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Microbiome science for agri-food systems transformation and One Health: why low- and middle-income countries must be at the center

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A Viewpoint on the Frontiers in Science Lead Article
Harnessing agri-food system microbiomes for sustainability and human health

Key points

- Microbiomes play essential roles in soil fertility, plant growth, animal and human health, and ecosystem stability, but their diversity and functionality are increasingly disrupted by industrial agri-food practices, antimicrobial misuse, and industrialized lifestyles-exacerbating One Health risks such as antimicrobial resistance, chronic disease, and climate vulnerability.
- Integrating microbiomes into the One Health framework creates an opportunity to harness the full potential of microbiome science and innovation to transform agri-food systems and address One Health challenges.
- Low- and middle-income countries must be at the center of microbiome innovation, research, and policy efforts, as they are both highly vulnerable to One Health threats and rich in microbial and agri-food diversity.

Introduction

Global agri-food systems face unprecedented and simultaneous pressures from various drivers, including climate change, ecosystem degradation, food insecurity, antimicrobial resistance (AMR), and zoonotic disease threats. These converging and emerging crises call for systemic approaches rooted in biological complexity, and interdependence across countries worldwide. One Health, as defined by the Food and Agriculture Organization (FAO), is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, plants, and ecosystems (1). However, a critical dimension often missing from One Health strategies is microbiome science, the study of complex communities of microorganisms that inhabit specific environments and their interactions, functions, and roles in host and ecosystem health (2).

Microbiomes are foundational to health, sustainability, and resilience. They underpin soil fertility, plant growth, animal productivity, food quality, and human immune function among others. Yet the diversity and functionality of microbiomes are increasingly disrupted by industrialized agri-food system practices and lifestyles, including the increasing consumption of ultra-processed foods. These disruptions contribute to a wide array of One Health threats, from chronic disease and compromised immunity to declining crop yields, soil degradation, and climate vulnerability (2).

This Viewpoint argues that microbiome science and innovations hold transformative potential, offering actionable pathways to restore and enhance the functioning of agri-food systems and contribute to achieving One Health goals worldwide. For this potential to be realized, however, the fair, inclusive, and context-appropriate integration of microbiome science and its applications in policy, research, and innovation, and the active participation of low- and middle-income countries (LMICs), are essential.

Microbiome diversity and functionality

Microbiomes, and their diversity, are deeply functional. They regulate biogeochemical cycles, modulate immune responses, protect against pathogens, and influence nutrient availability and climate feedback loops, among other functions. In agri-food systems, soil microbiomes support and promote plant health and productivity through nitrogen fixation, disease suppression, and drought resilience. In animals and humans, gut microbiota contribute to digestion, metabolism, inflammation regulation, and immune responses. In their lead article, Fernández-Gómez et al. (3) highlight how advances in technologies, especially in high-throughput sequencing technologies, have enhanced our understanding of microbiome composition and functions across environments. Beyond identifying which microbes are present, what matters most is what microbes do together, and how microbiome functions are altered by human activity.

Anthropogenic disruptions to microbiomes' composition and functionality are now well-documented and have direct consequences for ecosystems and host health. In humans, the loss of biodiversity in microbiomes is associated with inflammation, metabolic diseases, allergies, autoimmune disorders (4), and reduced vaccine efficacy (5). In animals, disturbed microbiomes can increase disease susceptibility, impair feed conversion, and promote AMR (6). In plants, microbial imbalances can reduce resilience to pests, diseases, and climate stress, affect plant growth, and impact nutritional content (7). In ecosystems, dysbiosis can limit carbon sequestration, oxygen production, and nutrient cycling, and weaken natural climate regulation mechanisms (8).

This degradation of microbiome functionality is accelerating owing to various agri-food systems practices, including soil tillage and soil overuse, agrochemical dependence, antimicrobial misuse, monocultures, and the global spread of ultra-processed diets (9).

Microbiome science and innovation, and the LMIC blind spot

One Health threats do not stop at national borders. The article by Fernandez-Gomez et al. (3) could benefit from a stronger focus on the importance of microbiome science and innovation for LMICs, and their fundamental role in both One Health and global health. Despite its importance in health and agri-food systems, microbiome research remains heavily concentrated in—and focused on—high-income countries (HICs). Most microbiome datasets come from controlled environments in these countries, limiting their applicability to LMIC contexts. This gap not only distorts the scientific process but risks exacerbating already significant inequalities in LMIC participation in research, and in access to microbiome-based innovations and the resilience-building investments they urgently need.

Yet, from both microbiome and global food security and health perspectives, LMICs are where the stakes are highest—and where the opportunities are greatest—for the following reasons.

- They host some of the world's richest reservoirs of microbial diversity, often in less industrialized or ecologically better-preserved regions.
- Their agri-food systems are highly diverse, spanning traditional subsistence models, pastoralism, agroecological systems, and emerging commercial enterprises, each with their own associated microbiomes.
- LMICs face disproportionate exposure to One Health risks: zoonotic diseases, AMR, food insecurity, undernutrition, and climate vulnerability.
- Smallholder farmers and indigenous communities are key custodians of both biological and cultural knowledge, essential to co-designing microbiome-based solutions.

However, without targeted investment and inclusive research and innovation policies, LMICs risk being left behind in the microbiome revolution. A lack of infrastructure for sequencing, bioinformatics, and research collaboration limits both the generation and use of locally relevant data. This leaves local and global policies blind to the microbiome realities of LMICs and overlooks microbiomes as strategic assets for more inclusive economic growth and social development.

Integrating microbiome science into One Health offers an opportunity not only to address global health risks but also to strengthen both local and global agri-food systems. It enables more

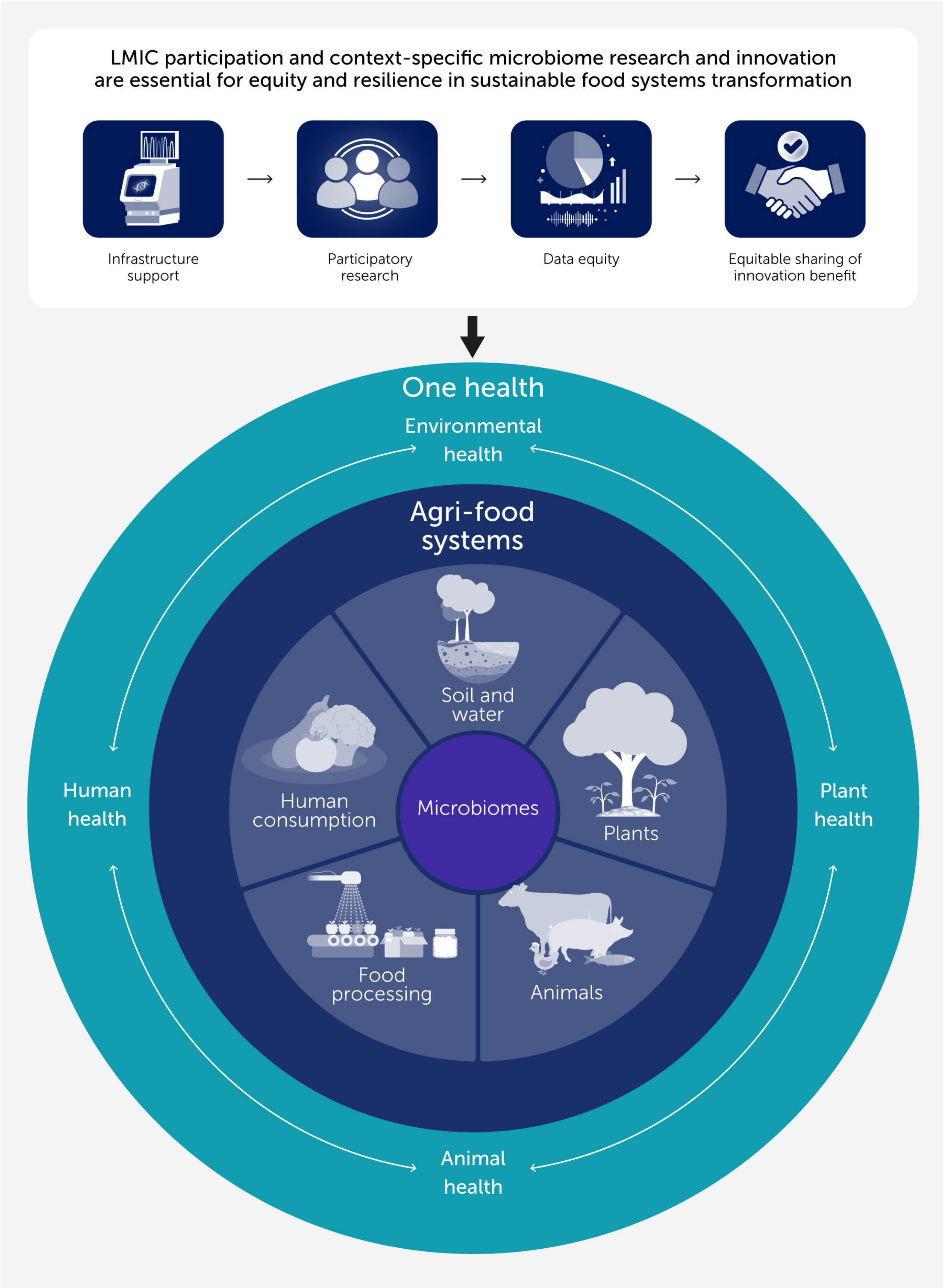

FIGURE 1
Integration of microbiome science across agri-food systems within the One Health framework. The essential role of low- and middle-income countries in advancing microbiome science to support global food security, equitable research, and sustainable health outcomes is also highlighted.

targeted interventions tailored to ecological and socioeconomic contexts, including those in LMICs (Figure 1). Examples include:

- microbial soil amendments to restore soil fertility and reduce reliance on synthetic inputs.
- phage therapy and probiotics to reduce antibiotic use in livestock and aquaculture.
- fermented foods to improve nutrition and gut health.
- microbiome monitoring for early detection of zoonotic threats or AMR hotspots.

These interventions can enhance productivity, sustainability, and equity, provided they are developed through participatory, place-based approaches that include LMIC actors from the outset.

Recommendations: integrating microbiomes into policy and practice

The following steps are critical to realize the transformative potential of microbiome science and innovation in One Health and agri-food systems transformation.

- Mainstream microbiome functions in One Health frameworks: One Health policies must explicitly address the threats to, and the opportunities offered by, microbiome functions in ecosystem services, to improve health outcomes and achieve sustainability targets.
- Support infrastructure and participation in microbiome research in LMICs: this includes funding for labs, sequencing technologies, capacity development, and open-access platforms to ensure local data ownership and interpretation.
- Foster co-design of microbiome innovations: efforts must engage local producers, scientists, and communities in LMICs in the design, testing, governance, and commercialization of microbiome-based solutions.
- Include microbiome indicators in agri-food system monitoring: functional microbiome metrics should be developed as early warning systems for degradation, disease, and sustainability trends.
- Establish legal and institutional frameworks: LMIC governments should enable active participation in global microbiome science initiatives, including investment in research infrastructure, adoption of equitable data sharing policies, and uptake of scientific findings into national development strategies.
- Engagement of legislative bodies: these should mandate and resource participation in microbiome research to translate global scientific progress into local impacts.
- Ensure equitable benefit sharing: all actors should respect principles of data sovereignty, Indigenous knowledge protection, fair access to microbial-derived innovations, and the equitable sharing of benefits derived from commercialization.

Conclusions

Microbiomes are not a new trend or a marginal concern. Research has delivered compelling evidence that microbiomes are the living infrastructure that sustains agri-food systems and planetary health. Recognizing their diversity and tapping into their functionality is essential for effective One Health strategies and for transforming agri-food systems toward greater sustainability, resilience and equity. To succeed, we must bring LMICs closer to the center of microbiome innovation, research, and policy efforts. For microbiome science to be transformative, it must be inclusive. The health of people, animals, plants, and the planet, depends on it.

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