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Reducing risk of poor diet quality through food biodiversity

Five blind spots that make it complicated

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KEY MESSAGES:

- → **Food biodiversity is a potential lever to improve Earth system resilience and promote healthier, diverse diets in a win-win scenario.**
- → **However, various blind spots in our current knowledge make this recommendation complicated: the relationship between biodiversity in farms and biodiversity on plates is not straightforward, scientists measuring biodiversity in production systems and measuring diversity in diets do not measure the same things, food biodiversity measurements tend to focus on either the global or very local scale, consumption (dietary intake) of food biodiversity is often overlooked, and diet diversity doesn't necessarily guarantee diet quality.**
- → **This paper explores these blind spots, and policy and research efforts to address them.**

Diminishing biodiversity and rising malnutrition

Poor diets are one of the greatest risks to adequate nutrition and health. Low-quality diets are responsible for the greatest burden of disease worldwide, affecting countries and population groups at all levels of economic development (1–3). The triple burden of malnutrition – the coexistence of micronutrient deficiencies, undernutrition, and overweight and obesity – has manifested itself in almost every nation on Earth. The long- and short-term effects of malnutrition hold back sustainable and inclusive global development and convey unacceptable human consequences. The United Nations Decade of Action on Nutrition 2016–2025 and the Sustainable Development Goals (SDG) provide global and national stimuli to address malnutrition and fast-track progress on food and nutrition security (4).

"Eat a variety of foods" or dietary diversity is a widely acknowledged and established public health recommendation to promote a healthy, nutritionally adequate diet (5). Healthy diets should be diverse and combine large amounts of vegetables, fruits, legumes, whole grains, nuts, seeds and unsaturated oils and moderate amounts of seafood and poultry, with low amounts of processed meat, added sugar and salt, refined grains and starchy vegetables (3). The recommendations for dietary diversity are based on the premise that consuming a wide variety of nutrient-dense foods will ensure an adequate intake of essential nutrients and in turn will lead to improved diet quality and optimal health outcomes (6). The actual composition of a diverse, balanced and healthy diet varies according to individual needs, locally available foods, dietary customs and cultural contexts. Transitions towards food biodiverse diets, such as the Mediterranean (7), pescatarian and vegetarian diets are projected to significantly decrease diet-related non-communicable disease risks, including coronary heart disease, stroke and type 2 diabetes, worldwide (8–10).

However, rapid socioeconomic, demographic and technological changes coupled with agriculture policies skewed towards a narrow range of staple crops, crop varieties and animal species, are driving human diets and associated agricultural production systems towards more resource-intensive, ultra-processed, energy-dense and nutrient-poor foods (11, 12). This has led to unprecedented shifts in global food systems and dietary patterns. Diet-related diseases and overweight and obesity risks are expected to continue to rise exponentially, while forms of undernutrition and micronutrient deficiencies are declining at insufficient rates (2, 4, 13, 14).

The global food system transformation is also driving a progressive homogeneity of diets (15). Although plants account for over 80% of human diets worldwide and an estimated 30,000 edible terrestrial plant species are available for consumption, our global food system is made up of only 150–200 commercially available species (16). In excess of half the global food energy need is supplied by four staple crops: rice, potatoes, wheat and maize, and only 30 crops supply an estimated 95% of human food energy need (15, 16). Food biodiversity – the diversity of plants, animals and other organisms that are used for food, both cultivated and from the wild – has the potential to underpin diverse, nutritious diets (17, 18), but global shifts in human diets and food systems are driving biodiversity loss worldwide (15, 19, 20).

Food biodiversity and Earth system resilience

Diets inextricably link human and planetary health. The global food system is the prime driver of low-quality diets and, in parallel, the transgression of several planetary boundaries that define a safe operating space for humanity in a stable Earth system (21, 22). Monoculture cropping systems and intensive livestock production generate substantial environmental costs (23–25). To illustrate, the rearing of livestock for meat, eggs and dairy alone produces 15% of total global greenhouse gas emissions and uses 70% of global agricultural land, including one-third of all arable land (26, 27).

Understanding and using food biodiversity and associated traditional knowledge provides levers of change towards more sustainable food systems in the face of mounting climate pressure on crop yields and on the nutritional content of foods (3). Biodiversity for food and agriculture contributes to Earth system resilience through a number of collective strategies, such as the protection and restoration of ecosystem services, sustainable use of soil and water resources, agroforestry, diversification of farming systems, cultivation practices, and use of neglected and underutilized stress-tolerant crop species (28, 29). Nonetheless, the threat to food biodiversity is occurring at a general rate of species extinction estimated to be 100 to 1,000 times the natural rate (22).

We need to transition from business as usual to sustainable intensification without compromising the Earth system. One school of thought gaining traction is that agricultural production systems based on food biodiversity, can result in both Earth system resilience and high-quality diets. Global shifts from current uniform, non-diverse diets to more diverse, nutritious and sustainable diets have the potential to avert 10.8–11.6 million premature deaths per year (3) and reduce food-related greenhouse gas emissions by 29%–70% by 2050 (30, 31).

Blind spots in food biodiversity knowledge

It seems simple to recommend that the world should increase its food biodiversity in production systems so that it can improve Earth system resilience and promote healthier diets in a win-win scenario. However, various blind spots in current knowledge make this recommendation more complicated than it appears at first sight:

- The relationship between biodiversity on farms and biodiversity on plates is not straightforward (32–34)
- Food biodiversity measurements tend to focus on either the global or very local scale (35)
- Consumption (dietary intake) of food biodiversity is often overlooked (18)
- Scientists measuring biodiversity in production systems and measuring diversity in diets do not measure the same things (36)
- Diet diversity doesn't necessarily guarantee diet quality (37).

Translating agricultural biodiversity to diverse diets: lost in translation?

The relationship between diverse agricultural production systems and diverse, nutritious and sustainable diets is intricate and mitigated by multiple factors, such as markets (access and availability of nutritious and safe foods), gender relations, control over and access to resources, wealth, cultural values and the existing degree of on-farm diversity (33, 34, 38). Increasing agricultural biodiversity on farm, typically the number of crop species and occasionally livestock species, can contribute to dietary diversity (33, 34, 39) and the consumption of fruit and vegetables, food energy and micronutrients in smallholder subsistence farming households in low- and middle-income countries (40). However, some studies indicate that, to have nutritionally meaningful impacts on dietary diversity, unrealistically large increases are required in the number of distinct crop or livestock species managed on farm (34).

Researchers identify two main pathways for smallholder farmers to improve diets. The first is to increase and consume on-farm diversity, the second is to specialize more in cash crops to earn income to purchase and consume more diversity. Most farmers use a combination of both. For individual smallholder farmers, maintaining agricultural biodiversity can sustain beneficial ecosystem functions on farm, reduce costs of external inputs, and facilitate access to new market opportunities, increasing and smoothing income so indirectly improving access to more diverse and nutritious diets (33). Conversely, on-farm crop diversification might sacrifice economic gains from agricultural specialization (41). On the other hand, investing in a narrow range of cash crops might increase income from agriculture production, but might also result in longer-term consequences of land degradation. Another major consideration with the income pathway is that increased income does not translate directly into healthier diet choices, and in order for the increased income to result in better diet, nutrition education and communications efforts must be established (28). Otherwise, the trend observed is increased income spent on food but not necessarily healthier food choices.

Given evidence that both increased income and increased on-farm diversity strategies can be effective in improving diet diversity, albeit via different pathways, there is a need to better understand the trade-offs between diets, income and ecosystem health that will occur within very specific contexts, geographies, and within sets of smallholder farmer priorities (38).

Food biodiversity is measured and analyzed at different scales

At global level, increasing the food production of a diversity of vegetables, fruits, legumes, and nuts and seeds is critical for the global population to achieve a sustainable and healthy diet by mid-century (3). However, food is actually chosen and consumed by individuals in households and produced on farms. There is a large gap when moving from global level to farm level or individual analysis and one blind spot is the 'missing middle' or the functioning of food systems within different production and market systems (35). These have been described by the High Level Panel of Experts on Nutrition as traditional, mixed and modern food systems that are influenced by culture, income levels and consumer needs (convenience, taste, budget, time available) (28).

Consumption of food biodiversity is often overlooked

There is a strong and rising demand from global development actors for simple indicators that reflect at least one aspect of food and nutrition security or diet quality, particularly for vulnerable populations. Therefore, most studies measure dietary diversity as a simple count of distinct foods or food groups consumed over a prespecified recall period (33, 34, 42). These widely disseminated and applied dietary diversity scores are often based on less resource-intensive self-reported dietary assessments methods such as list-based questionnaires or open-ended 24-hour dietary recalls. They reflect the various food sources of macro- and micronutrients in diets. To give an example, one widely used food-group diversity score is the Minimum Dietary Diversity for Women (MDD-W) (43, 44). It assesses the proportion of women of reproductive age (15–49 years) who consumed in the previous 24 hours at least five out of ten predefined food groups:

- Grains, white roots and tubers, and plantains
- Pulses (beans, peas and lentils)
- Nuts and seeds
- Dairy
- Meat, poultry and fish
- Eggs
- Dark green leafy vegetables
- Other vitamin A-rich fruits and vegetables
- Other vegetables
- Other fruits.

The MDD-W has been validated as a proxy for the probability of micronutrient adequacy of women's diets in low- and middle-income countries (45).

One blind spot important from a biodiversity point of view is that indicators based on food groups do not tell us anything about the species and varieties that diets are made up of. For most food biodiversity, there are substantial variations between species and within species in the content and density of important nutrients and other health-promoting components (46–49). Food-group diversity scores are not designed and are thus inappropriate to assess the hypothesized benefits of within food-group biodiversity, such as the biological nutrient variations within species, subspecies, varieties, cultivars and breeds, the evenness of food energy allocation or the dissimilarity in nutritional traits across food groups (37, 50).

A mismatch of agricultural biodiversity and dietary diversity indicators

The assessment and elucidation of linkages between agricultural biodiversity and dietary diversity are hampered by the fact that indicators used to measure on-farm diversity and those used to measure dietary diversity are not aligned. Moreover, within each specific domain (i.e. agroecology and nutrition), there are numerous indicators and various methods by which they are collected (51, 52). Dietary and ecological diversity indicators are not designed to assess the multifarious relationships between food biodiversity and diet quality. Research linking food biodiversity, agricultural production diversity and diet quality has applied multiple metrics without validation from a nutritional point of view (33).

The selection and number of food groups indisputably alters the association between agricultural biodiversity and dietary diversity, particularly when the selected food groups do not align with those crop species or crop groups used to define agricultural biodiversity. To illustrate, consider three smallholder farms. The first grows only maize, and so has a production diversity (PD) of one. The second farm grows maize and millet (PD = 2) and the third farm grows maize, millet and sorghum (PD = 3). If the individuals on these farms consumed only their subsistence food production (maize; maize and millet; or maize, millet and sorghum) then the individual-level dietary diversity score would be 1 in all cases, as all of the species are from the 'grains, white roots and tubers, and plantains' food group. In this simplified scenario there would be no relationship between agricultural biodiversity and dietary diversity (36). Intuitively however, increasing the number of species within the same food group might lead to lower net nutritional benefits than when species of distinct food groups are added to the production landscape.

This example illustrates the difficulty in coming to terms with the relationship between production diversity and food biodiversity for diet diversity. On the one hand, a production diversity score of 3 may mean a more ecologically resilient farm but the unchanged dietary diversity score of 1 in this example will not help meet minimum standards of diversity for a woman of reproductive age. In the real world, this simple example becomes more complex since diets are influenced not just by what is grown on farm but consumers' access to markets, preferences, seasonality of wild and domesticated foods and other significant influencing factors that have not been well captured in analytical frameworks to understand the linkages between production and diet diversity.

Dietary diversity does not guarantee diet quality

Diversity scores assess only one aspect of diet quality (53). Individual-level dietary diversity scores capture one important dimension of diet quality: the consumption of nutrient-dense food groups, such as fruit and vegetables, nuts and seeds and pulses. Nevertheless, individual-level dietary diversity scores do not capture other imperative diet-quality dimensions. To illustrate, food-group based indicators do not provide any information on (Figure 1):

- Richness: number of distinct species per day
- Evenness: distribution of food energy, nutrients or species abundance across food groups
- Disparity: level of (dis)similarity between species (e.g. vitamin A content) or food items (e.g. level of food processing).

The figure also illustrates a huge blind spot in understanding the processing level of the diversity consumed. We cannot see if the species is consumed fresh, minimally processed or as ultra-processed food. Level of processing is a critical factor to be considered in assessment of overall diet quality based on any given dietary pattern (55–57). In fact recommendations to eat diverse foods, if not accompanied also by recommendations that those foods be predominantly fruits, vegetables, whole grains and seeds, will not lead to healthy diets (58).

Efforts to address the blind spots

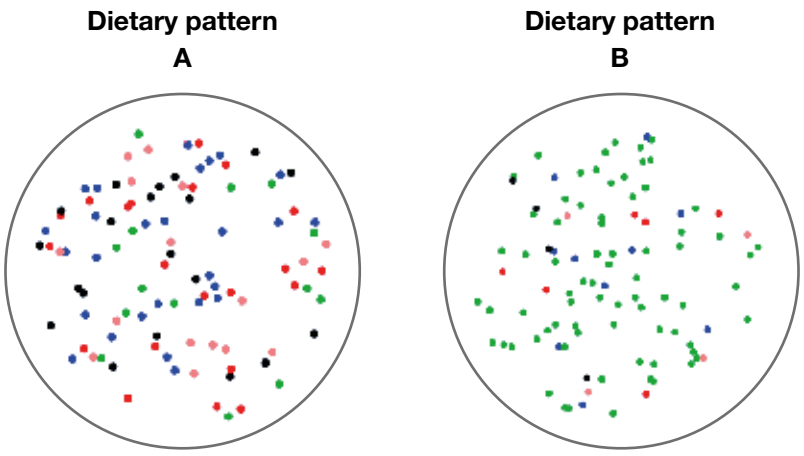
Linking diverse diets and agricultural biodiversity through food-based dietary guidelines

There is growing recognition of the central roles of structural, environmental, cultural, social and psychological factors in dietary behaviour (59). To halt global transitions towards low-quality, homogenous diets and redirect human behaviour towards more food-biodiverse and sustainable diets, we need more than just a robust scientific evidence base. Clear policy measures are best suited to changing dietary patterns (3, 60). For example, the determination that trans fatty acids could not be classified as 'Generally recognized as safe' led to a public-health decision by the US Food and Drug Administration in 2015 to ban them in the food supply system.

A softer policy intervention is nudging the public towards healthy food choices through guidelines. Dietary diversity is advocated in food-based dietary guidelines and in the 'Healthy Diet' and 'A healthy diet sustainably produced' fact and information sheets from

FIGURE 1 – Representation of two dietary patterns where 100 food items are consumed

Distinct species are indicated by their colour. Richness is the absolute number of species in a dietary pattern: in both dietary patterns it is equal to five. Evenness is the equitability of the species abundance distribution across food groups: in dietary pattern A all species are present in equal abundance and so it is perfectly even, while dietary pattern B is very uneven since it is dominated by the green species. Disparity is the level of similarity between species: for example red and pink species are more similar to each other (nutritional traits/attributes) than the red and the black species (Adapted from (54)).



the World Health Organization. However, most national dietary guidelines do not reflect the available evidence on nutritious, sustainable and healthy diets, and include no or lenient limits for animal-source foods, particularly meat and dairy (61), despite an opposing evidence base (62, 63).

Guidelines also offer a potential strategy to link sustainable agricultural production to biodiverse diets. A few countries (Brazil, Germany, Qatar, Sweden) have introduced sustainability criteria into their national dietary guidelines (Box 1, (55)). Others (the Nordic countries, Netherlands, France, Estonia and the UK) have issued quasi-official guidelines by government-funded entities. However, whether or not dietary guidelines should include sustainability or biodiversity criteria is ultimately a political decision and as such has been a major issue of discussion in several countries.

Developing indicators that cut across food and farms

One way to explore the link between on-farm biodiversity and dietary diversity is to adopt novel nutritional measures from established diversity sciences describing diversity in ecological and economic systems. One such measure, Dietary Species Richness, counts the number of unique plant and animal species consumed in the previous 24 hours. Dietary Species Richness has been successfully applied as a cross-cutting measure of food biodiversity and micronutrient adequacy of diets in wet and dry seasons in seven rural contexts of low- and middle-income countries (18). Measuring the number of species consumed during dietary assessments provides a unique opportunity to cut across two critical dimensions of sustainable development – human and planetary health – and complements existing metrics of healthy and sustainable diets. Decision-makers often struggle to harmonize environmental and food policy actions so dietary species richness is a valuable metric in this regard, as it integrates food biodiversity, nutrition and health aspects of food systems. Nevertheless, assessing Dietary Species Richness is challenging, it has been estimated that previous studies have misidentified 6%–10% of species (64). Guidelines have recently been prepared to adequately record species during dietary intake assessments (17).

BOX 1 – Extract from Swedish food-based dietary guidelines (55)

- High-fibre vegetables have a lower environmental impact than salad greens. They tend to be grown outside (not in greenhouses). They are also more robust, which reduces waste due to damages during transport.
- Although people should consume more seafood for health, many wild fish stocks are endangered or are harvested unsustainably, while aquaculture also has its problems. People should therefore buy ecolabelled products. Mussels can help reduce marine eutrophication.
- One of the ways to increase physical activity is to use the stairs instead of the lift, and cycle or walk to work, and these behaviours can also reduce the environmental impact.
- Cereals have a relatively small climate impact. Due to the high greenhouse gas emissions associated with rice, other grains and potatoes are a better choice for the environment.
- Rapeseed oil and olive oil generally have a lower environmental impact than palm oil, but the relationship gets inverted when palm oil is produced without deforestation (e.g. in old plantations).
- Dairy products have high environmental impacts since dairy cows produce methane. However, grazing animals can help bring about a “rich agricultural landscape and biodiversity”.
- Drinks made of oats and soya are ecofriendly, chose the ones enriched with vitamins and minerals.
- Reducing meat consumption can benefit both health and the environment. By cutting down on quantity people may be able to afford to buy meat produced more sustainably, with attention paid to the welfare of the animals. Different meat types have different climate impacts: poultry has the smallest impact on climate, followed by pork. On the other hand, free range beef and lamb can also have other positive environmental effects – animal grazing can help maintain diverse agricultural landscapes and support biodiversity.
- Sweets can also have a high environmental impact: a bag of jelly beans actually has as much of a climate footprint as a small portion of pork. These are referred to in the report as an “unnecessary environmental impact”.

Pointers for research and policy

In an interconnected, multi-stakeholder global food system, balancing the nurturing of human health with environmental stewardship presents numerous policy challenges (14). Despite growing awareness of the benefits of agricultural biodiversity for dietary diversity and the benefits of diverse diets for human nutrition and health, many barriers and perverse subsidies make it difficult to mainstream biodiversity in food production and consumption (65). Food and agricultural policies and research must be reoriented to encourage agricultural biodiversity, nutrition and sustainability, rather than prioritizing the productivity of a narrow-range of monoculture crop and livestock species that adversely affect human and planetary health (3, 66).

Diversified agricultural production systems and diverse diets can be mutually reinforcing. If we want to eat it, we must grow it. Therefore, policy interventions must develop and strengthen markets that promote and encourage traditional, neglected and underutilized crop species, varieties, cultivars and breeds (34, 66, 67). This is a promising strategy to improve the availability, accessibility and affordability of food biodiversity and high-quality diets for all strata of society. Moreover, policy and research reorientation might also include transforming agricultural extension services to encourage a plethora of food biodiversity and foster synergies between scientific and local knowledge and biocultural heritage (e.g. participatory plant breeding). Global food industry and gastronomy movements also have the power to shape dietary patterns and champion food biodiversity. For example, the Chefs' Manifesto of the SDG2 Advocacy Hub is a thematic framework, which outlines how chefs can contribute to the SDGs through simple, practical actions (Box 2).

BOX 2 – The Chefs' Manifesto eight thematic areas

1. Ingredients grown with respect for the Earth and its oceans
2. Protection of biodiversity and improved animal welfare
3. Investment in livelihoods
4. Value natural resources and reduce waste
5. Celebration of local and seasonal food
6. A focus on plant-based ingredients
7. Education on food safety and healthy diets
8. Nutritious food that is accessible and affordable for all.

For researchers, there is a need to go beyond food-group diversity, and collect food composition and consumption data on wild and cultivated food biodiversity (17). To connect human diets to global food systems, additional research is needed on consumer behaviour and food environments. This includes understanding the sources of food biodiversity (wild, on-farm production, purchased) (18, 33) and the relative contribution of wild and cultivated food biodiversity to both diet quality and sustainability (39). Monitoring the contribution of agricultural biodiversity to global diets facilitates the identification of a multitude of species with the greatest potential to improve nutrition in various local contexts and provides additional granularity to assess the importance of food biodiversity in ensuring diet quality (18, 68). Further research into the multifunctionalities of food biodiversity (e.g. long-term productivity, stability and resilience to shocks) is critical to understand the context-specific factors that facilitate or hinder the role of agricultural diversification in positively influencing food environments and dietary patterns (35).

To conclude, increasing food biodiversity is vital to reduce malnutrition risks to human health and to increase resilience in a stable Earth system. It will require greater clarity on current blind spots regarding the complex relationship between agricultural biodiversity and food biodiversity. It will also need practices, policies and metrics that both facilitate transitions to diversified sustainable agricultural systems, and raise awareness and stimulate demand for diverse diets.

References

1. Gakidou E, et al. (2017) Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2016: A systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*. doi:10.1016/S0140-6736(17)32366-8.
2. Springmann M, Godfray HCJ, Rayner M, Scarborough P (2016) Analysis and valuation of the health and climate change cobenefits of dietary change. *Proceedings of the National Academy of Sciences* 113(15):4146–4151.
3. Willett W, et al. (2019) Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet* 6736(18):3–49.
4. FAO, IFAD, UNICEF, WFP, WHO (2018) *The State of Food Security and Nutrition in the World in 2018. Building climate resilience for food security and nutrition*.
5. Montagnese C, et al. (2015) European food-based dietary guidelines: A comparison and update. *Nutrition*. doi:10.1016/j.nut.2015.01.002.
6. Ruel MT (2003) Operationalizing dietary diversity: A review of measurement issues and research priorities. *Journal of Nutrition* 133:3911S-3926S.
7. Estruch R, et al. (2018) Primary prevention of cardiovascular disease with a Mediterranean diet supplemented with extra-virgin olive oil or nuts. *New England Journal of Medicine*. doi:10.1056/NEJMoa1800389.
8. Reedy J, et al. (2014) Higher diet quality is associated with decreased risk of all-cause, cardiovascular disease, and cancer mortality among older adults. *Journal of Nutrition*. doi:10.3945/jn.113.189407.
9. Tilman D, Clark M (2014) Global diets link environmental sustainability and human health. *Nature* 515:518–522.
10. Perignon M, Vieux F, Soler LG, Masset G, Darmon N (2017) Improving diet sustainability through evolution of food choices: Review of epidemiological studies on the environmental impact of diets. *Nutrition Reviews*. doi:10.1093/nutrit/nuw043.
11. Ranganathan J, et al. (2016) *Shifting Diets for a Sustainable Future* (World Resources Institute) doi:10.2499/9780896295827_08.
12. Springmann M, et al. (2018) Options for keeping the food system within environmental limits. *Nature*. doi:10.1038/s41586-018-0594-0.
13. Rockström J, Stordalen GA, Horton R (2016) Acting in the Anthropocene: the EAT–Lancet Commission. *The Lancet*. doi:10.1016/S0140-6736(16)30681-X.
14. Whitmee S, et al. (2015) Safeguarding human health in the Anthropocene epoch : report of The Rockefeller Foundation – Lancet Commission on planetary health. *The Lancet* 386(10007):1973–2028.
15. Khoury CK, et al. (2014) Increasing homogeneity in global food supplies and the implications for food security. *Proceedings of the National Academy of Sciences* 111(11):4001–4006.
16. FAO (Food and Agriculture Organization) (2010) *Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (FAO, Rome, Italy).
17. FAO (Food and Agriculture Organization), Bioversity International (2017) *Guildelines on Assessing Biodiverse Foods in Dietary Intake Surveys* (FAO, Rome, Italy)..
18. Lachat C, et al. (2017) Dietary species richness as a measure of food biodiversity and nutritional quality of diets. *Proceedings of the National Academy of Sciences*. doi:10.1073/pnas.1709194115.
19. Vermeulen S, Campbell B, Ingram J (2012) Climate change and food systems. *Annual Review of Environmental Resources* 37:195–222.
20. Maxwell SL, Fuller RA, Brooks TM, Watson JEM (2016) Biodiversity: The ravages of guns, nets and bulldozers. *Nature* 536(7615):143–145.
21. Campbell BM, et al. (2017) Agriculture production as a major driver of the earth system exceeding planetary

boundaries. *Ecology and Society*. doi:10.5751/ES-09595-220408.

22. Steffen W, et al. (2015) Supplementary Materials, Planetary boundaries: Guiding human development on a changing planet. *Science*. doi:10.1126/science.1259855.
23. Auestad N, Fulgoni VL (2015) What current literature tells us about sustainable diets: emerging research linking dietary patterns, environmental sustainability, and economics. *Advances in Nutrition: An International Review Journal*. doi:10.3945/an.114.005694.
24. Nelson ME, Hamm MW, Hu FB, Abrams SA, Griffin TS (2016) Alignment of healthy dietary patterns and environmental sustainability: a systematic review. *Advances in Nutrition: An International Review Journal*. doi:10.3945/an.116.012567.
25. Hallström E, Carlsson-Kanyama A, Börjesson P (2015) Environmental impact of dietary change: A systematic review. *Journal of Cleaner Production*. doi:10.1016/j.jclepro.2014.12.008.
26. Aleksandrowicz L, Green R, Joy EJM, Smith P, Haines A (2016) The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: A systematic review. *PLoS ONE*. doi:10.1371/journal.pone.0165797.
27. Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A Tempio G (2013) Tackling Climate Change Through Livestock: A Global Assessment of Emissions and Mitigation Opportunities (FAO, Rome, Italy).
28. HLPE (High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security of the FAO) (2017) Nutrition and food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (Rome, Italy).
29. FAO (Food and Agriculture Organization) (2019) *The State of the World's Biodiversity for Food and Agriculture* eds Belanger J, Pilling D (FAO Commission on Genetic Resources for Food and Agriculture Assessments, Rome, Italy) Available at: http://www.fao.org/3/CA3129EN/CA3129EN.pdf.
30. Payne CL, Scarborough P, Cobiac L (2016) Do low-carbon-emission diets lead to higher nutritional quality and positive health outcomes? A systematic review of the literature. *Public Health Nutrition*. doi:10.1017/S1368980016000495.
31. Springmann M, et al. (2018) Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *The Lancet Planetary Health* 2(10):e451–e461.
32. Verger EO, Ballard TJ, Dop MC, Martin-Prevel Y (2019) Systematic review of use and interpretation of dietary diversity indicators in nutrition-sensitive agriculture literature. *Global Food Security* 20:156–169.
33. Jones AD (2017) Critical review of the emerging research evidence on agricultural biodiversity, diet diversity, and nutritional status in low- and middle-income countries. *Nutrition Reviews*. doi:10.1093/nutrit/nux040.
34. Sibhatu KT, Qaim M (2018) Review: Meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. *Food Policy* (April):0–1.
35. Remans R, DeClerck FAJ, Kennedy G, Fanzo J (2015) Expanding the view on the production and dietary diversity link: Scale, function, and change over time. *Proceedings of the National Academy of Sciences*. doi:10.1073/pnas.1518531112.
36. Berti PR (2015) Relationship between production diversity and dietary diversity depends on how number of foods is counted. *Proceedings of the National Academy of Sciences*. doi:10.1073/pnas.1517006112.
37. de Oliveira Otto MC, et al. (2018) Dietary diversity: implications for obesity prevention in adult populations: a science advisory from the American Heart Association. *Circulation*. doi:10.1161/CIR.0000000000000595.
38. Fanzo JC (2017) Decisive decisions on production compared with market strategies to improve diets in rural Africa. *The Journal of Nutrition*. doi:10.3945/jn.116.241703.
39. Powell B, et al. (2015) Improving diets with wild and cultivated biodiversity from across the landscape. *Food Security* 7(3):535–554.

40. Jones AD, et al. (2018) Farm-level agricultural biodiversity in the Peruvian Andes is associated with greater odds of women achieving a minimally diverse and micronutrient adequate diet. *Journal of Nutrition*. doi:10.1093/jn/nxy166.
41. Sibhatu KT, Krishna V V, Qaim M (2015) Production diversity and dietary diversity in smallholder farm households. *Proceedings of the National Academy of Sciences* 112(34):10657–62.
42. Salehi-Abargouei A, Akbari F, Bellissimo N, Azadbakht L (2015) Dietary diversity score and obesity: a systematic review and meta-analysis of observational studies. *European Journal of Clinical Nutrition*. doi:10.1038/ejcn.2015.118.
43. FAO, FHI360 (2016) Minimum dietary diversity for women- a guide to measurement (FAO, Rome Italy) doi:10.1016/S0167-6393(00)00055-8.
44. Martin-Prevel Y, et al. (2017) Development of a dichotomous indicator for population-level assessment of dietary diversity in women of reproductive age. *Current Developments in Nutrition* 1(12):cdn.117.001701.
45. Martin-Prevél Y, et al. (2015) Moving forward on choosing a standard operational indicator of women's dietary diversity (FAO, Rome, Italy).
46. FAO/INFOODS (2017) FAO/INFOODS Food Composition Database for Biodiversity Version 4.0 - BioFoodComp 4.0. 33.
47. Thilsted SH, et al. (2016) Sustaining healthy diets: The role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. *Food Policy* 61:126–131.
48. Lutaladio N, Burlingame B, Crews J (2010) Horticulture, biodiversity and nutrition. *Journal of Food Composition and Analysis* 23(6):481–485.
49. Burlingame B, Mouillé B, Charrondière R (2009) Nutrients, bioactive non-nutrients and anti-nutrients in potatoes. *Journal of Food Composition and Analysis* 22(6):494–502.
50. Burlingame B, Charrondière R, Mouillé B (2009) Food composition is fundamental to the cross-cutting initiative on biodiversity for food and nutrition. *Journal of Food Composition and Analysis* 22(5):361–365.
51. Kennedy G, Stoian D, Hunter D, Kikulwe E, Termote C (2017) Food biodiversity for healthy, diverse diets. *Mainstreaming Agrobiodiversity in Sustainable Food Systems: Scientific Foundations for an Agrobiodiversity Index*, ed Bailey A (Bioversity International, Rome, Italy), pp 23–52.
52. Sibhatu KT, Qaim M (2018) Farm production diversity and dietary quality: linkages and measurement issues. *Food Security*. doi:10.1007/s12571-017-0762-3.
53. Verger EO, Dop MC, Martin-Prével Y (2017) Not all dietary diversity scores can legitimately be interpreted as proxies of diet quality. *Public Health Nutrition*. doi:10.1017/S1368980016003402.
54. Daly A, Baetens J, De Baets B (2018) Ecological diversity: measuring the unmeasurable. *Mathematics*. doi:10.3390/math6070119.
55. Fischer CG, Garnett T (2015) Plates, pyramids, planet: Developments in national health and sustainable dietary guidelines: a state of play assessment (FAO (Food and Agriculture Organization) and FRCN (The Food Climate Research Network at The University of Oxford)).
56. FAO (Food and Agriculture Organization) (2015) Guidelines on the collection of information on food processing through food consumption surveys (FAO, Rome, Italy).
57. Monteiro CA, et al. (2018) The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. *Public Health Nutrition*. doi:10.1017/S1368980017000234.
58. De Oliveira Otto MC, Padhye NS, Bertoni AG, Jacobs DR, Mozaffarian D (2015) Everything in moderation - Dietary diversity and quality, central obesity and risk of diabetes. *PLoS ONE*. doi:10.1371/journal.pone.0141341.
59. Marteau TM, Hollands GJ, Fletcher PC (2012) Changing human behavior to prevent disease: The importance of targeting automatic processes. *Science*. doi:10.1126/science.1226918.
60. Mozaffarian D (2016) Dietary and policy priorities for cardiovascular disease, diabetes, and obesity. *Circulation*. doi:10.1161/CIRCULATIONAHA.115.018585.

61. Ritchie H, Reay DS, Higgins P (2018) The impact of global dietary guidelines on climate change. *Global Environmental Change*. doi:10.1016/j.gloenvcha.2018.02.005.

62. Bolland MJ, et al. (2015) Calcium intake and risk of fracture: Systematic review. *British Medical Journal* (Online). doi:10.1136/bmj.h4580.

63. Kim K, et al. (2017) Role of total, red, processed, and white meat consumption in stroke incidence and mortality: A systematic review and meta-analysis of prospective cohort studies. *Journal of the American Heart Association*. doi:10.1161/JAHA.117.005983.

64. Łuczaj ŁJ (2010) Plant identification credibility in ethnobotany: A closer look at Polish ethnographic studies. *Journal of Ethnobiology and Ethnomedicine* 6. doi:10.1186/1746-4269-6-36.

65. IPES-Food (International Panel of Experts on Sustainable Food Systems) (2015) *The new science of sustainable food systems: overcoming barriers to food systems reform*. (IPES-Food) doi:10.1109/ISSCC.2010.5433958.

66. Garrett GS, Platenkamp L, Mbuya MNN (2019) Policies and finance to spur appropriate private-sector engagement in food systems: Implications for mainstreaming agrobiodiversity. *Agrobiodiversity Index Report 2019: Risk and Resilience* (Bioversity International, Rome, Italy).

67. Cook S (2018) *The Spice of Life: the Fundamental Role of Diversity on the Farm and on the Plate* (IIED and HIVOS, London and The Hague).

68. Remans R, et al. (2011) Assessing nutritional diversity of cropping systems in African villages. *PLoS ONE* 6(6). doi:10.1371/journal.pone.0021235.

Diverse local food species, Guatemala. Guatemala is a global hotspot for biodiversity. The plants used by local and indigenous people are often wild-collected or semi-domesticated and have not received much research attention to enhance their roles in the livelihoods of Guatemalan people—even if some have much higher nutrition values and higher stress tolerance than more commercial crops. Credit: Bioversity International/R. Robitaille

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