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Agricultural Biodiversity and Diets

Evidence, Indicators, and Next Steps

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Abstract

This chapter synthesizes key findings on how agricultural biodiversity influences diets, and, based on this evidence, provides both policy recommendations as well as priorities for a future research agenda that can help to inform the promotion of diverse food systems for healthy diets. Empirical evidence is reviewed of the linkages between terrestrial agricultural biodiversity, both cultivated and wild harvested, and the diversity and quality of human diets. Further, the principal pathways through which agricultural biodiversity may influence diets are identified. An assessment is provided of the research challenges inherent in linking agricultural biodiversity and nutrition. Diet diversity and quality indicators are reviewed and analyzed relevant to understanding the relationships between agricultural biodiversity and diets. The chapter concludes with a set of policy recommendations for driving change at global and country levels to inform policy aimed at producing more diverse foods and improving diet quality through the mainstreaming of biodiversity into overall development objectives.

Introduction

Global cereal production and inventories are expected to reach record high levels in 2017 (FAO 2017). Long-term trends in global cereal production, which for decades have demonstrated growth since the Green Revolution, have rendered such record-setting achievements almost common place. This unprecedented abundance, however, may obscure the less conspicuous trend that food supplies worldwide are becoming increasingly homogenous (Khoury

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et al. 2014). Indeed, of the tens of thousands of edible plant species on the planet, only three crops provide the majority of calories in human diets: rice, maize, and wheat (FAO 2010b). The declining diversity of agricultural production systems worldwide is worrisome for multiple reasons. Agricultural productivity is fundamentally dependent upon the supporting and regulating ecosystem services that are provided by species diversity (Hooper et al. 2005). Biodiversity within agricultural systems may also provide resilience to climate-related shocks, as well as help to preserve cultural identity (Johns et al. 2013; Mijatović et al. 2013).

Agricultural biodiversity may also play an important role in contributing to diverse, healthy diets (Lachat et al. 2018). Poor-quality diets are the largest risk factor in the global burden of disease (GLOPAN 2016). This burden is composed of both undernutrition (i.e., it is largely driven by micronutrient deficiencies associated with low-quality, monotonous diets) as well as obesity and diet-related chronic disease (e.g., type II diabetes, hypertension, cardiovascular disease) (see also Chapter 9). To be certain, malnutrition is a complex challenge and has numerous underlying causes, not all of which are related to diets (Scrimshaw and San Giovanni 1997). The promotion of healthy diets through diverse food systems, however, may uniquely contribute to addressing the multiple burdens of malnutrition currently faced by many low- and middle-income countries.

In this chapter we synthesize key findings on how agricultural biodiversity influences diets, and, based on this evidence, provide both policy recommendations as well as priorities for a future research agenda that can help to inform the promotion of diverse food systems for healthy diets that also consider consumer demand and the role of the private sector.

Agricultural Biodiversity and the Diversity and Quality of Diets

Empirical Evidence of the Linkages

The most comprehensive review to date found that in 19 out of the 21 studies reviewed, there was a small, positive association between agricultural biodiversity and household-level diet diversity (Jones 2017). If interpreted as causal, the magnitudes of these associations indicate that four to ten additional crop species would need to be added to household agricultural production systems to increase the food group diversity of household diets by one group.

Though this assessment included only studies that adjusted for factors which also contribute to differences in household-level diets (e.g., wealth and education), the cross-sectional nature of nearly all of the reviewed studies makes it difficult to assess whether such a large number of new crop species would actually need to be introduced to affect diets. Policies or programs, for example, that strategically incentivize or introduce new

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crops into farming systems may require fewer such crops to influence the diversity of diets, particularly if incorporating behavior change efforts into the program (Berti et al. 2004). Furthermore, the association between agricultural biodiversity and diet diversity was not always monotonically increasing, such that marginal increases among low-biodiverse farms were associated with greater increases in diet diversity than increases among intermediate or high-biodiverse farms. This relationship makes intuitive sense, particularly when considering food group diversity of household diets as the outcome of interest. If the crops produced on high-biodiverse farms contribute directly to household consumption, these farms are most likely providing a large number of different food groups as compared to low-biodiverse farms, which may produce only a small number of staple crops that are likely to be considered part of the same food group (e.g., grains, roots, tubers). If one considers intraspecies variation, it is possible that there would be a distinct association. However, almost no studies have examined the association of varietal diversity with diet diversity. One study that did examine this association found no difference in the association of crop species and varietal diversity with diet diversity (Jones 2016). Thus it is likely that species diversity is a more efficient strategy for improving diets (Berti and Jones 2013). Yet, where intake of specific staple crops are high (e.g., in centers of crop origin such as Southeast Asia for rice and the Andean region of South America for potato), increasing intake of micronutrient-rich varieties of key staples may be an effective complementary approach.

Because nearly all of the studies in the above-mentioned review assessed only food group diversity of diets and not diet quality (e.g., micronutrient density), it is not clear how changes in crop species richness, at any level of existing agricultural biodiversity, might influence the availability of limiting nutrients in diets. As discussed below, glaring gaps in our understanding of the composition of underutilized species, or of diverse varieties of common species, is another challenge to examining the contribution of species richness to diet quality. One study that assessed daily intakes per adult equivalent of several macro- and micronutrients within households found that crop species richness was positively associated with energy, protein, iron, zinc, and vitamin A intake (Jones 2016). Nonetheless, limited data are available to make generalizations about the relationship between agricultural biodiversity and diets. It seems likely, though, that not all forms of agricultural diversification will have equivalent impacts on diets. Diversification efforts that increase access to nutrients deficient in the diets of vulnerable groups, such as women and children, especially iron, vitamin A, zinc, and folate, may have a more pronounced public health impact than other approaches (Jones 2017). In addition to the type of species, the dietary impact of agricultural diversification will ultimately depend on the use of the crop by the household (i.e., as food or cash crop).

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Pathways

Raneri and Kennedy (2017) identify two principal pathways through which agricultural biodiversity may influence diets:

1. Direct consumption by households of self-produced plants and animals (or wild harvested/caught species).
2. The sale of agricultural crops for income which may then contribute to diets indirectly through the purchase of foods.

The nutritional importance of the second pathway may be even more important than the subsistence pathway. Households with more market-oriented farms can have more diverse diets than those with less market-oriented farms (Jones 2017). In addition to providing income that can be used to purchase diverse foods in markets, food crops destined for market may also be kept in part for own consumption, thus contributing directly to diet diversity. However, as Jones (2017:8) indicates:

> Despite the importance of market-oriented production for diet diversity, the relationship between agricultural biodiversity and diet diversity appears to be consistent across farms with varying degrees of market orientation. This observation is consistent with evidence that suggests that greater diversification, especially in highly subsistence settings, may reflect greater, and not foregone opportunities for market engagement by smallholder farmers who maintain a foundation of subsistence staple crop production, but have also diversified into one or more cash crops.

Therefore, any assessment of the potential for agricultural diversification to influence diets must examine the potential for

- new and different crops to contribute to diets via these distinct pathways;
- gains or losses to income either through specialization or diversification;
- synergies between increased diversity for own consumption and for market; and
- the influence of a host of other factors, including market access, gendered control of decision making, land size, labor availability, food price-to-wage ratios, and consumer preferences.

Furthermore, changes in landscape-level biodiversity (i.e., aggregation of changes across multiple households or large-scale changes in a region) may facilitate additional pathways for dietary change beyond the scale of individual households. Landscape-level agricultural diversification, for example, may influence the diversity of foods available at regional markets, thus increasing the likelihood that income generation can lead to more diverse diets. The ecosystem service functions provided by enhanced biodiversity at the landscape scale may also initiate positive feedbacks on total farm productivity and contribute

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to household resilience (Raneri and Kennedy 2017). The dietary contribution of sustainable forests and wild-harvested foods, at both landscape and household scales, is another important pathway to consider between agricultural biodiversity and diets.

Wild Foods

An insightful and comprehensive review by Powell et al. (2015) indicates that while the contribution of wild foods to energy intake among most populations is low, such foods may constitute 20–50% of dietary intake of essential vitamins and minerals that are commonly lacking in the diets of low-income households (e.g., vitamin A, iron, calcium, riboflavin) (Powell et al. 2015). In many contexts, wild vegetables and fruits—commonly harvested in and around agricultural lands near to homes—make up more than half of the total vegetable and fruit intake of a population (Powell et al. 2015). Powell and colleagues caution, however, that wild food availability and use are not analogous, and that such foods are lacking entirely from diets in many regions, including in parts of the Amazon and East and West Africa (Powell et al. 2015). Perhaps more importantly, studies of the nutritional contributions of wild foods, as well as the extent to and mechanisms by which they may influence diets (including their possible role in mitigating seasonal food shortages), are few and sporadic such that there are numerous knowledge gaps remaining in the research literature. For example, recent work indicating positive and negative associations of tree cover and deforestation, respectively, with consumption of animal-source foods, fruits, and vegetables among children are intriguing, yet do not provide mechanistic insights into how tree cover may influence diets (Ickowitz et al. 2014; Johnson et al. 2013; Jones et al. 2017). Forest cover may be a proxy for more diverse agricultural production systems associated with proximity to forests, or forests may provide food directly or provide ecosystem services important for enhancing production of fruits and vegetables. Well-designed research studies that are focused explicitly on elucidating these and other potential mechanisms are required to better understand these dynamics.

Challenges and Priorities for Research and Policy

Research Challenges of Linking Agricultural Biodiversity and Nutrition

Several aspects make it difficult to derive lessons on the impact of agrobiodiversity and nutrition. Both agrobiodiversity, as an input, and nutrition, as the outcome, are the most commonly hypothesized pathways tested. Both are very broad and complex concepts. For example, nutritional status is influenced not only by food intake, but also by health and care practices, which in turn are influenced broadly through sociocultural norms and political and economic

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conditions (UNICEF 2015). Similarly, the use of agrobiodiversity for nutrition is mediated through a range of factors including affordability, availability (which can be either season, landscape, or market based (e.g., Cruz-Garcia and Struik 2015), and acceptability which is influenced by culture, tradition, nutrition knowledge, and food preferences (see Chapter 12). There has been a lack of research that tests the reverse relationship, how consumer demand can drive changes in agricultural production or diversification. The way in which these multiple agroecological, market, social, and cultural contexts shape the relationships between agricultural biodiversity, diets, and nutrition is important yet difficult to measure through commonly used research methods. Masset et al. (2012) have highlighted many of the challenges in assessing the impact of agriculture interventions on nutrition. Many of these factors are applicable here: study design, measurement of participant exposure to the intervention, and attention to metrics. Additionally, there are methodological gaps in how we measure dietary intake, in order to understand the role of agrobiodiversity in diets, as well as scientific gaps in documenting the actual nutrient composition of biodiverse foods (Kennedy et al. 2017b).

Typical impact studies in the field of nutrition focus on one specific intervention and one outcome (e.g., supplementation with vitamin A capsules to reduce vitamin A deficiency). In real life, it is both difficult and costly to test more complex relationships between agrobiodiversity and nutrition using a classical clinical-style randomized controlled trial model. Thus, cross-sectional studies are often used to try to understand some of the relationships, particularly at the level of production or market diversity and diversity of diets. Currently, scientists lack consensus on the appropriate metrics for measuring on-farm diversity as well as diet diversity. The biological significance of findings relating these concepts is also not clear.

One important critique is the mismatch between the agricultural biodiversity measurement and the nutritional meaning of the outcome measure chosen. Many disparate "count" metrics are used to measure agricultural biodiversity on farm or within landscapes, with no standardization to date. Agricultural biodiversity measures include counts of the number of plant species and varieties produced on farm, counts of plant and animal species, and, in other cases, the number of wild foods gathered. Agroecological concepts of species evenness and richness, such as the Simpson, Shannon, and Margalef indices, have also been applied. On the nutritional side, simple aggregate measures of dietary diversity are the most common outcome chosen; these metrics, however, do not usually reflect dietary biodiversity. Despite this, studies vary between measuring this at household, woman, or child level. A strong critique of the available evidence base is that dietary diversity, when measured at the household level, is not a nutrition outcome (Verger et al. 2016). Often, there can be a mismatch between the count used to measure agricultural biodiversity and the count used to measure dietary diversity. Even when individual level scores are used to test the relationship, there can be inconsistency in the number of food groups

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and the reference period (i.e., 24 hours or 7 days) used to derive the dietary diversity score (Jones 2017).

Another challenge for understanding the impact of the full range of agricultural biodiversity is that efforts to map inverse relationships between production diversity and diet diversity often neglect to include the contribution of wild and semi-wild foods and markets. Both wild plant and animal foods contribute to diet quality and may have important socioeconomic and cultural values to communities (Powell et al. 2015). These foods, even if not cultivated, are often collected from or around farms, and opportunities to leverage domestication possibilities can be missed when interventions are considered to diversify production systems. With increasing feminization of agriculture and increasing migration from rural areas, essentially resulting in part-time farming, the complementary role of markets to household agrobiodiversity production is often undocumented. Research to better understand how markets in local food systems can be utilized to leverage the agrobiodiversity available at a landscape level may offer more insight into the production, market, and diet nexus of biodiversity in local food systems.

Finally, analysis of the nutrient adequacy of diets strongly depends on the public availability of food composition data. National food composition tables often include data on the most commonly consumed foods by the majority of the population. This means that underutilized and biodiverse foods, which are often integral parts of traditional food systems, can be missing. Many studies document significant differences in nutrient content of varieties within species (Burlingame et al. 2009). Average values of the nutrient content of a species, when not considering differences among varieties, could incorrectly estimate the roles of nutritious biodiverse foods in the diet and further obscure important connections between agricultural biodiversity and nutrition (Lachat et al. 2018).

Importance of Diet Diversity and Quality Indicators

Despite the difficulties of evaluating the role of agricultural biodiversity in diets, the body of evidence is beginning to grow, and further detailed guidance is available on how to consider agricultural biodiversity in study design for dietary intake assessment (Kennedy et al. 2017b). It is important that we bear in mind the limitations of the various indicators most commonly used and how they may highlight or blur biodiversity–nutrition relationships. In addition, recent calls have been made for more attention to studies of diet quality that tackle issues beyond dietary diversity and that include considerations of both balance and moderation (Herforth 2016).

Individual diet diversity indicators have been validated for micronutrient adequacy in the diets of infants and women of reproductive age (FANTA 2006; Martin-Prevel et al. 2015). Household measures of diet diversity—such as the Household Diet Diversity Score (HDDS) (Swindale and Bilinsky 2006) and

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the Food Consumption Score (FCS) (World Food Programme 2008)—have been validated for energy intake and are intended to be used as food security indicators and not as nutrition indicators (Hoddinott and Yohannes 2002; Wiesmann et al. 2009). Recent validations of the HDDS and FCS concluded that despite its common application, these household-level indicators may not be viable indicators of household food security, and improvements seen cannot be used to assume improvements in household diets (Lovon and Mathiassen 2014; Vellema et al. 2016).

When applying household measures of diet diversity as nutrition outcome indicators, a main concern is that they do not account for intrahousehold dynamics, which often leave women and young children vulnerable to malnutrition, even when households have access to nutritious foods (Dang and Meenakshi 2017). Understanding the often intricate gender dynamics and norms within households can be challenging, yet it is crucially important (see Chapters 8 and 13). Properly targeting dietary intake assessments to nutritionally vulnerable individuals within households must be a priority goal.

Simple food group-based diet diversity scores may mask important variation in diets. Thus it is important to look at other measures of diet quality as nutrition outcome indicators. Diet diversity indicators focus on the contribution of food groups to diets and as such do not consider how variation within food group consumption can contribute to diet quality, nor do they fully capture the contribution of diverse species to the diet. Several studies have assessed the association of intragroup variety with energy and nutrient intake and health outcomes. Foote et al. (2004), for example, demonstrated that intragroup variety for some food groups (i.e., dairy, grain, fruit, and vegetables) showed strong associations with nutrient adequacy of single nutrients. Dietary species richness (DSR) is an indicator that measures biodiversity (as a count of the number of different species consumed) in the diet and is associated with individual micronutrient intake (Lachat et al. 2018). The indicator allocates a score for each unique species consumed in the daily diet, even when multiple food sources from a single species are present (e.g., if cow meat, cow milk, cow yoghurt, cow cheese, and chicken meat are consumed, then the DSR is 2). Presenting the species richness per food group consumed has the potential to allow for more in-depth understanding of how diversity within food groups can contribute to diet quality and nutrition. This indicator also offers an opportunity to be used with landscape or farm species richness indicators (i.e., counts of the number of unique species in a landscape) to measure and compare biodiversity using a single metric (species richness) in diet and agriculture. However, it remains important to consider the nutritional contribution and significance of multiple uses of the same species. For example, both the root and the leaves of cassava (*Manihot esculenta*) are consumed and provide distinct nutritional contributions to the diet.

The modernization and transitioning of food systems is a common global trend (see Chapter 6 and 8), and has been accompanied by an increase in

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diet-related noncommunicable diseases (e.g., diabetes, overweight, and obesity) in both urban and rural environments (HLPE 2017). There is extensive evidence related to the relationship between the increased consumption of ultraprocessed foods (i.e., foods that are often high in saturated fats, salts, and sugars and low in micronutrients and fiber) and an increased risk of noncommunicable diseases (Forouzanfar et al. 2015; Louzada et al. 2015). The NOVA classification system was developed by Monteiro et al. (2016) to assist with identifying ultraprocessed foods; however, the broad definition of ultraprocessed foods can make it difficult to operationalize (Gibney et al. 2017). Efforts to measure diet quality could also consider the dietary balance between fresh, minimally processed foods and ultraprocessed foods by presenting the percent of daily energy consumed that comes from ultra-processed foods.

Finally, nutrient adequacy indicators can provide rich insights into the details of micronutrient consumption and how biodiverse foods contribute to daily nutrient intakes. Recommended daily intakes (RDIs) of different nutrients have been established by different international bodies (e.g., the World Health Organization and Institute of Medicine), and many countries also have established their own RDIs. Including indicators that allow for comparison of population intakes compared to RDIs can provide detailed information on specific micronutrient gaps. The technical skills and costs (financial and time) required to collect and analyze these data are often reasons why these indicators are not included.

Each of the diet quality indicators have strengths and weaknesses (summarized in Table 10.1). Such a suite of diet quality indicators would ideally be selected for research studies to ensure different dimensions of diet quality are included that capture different elements of biodiversity.

Policy Recommendations

The recognition that hunger, food security, nutrition, and sustainable agriculture are deeply interrelated is clearly stated in the second sustainable development goal of the United Nations, yet food systems are currently not necessarily delivering healthy and sustainable diets (HLPE 2017). Universal, specific priorities for policy action aimed at producing more diverse foods and improving diet quality are clearly spelled out in the Foresight Report of GLOPAN (2016) and include recommendations such as "making fruits, vegetables, pulses, nuts, and seeds much more available, more affordable, and safe for all consumers." Integrated policy approaches and actions are required across the environment, agriculture, and health sectors to promote greater diversity and to better mainstream agrobiodiversity into relevant sustainable development goal indicators for improved tracking of the multiple long-term ecosystem services food-based approaches can deliver for human well-being (Hunter et al. 2015).

To drive change at global and country levels and to inform policy, however, significant research gaps need to be addressed to better link agrobiodiversity,

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Table 10.1 Summary of commonly used indicators to measure diet quality and their relevance to agricultural biodiversity.

Diet Diversity and Quality Indicators	Strengths	Weaknesses
Household diet diversity score Food consumption score	Quick to administer Limited technical skills required Widely used Collected with qualitative diet recall	Food security (access) indicator, not nutrition Does not consider intra-household dynamics Does not capture biodiversity May not consider biodiverse foods if limited food list used
Individual diet diversity score for women of reproductive age and infants aged 6–23 months	Quick to administer Limited technical skills required Widely used Collected with qualitative diet recall Validated as a proxy for micronutrient adequacy from the diet	Limited to food group diversity Does not capture biodiversity
Dietary species richness	Quick to administer Captures diversity in the diet Collected with qualitative diet recall	Requires additional technical skills to differentiate one species from another
Percent of energy from ultraprocessed foods	Captures one component of dietary balance	Requires quantitative dietary recall and specific technical skills Additional financial and time cost required Difficult to categorize ultra-processed foods
Micronutrient intake	Provides specific detail about the nutrient intake of the diet Can capture contribution of biodiversity in the diet if not using a limited food list	Requires quantitative dietary recall and specific technical skills Additional financial and time cost required
Prevalence of micronutrient inadequacy	Considers intrapersonal variation in daily diet	Requires repeat dietary recalls on a subsample of individuals
Mean micronutrient density adequacy ratio	Only requires one dietary recall	Does not consider intrapersonal variation in diet

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agriculture, nutrition as well as to document the role of agricultural biodiversity in improving nutrition (Hunter et al. 2016). Perhaps unexpectedly, areas that are rich in agrobiodiversity also often suffer from high rates of micronutrient deficiencies. The nutritional content of many traditional foods are often undocumented and as such, there is the need for more dietary intake and food composition data, particularly of traditional foods, which are often more affordable, available, and accessible to vulnerable groups. Food composition data is currently only available for a minor portion of the world's edible biodiversity, and national governments often lack the resources and capacity to collect information about what people actually consume (GLOPAN 2016). The International Network of Food Data Systems (INFOODS)—a forum for the international harmonization of food composition activities aimed at improving the quality, availability, reliability, and use of food composition data—has made efforts to collate food composition data on biodiverse foods (FAO/INFOODS 2013). Further efforts, however, are needed for countries to acknowledge the importance of biodiverse foods for inclusion in national food composition tables. Improving the evidence base on the importance of agrobiodiverse foods in diets, through use of appropriate dietary assessment tools and indicators, can better inform policy makers on how to identify foods to include in national programs including *in situ* conservation to improve nutrition (Bioversity Intl. 2017; Hunter et al. 2015; Hunter et al. 2016).

Research is needed on different policy options that can create incentives for people to diversify agricultural production systems for better nutrition and quality diets. This may include incentives for food companies to integrate neglected and underutilized species into national biodiversity conservation strategies and targets, as well as identifying opportunities for public procurement programs and public institutions including schools and hospitals to utilize nutritious biodiverse foods in feeding programs (Bioversity Intl. 2017; Kennedy et al. 2017a).

One pioneering example is provided by the Biodiversity for Food and Nutrition (BFN) project in Brazil, which is using nutrition information on biodiverse foods to guide its policies for food and nutrition security. Here, promising results in reshaping the food system by using agricultural biodiversity are being obtained through the BFN project, which is funded by the Global Environment Facility. Making use of Brazil's multisectoral plans to address malnutrition, six national ministries and partner organizations analyzed gaps between development and biodiversity plans, identifying new partnerships and making available new budgets to assess the nutrient content of 70 promising species of Brazilian flora. The government of Brazil has given the BFN initiative full support, agreeing to use nutrition information generated by the project to inform their food and nutrition security policies, particularly the two national policy instruments with the greatest potential for nutrition impact: The Food Acquisition Program (PAA) and the National School Feeding Program (PNAE). The two policies, which regulate food procurement and distribution

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to school children and vulnerable segments of the population, also provide economic incentives to family farming for the sustainable production of biodiversity, creating positive downstream benefits (Beltrame et al. 2016). Another important step toward mainstreaming biodiversity for enhanced food and nutrition security in Brazil was the signing in 2016 of Ordinance 163 that officially defines and recognizes "Brazilian Sociobiodiversity Native Food Species of Nutritional Importance." Aside from facilitating the procurement of sociobiodiversity species by national school feeding programs and the incentives for family farmers to continue to grow and market these species, the ordinance is helping to better monitor and track the consumption of biodiversity within the PAA and PNAE. Increased purchases of sociobiodiversity products by the national food procurement programs have already been reported but still remain negligible compared to the bulk of total foods purchased (Beltrame et al. 2016).

Investments in research and development of innovative, light-weight end-user technologies, such as mobile apps, that facilitate collection and analysis of quantitative dietary recalls to capture information on food agrobiodiversity will facilitate the uptake of these tools into large-scale agricultural projects where nutrition-assessment capacity is limited. This will assist in building the evidence base around how medium- and high-agrobiodiverse diets contribute the necessary micronutrients, which can be used to promote diverse local and Indigenous foods that have the potential to improve diet quality.

Other evidence gaps include investigations into the profitability and sustainability of promoting food systems that put agricultural biodiversity at their core, as well as cost-benefit analyses of investing in nutrition and expected nutrition benefits of interventions that use agricultural biodiversity.

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