due to the diversity of methods and approaches used in the existing literature, quantitative comparison of the same food and nutrition security outcome or explanatory pathway linking forests and food consumption within and across cases was not possible. We therefore coded food and nutrition security outcomes as positive, negative, or mixed through the knowledge and best available expert judgment by the coder. We included publications that linked forests and food and nutrition security either through spatial proximity indicators (e.g., km) or indicators related to forest use (e.g., collection of NTFP). We grouped the publications into three categories according to how they assessed the linkages between forests and food and nutrition security:

1. Direct assessment of linkages between forests and food and nutrition security: papers that explicitly examined the relationship between forests and a food and nutrition security indicator, where proximity to forest was at least one of the predictor variables. This group is depicted by the inner part of tree crown in Figure 2.
2. Indirect assessment of forest-food linkages: papers that included forests in the description of the predictor variable(s), but the actual pathways linking forests to food and nutrition security were not assessed. This group is depicted by the middle part of the tree crown in Figure 2.
3. No explicit assessment of forest-food linkages: papers in which food and nutrition security was measured for a population that used the forest (products) in some ways rather than being described as living in a given distance from forest areas. This group is depicted by the outer part of tree crown in Figure 2.

Table 1. Search string

Main terms	Expanded terms
Forest:	*forest* OR *tree* OR *wood* OR *jungle* OR "wildlife consumption" OR "bushmeat" OR "wild meat" OR "wild food*" OR "wild fruit*" OR "wild vegetable*"
AND	
Food security and nutrition security:	"food security" OR "food insecurity" OR "food consumption" OR "diet* intake" OR "nutrition* transition" OR "nutrition* security" OR "malnutrition" OR "diet* quality" OR "diet* diversity" OR "food dependence" OR "human* health" OR "child* health" OR "child* diet*" OR "human* diet*" OR "human* nutrition*" OR "child* nutrition*"

The table shows how terms related to forest and food and nutrition security were combined to create the search string.

Review protocol

The pool of research that assesses linkages between forests and food and nutrition security is quite recent and modest in size. For this reason, we applied a scoping review protocol, where we adopted a pragmatic sampling strategy, combining different targeted searches to secure a sufficient and robust coverage of the core literature. The applied sampling strategy was based on a modified version of the review protocol by Foli et al.[88] to examine how trees and forests contribute to food production. The final searches took place in December 2021 and January 2022 using Web of Science, Scopus, and CAB. We combined terms related to forests and food and nutrition security to create the search string (Table 1).

The Boolean separator AND was used to capture articles that assessed both forests *and* food and nutrition security. Yet, to account for the fact that forests could be referred to as, e.g., tree cover or deforestation (and food security likewise could be assessed with, e.g., diet quality or children's diets), we used the OR separator to ensure that the search string captured as many papers as possible. Moreover, we used the * function to increase the coverage. For example, *forest* would cover words such as deforestation, afforestation, forest cover, humid forests, and dry forests.

We ran the search string on titles, keywords, and abstracts. This resulted in a total of 28,560 hits from the three databases. The majority of the publications were related to other research topics, such as food safety hazards, biology, and psychology. To obtain a manageable pool of papers, we applied the search string to titles. This resulted in 785 publications (Web of Science: 231, CAB: 215, SCOPUS: 339), or 435 after removing all duplicates. We also removed four non-English publications, leaving a pool of 431 papers. We then conducted a two-phase screening process based on the following three inclusion criteria. Publications should:

- Examine linkages between proximity to/use of forests and food and nutrition security
  - o For example, some studies examined relations between forests and agriculture[89] or forests, and income.[90] Such studies were excluded from the analysis since they did not apply measures of dietary diversity, health measures related to food consumption (e.g., height for age or weight for length), nutrition measures, or food security measures (see Table S6 for list of food and nutrition security indicators included). Moreover, several studies on linkages between forests and mental health were excluded
- Be based on a scientific study including primary or secondary data
  - o We only included scientific studies that used primary or secondary data. Although we acknowledge the importance of synthesis reports on the topic, such as HLPE's *Sustainable forestry for food security and nutrition* and IUFRO's *Forests*, *Trees and the Eradication of Poverty*: *Potential and Limitations*, we did not include policy reports, as these summarized findings were from the literature and would thus have resulted in double counting
- Focus on low- or middle-income countries
  - o Studies that focused on high-income countries were excluded

In the first phase of the screening process, we read the abstracts and applied the three inclusion criteria outlined above. This reduced the number of publications from 431 to 145. In the second phase, we read the full articles and, by applying the three inclusion criteria again, we reduced the number of relevant papers to 63. We note that we did not apply any inclusion criteria related to the methodology or the robustness of results.

To reach a point of diminishing returns at which we were satisfied we had captured much of the core literature, we searched the reference sections of all recent publications (published after 2019). This final snowballing method resulted only in two additional publications, thereby confirming the strength of our search string. We thus ended with a total of 65 publications (see Table S1 for a full list of these publications)

Data extraction

Each of the 65 articles were coded using a pre-determined coding scheme (Tables S2 and S3). The articles were coded and the following information was recorded for each article:

- Main results on the effect of forests on food and nutrition security: i.e., positive, negative, or mixed
- Type of pathway described:
  - o Positive explanatory pathways: direct contribution, agroecological, income, fuelwood energy
  - o Negative explanatory pathways: less food access, less food availability, less food stability
- Food security and nutrition metrics used in the article (i.e., dietary diversity scores, health measures, measures of nutrient intake)
- Rural or urban focus (or both)
- Single or multiple countries
- Study scale (local, national, regional, or international)
- Sample size
- Data type (quantitative, qualitative, or mixed)
- Data source (primary or secondary)
- Unit of analysis (household or individual)
- Study design
- Country
- Continent

Unit of analysis

The literature synthesis was based on the aggregate findings from each of the selected articles, rather than the individual cases described within articles (28% of articles included study sites spanning multiple countries). This means that we could lose out on some of the internal nuances as some articles might find a positive relationship between forests and food and nutrition security in one country and a negative relationship in another. To avoid this over-simplification, we recorded both groups of positive and negative relationships within a case (article) when aggregate findings pointed in both directions.

Statistical tests

We used chi-square analysis and t tests to examine possible associations between our outcome variables (positive or negative relationships reported in publications between forests and food and nutrition security) and the methodological features of the publications (e.g., sample size, study design, year of publication) (Table S5). No significant relationships were found. We used chi-square analysis and Fisher's exact test to test for associations between outcome variables and explanatory pathways. We only found a negative association between studies using health indicators and describing the income pathway ($p < 0.05$) (Table S7). In other words, whether the studies applied general health measures, dietary diversity scores, measures of nutrient intake, or food security indices did not appear to be related to the type of explanatory pathways they provided. Likewise, the study design, methodological approach (quantitative, qualitative, or mixed methods), geographic region, and year of publication were not significantly associated with the type of food and nutrition security outcome described. We also used chi-square analysis to test for associations between whether an article reported a positive or a negative outcome for food and nutrition security and (1) the type of assessment provided in the article (direct assessment, indirect assessment, no explicit assessment of forest-food linkages), and (2) the explanatory pathways in focus to describe forest-food linkages (Table S4). Finally, we tested for associations between the geographical location (Asia, Africa, or Central and South America) and (1) the type of food and nutrition security metrics used and (2) the type of explanatory pathway in focus to describe forest-food linkages (Table S8).

The role of wild foods

The aim of this review is to contribute with new insights on the linkages between forests and food and nutrition security. A substantial body of literature explores relationships between wild food consumption and food and nutrition security. For example, a recent study found that consumption of wild meat was associated with higher hemoglobin concentration among rural Amazonian children most vulnerable to poverty.[91] Despite the importance of such studies, we focus on the literature measuring both wild food consumption and some indicator of forest proximity or forest use. In other words, studies focused on, for example, wild food consumption in urban areas, were excluded. Reasons include: (1) many wild foods tend to be found outside of the forest[37] and can therefore not be used to examine the role of forests in relations to food and nutrition security, and (2) a fairly recent comprehensive review of the linkages between wild foods and nutrition exists[92] that assessed the current state of evidence on how wild and cultivated biodiversity in all forms is related to people's diets and nutrition.

Assessment of forest proximity versus forest use

We distinguished between (1) effects on food and nutrition security due to households' proximity to forest and (2) effects on food and nutrition security due to changes in households' use of forest resources. Studies that examine proximity to forests tend to apply a cross-sectional comparison of different study sites with different levels of forest cover within a certain radius (often 10 km).[20,22] Studies that examine changes in forest use tend to examine differences in use and consumption of wild forest products among local populations.[33,44] Such studies often find that improved forest use is positively associated with food security when looking at a specific population over time.[45,93] However, these populations might also be more food insecure compared with populations located far from forests.[56] We addressed this by including both type of studies (proximity and/or forest use).

Definition of food and nutrition security

Food and nutrition security is defined as a state where all people at all times have physical, social and economic access to food of sufficient quantity and quality in terms of variety, diversity, nutrient content, and safety to meet their dietary needs and food preferences for an active and healthy life, coupled with a sanitary environment, adequate health, education, and care.[1]

As described previously, we use the term food and nutrition security to cover various measures of food security, dietary quality, and health indicators included in the literature. While we acknowledge that food safety (and food safety hazards) is an important component of food security,[94] we made a deliberate choice not to include studies on food safety hazards as it was beyond the scope of this study. Measures such as prevalence of stunting, wasting, anemia, dietary diversity, nutrient adequacy, Household Food Insecurity Access Scale, and days without food are considered indicators of food and nutrition security. We note that this does not provide an exhaustive list of all food security metrics (e.g., food safety hazards were not included in the list). Yet, it captures the commonly used metrics.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.oneear.2022.11.005.

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AUTHOR CONTRIBUTIONS

R.S.O. and L.V.R. conceived the idea and designed the data collection process. R.S.O. collected and coded the data. R.S.O., L.V.R., and C.M.H. designed the analysis. R.S.O. conducted the analysis. R.S.O., L.V.R., and C.M.H. contributed interpretations of results. All authors contributed to the writing of the paper.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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