



Food and Agriculture Organization
of the United Nations



MICROBIOME: THE MISSING LINK?

SCIENCE AND INNOVATION FOR HEALTH, CLIMATE
AND SUSTAINABLE FOOD SYSTEMS

HOW CAN WE TRANSFORM OUR DIETS AND FOOD SYSTEMS TO SOLVE HARD-CORE PROBLEMS OF UNDERNOURISHMENT, WHILE AT THE SAME TIME TACKLING THE EMERGING PANDEMIC OF OBESITY AND DIET-RELATED NON-COMMUNICABLE DISEASES?

HOW WILL WE BE ABLE TO FEED 10 BILLION PEOPLE BY 2050 WITHOUT DESTROYING OUR NATURAL RESOURCE BASE?


CAN WE STOP AND POSSIBLY EVEN REVERSE THE LOSS OF BIODIVERSITY, ENVIRONMENTAL DEGRADATION, AND CLIMATE CHANGE?

THESE ARE BIG QUESTIONS!

The world is afloat with views on how best to go about these issues. Unfortunately, the fact is that we have so far not been very successful in resolving any of these issues in a significant way. Beyond the point of lack of political commitment, this fact also begs the question whether there is maybe something amiss in our understanding of the causes of these problems.

Are we overlooking something?

The views expressed in this document are those of the author(s) and do not necessarily reflect the views or policies of the Food and Agriculture Organization of the United Nations (FAO).



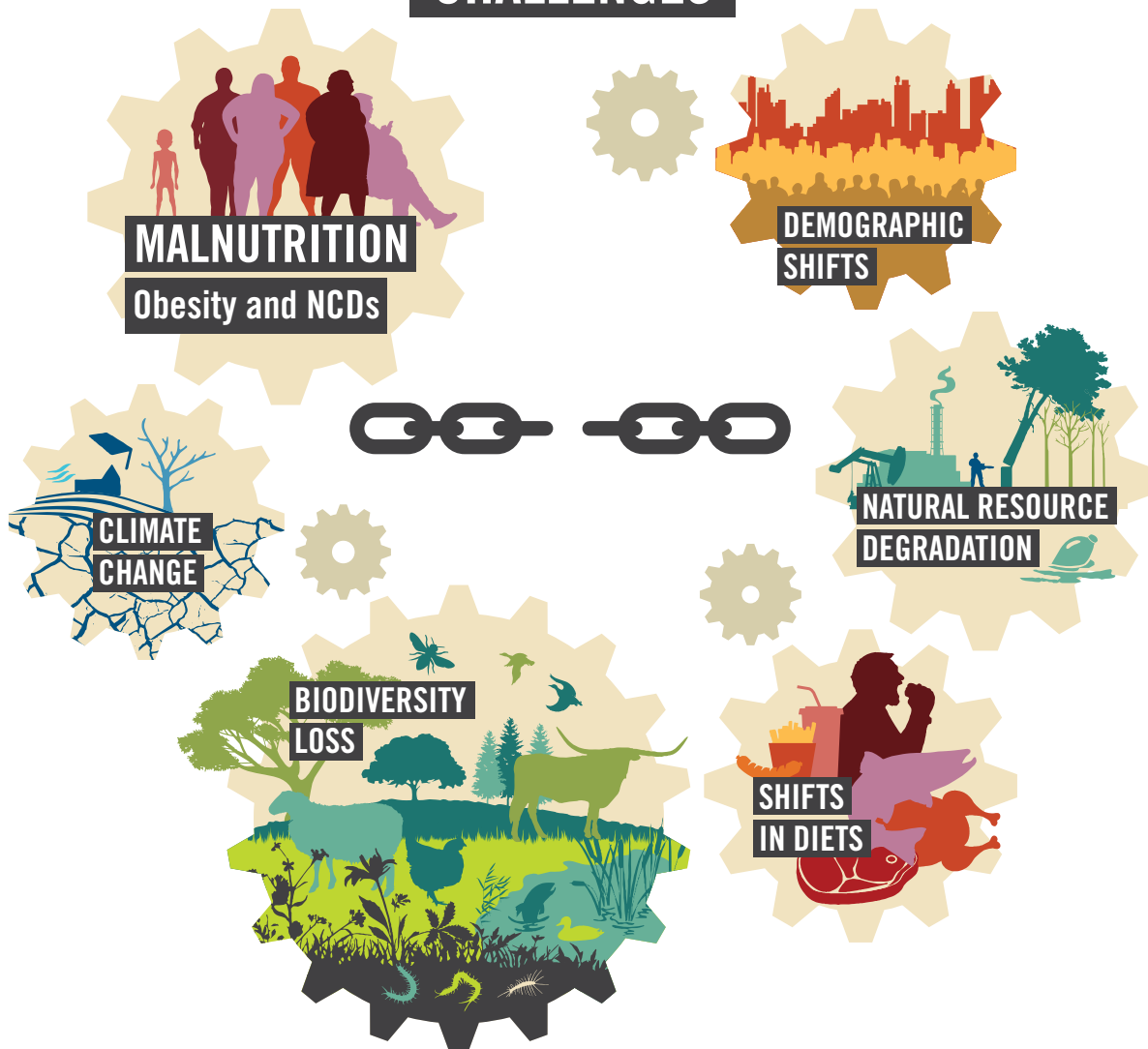
In search for answers, an informal group of people got together first to look into the question about alternative explanations for the obesity and non-communicable diseases (NCDs) pandemic. A review of recent scientific literature showed how gut dysbiosis, an imbalance in the gut microbiome, is a common factor in obesity and various diet-related NCDs. A further search for factors that can cause dysbiosis led to the identification of a variety of possible causative factors, including lifestyle factors, use of antibiotics, diet composition, the presence of various chemical compounds in our food, etc. Some of these compounds can enter our food as agro-chemicals used during production, or additives used in processing and transformation. Others, like mycotoxins are the result of poor practices.

This finding led the group to expand its exploration to the role of the microbiomes of for example animals, plants, soils, rivers, oceans, etc. and how their disturbance could affect for example soil fertility, carbon sequestration, plant and animal growth and health, etc.

The group has since evolved in an interdisciplinary team that is focusing on a systematic review of transformative scientific research into the role of the microbiome in nutrition and health, agriculture and food systems, and the bioeconomy at large. This note outlines some preliminary findings, implications and opportunities with the idea of stimulating further thinking and exploration.

The team currently consists of: **Karel Callens**, bio engineer by training and Deputy Strategic Programme Leader, Food Security and Nutrition; **Catherine Bessy**, agronomist and food scientist and Food Safety officer; **Anne Bogdanski**, biologist by training and Natural Resources officer; **Fanette Fontaine**, Associate professor of microbiology; **Ceren Gurkan**, economist by training and Programme Officer; **Sarah Nájera Espinosa**, Food Safety consultant, with a background in environmental science; **Dylan Warren Raffa**, plant and soil expert and PhD Fellow on Agrobiodiversity; and **Susan Grooters**, epidemiologist.

CHALLENGES



LOOKING FOR THE BEST PATH TOWARDS NOURISHING 10 BILLION PEOPLE

Unhealthy diets now pose a greater risk to morbidity and mortality than unsafe sex, alcohol, and drug and tobacco use combined. They are at the root of the global obesity and diet-related non-communicable disease (NCD) pandemic. The ways of food production that lead to these unhealthy diets also pose a major threat to climate stability and ecosystem resilience, and constitute the most important driver of environmental degradation and natural resources depletion.

Malnutrition comes in different forms. While nearly a third of the world's population is overweight or obese, one out of nine people remains undernourished, and more than one out of three suffers from micronutrient deficiencies. Three quarters of all deaths globally are due to NCDs, and three quarters of all NCD-related deaths occur in low- and middle-income countries. **People often suffer from multiple forms of malnutrition and diet-related health problems** over their lifetime and sometimes even at the same time.

Even though we waste roughly over a third of all food produced worldwide, there remains enough to feed everyone. Yet hunger persists and malnutrition is on the rise. While poverty and inequality play a big part, something even more fundamental is amiss. The natural world, the bedrock of poor people's livelihoods, and arguably our global economy, is under severe pressure. This is likely the biggest challenge defining the twenty-first century. Climate change, biodiversity loss, soil degradation, and other forms of manmade environmental damage demonstrate how our food system is mining nature, and in the process undermining its very foundation. While the poor are the first to experience the consequences, there is a growing ripple effect throughout the global food system and society.

Although poverty levels have steadily gone down, we are on a trajectory where poverty reduction risks following the same path as malnutrition, slowing down after a period of relative improvement. Inequality, a key

determinant of poverty, is already on the rise. A major factor in this relapse are the **hidden environmental and health costs of the economic growth and agricultural intensification** that have supported growth in food supplies and incomes.

We are on a path where we are degrading our natural resource base, including its biological resources, to the point where major disruptions in our food system and in the socio-economic fabric of society will inevitably force the system to change. We are at a crossroads: the choice is between doing nothing, risking our future food security and health, or deciding to take action, whereby action means radically rethinking our food system from a sustainable bioeconomy perspective.

Bioeconomy is about exploiting synergies and considering hard trade-offs between the food system and other parts of the economy that depend on biological resources and processes for the production of goods and

services. It entails the sustainable use of renewable biomass and efficient bioprocesses to achieve sustainable production. In some instances, it might also mean to conserve the biological resource base rather than using it. It relies on the use of enabling and converging technologies, including biotechnology; and it requires integration of policies and actions across agriculture, health and other sectors and industries.

In the short term, there is little that we can do to curb the global demand for food and other products that depend on biological resources. **Demand will continue to rise as the world population grows** to ten billion before eventually shrinking again. However, by taking a bioeconomy approach, we can alter the nature of this demand and the processes through which the food system and bioeconomy meet that demand. This approach could accommodate the necessary increases in agricultural production, without continuing to degrade our natural resource base.

SMALL THINGS CAN MAKE A BIG DIFFERENCE

Bioscience is uncovering the pathways and **common drivers behind the triple challenge of obesity and NCDs, climate change, and biodiversity loss**. In the process, microbiology and the inter-disciplinary study of the microbiome have rediscovered microorganisms as a vast and untapped natural resource with great potential to shift the balance of the 'nature – food systems – people' equation back into the healthy zone.

The microbiome refers to the combined genetic material of all microorganisms living in a given ecosystem, including in the human body. Current estimates put the total number of different microbial species at one trillion, of which we currently only know about 0.001 percent. Because of the convergence of techniques across computing, bio-engineering and genomics, we are now able to detect and study this wealth of microbial species that, up until very recently, were undetectable.

The diversity of microorganisms surpasses by far the diversity of all the other living organisms on earth. They perform many, often critical, functions in the ecosystems in which they

live. Perhaps the most critical discovery to date is that microbiome diversity, rather than any particular microorganism, is at the root of microbiome ecosystem resilience, including the resilience of the human body to withstand stress and disease.

Within the sphere of human health, gut dysbiosis, or the loss of microbiome diversity and shifts in the composition of the microorganisms populating the gut, can result in loss or alteration of a healthy microbiome. Dysbiosis affects various functions, including digestion, energy metabolism, immunity, intestinal permeability and brain function. **The link between gut dysbiosis and obesity and food related NCDs** like diabetes, cancer, heart disease, allergy, irritable bowel syndrome, etc. **is now established.**

Microbiome research is adding depth to our understanding of nutrition, and of how diets and food products, mediated by the gut microbiome, affect human health. The gut microbiome metabolizes certain food components not digested by the human gut, making a large variety of metabolites available for human

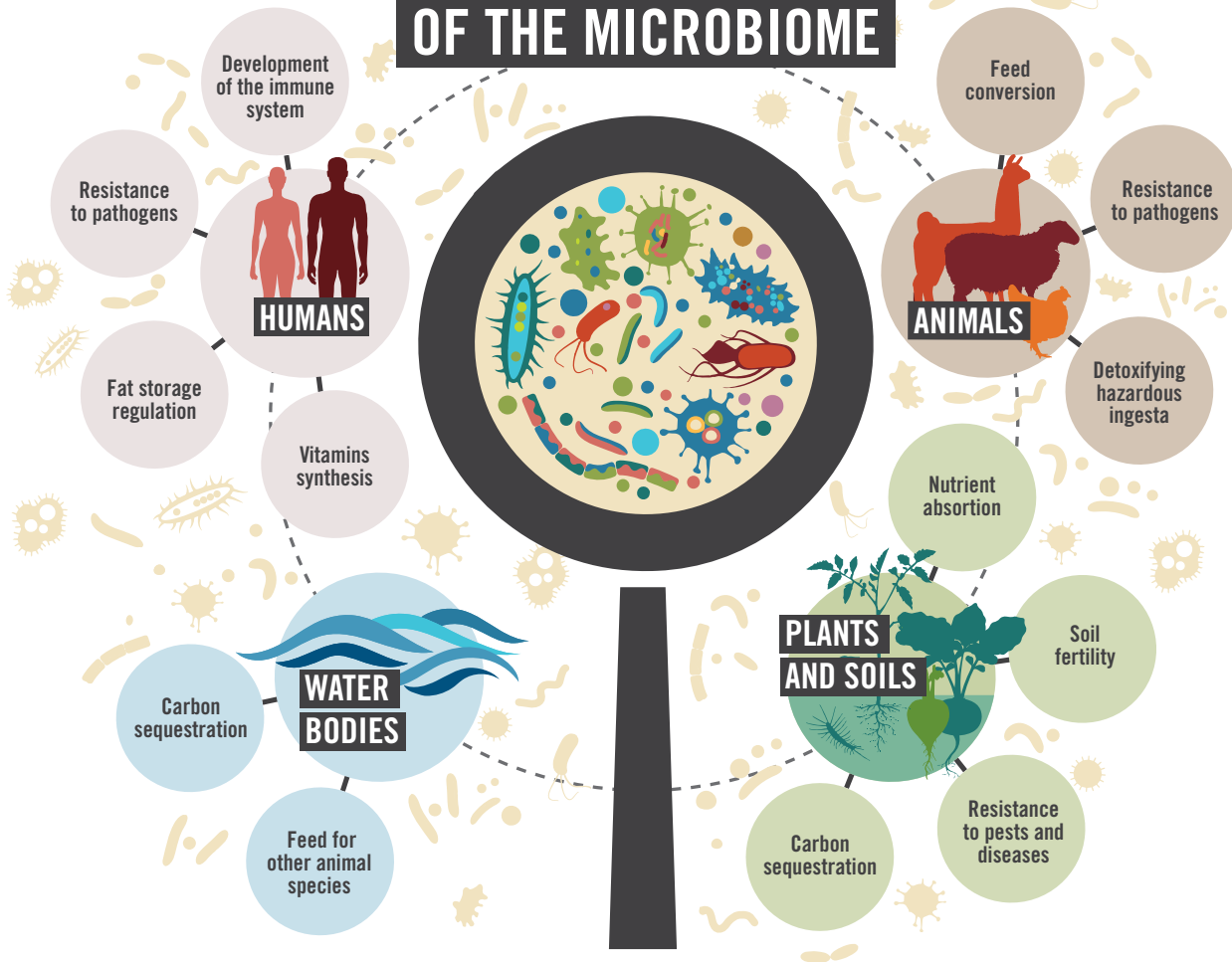
cells to digest further, or for other microbes to use. Much of this process, including the presence and function of bacterial metabolites were unknown until recently. This research shows that in addition to genetic factors diet composition directly affects the ecology of the gut microbiome and thus its functionality and this may result in adverse health effects. In addition, recent research suggests that the presence in food of certain compounds can influence the microbiome ecology: this appears to be the case for some pesticide residues, certain additives and veterinary drug residues, for example. What emerges is that we need to consider the microbiome as a functional part of our body and look at how our diet over time, starting from the first thousand days of a person's life, affects nutrition and health.

Similar to what we are learning about the human gut microbiome, **we are now also discovering how the microbiomes of soils, rivers, lakes and oceans are key to environmental health.** The microbiome plays a central role in agricultural production and productivity, forestry, fisheries and aquaculture,

and in the continuous regeneration of the natural resource base. Agriculture and natural resource management practices that protect and enhance microbiome diversity are the foundation of sustainable food systems. For example, we now understand the negative impacts of agrochemicals on soil fertility, of fertilizer runoffs on algal blooms in lakes, rivers and oceans, and the positive impacts that various bacteria and fungi, living in association with plants, can play on nutrient absorption, metabolism and plant health.

From a climate change perspective, the recent Intergovernmental Panel on Climate Change (IPCC) Report on Climate Change and Land highlights the important role of soil microbiome in climate change, from the perspective of impact as well as adaptation and mitigation. A soil's microbiome plays an essential role in major natural cycles on earth (like nitrogen and carbon cycles) which underpin the functioning of soils and their ability to capture and store carbon. The microbiome of oceans, lakes and rivers play a similarly important role in climate change.


POSITIVE SERVICES OF THE MICROBIOME



POTENTIAL APPLICATIONS
OF THE LATEST DISCOVERIES ON THE
MICROBIOME



**CREATING
SUSTAINABLE BUSINESS
OPPORTUNITIES**



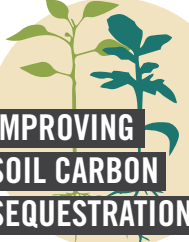
**REDUCING
ANTIMICROBIAL GROWTH
PROMOTERS USE**




**REPLACING INORGANIC
FERTILIZERS AND
PESTICIDES**



**IMPROVING
WASTE TREATMENT**



**IMPROVING
SOIL CARBON
SEQUESTRATION**



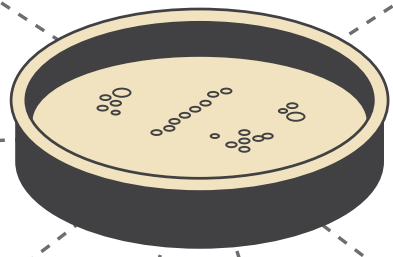
**PREVENTION
AND TREATMENT
OF DIET-RELATED
NON-COMMUNICABLE
DISEASES**



**PREVENTION
AND TREATMENT OF
INFECTIOUS DISEASES**



**OPPORTUNITIES
FOR BIOFUEL
PRODUCTION**



FROM THE MICROBIOME TO THE BIOECONOMY

Microbiome research holds one of the keys to the intertwined goals of food system sustainability and healthy diets for all. It provides insights into how to produce more with less, reduce external input use, regenerate the fertility and health of our soils and water bodies, enhance food production and productivity, and help people prevent and treat various NCDs, as well as infections that have become resistant to antibiotics.

From biological and ecological perspectives, the case of the microbiome is clear. However, does it also make social and economic sense? The burden of ill health, environmental degradation and climate change are massive, and the associated costs are largely unaccounted for in the prices of food and other products and services that depend on nature. Hidden costs often only materialize in the distant future, well beyond the time when the actions that led to these costs took place. For example, exposure to antibiotics and malnutrition in early childhood may only affect

health several decades later. Similarly, climate change has been in the making for many decades. This cause-effect time lag is not a great formula for accountability.

The public sector has a great responsibility towards people, and especially towards future generations, to lower this burden and to hold those who generate the hidden costs accountable for covering and, where possible, reducing them. This is indeed challenging not in the least because it may not be politically attractive to do so. While there is scope to improve efficiency by cutting food loss and waste, this will not be enough. It also does not solve health issues. We will not be able to face up to this complex challenge without major new investments, both public and private, in renewability and the efficiency with which we use our natural resources.

An important aspect of the bioeconomy approach is to look towards science, technology and innovation for new ways of producing not only more, but also better and healthier food

with much fewer natural resources, while at the same time regenerating our degraded natural resource base. Microbiome science has opened up an important window of opportunity for this type of radical change through very practical solutions that also hold great business potential and are therefore politically attractive. The European Union, for example, is investing heavily in national and regional bioeconomy strategies and the cross-disciplinary research and innovation that go with such strategies. Other countries are also making major inroads – for example, through collaborative research platforms like the Human Microbiome Project and the Earth Microbiome Project, which bring together research centres, universities, companies, as well as scientists, consumers, farmers, food processors and health practitioners.

Some of the latest microbiome discoveries and innovations have demonstrated a potential to rethink the way we produce our food, while preserving and leveraging our natural resources, for example: replacing antimicrobial growth promoters, inorganic fertilizers, and pesticides; improving plant nutrition; promoting soil carbon sequestration and soil remediation; enhancing animal feed conversion; reducing

methane production by ruminants; increasing biofuel production; enhancing waste treatment; development of new antimicrobials; and prevention and treatment of various diet-related communicable diseases, antimicrobial resistant infections, etc. In fact, many of these applications are already being tested or applied.

Public sector investment in microbiome research and innovation is rapidly gaining traction in a growing number of countries. Private sector interest is large and also growing as microbiome research is leading to new products and services and opening up new markets. Scientific discovery and innovation are taking place ever more rapidly. However, the speed at which this new knowledge leads to policy debate and change remains painstakingly slow. Developing countries also run the risk of staying behind. The fact that **microbiome science cuts across traditional borders of scientific domains**, technical disciplines and economic sectors adds to the complexity of the policy, regulatory and institutional implications of these developments. It is, however, time to look thoroughly at this **myriad of tiny beings that may explain the missing links between our biggest challenges**.

WHAT IS FAO'S ROLE?

Unpacking complex issues, engaging with multiple stakeholders and bridging boundaries between science and policy are core functions in which the Food and Agriculture Organization of the United Nations (FAO), has a comparative advantage. Faced with the challenges and opportunities described above, FAO needs to engage with the scientific community worldwide to identify and share innovative ideas and solutions that can bring rapid and tangible food systems change. From a microbiome science perspective, this entails investing in a dedicated science-policy interface, the purpose of which would be to:

- monitor the latest scientific research in the microbiome domain as it pertains to healthy diets, agriculture, climate, the environment, and food systems and the bioeconomy more broadly. This would also include assessing which evidence is solid enough to inform sound policy and technical advice (e.g. scientific literature and systematic reviews, expert consultations);
- assess the implications arising from the combination of innovations in the food system and research on the role of microbiome in human health for policy, legislation, standards and other normative instruments at national, regional and global levels (e.g. implications for food safety risk assessments and standards, implications for food-based dietary guidelines);
- inform research on issues that need further investigation from a microbiome perspective (e.g. related to the impact of specific compounds on the gut microbiome, country assessments of factors that drive NCDs through gut dysbiosis);
- promote debate among the scientific community, policy-makers, private sector actors and consumers; and
- promote long-term partnership with centres for scientific research and innovation, including south-south and other forms of cross-country cooperation, as a means of promoting greater uptake of new science, innovation, development and application by end-users.

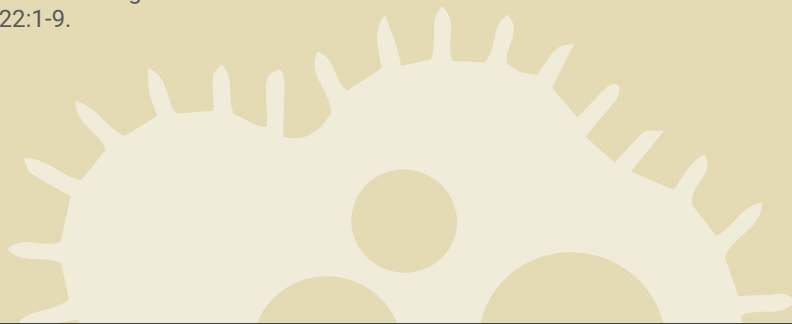
FAO'S ROLE

BRIDGING BOUNDARIES BETWEEN
SCIENCE AND POLICY



REFERENCES

- Blaser, M.J. 2014. The Microbiome Revolution. *J Clin Invest.* 124(10):4162-5
- Clemente, J.C., Ursell, L.K., Parfrey, L.W. & Knight, R. 2012. The impact of the gut microbiota on human health: An integrative view. *Cell.* 148(6):1258 -1270.
- Domínguez Bello, M.G., Knight, R., Gilbert, J.A. & Blaser, M.J. Preserving microbial diversity. 2018. *Science.* 362(6410): 33-34.
- Doré, J., Multon, M.C., Béhier, J.M., Affagard, H., Andremont, A., Barthélémy, P., et al. 2017. The human gut microbiome as source of innovation for health: Which physiological and therapeutic outcomes could we expect? *Therapies.* 72(1):21 -38.
- Flandroy, L., Poutahidis, T., Berg, G., Clarke, D., et. Al. 2018. The impact of human activities and lifestyles on the interlinked microbiota and health of humans and ecosystems. *Sci. Total Environ.* 627:1018-1038.
- Gentile, C.L. & Weir, T.L. 2018. The gut microbiota at the intersection of diet and human health. *Science.* 362(6416): 776-780.
- Golonka R.M., Yeoh, B.S. & Vijay-Kumar, M. 2019. Dietary Additives and Supplements Revisited: the Fewer, the Safer for Gut and Liver Health. *Current Pharmacology Reports.* 5(4): 317-317.
- Hadrich D. 2018. Microbiome Research Is Becoming the Key to Better Understanding Health and Nutrition. *Front Genet.* 9:212
- Jin, Y. X., Wu, S. S., Zeng, Z. Y. & Fu, Z. W. 2017. Effects of environmental pollutants on gut microbiota. *Environmental Pollution.* 222:1-9.
- Locey, K.J. & Lennon, J.T. 2016. Scaling laws predict global microbial diversity. *Proc Natl Acad Sci U S A.* 113(21):5970 -5975.
- Lynch, S.V. & Pedersen, O. 2016. The Human Intestinal Microbiome in Health and Disease. *N Engl J Med.* 375(24):2369 -2379.
- Sheth, R.U., Cabral, V., Chen, S.P. & Wang, H.H. 2016. Manipulating Bacterial Communities by in situ Microbiome Engineering. *Trends Genet.* 32(4):189 -200.
- Tamburini, S., Shen, N., Wu, H.C. & Clemente, J.C. 2016. The microbiome in early life: Implications for health outcomes. *Nat Med.* 22(7):713 -722.
- Tsiaooussis, J., Antoniou, M.N., Koliarakis, I., Mesnage, R., Vardavas, C.I., Izotov, B.N. & Tsatsakis, A. 2019. Effects of single and combined toxic exposures on the gut microbiome: Current knowledge and future directions. *Toxicology Letters.* 312:72-97.
- Wallace, R.J., Sasson, G., Garnsworthy, P.C., Tapio, I., Gregson, E., Bani, P., et al. 2019. A heritable subset of the core rumen microbiome dictates dairy cow productivity and emissions. *Sci Adv.* 5(7):eaav8391.
- Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S. et al. 2019. Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet.* 393(10170):447-492.
- Zmora, N., Suez, J. & Elinav, E. 2019. You are what you eat: diet, health and the gut microbiota. *Nat Rev Gastroenterol Hepatol.* 16(1):35-56.





HUNGER ERADICATION, FOOD SECURITY AND NUTRITION PROGRAMME MANAGEMENT TEAM (SP1)

Deputy-SPL1@fao.org

www.fao.org

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO)

Viale delle Terme di Caracalla

00153 Rome, Italy



Some rights reserved. This work is available under a CC BY-NC-SA 3.0 IGO licence