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Vansant, Emilie C.; Mausch, Kai; Ickowitz, Amy; McMullin, Stephe; Karanja, Alice; Rasmussen, Laura Vang

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What are the links between tree-based farming and dietary quality for rural households? A review of emerging evidence in low- and middle-income countries

Emilie C. Vansant1 | Kai Mausch2 | Amy Ickowitz3 | Stepha McMullin2 | Alice Karanja2 | Laura Vang Rasmussen1

1Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark
2World Agroforestry (ICRAF), Nairobi, Kenya
3Center for International Forestry Research, Bogor, Indonesia

Correspondence
Emilie C. Vansant
Email: ecv@ign.ku.dk

Abstract
1. In most low- and middle-income countries (LMICs), conventional agricultural policy promotes specialized production systems of carbohydrate-rich crops to address hunger and food insecurity. For rural populations, however, increased landscape uniformity can reduce both agrobiodiversity and wild biodiversity, which can contribute to diet uniformity. Although maintaining diversity in and around agricultural systems is far from a new approach, there is growing empirical attention on the contribution of trees on/around farms to dietary quality. While recent research suggests that forests can contribute to improved diets, there is only emerging evidence on how incorporating trees into farming systems not only benefits nature but also positively affects the diets of rural households.

2. This review synthesizes the existing empirical research on the linkages between different types of tree-based farming systems and indicators of dietary quality in LMICs. The objective is to build a foundation for future research that supports sustainable production systems with dual benefits for people and the natural environment.

3. The small, yet heterogeneous literature pool (n = 36 studies) reflects the high variance in how trees on/around farms are examined across cultural and geographical contexts. Our analysis identifies three major outcomes: (a) managing tree-based farming systems for both direct provision of wild and cultivated foods, as well as income used to purchase foods, may give households more strategies for dietary diversification and improve dietary quality; (b) the relationship between different tree-based farming systems and dietary quality is moderated by socio-economic and biophysical factors at the national, landscape and household levels; and (c) indigenous populations engaged in traditional forms of subsistence-oriented tree-based farming seem to maintain high levels of dietary diversity, indicating the importance of local knowledge and biodiversity.
stewardship to maintain these food sources in the face of commercial agricultural expansion.

4. Our synthesis of existing evidence highlights a need for a more nuanced understanding of how different types of tree-based farming systems contribute to dietary quality. Combining research methods from the domains of agriculture, forestry and nutrition can lead to more precise measurement of tree-based farming/diet linkages, and in doing so, support programs promoting increased landscape and dietary diversity in LMICs.

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KEYWORDS
agroforestry, dietary quality, landscape approach, nutrition, trees on farms

1 | INTRODUCTION

Rising global demand for commodity crops drives large-scale agricultural expansion and deforestation, predominately in low- and middle-income countries (LMICs) (Winkler et al., 2021). Despite pushes for agricultural intensification and specialization in these regions, trees on/around farms remain prevalent in production systems: half of all agricultural land in LMICs is estimated to have at least 10% tree cover (Zomer et al., 2016). There is already some evidence on the associations between tree-based farming systems and positive ecological outcomes including, among others: soil enrichment (Mendez et al., 2009; Sileshi & Mafongoya, 2006), improved water regulation (Ilstedt et al., 2007), enhanced carbon sequestration (Nair et al., 2009; Takimoto et al., 2008) and increased biodiversity (da Silva Moço et al., 2009; Johnson et al., 2009). However, there has been comparatively little explicit focus on how incorporating trees into farming systems influences dietary quality. We review the emerging research on this topic to elucidate linkages between tree-based farming systems and diets and in doing so, build a foundation for future research on sustainable production systems that support people and the natural environment.

Policies promoting specialized crop production in LMICs, often at the expense of biodiversity and tree cover, may contribute to micronutrient deficiencies for rural populations (Ickowitz et al., 2019; Lachat et al., 2018; Vira et al., 2015). Increased reliance on a handful of energy-dense, input-responsive crop and livestock species has also eroded genetic pools of plant and animal species as well as the diversity of foods that people consume (IPES-Food, 2016). A narrow focus on increasing food production through intensive agriculture in these regions is not sufficient to eliminate the problem of malnutrition, which is the leading cause of mortality and morbidity worldwide (Global Nutrition Report, 2020).

Several high-level policy reports have recently identified the re-orientation of conventional agricultural development policies as a key strategy to achieve healthy diets for nearly 10 billion people by 2050. These reports cite the need for a more sustainable approach to food production with enhanced agrobiodiversity (Global Panel on Agriculture and Food Systems for Nutrition, 2020; IPES-Food, 2016; Rockström et al., 2019), as diverse crop production and species richness can contribute to improved dietary quality (Jones, 2017; Lachat et al., 2018). At the 2021 United Nations Food Systems Summit, key action items included strategies to synergistically increase access to nutritious food and promote nature-positive production; in line with this objective, scientists highlighted the imperative of maintaining trees in landscapes (Hodson et al., 2021). Tree-based farming systems have the potential to address multiple UN Sustainable Development goals such as SDG 1 (No Poverty) through income and improved crop yields, SDG 2 (Zero Hunger) through food provision, SDG 12 (Sustainable Consumption and Production) through environmental protection and SDG 15 (Life on Land) through supporting ecosystems and biodiversity. As a form of integrated land-use management, tree-based farming systems can facilitate synergies between the policy domains of agriculture and forestry, creating space for more holistic interventions to improve both food and nutrition security as well as protection of nature (van Noordwijk et al., 2018).

Recent research shows that the conservation and regeneration of trees in and around farmland can contribute to natural resource management and environmental protection while also increasing social and economic benefits at farm and landscape levels. The potential benefits of trees to household farm productivity include increased soil fertility and crop yields (Garrity et al., 2010; Reed et al., 2017), microclimate regulation (Place et al., 2016), as well as enhanced pest and weed control (Hoehn et al., 2010; Pumariño et al., 2015). Tree-based farming systems can also support ecosystems at the wider landscape scale through greater biodiversity conservation (Bhagwat et al., 2008) and climate regulation through carbon sequestration (Kuyah et al., 2017) compared to cleared or intensively developed landscapes. The extent to which tree-based farming systems can effectively support diverse production through ecosystem services differs with tree–crop species combinations, spatial arrangement/density, environmental conditions and management practices (e.g. conventional or organic). Yet research from both tropical and temperate regions consistently shows that the presence of trees in cropping systems can provide long-term benefits to ecosystems at multiple scales.
Leveraging the environmental services of trees to improve agrobiodiversity and natural resource management on farms and in landscapes can also benefit the diets of rural people (Powell et al., 2015; Sunderland et al., 2013). At the farm level, linkages between agrobiodiversity and better dietary quality are well-documented (Chegere & Stage, 2020; Jones, 2017; Jones et al., 2014; Koppmair et al., 2016; Powell et al., 2015). At the landscape scale, recent research suggests that trees in forests can increase availability and access to a variety of nutritious foods, either directly by serving as a source of wild foods, including fruits, vegetables, nuts and a wide array of hunted wildlife species (Baudron et al., 2019; Galway et al., 2018; Ickowitz et al., 2014; Powell et al., 2013; Tata Ngome et al., 2019), or indirectly through income (Angelsen et al., 2014) and/or vital ecosystem services to agriculture, such as pollination (Baudron et al., 2017; Meaza & Demssie, 2015; Reed et al., 2017). As agricultural research and policy are primarily focused on annual crops (or tree cash crops), the contributions of trees on/around farms to dietary quality remain relatively understudied despite their potential to provide dual benefits for people and the surrounding ecosystems.

This paper synthesizes existing empirical research that addresses linkages between tree-based farming systems and indicators of dietary quality in LMICs to build a foundation for future research on sustainable production systems that support people and the natural environment. In doing so, this review adds to the broader discourse on tree cover–agrobiodiversity–diet linkages through focusing on agricultural systems that integrate trees, here referred to as ‘tree-based farming systems’. This phrase captures the many ways that trees are integrated into and around farmland, including: trees on farms (such as trees inter-cropped into annual cropping systems), home gardens, shifting cultivation (swidden, slash-and-burn), timber/tree-crop plantations and forest-edge farming. Adopting a broad definition of tree-based farming systems permits an investigation of the different pathways linking trees to diets: by providing either food for household consumption (direct provision pathway), marketable products (income pathway), or ecosystem services to increase agricultural production (agroecological pathway) (Baudron et al., 2019). In addressing these pathways, this paper draws upon a small but heterogeneous pool of research to answer the following questions: (a) what is the empirical evidence for linkages between tree-based farming systems and dietary quality in LMICs?; (b) what are the most common research approaches and covariates used in evaluating these linkages?; and (c) how can future research be designed to better understand the relationships between tree-based farming systems and diets? Finally, we consider the implications of our findings for informing future research and policies on the integration of trees into farming systems to promote landscapes that support diets and ecosystems.

2 | LITERATURE SEARCH AND DATA ANALYSIS

A literature search was conducted for peer-reviewed, empirical research (in English) describing at least one tree-based farming system and a measure of dietary quality. Literature was gathered from diverse disciplines, including, among others: nutrition, agriculture development, ecology, anthropology and forestry. A comprehensive search query was developed to capture the terminology used across these fields of study. Keyword searches combined words and phrases associated with tree-based farming systems (“tree-based”,

FIGURE 1 Literature review flow chart, adapted from Ruel et al. (2018)
“agroforest**”, “shifting cultivation”, “plantation**”, etc.) as well as terms specifying dietary quality outcomes, including (“food security”, “nutrition”, “diet” diversity”, “diet” quality”, “undernutrition”, “over-nutrition”, “malnourish**”, “nutrient deficienc**”, etc.; see Table S1 for full search query). Versions of the query were tested with Web of Science, SCOPUS and CAB Abstract databases. The search was deemed comprehensive when adding to the search query ceased to generate any new papers related to the research questions.

The final keyword topic query was used to search literature on Web of Science, resulting in 12,414 papers (Figure 1) with no additional papers identified through SCOPUS or CAB Abstracts. Papers were then assessed using the following four inclusion criteria: (a) study area should be within a LMIC; (b) the study should include one or more tree-based farming system; (c) the study should measure one or more indicators of dietary quality within a determined population; and (d) all or a defined part of the study population (for which a dimension of dietary quality is measured) engages in tree-based farming. Using the ‘search within results’ function (n = 12,414), a keyword topic search was conducted to exclude papers that did not comply with the first criterion. Eliminating all non-LMIC-based studies and non-relevant subject areas resulted in 1,274 papers (Figure 1, Table S1). The remaining paper abstracts were then screened for relevance of subject matter following the second, third and fourth inclusion criteria. No time frame was specified in the initial search; however, given the relative weakness of the search databases in identifying older citations from the humanities, bibliographies of included papers were also reviewed to identify studies absent from the keyword searches (Martín-Martín et al., 2020), resulting in five additional papers.

Upon completion of the title and abstract screening, 85 papers were selected for a full-text review and a critical appraisal. Some papers that were originally flagged as examining one or more tree-based farming systems and dietary quality were reassessed for how well these phenomena are described and/or measured. In general, the papers rejected (n = 49) at this stage did not adequately describe trees on/around farmland either as associated with dietary quality outcomes (as part of the predictor variable) or as practiced by the study population. An example of literature in this ‘grey area’ includes studies that examine the effect of a home garden intervention on people’s dietary quality but do not explicitly mention trees as a component of the home garden. Some of the screened papers that assessed dietary quality also measured food security or insecurity, such as number of hungry months or degree of self-sufficiency. These indicators were not assessed in the context of this review as they are generally more difficult to link directly to tree-based farming practices. We focus solely on dietary quality to gear our recommendations towards supporting nutrition-sensitive interventions at the landscape scale.

Finally, 36 peer-reviewed papers published in the period 1979–2020 were selected for data extraction, with the majority (27) published within the last 10 years (see Data Sources). Given the scarcity of existing papers that fit the search criteria, the papers were not screened for robustness of methods or intervention design. Papers were coded by the first author of this paper with the help of an assistant, with the first five papers coded together and subsequent meetings to ensure consistency in interpretation. Papers were categorized by study location, explanatory pathway explored, type of tree-based farming system included and type of assessment (direct, indirect and no explicit assessment) (Table S4). It was not possible to conduct a quantitative meta-analysis of the literature pool due to the heterogeneity in the units of observation (households, mother and child pairs, villages, etc.), tree-based farming system descriptions, dietary quality metrics and outcomes described. Therefore, to make meaningful comparisons between papers, the literature is divided into three groups for analysis: (a) direct assessment of tree-based farming system/diet linkages: papers that explicitly examine the relationship between tree-based farming systems and a dietary quality indicator, where practicing a form of tree-based farming is at least one of the predictor variables; (b) indirect assessment of tree-based farming/diet linkages: papers that include tree-based farming systems in the description of the predictor variable(s), but their role and/or influence on dietary quality is not the focus of the study; and (c) no explicit assessment of tree-based farming/diet linkages: papers in which dietary quality is measured for a population that engages in some forms of tree-based farming system as per the study area description, but the farming systems are not included as predictor variable(s) (Table S3). These groupings inform how tree-based farming systems might lead to better dietary outcomes (direct assessment), be one of many factors contributing to better dietary outcomes (indirect assessment) or present an ‘unknown’ factor in relation to how to achieve better dietary outcomes (no explicit assessment).

3 | LITERATURE OVERVIEW

3.1 | Spatial distribution of selected papers

The 36 selected papers address tree-based farming system/diet linkages in various geographic contexts, spanning 27 different LMICs. A majority (30) of the papers use subregion-level data, while six use broad-scale panel data to assess trends at the national, regional or multiregional level. Figure 2 illustrates the global distribution of study areas. As the literature search was only conducted in English, it is possible that non-English speaking regions are under-represented. Only five out of the 36 papers directly assess tree-based farming system/diet linkages, four of which have study sites in sub-Saharan Africa. The rest of the literature has a more even spatial distribution across LMICs.

3.2 | Classifying tree-based farming systems

We group the different tree-based farming systems examined into four categories: (a) home gardens/trees on farms (including inter-cropped fruit trees and multipurpose trees on farmland), (b) shifting cultivation systems, (c) timber/plantation tree crops, and (d) forest-edge farming (e.g. the use of nearby forest for livestock grazing; Table S2). Although these distinct systems all fall under the term ‘agroforestry’ as defined by World Agroforestry (ICRAF) and the Food and Agriculture Organization of the United Nations (Liu...
FIGURE 2  Geographic distribution of studies (n = 36). Four of these studies span multiple countries/regions, resulting in 48 different study areas. Percentages of the studies in each region are given for each pathway, type of tree-based farming system and type of assessment of tree-based farming system/diet linkages (direct, indirect and no explicit assessment). Note: All tree-based farming systems are noted for each study area. As many studies included multiple tree-based farming systems, the total number of tree-based farming systems addressed per region is higher than the number of studies, meaning that the sum of the percentages reflected in the blue circle charts is higher than 100%.
et al., 2019), they are separated in this study to facilitate an in-depth analysis of the role of trees.

3.3 | Measures of dietary quality

The selected papers use a variety of indicators as proxies for assessing dietary quality, including dietary diversity scores, food variety scores, intake levels of key macro/micronutrients, caloric intake, intake of key food groups (i.e. fruits and vegetables) and frequency of food consumption over a reference period. The included papers typically gather this type of data by asking respondents to recall all foods consumed over a reference period (usually 24 hours, 7 days or 1 month). Sixteen papers use the 24-hour recall method to obtain data on food consumption for individuals or households, seven use a food frequency questionnaire and seven use a range of non-standard food consumption surveys to measure food intake for a study population at the individual or household level. The six remaining papers use a mix of qualitative and quantitative methods to gather data (or use publicly available data) on dietary quality, including village-level focus groups (Behera et al., 2016), food diaries (Broegaard et al., 2017; Thamilini et al., 2019) and participatory observation (Dounias et al., 2007; Fleuret, 1979), with reference periods spanning from 1 day to several weeks. Only one paper relies entirely on anthropometric measurements to assess the relationship between trees on farms and nutritional outcomes (Miller et al., 2020); although anthropometric measurements alone are not proxies for diet quality, this paper is retained due to its explicit focus on the importance of trees on farms for household nutrition.

Most of the papers (26) use retrospective data to calculate a dietary diversity score as an indicator of dietary quality. Dietary diversity scores can be used to measure household access to food or can serve as a proxy for caloric or nutrient adequacy at the individual level (Kennedy et al., 2013). Seventeen of the papers report dietary diversity scores at the household level, while nine papers report the score at the individual level. Some examples of calculated indicators include the minimum dietary diversity score for women (Desalegn & Jagiso, 2020; Ghosh-Jerath et al., 2020), mean household dietary diversity score (Baudron et al., 2017, 2019; Blundo-Canto et al., 2020; Fernandez & Méndez, 2019; Fréant et al., 2019; Hamann, 2018; McMullin et al., 2019; Rasmussen et al., 2020; Remans et al., 2011; Sibhatu, 2019; Thamilini et al., 2019), household nutrient deficit score (Thornhill et al., 2016) and food variety score (Ogle et al., 2001; Powell et al., 2013b; Thamilini et al., 2019). Eleven papers combine these retrospective methods with physical assessments to calculate anthropometric measurements, BMI, haemoglobin levels and MUAC (mid-upper arm circumference) as indicators of nutritional status. About half (19) of the papers triangulate data from multiple nutrition assessment methods or derive different indicators from the results of a single method to provide a more complete picture of the dietary quality of the study population(s).

3.4 | Explanatory pathways

All of the literature reviewed addresses how tree-based farming systems can contribute to dietary quality along two principal pathways¹: (a) direct provision through edible tree products, and/or (b) contribution to household income through the sale of tree-based products, which can be used to purchase nutritious foods that in turn might improve dietary quality. The type of tree-based farming system examined is in turn associated with which of these pathways the researchers hypothesized as relevant (Figure 3). For example, all of the papers assessing a population with home gardens and/or on-farm trees (23) explore how these systems affect dietary quality through direct provision of fruits, nuts and/or vegetables (i.e. the direct provision pathway). About half (11) of these papers also examine how the systems can provide income to augment and diversify household food consumption (i.e. the income pathway). The same pattern can be seen with the papers that focus on shifting cultivation/agroforestry and forest-edge farm systems. A greater proportion of the papers examining timber/plantation tree crops address

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¹ Explanatory pathways addressed by papers based on tree-based farming system(s) included. Percentages given for studies that addressed the income pathway only, the direct provision pathway only and both the income and provision pathways—broken down for papers that included home gardens/trees on farms (n = 23), shifting cultivation systems (n = 10), timber/plantation tree crops (n = 18) and forest-edge farms (n = 15).
the income pathway (15), either exclusively (5) or in combination with the direct provision pathway (10).

3.5 | Dietary outcomes across tree-based farming systems

Out of the 36 papers, 12 find a positive association between tree-based farming and dietary quality indicators, 11 report mixed outcomes and 13 have neutral/non-stated outcomes (Figure 4). Mixed outcomes include (a) different dietary quality outcomes for different tree-based farming systems examined (without any comparison to non-tree-based farming systems) or (b) different dietary quality outcomes for different indicators measured for individuals/households engaged in a single type of tree-based farming system. Neutral or non-stated outcomes include, for example, studies that do not draw any conclusions about how the dietary quality of the study subjects might be related to their farming practices. No papers report exclusively negative dietary quality outcomes in relation to tree-based farming systems, which may indicate a bias towards reporting positive results. We observe a significant association between the type of assessment (direct, indirect and no explicit assessment) conducted and the reported dietary quality outcomes ($\chi^2 = 10.38, p = 0.04$) with more positive dietary quality outcomes reported for studies that directly assess the role of tree-based farming systems as an explanatory variable. It is also worth noting that none of the papers that described or hypothesized associations make any conclusions about causal impact. Most of the papers do not explicitly include ‘engaged in tree-based farming’ as a predictor variable, and none of the papers use an experimental or quasi-experimental design that would allow for the estimation of causal impacts of tree-based farming systems.

Figure 4 illustrates the tree-based farming system/diet association grouped by explanatory pathway and the type of tree-based farming system included. Chi-square tests reveal no significant association between pathway or the type of tree-based farming system and the study outcome. Positive study outcomes seem to be evenly distributed across the type of tree-based farming system examined.

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**FIGURE 4** Results for all studies (top), by explanatory pathway (middle) and by type of tree-based farming system included (bottom). Note: Each paper selected for this review describes either a positive, mixed or neutral/non-stated association between tree-based farming system(s) and dietary quality. The graphs above show how these outcomes relate to the type of explanatory pathway explored and type of tree-based farming system included. For each grouping, the proportion of studies that include positive, mixed and neutral/non-stated associations is given. Chi-square tests revealed no significant association between pathway and study outcome ($\chi^2 = 8.18, p = 0.08$) nor presence/absence of shifting cultivation, timber/plantation tree crops, or forest-edge farming systems and study outcomes ($\chi^2 = 0.11, p = 1.0; \chi^2 = 1.51, p = 0.50; \chi^2 = 0.12, p = 1.0$ respectively). There appears to be a significant association between presence/absence of home gardens/trees on farm and study outcome ($\chi^2 = 10.38, p = 0.003$), but we hypothesize that this is due to the large number of papers that include home garden/trees on farm relative to other tree-based farming systems.
For explanatory pathways, however, a greater percentage of studies that analyse both direct provision and income pathways identify a positive association between tree-based farming system(s) and dietary quality. This indicates that research approaches that look at only income contributions or only the direct provisional capacity of trees are likely to underestimate the real contribution of tree-based farming systems to dietary quality.

4 | RESULTS

4.1 | Direct assessment of tree-based farming system/diet linkages

All five studies with a direct assessment were published within the last 5 years; four use data from sub-Saharan Africa and one uses data from Indonesia. Three use primary data from local-level fieldwork, while the other two analyse secondary data at the national scale. A summary of the papers’ characteristics and their findings can be found in Table S2. Four out of the five studies identify positive associations with dietary quality outcomes, but more empirical research is necessary to extrapolate the findings across a larger scope of contexts. Despite the heterogeneous nature of the five papers, all papers show how the benefits of different types of tree-based farming systems to household dietary quality depend on the diversity of such systems and their orientation (subsistence vs. commercial), as well as important biophysical and socio-economic moderators. Socio-economic factors that moderate the direct food provision and income explanatory pathways include education, wealth, land holdings, market integration and gender relations; and biophysical factors include tree function (marketable products vs. provisioning services), proximity to forest or woodland, and agroecology/climate.

Although there is substantial variation in empirical approach, all five papers report positive associations between cultivation of trees within diverse production systems and dietary quality. For example, in a follow-up to an NGO-led intervention, Bostedt et al. (2016) evaluate the effects of an agroforestry extension service in Western Kenya. In a zone typically dominated by dryland agropastoralism, the authors find that farmers with access to agroforestry extension (including provision of tree seedlings to plant on farms and home gardens) had a significantly higher mean dietary diversity score when compared with a group of farmers who did not receive extension services (Bostedt et al., 2016). In a study examining links between tree-based land systems and diets in Indonesia, Ickowitz et al. (2016) also investigate the direct provisioning pathway and use food frequency data from a national survey to arrive at a similar conclusion.

They find that children living in areas with shifting cultivation/agroforestry land-use systems consume micronutrient-rich food groups more frequently than those living in other land-use systems.

Desalegn and Jagiso (2020) test the associations between tree-based farming systems and dietary quality at the local level, using different dietary diversity metrics for mothers and children in three Ethiopian agroforestry land-use systems with distinct agro-climates. They find that the average diet diversity scores for mothers and children living in highland agroforestry systems are significantly higher relative to those in the mid- and lowland agroforestry systems after controlling for potential confounders such as agroecology, sources of income and education. The authors postulate that the positive association is partially because a greater proportion of the highland group manages diverse mixed agroforestry systems, with a greater number of households growing fruit trees than in the mid- and lowland climatic zones. They find that mothers and children from households that do not cultivate fruit trees are more likely to consume less diverse diets than the other study groups. Similarly, in their study of trees on farms in Uganda, Miller et al. (2020) find that having trees on farm, especially fruit trees, is associated with better nutritional status for children via the income pathway, and is associated with a decrease in the prevalence of child wasting (Miller et al., 2020). In assessing how farmer-managed natural regeneration is associated with dietary diversity, Binam et al. (2015) find that farmers who actively manage tree regrowth on their farmland are more likely to experience an increase in dietary diversity.

Education and wealth, often interlinked, also emerge as important moderators. Bostedt et al. (2016) note that the education level of households that received an agroforestry intervention is significantly higher than the control, which can influence the household’s daily dietary choices and the likelihood of agroforestry adoption. The authors acknowledge this is probably due to self-selection, with more highly educated households seeking advice from extension services. This parallels findings in other studies that evaluate agriculture and nutrition projects, where education is shown to enhance the efficacy of various nutrition-sensitive interventions (Rasolofoson et al., 2020). With tree-based farming, education and wealth are key assets that can motivate farmers to make the initial long-term investment and the ability to manage the time-lag between planting and harvest. Knowledge of the indirect benefits trees may have can help households make informed land-use decisions.

Including an impact assessment was not one of the inclusion criteria for this review. Measuring the influence of socio-economic factors can raise the issue of reverse causality. Households with higher incomes are more able to purchase diverse foods and are also more able to invest in on-farm tree planting (Miller et al., 2020). Therefore, it is not always simple to ascertain if a household’s income facilitates the adoption of tree-based farming systems, or if the adoption of tree-based farming systems results in increased income and improved diets. Further in-depth exploration of farmer motivations for adopting different tree-based farming systems is needed to tease out the nuances and directionality of these relationships.

4.2 | Indirect assessment of tree-based farming system/diet linkages

Sixteen studies describe engagement in one or more tree-based farming systems as explanatory variable(s) without explicitly
addressing the role of trees within the farming system in relation to dietary quality. These studies address dynamics at the landscape scale that shape the use of tree-based farming systems, such as degree of agricultural specialization and market integration. They also address socio-economic factors at the household level influencing tree-based farming system management, such as wealth, asset control and gender-driven power dynamics.

Increased agricultural specialization and size of tree-based farming systems often coincide with cash crop expansion, deforestation and/or a reduction in fallow area. Such land-use changes that reduce production diversity appear to be associated with reductions in dietary diversity. Four studies analyse tree-based farming systems and dietary quality in the context of land-use change and how these changes influence the way in which households acquire and consume food (Behera et al., 2016; Blundo-Canto et al., 2020; Broegaard et al., 2017; Friant et al., 2019). Land-use changes often imply an increase in market integration, either through shifts from subsistence to cash cropping, or agricultural expansion at the expense of forests or forest-dependent land-use systems, such as shifting cultivation. For example, Blundo-Canto et al. (2020) find that over a 15-year period, expansion of cash cropping and reduction in forests in the Peruvian Amazon led to increased household dependence on markets for food and reduced household dietary diversity. Over this period, households in the region that grow oil palm experienced a greater decline in household dietary diversity than households engaged in traditional forms of shifting cultivation. The authors postulate that increased specialization in crop production led to reduced household access to cultivated food sources. Dietary data from a village-level assessment in India highlight a similar trend, where the greater availability of wild fruits in traditional shifting cultivation areas helps households achieve higher dietary diversity when compared to villages with more commercial agriculture (Behera et al., 2016). Parallel conclusions were drawn in a study from Laos, where a comparison of villages with different degrees of market integration found that households practicing shifting cultivation could collect more wild foods from agricultural fields than households practicing market-oriented maize cultivation (Broegaard et al., 2017). Indeed, agroforest and fallow areas are known repositories of wild foods, including vitamin A-rich fruits and vegetables (Friant et al., 2019; Powell et al., 2013b). In a study of coffee-based agroforestry systems in Mexico, Fernandez and Mendez (2019) find that green leafy plants, shade and fruit trees grown within coffee plots provide households with an important source of micronutrients, including iron and vitamin A. These findings indicate that certain tree-based farming systems integrated with forests or uncultivated landscapes may facilitate greater availability of wild and cultivated foods for households.

These papers on land-use change challenge the assumption that greater market orientation results in better diets by increasing food access. While some other studies find positive associations between market access and dietary diversity (Khiu & Amuakwa-Mensah, 2021; Koppmair et al., 2016; Sibhatu & Qaim, 2018), we see that increased commercialization of agriculture—which often accompanies greater market integration—does not necessarily translate into higher quality diets. This is possibly due to the loss of wild biodiversity and agrobiodiversity that often follows monoculture expansion (Mehraban & Ickowitz, 2021). The conflicting findings on the benefits of greater market orientation may be because (a) increased commercialization of agriculture does not automatically equal better market access, and/or (b) variability in both how market orientation and market access are measured and how markets are characterized. The proximity and type of market can also help determine a household’s opportunities for selling tree-based farm products, which can in turn lead to higher income and purchasing power, and/or interest in farm expansion, possibly resulting in deforestation and reduced availability of wild foods. For example, an investigation of forest-edge farming and agroforestry in Nigeria finds market access to be potentially more beneficial to dietary diversity of households than forest proximity, at least in the early and intermediate stages of deforestation (Friant et al., 2019). The authors postulate this is because the households with access to both markets and forest can buy and sell a variety of food resources while retaining access to wild foods; they conclude that improved access to markets can improve dietary diversity when coupled with forest protection. As suggested by the papers that examine tree-based farming systems in the context of land-use change, household diets can benefit from access to both markets and wild, tree-sourced foods. The findings lend greater nuance to the debate around the influence of market integration on diets, suggesting that conservation of wild and agrobiodiversity through retention of trees in and around farmland can positively influence the dietary diversity of households with market access. Yet rural households that prioritize agricultural commercialization and specialization at the expense of tree-based landscapes may possibly find fewer dietary benefits from market integration.

It would be an oversimplification to suggest that trees in subsistence-oriented systems are inherently more beneficial to dietary quality than trees in commercially oriented farming systems. Six papers illustrate the complexities of evaluating the dietary benefits of any one farming system orientation by comparing different commercial tree-crop production systems (Behera et al., 2016; Blundo-Canto et al., 2020; Euler et al., 2017; Hamann, 2018; Kiyingi et al., 2016; Sibhatu, 2019). Though the studies vary considerably in scope and research design, the conclusions highlight important moderating covariates to be considered in future research. In separate studies examining the association between small-scale oil palm adoption and the dietary quality of rural households in Indonesia, both Euler et al. (2017) and Sibhatu (2019) compare farmers who have converted their farmland to oil palm production with smallholders that specialize in traditional tree cash crops, such as rubber. Though both groups are considered to be engaged in tree-based farming, the results from both papers indicate that while oil palm cultivators enjoy higher dietary diversity than non-adopters (rubber and other traditional crop cultivators); they also have significantly more farm area devoted to production (Euler et al., 2017; Sibhatu, 2019). It is therefore important to consider how farmland area and crop type affect the relationship between commercially oriented tree-based farming systems and dietary quality. Behera et al. (2016) also distinguish between...
traditional and modern tree-based cash crop regimes, with traditional systems characterized by a diverse array of subsistence crops that only recently became commercialized. Yet the greater land and labour demands of the specialized tree cash crop systems causes the abandonment of traditional home gardens, which results in an inverse relationship between agricultural commercialization and household dietary diversity (Behera et al., 2016). The significance of the type of tree crop is further substantiated by Blundo-Canto et al. (2020), who differentiate households by type of crop production, comparing 'specialized tree cash crop growers (oil palm and cacao)', 'diverse cacao growers' and 'oil palm growers with diverse income sources'. Although all three of these groups can be classified as timber/plantation tree crop farming systems, the degree of farming system and income diversification are greater influences on dietary quality than the type of tree cash crops.

Tree-based farming households that source foods from both the direct provision and income pathways (i.e. supplement market-based diets with foods sourced from trees managed in and around farmland) have more strategies for diversifying diets and achieving higher dietary quality. Hamann (2018) finds that when comparing farmers engaged in small-scale versus industrial-scale oil palm production, ownership of a home garden is the greatest determinant of dietary diversity regardless of production sector. The authors conclude that oil palm farmers who maintain a subsistence farming system benefit from higher dietary diversity than oil palm farmers who rely only on the income pathway to access food. The planting of home gardens and/or their improvement is a well-studied agricultural intervention to improve household nutrition (Rammohan et al., 2019). For studies that describe the integration of trees in home gardens, the efficacy of these systems in improving household diets can be affected by forest proximity (Baudron et al., 2017), crop diversity (Thamilini et al., 2019), types of fruit trees included (McMullin et al., 2019) and ownership of additional productive farmland (Rammohan et al., 2019). Recent research into these traditional subsistence systems shows how on-farm trees can also make important contributions to household income and indirectly household diets. For example, home garden and agroforestry products can supplement the farming households’ income during lean seasons, providing a crucial safety net in times of food insecurity (Binam et al., 2015; Desalegn & Jagiso, 2020; Thamilini et al., 2019). In Mexico, Fernandez and Mendez (2019) find that farmers also use the trees in their coffee plots for firewood, timber and medicinal products, which can indirectly contribute to increased agricultural production and income. The amount of income from these systems that goes to food (and whether that is nutritious food) can be affected by gender inequality and control of assets, education, distance to market and quality of the food at these local markets (Fernandez & Mendoza, 2019).

Such socio-economic factors at the household level also influence how and for what purpose tree-based farming systems are managed. Land-use decisions on use of on-farm trees are often made at the household level (Somarriba et al., 2017), and are therefore influenced by gendered power structures and cultural norms. In Africa, male-headed households are found to be more engaged in on-farm tree-growing than female-headed households, in part due to greater land tenure security (Miller et al., 2017a). In the highlands of Ethiopia, men are reportedly more likely to plant trees for construction and farm inputs, whereas women prefer to grow fruit trees for food and supplementary income (Meaza & Demssie, 2015). Gender can play a pivotal role in determining not just what types of trees are planted, but how they are used—which may influence household diets. As a result, methods for studying these complex socio-economic dynamics must transcend simple food consumption surveys and quantification of income from agricultural production; empirical analysis of farming systems should encompass social, as well as environmental characteristics. Rasmussen et al. (2020) substantiate this claim by examining how wealth, farm system type and landscape contexts interact in relation to certain household dietary profiles in Ethiopia. They find that diets with high consumption of fruits and vegetables are associated with farming system type (in this case, coffee-agroforestry), whereas low-diversity diets and diets high in oils and sugars are associated with household wealth. This study is one of the first to develop nuanced farm typologies, which are then assessed in relation to key socio-economic household and landscape variables, as well as dietary profiles. More research is needed to tease apart the role of trees from the many other possible influences on household dietary quality, including forest proximity, labour demands, additional income sources, market integration and other key household assets.

4.3 No explicit assessment of tree-based farming system/diet linkages

Fifteen studies measure the dietary quality of a population that cultivates a form of tree-based farming system without explicitly analysing the relationship between the two phenomena. Some of these studies focus on assessing the dietary quality of indigenous populations, where limited market access may increase reliance on ‘traditional forms of tree-based farming’ (a general term we use to characterize long-standing practices of subsistence-oriented, tree-based polyculture cultivation by certain indigenous populations) as well as forest resources for agricultural inputs and ecosystem services. With the study population, not the farming system, as the principal focus, the research in this subfield takes two distinct forms: cross-sectional dietary studies and ethnobotanical studies. The cross-sectional dietary studies quantitatively assess the determinants of dietary quality for a certain population in order to devise appropriate and effective interventions for addressing malnutrition. Although the populations in these studies are described as practicing different types of agroforestry, the incorporation of trees or use of tree-based systems are not examined as potential determinants of dietary quality. For example, Bosha et al. (2019) and Dafursa and Gebremedhin (2019) assess linkages between dietary quality outcomes and independent socio-economic variables for enset growers in Southern Ethiopia. Both studies use statistical modelling to identify predictors of dietary diversity, including socio-economic status, home gardening (inclusion of trees not explicitly mentioned in studies) and paternal knowledge of infant and young child feeding (Dafursa & Gebremedhin, 2019) as well as seasonality (Bosha et al., 2019). In India, indigenous food
consumption is examined as a determinant of dietary quality in two cross-sectional studies of populations who practice agroforestry. Both find indigenous food intake to make a significant contribution to micronutrient intake in women (Ghosh-Jerath et al., 2016, 2020). In a study of different rural village populations in Thailand, Tienboon et al. (2008) also find that indigenous foods and cultural consumption habits are important influences on dietary diversity. Finally, a study in Nepal that examines the efficacy of nutrition-sensitive agriculture interventions (including the provision of trees) reports a positive effect on the dietary quality of rural households (Talukder et al., 2006).

The high dietary quality of the populations that practice traditional types of tree-based farming, as reported by ethnobotanical studies, suggests that tree-based farming systems can facilitate the consumption of hunted, gathered and/or cultivated indigenous foods that support household dietary diversity. In a study based in the East Usambara mountains of Tanzania, where farm plots and land boundaries contain wild and cultivated fruit trees, Fleuret (1979) combines participant observation and in-depth village surveys to show how trees on and around farms provided important sources of calcium and vitamin A, especially for village children. These findings are later substantiated by Powell et al. (2013b), who combine community-based participatory methods, a qualitative 7-day food-use questionnaire and two 24-hr recalls to investigate the nutritional importance of wild foods in the diets of mothers and children in the same study area. They find that households obtain and consume more wild species from cultivated areas in farms (generally with high tree cover), fallows and agroforests than from the forest; agricultural factors are significantly associated with wild food consumption, while forest use and access are not. This rigorous nutritional assessment yields evidence on how wild foods from tree-based farming systems can be an important source of micronutrients in diets. Though this literature does not treat cultivation of tree-based farming systems as a determinant of dietary quality, the papers consistently show that populations practicing traditional tree-based farming have access to a diverse array of wild and cultivated food sources.

The ethnobotanical studies analysing the diets of indigenous populations practicing traditional tree-based farming all indicate a positive relationship between these subsistence farming practices and dietary quality, using mixed methods from both anthropological and nutritional disciplines. In a comparison of rural Cameroonian tribes, Koppert et al. (1993) observe that, while all households have adequate diets, the agriculturalist-hunter tribes living at the forest edge have more balanced diets than the neighboring fishing populations or hunter-gatherers. Dewey (1981) substantiates his cross-sectional nutritional survey on land-use change in Tabasco, Mexico with qualitative household interviews, finding a negative relationship between dietary quality of children and the abandonment of subsistence shifting cultivation for cattle production and cash cropping. Similarly, da Silva and Begossi (2009) observe that the displacement of shifting cultivation activities by commercial fishing increases the consumption of market and imported food products by some rural Amazonia populations in Brazil, but does not necessarily improve household diets. Also in Brazil, Murrieta et al. (1999) assess the diets of three tribal groups in the Amazon facing changes in their natural environment and socio-cultural organization due to increasing acai palm extraction. The analysis shows how the households that maintain traditional shifting cultivation practices and participate in the local market through acai palm cash cropping have the most stable dietary adequacy across dry and rainy seasons. These results suggest that for rural households, traditional tree-based farming practices and market participation are not mutually exclusive strategies for diversifying diets.

Few of these interdisciplinary studies use the dietary quality assessment methods commonly used by the nutrition community (FAO, 2018) and are therefore rarely included in systematic reviews of the nutrition literature. The dates of the older ethnographic studies suggest that the methods used precede the more recent flux of modern dietary quality assessments and indicators used in current research. Yet, studies that pair quantitative dietary quality assessments with qualitative reporting shed light on the social, environmental and cultural nuances of tree-based farming systems. In particular, ethnobotanical studies of indigenous populations provide a holistic picture of the socio-cultural and ecological systems in which traditional tree-based farming systems are embedded, illustrating the potential importance of local knowledge and biodiversity stewardship in maintaining wild and cultivated sources of foods in the face of commercial agriculture expansion.

5 | CONCLUSIONS

5.1 | Linkages between tree-based farming systems and dietary quality: Summarizing existing evidence

Given the wide spectrum of tree-based farming systems and biophysical and socio-ecological contexts considered in this literature, we can only derive some broad hypotheses about how tree-based farming can best support dietary quality in LMICs. First, the papers highlight the importance of diversity at multiple scales. We note that diversity within tree-based farming systems may improve dietary quality by supplying farmers with a greater variety of marketable products or foods for direct consumption. These observations are substantiated by other studies that find small but positive associations between production diversity and dietary diversity (Jones, 2017; Mehraban & Ickowitz, 2021; Sibhatu & Qaim, 2018). Yet, more research is needed to better understand how trees specifically can affect the significance of this association. Managing tree-based farming systems for both commercial and subsistence purposes might also strengthen farm system and income resilience in the face of adverse climatic conditions, seasonal food shortages and uncertain market conditions, thereby indirectly supporting year-round dietary quality for households (Desalegn & Jagiso, 2020; Fernandez & Mendez, 2019; McMullin et al., 2019; Miller et al., 2020). Households with diverse production systems may also help
Second, we can extract several key covariates from the literature that we hypothesize are important for moderating tree-based farming-diet linkages. The capacity of a tree-based farming system to improve household diets, either through direct provision or through increased income, is dependent on biophysical moderators, such as elevation, climate and other agroecological characteristics of the larger landscape. It is also important to tease apart the influences of socio-economic factors at both the landscape and the household levels, which can affect the adoption/use of trees on farmland. These factors include market access, wealth, education, agriculture extension, farm area, tenure security, gender and cultural norms around land-use decisions. Indeed, there is already evidence that trees on farms can increase total gross annual income for rural households (Miller et al., 2017b). Yet, many of these socio-economic factors can help determine whether tree-based farming households reinvest this increased income into purchasing foods that improve diets directly or into improving the capacity of their farms to produce more food. These complex feedback loops are difficult to quantify and have yet to be thoroughly investigated.

Third, indigenous populations that practice traditional forms of tree-based farming can diversify diets by sourcing foods from cultivated areas, wild landscapes and local markets. Ethnobotanical studies provide insights into how farming systems and food cultures intersect; qualitative data from anthropological fieldwork indicate that traditional forms of tree-based farming systems can contribute to positive dietary outcomes. In particular, indigenous local knowledge is increasingly recognized as a key component of socio-environmental movements, spurring initiatives to develop methods that hybridize ethnobotany with science and technology studies (Congretel & Pinton, 2020). Future nutrition-sensitive agriculture initiatives should therefore use interdisciplinary approaches that incorporate such local, deep-rooted knowledge for an improved understanding of the factors that might enable or constrain adoption of tree-based farming systems as well as how certain tree products are used and consumed.

Finally, many of the studies we reviewed show positive associations between tree-based farming systems, household income and improved dietary quality. The relative benefits for income and diet quality, however, depend on the type of tree-based farming system in place: (a) home gardens/trees on farms, (b) shifting cultivation systems, (c) timber/plantation tree crops or (d) forest-edge farming. Even within these distinctions, the degree to which each system can influence diets varies with the configuration and diversity of food and/or income-provisioning tree species grown. The same can be said for environmental benefits: each type of tree-based farming system also likely has varying impacts on different environmental outcomes, such as the conservation of biodiversity and ecosystem services. Although outside the scope of this review, other research points to the ecologically restorative role of trees on/around farms when compared to non-tree monocultures (Barrios et al., 2018). Substantial evidence shows that the degree of diversity in tree-based farming systems can impact both landscape-level biodiversity and capacity for carbon sequestration (Somarriba et al., 2017). Therefore, we can postulate that diverse, multistrata home gardens or successional indigenous polycultures likely confer more environmental benefits than monoculture tree/plantation crop systems. While our synthesis also suggests that agro- and wild biodiversity within tree-based farming systems can play an important role in augmenting dietary quality, it is unlikely all tree-based farming systems confer environmental and dietary benefits in equal measure. Future policies and programs will need to consider these trade-offs and synergies in designing optimal tree-based farming systems that maximize co-benefits for people and nature.

### 5.2 Directions for future research

Until recently, trees outside the forests, and their contributions to dietary quality, have been overlooked in landscape and nutrition research in LMICs (Brandt et al., 2020; Miller et al., 2017b). In large-scale household surveys, the prevalence of non-forest trees is under-reported, especially those in home gardens and/or with no obvious productive function (Miller et al., 2017b). Those studies that do distinguish and attempt to measure the contribution of non-forest trees have largely focused on other indicators of human well-being, such as income or broader food security metrics. In other words, the indicators used to assess both the type of tree-based farming systems as well as the food security outcomes are many and varied, which can hinder empirical comparisons across studies and areas. Thus, it is pertinent for future research to use similar survey instruments across regions or countries; data collection tools would ideally include both natural and social sciences methods. For example, surveys could couple botanical assessments of wild and cultivated trees on/around farms with in-depth household interviews exploring how the trees and tree products are actually used (direct consumption, sale, to improve agricultural production, etc.).

Greater uniformity in methods applied across disciplines could also facilitate better comparisons of different types of tree-based farming systems and their effect on dietary quality, ideally assessing the income provision and ecosystem supporting capacities of trees in and around farmland. Yet this would also require a standard way of classifying tree-based farming systems across disparate geographical and cultural contexts. Currently, the classifications for tree-based farming systems have broad and often overlapping definitions that do not account for the degree to which trees are integrated in farming systems, or the ways in which the trees are used by the household. This is the case for research based in high-income countries as well: a review evaluating the studies of trees in urban food systems (e.g. community gardens, urban agriculture) finds that the terminology for tree-based farming systems lacks consistency across studies (Park et al., 2019). As more research emerges, it will be helpful to further develop our four-category typology of tree-based farming systems to facilitate more rigorous comparisons at multiple scales. Future research would also benefit from more precise and consistent terminology across
disciplines describing the roles of trees in agricultural systems, taking into account degree of tree cover, configuration, productive function and tree species diversity. While we acknowledge that our classification of tree-based farming systems is neither exhaustive nor mutually exclusive, it can serve as a first step to design ‘successful’ tree-based systems with an enabling political environment, appropriate biophysical conditions and management practices that maximize ecosystem services and contributions to dietary quality.

The papers included in this synthesis illustrate the complexities around reversing the co-trends of increasing landscape and diet homogeneity in LMIC contexts. While the evidence suggests that tree-based farming systems can positively affect rural household diets, the extent of these benefits is moderated by biophysical features of the landscape as well as socio-economic factors at the institutional and household levels. Rigorous impact assessments would be required to isolate the various influences and attribute differences in dietary patterns to trees in the farming system or the type of farming system. This would allow for a better understanding of the extent to which different tree-based farming systems contribute to food consumption, income generation and agricultural productivity across various regional contexts, and how increasing market access interacts with the integration of trees in and around farmland to affect diets. This more nuanced understanding of the different types and roles of tree-based farming systems across contexts will be useful in developing more targeted policy recommendations that move beyond simply suggesting that planting trees on farms will improve diets.

Tree-based farming systems provide households with an on-farm source of food and an avenue for income generation. As part of diverse production systems, trees in and around farmland can help increase agrobiodiversity as well as landscape biodiversity, and thus provide alternatives to wild sources of fuel, fodder and food. The emerging evidence illustrates the myriad and intricate ways in which tree-based farming—in its many forms—can influence the diets of rural households in LMICs. Our synthesis highlights the imperative of future research and policy to move beyond the forest-agriculture dichotomy by systematically addressing the linkages between trees, farming and dietary quality. Improved visibility and understanding of the role that trees play in promoting more ecologically sustainable and nutritious diets is a key step to designing more sustainable landscapes for people and the planet.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHORS’ CONTRIBUTIONS

E.C.V had the conception of the study within the guidelines of the grant agreement to contribute to the CIFOR-ICRAF Nutri-scapes Transformative Partnership Platform. The objectives of the platform parallel those of her PhD work within the FORESTDIET project. E.C.V designed the study and carried out the analysis with inputs from co-authors on the interpretation of the results. All co-authors (L.V.R., K.M., A.I., S.M. and A.K.) contributed to the writing of the manuscript and approved its publication.

DATA AVAILABILITY STATEMENT

Data are archived in the World Agroforestry Research Data Repository https://doi.org/10.34725/DVN/GHA3W7 (Vansant et al., 2022).

ORCID

Emilie C. Vansant https://orcid.org/0000-0002-7350-749X
Kai Mausch https://orcid.org/0000-0002-2962-7646
Amy Ickowitz https://orcid.org/0000-0002-0965-7661
Stepha McMullin https://orcid.org/0000-0002-0976-1880
Alice Karanja https://orcid.org/0000-0001-9095-4905
Laura Vang Rasmussen https://orcid.org/0000-0001-7786-6783

ENDNOTE

1 A third indirect pathway describing the ecosystem services provided by tree-based farming is only mentioned in four papers (Baudron et al., 2017, 2019; Binam et al., 2015; Powell et al., 2013b) and therefore is not included in the literature overview.

REFERENCES


**DATA SOURCES**


**SUPPORTING INFORMATION**

Additional supporting information can be found in the online version of the article at the publisher’s website.