Transforming food systems with trees and forests

Amy Ickowitz, Stepha McMullin, Todd Rosenstock, Ian Dawson, Dominic Rowland, Bronwen Powell, Kai Mausch, Houria Djoudi, Terry Sunderland, Mulia Nurhasan, Andreea Novak, Vincent Gitz, Alexandre Meybeck, Ramni Jamnadass, Manuel R Guariguata, Céline Termote, Robert Nasi

The global food system is failing to deliver sufficient and nutritious food to all, while damaging the earth and unsustainably drawing down its resources. We argue that trees and forests are essential to solving these challenges. We outline the current contributions of trees and forests to the global food system and present recommendations to leverage these contributions as part of the efforts to reshape food systems to better support healthy diets and environmental sustainability. Trees and forests provide nutrient-rich foods, incomes for food security, ecosystem services for food production, and add resilience to food systems. At the same time, trees and forests protect biodiversity and mitigate climate change through carbon sequestration. We recommend four approaches to realise the full potential of trees and forests to contribute to healthy and sustainable food systems: scaling up current tree-based food production, reorientating some agricultural investments towards nutrient-dense food production, repurposing production incentives from support of calorie-rich but nutrient-poor foods to support nutrient-dense foods, and integrate nutrition objectives into forest conservation and restoration programmes. Trees and forests have important roles to play in the transformation of our food systems, but more needs to be done to ensure that these roles are realised.

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Center for International Forestry Research, Situ Gede, Bogor, Indonesia (A Ickowitz PhD, D Rowland MSC, B Powell PhD, H Djoudi PhD, T Sunderland PhD, M Nurhasan MSc, V Gitz PhD, A Meybeck MA, R Nasi PhD); **World Agroforestry (ICRAF), Nairobi, Kenya** (S McMullin PhD, T Rosenstock PhD, I Dawson PhD, K Mausch PhD, A Novak MSc, R Jamnadass PhD); **The Alliance of Bioversity International and the International Center for Tropical Agriculture, Montpellier, France** (T Rosenstock); **Scotland's Rural College (SRUC), Kings Buildings, Edinburgh, UK** (I Dawson); **Centre for Development Environment and Policy, SOAS University of London, London, UK** (D Rowland); **Department of Geography, The Pennsylvania State University, State College, PA, USA** (B Powell); **Faculty of Forestry, University of British Columbia, Vancouver, BC, Canada** (T Sunderland); **The Alliance of Bioversity International and the International Center for Tropical Agriculture, Rome, Italy** (A Novak); **Center for International Forestry Research, Lima, Peru** (M R Guariguata PhD); **The Alliance of Bioversity International and the International Center for Tropical Agriculture, Nairobi, Kenya** (C Termote PhD)

Correspondence to:
Dr Amy Ickowitz, Center for International Forestry Research, Situ Gede, Bogor 16115, Indonesia
a.ickowitz@cgiar.org

Introduction

The global food system is not delivering sufficient, safe, and nutritious food to all. Suboptimal diets are now the largest contributors to global mortality and morbidity.[1] More than 2 billion people experience food insecurity, and close to 700 million are undernourished.[2] At the same time, overconsumption is rising globally, with 39% of all adults considered overweight or obese.[3]

The global food system does not produce the diversity of foods needed for healthy diets. Only 15 crops provide 90% of humanity's energy intake,[4] with rice, maize, and wheat alone accounting for 48% of global average daily calories.[5] Nutrient-rich foods are produced in insufficient quantities to provide healthy diets for all.[6] Only 40 countries, representing 26% of the world's population, have an adequate supply of fruits and vegetables to meet dietary recommendations.[7] Even small quantities of animal source foods can substantially reduce the burden of malnutrition in populations with high rates of stunting and micronutrient deficiencies.[8] Yet, animal source foods remain inaccessible or unaffordable to some of the world's poorest and most vulnerable populations. At the same time, animal source foods are increasingly being eaten in unhealthy quantities in many other populations, with negative impacts on both population health and environmental sustainability.

The negative impacts of the global food system on planetary health are well known. The system generates more than a third of global anthropogenic greenhouse gas emissions,[9] accounts for approximately 70% of freshwater withdrawals, and accounts for a quarter of ocean acidification.[10] Unsustainable farming practices and agricultural expansion into natural habitats drive soil erosion, nutrient depletion, and loss of pollinators. These impacts can reduce productivity that, in turn, can exacerbate unsustainable agricultural practices by creating increased dependence on chemical inputs, increased cropping intensity, and driving agricultural expansion into remaining natural landscapes, especially forests.[10–12] In the absence of improvements to agricultural practices, mitigation measures, and dietary choices, the negative environmental impacts of our food systems will only get worse, and are projected to further increase by at least 50% between 2010 and 2050.[13]

It is increasingly evident that nothing short of a radical transformation of food systems will end global hunger and malnutrition while reversing to acceptable limits the environmental damage our food systems have already caused.[12,14] A new global food system must produce greater quantities of a more diverse range of nutrient dense foods, rather than only providing more calories.[15] It must also produce these diverse foodstuffs sustainably, reversing current trajectories of land degradation so that production acts as a net carbon sink and reservoir of biodiversity.

In this Viewpoint, we consider the roles of trees and forests in this food system transformation. These ecosystems and plants have rightly received attention for their roles in the mitigation of climate change and conservation of biodiversity. However, their potential for contributing to food systems transformation has largely been overlooked because of the absence of a comprehensive and system-wide approach to food systems, problems related to measuring and recording multiple contributions from trees and forests, and a focus on forests as sources of timber rather than food—a perspective we consider to be in danger of being mistakenly replicated in current discourses in the international development community that see trees and forests primarily as global carbon stores.[16] Our position on the roles of trees and forests in food systems has been developed through research within the Forests, Trees, and Agroforestry programme,[17] which is the world's largest research for development programme to enhance the role of forests, trees, and agroforestry in sustainable development and food security, and to address climate change.

In this Viewpoint, we explore how trees and forests already contribute substantially to nutrient-rich food

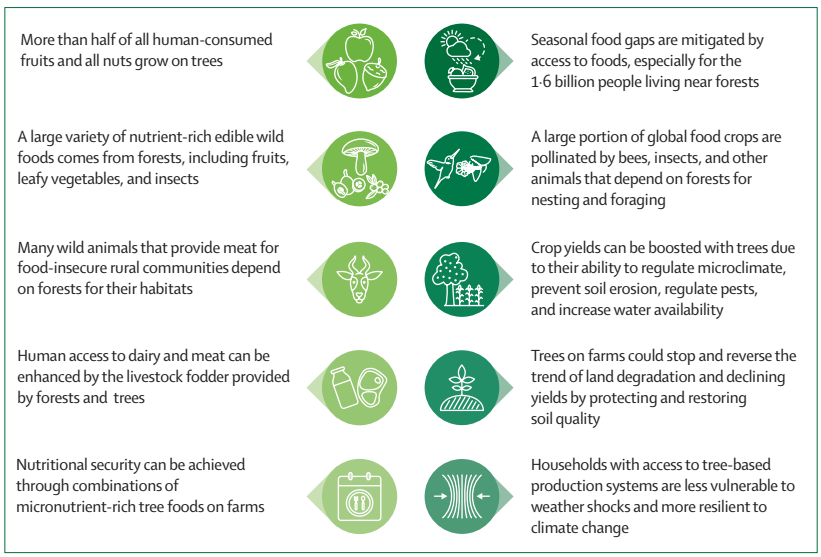

Figure: **Ten reasons why trees and forests are crucial for transforming the food system**

production and help support the sustainability and resilience of food systems (figure). We then provide perspectives on how these contributions can be further enhanced to achieve broader nutritional and environmental sustainability, framed around four areas of intervention: scaling existing tree-based agricultural system solutions by building on current knowledge, reorienting agricultural research from investments in staple crops to more diverse nutrient-dense tree foods and other foods, repurposing producer and consumer incentives towards nutrient-dense foods and more sustainable production practices, and explicitly integrating food and nutrition objectives into forest restoration and conservation practice and policy.

The role of trees and forests in healthy diets and sustainable food systems

Nutrient-rich foods

Tree cover has been linked to greater dietary diversity[18–20] and to higher consumption of fruits and vegetables.[19,20] All nuts and more than half of all human-consumed cultivated fruits grow on trees.[21] Most of these foods are nutrient-rich. Jansen and colleagues[22] reported that across seven sites in tropical countries, tree-sourced foods had four times the density of vitamin C and nine times the density of vitamin A compared with other consumed foods. Agroforestry systems, where trees are retained and cultivated in farmland along with crops and livestock, support the production of a wide variety of tree and non-tree foods. Several studies have shown positive associations between the use of agroforestry practices and food and nutrition security.[23–25]

Forests are an especially important source of food for the 1·6 billion people globally living within 5 km of them.[26] The direct provisioning of wild foods by forests has been shown to substantially contribute to dietary adequacy in multiple locations.[27,28] Rowland and colleagues[29] found that half of people surveyed who live in forested areas across 25 tropical countries consumed some forest foods, with the top quartile of food forest users obtaining 14·8% of their recommended intakes for fruits and vegetables from forests.

Direct provisioning of food from forests is not confined to the tropics, although quantifying relative contributions across countries globally is difficult because data on forest-sourced foods are generally not systematically collected.[30] However, a 2020 survey of households in 28 European countries found widespread local collection and consumption of forest plants and fungi, and indicated that the official data underestimated actual consumption by a factor of around ten.[31] In its 2020 Global Forest Resources Assessment, the Food and Agriculture Organization[32] asked countries to report on their ten most commercially important non-wood forest products, including food. The data showed substantial contributions of forest foods in many countries in both in weight and in value.

Forests are also an important habitat for animals that provide meat, a primary source of key nutrients in some rural communities. For example, forest dwellers in the Congo Basin and the Amazon rely heavily on bushmeat,[33] as do rural communities in Madagascar where wild meat was found to contribute almost three-quarters of the total iron consumed in one site in the east of the country.[34] Another study in Madagascar found that reduced access to wild meat was predicted to substantially increase rates of anaemia in children.[35] Riparian forest cover has been associated with increased freshwater fish consumption,[36] and forest or trees on farms provide animal fodder that enables communities to rear livestock that provide nutritionally important foods such as meat and milk.[37]

Provision of fuel and income

Trees and forests on farms provide woodfuels, including firewood and charcoal, that are crucial sources of cooking energy for approximately 2·4 billion people[38] who do not yet have access to affordable alternative energy sources that would be less environmentally damaging and less detrimental to human respiratory health. For these people, woodfuel use enables the consumption of nutrient-rich foods, such as meats and legumes, that they would otherwise have to forgo because they would be unable to prepare them, instead having to rely on more easily cooked but less nutritious foods.[39]

Trees and forests also provide incomes that can contribute to food security and nutrition. These incomes come from employment in the logging industry, ecotourism, and the collection and sale of a wide range of non-wood forest products. A study of more than 8000 households from sites across 24 tropical countries found that incomes from forest products comprised 22% on average of total household incomes.[40] Tree crops also provide income to millions of farmers in both

high-income and low-income countries, including globally traded commodities such as cocoa, coffee, olive oil, rubber, palm oil, and several nuts and fresh fruits. The production and export of many of these products are crucial sources of income to growers, traders, and corporations. Three of California's top ten commodities are tree foods, earning farmers in that state more than US$9 billion a year.[41] In 2018, olive production earned Spain, Italy, and Greece more than $17 billion combined.[42] In the tropics, many commodities, including cocoa and coffee, are grown by millions of tropical smallholders for whom their sale is a primary income to support families.[43]

Ecosystem services for agriculture

Trees and forests provide crucial ecosystem services for agriculture, including pest and disease regulation, pollinator habitat, microclimate control, water and nutrient cycling, carbon sequestration, protection against soil erosion, and nitrogen fixation.[44] In a systematic review, 68% of studies showed net positive or neutral effects on food crop yields of trees present in farmland and in neighbouring natural habitats. 47% of studies showed a strictly positive effect.[45]

Many fruits and vegetables rely on animal pollinators that depend heavily on trees to provide their habitat and food.[46] The ongoing decline of these pollinators globally, due in part to insecticide use, makes maintaining the role of trees in habitat provision even more crucial.[47] If these pollination services were to disappear entirely, about 2·2 billion people already consuming insufficient vitamin A would see declines in supply.[48]

Forests and planted trees regulate water availability and climate from micro to macro scales. At the micro end of the spectrum, evapotranspiration from trees reduces temperature in the immediate vicinity, supporting crop production in agroforestry systems under stressful conditions.[49] At the meso scale, trees and forests facilitate water infiltration into soils and can improve groundwater recharge locally to enhance crop production.[23] They can also protect against flooding through water infiltration and interception.[50,51]

By protecting soil through acting as windbreaks and soil stabilisers, trees and forests reduce top soil loss, with benefits for crop yields.[52] Leguminous fertiliser trees established with crops also support yields through symbiotic associations with below-ground micro-organisms that fix nitrogen and other nutrients in the soil, reducing dependence on inorganic fertilisers and helping smallholder farmers in the tropics who cannot afford such inputs.[53]

Although the impact of trees and forests on food production is generally positive, this association is not always the case. In some cases, trees can reduce yields by competing with food crops for important resources such as sun, water, soil nutrients, and pollination services.[45] In addition, all tree-based systems are not equally beneficial, and although some might provide nutritional benefits they might also generate environmental costs depending on what they are replacing.[30] For example, replacing a forest with a monoculture of trees, even those yielding nutritious foods such as almonds or cashews, can have a net negative impact on biodiversity or greenhouse gas emissions. Similarly, intensified tree plantations can have negative consequences due to high water demands and high pesticide use. Thus, tree-based systems do not automatically provide positive nutritional and environmental outcomes, but can often offer these potential outcomes when suited to local agroecological conditions.

Trees can also provide additional benefits to the planet in general, and to the global food system. The role of trees and forests in the global carbon budget is well known; they act as important natural carbon sinks[54] and comprise nearly three-quarters of the mitigation potential of natural climate solutions.[55] This mitigation counters yield reductions of key staple crops already occurring due to anthropogenic greenhouse gas emissions.[56] It also counters the adverse impacts that these emissions have on crop nutritional quality.[57]

Stability and resilience of the food system

Trees generally survive extreme weather events better than annual crops, which can make them more reliable food sources in the face of increased regularity of these events due to climate change.[58] In some arid areas, tree foods are the only ones still abundant at the end of the dry season.[59]

The important role of forest foods in supporting lean-season diets has been shown in both Africa and Asia.[60,61] Older and low-income households in particular are more likely to rely on wild foods, including wild tree foods, during scarcity periods.[62] Trees in agroforestry systems also fill seasonal gaps in food production. Growing a diversity of tree foods with different seasonal patterns and valued nutrient profiles supports year-round nutritional security.[63] These portfolios can also mitigate the impacts of seasonal food price fluctuations that affect the affordability of nutritious diets.

Trees and forests also provide a safety net to households by contributing both wood and non-wood products that can be sold for income.[64] Among low-income households, extracting more environmental resources, most of which are from forests, is an important income-generating coping strategy during times of hardship.[65] Several case studies have documented a range of forest products, including tree foods, sold by the lowest income households for purchase of other types of food in times of crisis.[66] Whether directly consumed as food or sold for food purchases, forest and tree products are, in many cases, the only resources accessible to women and other marginalised groups when hardship strikes, and are therefore key resources to reduce their vulnerabilities.[67]

There is considerable scope to reap greater benefits for both human and environmental health from the broader

inclusion of trees and forests in food systems. We highlight four important areas for intervention based on our research and development experiences.

Building on current knowledge by scaling existing tree-based agricultural system solutions

Known measures required to realise the multiple benefits of trees and forests for food systems are not yet being adopted at a sufficient scale. For example, of the many known trees that provide nutrient-rich foods, the seeds and seedlings needed to plant them are only widely available for a few groups. One of the challenges in delivering tree planting material at scale has been that the requirements for doing so are, in part, different from better-researched and more widely scaled annual crops, so opportunities for the cross-application of learning are scarce.[66] Features unique to trees compared with annual crops include the vast diversity of species, their generally high multiplication rates, the long time until maturity, and that they are field-planted by growers generally as seedlings rather than as seeds. It is essential to work closely with small-scale and medium-scale tree seed suppliers and nursery enterprises to address these challenges.[66] If given appropriate support, these providers can sustainably supply tree planting material because of their low transaction costs in reaching growers with a diversity of tree species. However, providers do not yet receive sufficient help in business planning, seed sourcing, technology use, or through appropriate national-level policy development and implementation.

Scaling tree-based solutions also requires secure tree and land tenure, which is not yet the case for many tree growers. To be effective, measures to increase land tenure security should be connected with incentives for sustainable practices, including for tree maintenance on farms.[67] Providing tenure and access rights is especially important for removing barriers to tree planting for women and marginalised groups, thus allowing all members of a community to reap the benefits of trees.[67]

Tenure is the most often cited barrier to making the use of trees more widespread. However, a myriad of social, cultural, and economic factors constrain and enable the use of trees depending on the local context. For example, a synthesis of 22 agroforestry adoption studies in Africa examined the influence of 38 factors (such as education, distance to market, and farm assets) on adoption of agroforestry technologies, and found that only three factors—access to extension, farmer group participation, and land pressure—were positively associated with adoption of these technologies in more than 50% the of studies that investigated it.[68] Context specificity of the drivers of adoption of agroforestry technologies was further illustrated by the fact that 21 of the factors positively influenced adoption in some studies and negatively in others. These results align with earlier pantropical adoption syntheses,[69] and highlight the need for engagement with and integration of local knowledge before embarking on agroforestry programming.

Building on the existing knowledge of local communities regarding how to manage trees is important. Humans have managed trees in their landscapes to enhance food production since before the agricultural revolution.[70] Some of the best known examples are in the Amazon, where concentrations of certain trees on anthropogenic-rich soils are indicative of ancient harvesting, managed regeneration, and cultivation.[71] Traditions of use, propagation, management, and genetic manipulation to improve the key food-use traits of trees are embedded in many indigenous cultures globally,[72] and this knowledge can still be used today to support the further cultivation and domestication of food trees in new contexts.

Reorienting agricultural investments from staple crops to more diverse, nutrient-dense foods

The enhanced productivity of staple crops witnessed since the 1960s has been the result of billions of US dollars of public and private sector investment in breeding and crop management. These increases in productivity have decreased the relative purchase prices of staple crop foods compared with more nutritionally important fruits, nuts, and vegetables, partly explaining the lower consumption of these nutritious foods.[73] Reorienting research investments to improve the production of nutritionally important non-staple foods, including tree foods, is likely to be a prerequisite for increasing their consumption.[74,75] These improvements in production need to be paired with investments in appropriate consumption-facing measures, such as education and social marketing. These measures should be carefully designed to also increase awareness of the environmental implications of food choices to encourage consumption of sustainably produced foods. Finding the right balance between production-oriented and consumption-oriented interventions to maximise investment returns is an important topic for research, which has not yet been widely explored.[76]

Despite the need for change in investment priorities, global agricultural research funding has continued to focus on a few staple crops of low nutritional value that are largely produced unsustainably.[77] The Consultative Group for International Agricultural Research, for example, a consortium of institutions of which we are part, allocated more than 58% of its received funding to staple crops between 2012 and 2016.[78] However, a few donor governments, such as those of Switzerland, France, and Germany, have begun to shift their priorities to advance progress in more diversified production systems. For example, 51% of Swiss-funded agricultural research for development projects between 2013 and 2018 included an agroecological component, amounting to US$564 million in investments.[79] Such examples, however, remain a small amount of the annual global investment in the agricultural development research budget.[80] Given the multiple benefits of trees in producing nutrient-rich foods, in enhancing food system resilience, and in improving our environment, greater research investment is merited.

Repurposing producer and consumer incentives towards nutrient-dense foods and more sustainable production practices

Transformative food system change requires that international and national policies are repurposed to support the production and consumption of more nutrient-rich, sustainably produced foods, including tree foods. Current policies on the supply side distort incentives towards staple crop production through direct price support, and through indirect benefits such as targeted fertiliser subsidies for their production.[77] These incentives should be reduced or removed, and direct and indirect price interventions by governments, which are designed to consider more closely both nutritional needs and environmental impacts, should be implemented.[74] Some of these subsidies could be reallocated to the production of nutrient-rich foods including fruits, vegetables, nuts, and pulses (some of which grow on trees). Policies incentivising the integration of food trees in farms could increase their production to improve diets while providing environmental benefits. Combined payment for both ecosystem and nutrition services could be one approach to reward the growers of food trees. Where government policy requires that a certain percentage of farm area be tree cover as, for example, stipulated by the Brazilian forest code, additional rewards and support could be offered when these trees are sources of diverse foods. It will be important to specifically integrate sustainability standards with suggested policies of rewarding production of food trees to avoid over-exploitation of wild foods and any potential negative environmental impacts of intensified tree plantations. The modelling of the consequences of such changes in policy for all groups in society is needed to understand any potential unintended consequences, and to put any additional required compensatory measures in place.

Policies that encourage more nutrient-rich, tree-based food production will bring down the prices of these foods for consumers, resulting in greater consumption of healthy foods.[81,82] However, such economic incentives to increase consumption are unlikely to be enough. Increased consumer awareness of the impacts of food choices on their own health and on the environment is needed. Public awareness campaigns and social marketing strategies should therefore accompany economic incentives.

Real, large-scale change is often driven by grassroots movements that generate self-sustaining action by empowering, inspiring, and encouraging communities to adapt interventions to support their particular needs.[83] Further support to tangible examples involving trees and forests will complement work at the policy level. Efforts to better link consumers to producers are also required to promote nutritious, tree-based food mainstreaming. Improvements in storage after harvest, in sorting and processing facilities, and in transportation are all known to be required for delivering healthy perishable foods, including tree foods, in low-income and middle-income countries.[77]

Explicitly integrating food and nutrition objectives in forest restoration and conservation practice and policy

The Bonn Challenge[84] has the goal of restoring 350 million hectares of degraded and deforested lands globally by 2030. The restoration agenda has thus far been dominated by the objective of sequestering carbon to mitigate climate change.[85] Restoration initiatives often do not work, however, because they do not adequately consider the needs of local people or fully integrate them into restoration planning and actions.[86] Focusing more on food trees during restoration would not only sequester carbon and support diverse landscapes, but would supply healthy foods that can be eaten and traded by local communities to support their involvement in these initiatives, thereby improving their success.[22]

Efforts to conserve existing forests for objectives that go beyond climate mitigation and biodiversity conservation to encompass food security and nutrition would also increase their relevance to national and local stakeholders. These efforts require a change of mindset in global and national discourses to view forests as vital direct and indirect components of food systems, rather than as vegetation that needs to be sacrificed to grow staple crops—as is often the perspective in current national discourses. Thus, in making land use decisions, such as whether to remove the protected status of a forest so that it can be used for other purposes (eg, timber harvesting and farmland),[87] the full costs, including lost direct and indirect food and nutrition benefits, should be considered. We need to move away from the existing wood-focused productionist paradigm in the forestry sector to embrace a more systemic approach that accounts for all forest products and services, including wild foods.[30] The Collaborative Partnership on Forests[88] has proposed the development of a global core set of forest-related indicators to measure the contributions of forests towards sustainable development, including contributions to food and nutrition. These indicators are still under development, but we suggest that they should be strongly supported to ensure they capture the wider contributions of forests to society as well as possible so that these benefits are also considered in decision making and policy. Recognising that forests are an important source of food requires not only their protection, but that action is taken to ensure that communities reliant on forests have continued, inalienable access rights.

Conclusion

The current global food system relies heavily on a small set of calorie-rich but nutrient-poor staple crops, contributing to a narrowing of diets with a simultaneous epidemic of obesity, while damaging our environment and our future productive potential. The 2021 UN Food System Summit was an acknowledgment that the world needs new solutions to these challenges. Trees and forests play an often overlooked, yet crucial, role in our current food systems, and have an essential role in the

necessary transformation of food systems to achieve better quality diets and long-term sustainability of food production. Trees and forests provide key environmental services, enrich biodiversity, restore degraded lands, and help to mitigate and adapt to climate change while providing key nutrient-rich foods that are undersupplied and underconsumed in our current food systems. Fully leveraging these contributions and scaling solutions will require a range of measures, including increased investments to scale current tree-based investments; a substantive reorientation of research, innovation, and incentives towards making nutrient-rich foods more available and accessible; and better integration of forestry and food policy and management. If all food system actors give trees and forests the attention they deserve, they can contribute to the transformation of our global food system for healthier people and a healthier planet.

Contributors

RN had the initial idea. AI, SM, MN, AN, and RN contributed to the conceptualisation. AI, SM, MN, TR, ID, DR, TS, CT, and MRG wrote the original draft. AI, SM, TR, ID, DR, TS, CT, MRG, AN, KM, VG, AM, HD, and BP contributed to the review and editing processes. RJ and RN contributed to the review process. AN was responsible for design of the figure.

Declaration of interests

We declare no competing interests.

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