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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

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KEY ISSUES IN MICRO-ORGANISMS AND INVERTEBRATES

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I. INTRODUCTION

1. The Commission on Genetic Resources for Food and Agriculture (Commission), at its Twelfth Regular Session, emphasized the need to assess the status and trends of micro-organisms relevant to food and agriculture. It requested FAO, together with relevant international organizations and scientific institutions, to prepare focused targeted assessments of the status and trends in the conservation and use of soil micro-organisms, biological control agents and plant pathogens, in particular of important crops, for presentation at its Fourteenth Regular Session. The Commission also requested its Secretariat to prepare further analyses and studies on the status and trends of micro-organisms for ruminant digestion; agro-industrial processes; and food processing.[1]

2. In response to these requests, the Commission Secretariat, in close collaboration with the relevant technical divisions of FAO, commissioned a series of studies.[2] At its Thirteenth Regular Session, the Commission welcomed the progress made in the preparation of these studies and requested its Intergovernmental Technical Working Groups to review the relevant assessments within their respective fields of expertise.[3]

3. At its Twelfth Regular Session, the Commission also requested its Secretary to inform, promote collaboration and ensure synergies with relevant international organizations and forums, in particular the Convention on Biological Diversity (CBD), to advance work on micro-organisms and invertebrates of relevance to food and agriculture. It further invited such organizations to report on their work, policies, programmes and activities for its consideration at its Fourteenth Regular Session.[4] The relevant inputs received are included in the information document *Submissions by International Organizations on the Prioritised Themes of the Session*.[5]

4. The present document aims to facilitate the Commission's deliberations in reviewing key issues related to micro-organisms and invertebrates of relevance to food and agriculture. It draws on the main outcomes of the aforementioned studies, on information provided by relevant international organizations and scientific institutions, and on progress made in the international initiatives on pollinators and on soil biodiversity established under the CBD and coordinated and facilitated by FAO. The Commission's advice on how to advance work in this area is sought.

II. KEY ISSUES IN MICRO-ORGANISMS AND INVERTEBRATES

5. As the world population grows and becomes increasingly urbanized, the demand for staple foods is also increasing. With rising pressures on land, water and labour resources, meeting this growing demand, while ensuring the sustainability of production systems, is a daunting task. The challenge is to find effective ways of scaling up sustainable agricultural practices, producing more from the same area of arable land, while conserving resources, reducing negative impacts on the environment, enhancing natural capital, including crop and crop-associated biodiversity, and capitalizing on biological processes that contribute to the delivery of ecosystem services. Addressing this challenge requires an ecosystem approach that recognizes the key roles that the different components of biodiversity for food and agriculture, including micro-organisms and invertebrates, play in maintaining and strengthening healthy and productive ecosystems and in supplying the genetic resources necessary to adapt to long-term changes.

Status and trends in the conservation and use of soil organisms, biological control agents and plant

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[1] CGRFA-12/09/Report paragraph 60.

[2] Background Study Paper No. 61. Micro-organisms and ruminant digestion: state of knowledge, trends and future prospects; Background Study Paper No. 62. Invertebrates in rice production systems: status and trends; Background Study Paper No. 63. Conservation and use of micro-organisms and invertebrates in integrated root-and-tuber crop-based systems: state of knowledge, trends and future prospects; Background Study Paper No. 64. Status and trends of the conservation and sustainable use of micro-organisms in agro-industrial processes; and Background Study Paper No. 65. Status and trends of the conservation and sustainable use of micro-organisms in food processes.

[3] CGRFA-13/11/Report, paragraph 91.

[4] CGRFA-12/09/Report paragraphs 61 and 64.

[5] CGRFA-14/13/Inf.8.

pathogens in rice and root and tuber production systems[6]

6. In rice and root and tuber systems, knowledge of the complexity and diversity of above- and below-ground micro-organisms and invertebrates is still limited. However, even if much remains to be better understood (What organisms are present? What is their function? How do they interact with each other and with their associated crops?) these organisms and their inter-relationships clearly perform essential functions that contribute to the delivery of key ecosystem services, including regulating services, such as disease and pest control, and supporting services, such as the decomposition of organic matter and nitrogen fixation, which contribute to maintaining healthy, fertile and productive soils.

7. Soil organisms and biological control agents can be used, moved or manipulated for the benefit of food production systems. The interactions and overlaps between these two groups of organisms are also important, and further research to evaluate the scope and impact of manipulation of the soil ecosystem to conserve or encourage beneficial biological control agents is needed. Soils contain enormous numbers of diverse living organisms assembled in complex and varied communities. A reduction in the diversity of soil communities could result in a reduction in the beneficial functions and services they deliver or to which they contribute, with possible far-reaching effects such as long-term deterioration of soil fertility and a gradual decline in agricultural productive capacity. Depending on the context, the introduction of soil-organism species that are known to be strongly interactive and to contribute to a specific ecosystem process may have beneficial effects. Several studies have, for example, reported beneficial effects of arbuscular mycorrhizal fungi inoculation of micro-propogated root and tuber crops, including improved viability of potato plants during transfer from *in vitro* conditions, and increased potato and cassava yields and sizes.

8. Different groups of micro-organisms and invertebrates provide biological control of crop pests. In rice production systems, for thousands of years, biological control of pests has been sustained through the conservation of natural enemies. This stable traditional system of “natural biological control” has been disrupted over the past 50 years by Green Revolution technologies, such as the application of modern insecticides and the switch to rice monocultures. After four decades of pest outbreaks beginning in the 1970s, and having investigated several different approaches to pest control (particularly chemical control and plant resistance), researchers now realize that the best strategy for controlling pests and avoiding serious pest outbreaks in rice fields is to maintain a natural faunal balance through the conservation of natural enemies in rice ecosystems and their surrounding environments. Given that the losses caused by pre- and post-harvest pests can be substantial, the potential benefits of using micro-organisms and invertebrates as biological control agents are vast, but as yet only partially tapped. The potential for soil organisms to assist in this function is still largely unknown.

9. Crop varietal diversity also plays an important role in minimizing the risk of insect pest and disease outbreaks: if one variety succumbs to a pest outbreak, farmers can still produce food using other varieties. However, studies have yet to investigate the effects of crop varietal diversity on the diversity and abundance of micro-organisms and invertebrates in the crop production system.

Status and trends of micro-organisms for ruminant digestion, agro-industrial processes, and food processing[7]

Micro-organisms in ruminant digestion

10. In the last decade, the steadily increasing demand for livestock products has brought about dramatic changes in the global ruminant livestock sector (cattle, sheep, goats, buffalos, camels and yaks). These changes include a shift in the size of regional livestock populations and in the types of management and feeding systems under which ruminant livestock are kept. As a result, the importance of rumen microbial ecology and the diversity of micro-organisms in the ruminant forestomach has

[6] Background Study Papers No. 62 and No. 63.
[7] Background Study Papers No. 61, No. 64 and No. 65.

gained increasing attention.

11. The gut microbiota and its collective genomes (microbiome) is estimated to contain 100 times more genes than the host animal and provides the ruminant with genetic and metabolic capabilities that it has not had to evolve on its own, including capabilities to hydrolyse and ferment inaccessible nutrients and toxins. Such processes require the involvement of diverse rumen microbes that have been redefined into three domains: bacteria (eubacteria); archaea (methanogens); and eucarya (ciliate protozoa and anaerobic rumen fungi).

12. Advances in molecular microbial ecology have revealed the presence of complex communities that have co-evolved with the ruminant host in response to the environmental conditions and the gut physiology of the host. Furthermore, it is also evident that there is genetic diversity within rumen bacterial species of practical and economic importance. For example, studies have demonstrated that the rumen bacterium *Synergistes jonesii*, which detoxifies forage from the economically important leucaena tree legume, is genetically diverse with respect to geographic region.

13. In the last decade, major innovations, such as metagenomics, have arisen in the field of rumen microbiology, with the advent of affordable nucleic-acid based-technologies and rapid evolution of DNA sequencing platforms that are culture-independent for studying the diversity of complex microbial ecosystems. These technologies have the potential to allow the capture and study of the entire microbiome (the predominant genomes) from the complex microbial community in the rumen and to determine the function ("what they are doing") in addition to the structure ("who is there") of the community.

14. Rapid advances in the development of publicly available annotation tools and computing platforms for assigning function to genes has also made the genome-sequencing of individual micro-organisms and the interpretation of the results both affordable and available to the broader research community. This has led to an increase in the number of rumen micro-organisms (more than 20) that have sequenced genomes that are publically available, but there is little information available on the genomic make-up of rumen anaerobic fungi and ciliate protozoa and no genomes from these organisms have been published.

15. To address these issues, a Rumen Microbial Genomics Network has been formed, comprising a consortium of advanced rumen microbiology laboratories, DNA sequencing institutions and curators of international public culture collections. The consortium will facilitate the sequencing and development of rumen microbial genomics approaches for access to methods, genome sequences and metagenome data relevant to the rumen microbial community. The reference genome information of more than 1000 rumen microbial isolates will establish a publicly accessible database of rumen microbial genes and assign function to these genes as a framework for characterizing the rumen microbiome in different ruminant genotypes and under varying dietary and environmental conditions. This information will be used to support international efforts to initiate genome-enabled research aimed at understanding rumen function in order to find a balance between food production and greenhouse gas emissions. It is possible that this reference collection will be biased towards micro-organisms from ruminants in industrialized production systems unless a coordinated effort is initiated to engage laboratories from countries and regions where the animals have evolved and adapted to the natural environment, particularly in tropical regions.

16. An opportunity exists for ruminant laboratories in emerging and developing countries to participate in the above-mentioned efforts and to provide DNA from rumen samples and cultures of rumen isolates from locally adapted breeds as contributions to the database, which will then represent a broader geographical census of micro-organisms that are relevant to many agro-economic zones and environment conditions. In addition, nutrition laboratories in developing countries with an interest in rumen microbiology would benefit from future interactions with advanced laboratories where local scientists could be advised and trained in the latest techniques in molecular microbial ecology.

Micro-organisms in agro-industrial processes

17. Micro-organisms and microbial products are essential to a range of agro-industrial processes.

They are used as biofertilizers (also referred to as bioinoculants) and biopesticides, and also contribute to bioremediation and the biological conversion of organic waste into value-added products. Background Study Paper No. 64 provides several examples of the use and conservation of micro-organisms in agro-industrial processes and explores the extent to which micro-organism diversity and practices used to safeguard this diversity are of importance.

18. One example of biofertilization involves the application of preparations containing artificially multiplied living cells of microbial strains to seed, soil or plant surfaces, to colonize the rhizosphere or the interior of plants and promote plant growth by increasing the supply or availability of nutrients in a form easily assimilated by plants.

19. Biopesticides, which are based on living organisms, including micro-organisms, enable the protection of agricultural crops against fungal, bacterial and viral diseases and against insects, nematodes and weeds. Over the past decades, significant efforts have been made to promote the use of biological rather than chemical pesticides, the highly intense and often indiscriminate use of the latter having raised major health and environmental concerns. Recently, the commercial status of biopesticides was reviewed and progress has been made towards addressing the significant technical barriers to their development and production.

20. Naturally occurring micro-organisms (bacteria, fungi, algae) are also being used in bioremediation to degrade and detoxify substances that are hazardous to human health and the environment. Archaea, bacteria and fungi have, for example, been used to treat olive mill wastewater, a substance that is poured into the soil or disposed of in sewage, causing significant soil and water pollution.

21. Furthermore, members of different genera of micro-organisms are involved in the biological conversion of agro-industrial organic waste into value added products. Waste materials, such as crop residues and animal manures, are converted into biofertilizers (compost), other metabolites such as enzymes, food additives, organic acids and pigments, and biofuels.

22. The demand for new microbial strains for use in innovative and economically viable agro-industrial products is steadily rising. Particularly, the development of microbial products that could complement chemicals that are already available for purchase is rapidly gaining interest. For the inoculation industry, research and field trials of plant growth promoting rhizobacteria have opened up new horizons. More research should focus on improving the efficacy of biofertilizers and biopesticides, both through manipulation of the biological agents and by reviewing and where possible improving the application technology.

23. Overall, additional research and development and capacity-building are needed for the implementation of sustainable agro-industrial practices involving the use of micro-organisms and microbial-derived products. Farmers applying microbial-based techniques need to be trained and encouraged, which would in turn require an appropriate policy framework supported by policy-relevant scientific information.

Micro-organisms in food processing

24. The use of micro-organisms in food processing constitutes a major part of the food biotechnology by which relatively bulky, perishable and frequently inedible raw materials are converted into safe, shelf-stable and palatable foods or beverages. While food fermentations play an important (but not necessarily vital) role in people’s diets in industrialized countries, they are essential to diets in developing countries. The value and benefits of fermented foods are now more recognized than ever before, even if the reasons for this increasing awareness are multifold and may differ between industrialized and developing countries. Basic understanding of the mechanisms by which fermentation improves food safety and stability has resulted in the development of new concepts for food preservation using live microbial strains. Moreover, while health benefits of fermented foods have long been recognized, the underlying mechanisms and the role of beneficial (functional) microbial strains were investigated and explored only during the twentieth century, leading to the development of the probiotic concept. Thus, the application of micro-organisms in food processes

relates mostly to fermentation, either directly or indirectly. Appropriate strains, by virtue of their functionality, will exert beneficial effects on the food substrate and/or on the human host. The intrinsic value of microbial strains for diverse applications in the food ecosystem and as genetic resources is appreciated and recognized. Yet, humankind is still far from fully exploiting and utilizing these valuable resources.

25. The “formal” food-processing sector in industrialized countries is well organized. Large-scale enterprises generally have sufficient resources at their disposal, both for supporting research and development and for securing sustainable use of modern technologies, including the controlled application of microbial strains in food processing. They have access to established culture collections (either internally or publicly) in which precisely characterized and defined microbial strains are maintained. By contrast, the “informal” food-processing sector in developing countries is diverse and has been driven by basic needs, availability of raw materials, gradual development of technologies, and cultural traditions. Although not as well organized and sophisticated as the formal sector, these small-scale artisanal enterprises produce a wide range of traditional fermented foods that meet the basic needs of millions of people for safe and nutritious foods. There is also an increasing appreciation of artisanal fermentation traditions that provide a wide range of unique products (e.g. cheeses from goat and sheep milk) and enrich culinary diversity even in the markets of industrialized countries. Moreover, traditional food fermentations represent an extremely valuable cultural heritage in most regions and harbour a huge genetic potential of valuable, but hitherto undiscovered, strains. Standardization of traditional (artisanal) food fermentations may be hampered by various factors. Approaches to overcoming basic constraints should include technical training and education of small-scale processors and making available appropriate and affordable starter cultures. Finally, certain micro-organisms associated with fermented foods enhance the nutritional value of foods through the biosynthesis of vitamins, essential amino acids and proteins, improving both protein and fibre digestibility and enhancing micronutrient bioavailability and degrading anti-nutritional factors. This is of particular importance for the most nutritionally vulnerable groups such as children, people with comprised health and the elderly.

26. With respect to ongoing global environmental changes, the effects of climate change, in particular, could threaten the existence and traditional livelihoods of around 2 billion people, many of whom rely on traditional, small-scale food fermentations. Developing mathematical models that would be able to predict the effects of changes in environmental conditions on microbial populations in traditional food fermentations may be of great value. Strategies should also include developing knowledge of process-related stress-response factors, which may have an effect on the performance of traditional strains, as well as on how they are stored and protected, which is of particular importance in developing countries.

III. INTERNATIONAL INITIATIVES FOR SOIL BIODIVERSITY AND POLLINATORS

The International Initiative for the Conservation and Sustainable Use of Soil Biodiversity

27. The International Initiative for the Conservation and Sustainable Use of Soil Biodiversity (International Initiative for Soil Biodiversity) was formally established in 2006 as a cross-cutting initiative within the CBD’s programme of work on agricultural biodiversity to increase the recognition of the essential services provided by soil biodiversity across all production systems and its relation to land management, to share information, and to increase public awareness, education and capacity-building.[8] FAO is the lead partner of the initiative.

28. Soil biodiversity is increasingly being addressed by the Commission. Under the Commission’s guidance, a series of assessment studies have been undertaken to identify the status and trends of the conservation and sustainable use of soil organisms of relevance to food and agriculture, including in

[8] Decision VIII/23 section B of the Conference of the Parties to the CBD.

relation to their (potential) roles and functions in the mitigation of, and adaptation to, climate change,[9] and in rice, and root and tuber production systems.[10] Assessments such as these particularly contribute to increasing understanding of the role of soil biodiversity in agricultural production, traditionally applied land-management practices, and ecosystem and environmental health (Goal 2 of the International Initiative for Soil Biodiversity).

29. FAO is currently also updating its Soil Portal to include all its soil-related work. This corporate knowledge base will include, *inter alia*, FAO's soil biodiversity web site and will also make reference to relevant international initiatives and forums, such as the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity, the Global Soil Partnership, the Global Soil Biodiversity Initiative and the Commission.

30. In September 2011, FAO launched the Global Soil Partnership (GSP), the Terms of Reference of which were approved by the FAO Council in December 2012. The GSP aims to create and raise awareness among decision-makers and stakeholders of the key role of soil resources in sustainable development; to guide soil knowledge networks and research by providing a global communication platform and targeting research to effectively address the real soil-related problems on the ground; to establish an active and effective network for addressing soil cross-cutting issues; and to develop global governance guidelines aiming at improved soil protection and sustainable soil management and productivity. The GSP will thus significantly contribute to achieving the four main goals[11] of the Soil Biodiversity Initiative. More information on the Global Soil Partnership is available at www.fao.org/globalsoilpartnership.

31. In December 2012, in the framework of the GSP, FAO organized the event "Securing healthy soils for a food secure world: a day dedicated to soils", in a plea for the institutionalization of World Soil Day. At its Thirty-eighth Session in June 2013, the FAO Conference will review this request and, upon agreement, it will be submitted to the United Nations General Assembly for its consideration. Parallel to this event, FAO, jointly with the Italian Institute for Environmental Protection and Research (ISPRA) and the Joint Research Centre of the European Commission (JRC/EC), organized a three-day workshop on "Managing living soils". During this workshop, due attention was given to the importance of mainstreaming work on soil biodiversity to address today's challenges with respect to sustainable and productive soil management and agricultural development. The discussions during this workshop contributed to the identification of possible priorities and future activities for the preparation of a draft Plan of Action for Pillar 1 of the Global Soil Partnership on promoting sustainable soil management. Similar workshops are being organized to develop plans of action for the other four pillars of the GSP.

International Initiative for the Conservation and Sustainable Use of Pollinators

32. Pollination services by animals, especially by insects, are among the most widespread and important processes that structure ecological communities in both natural and agricultural landscapes. The total economic value of crop pollination worldwide has been estimated at €153 billion annually (Gallai *et al*., 2009).[12] The leading pollinator-dependent crops are vegetables and fruits, representing about €50 billion each, followed by edible oil crops, stimulants (coffee, cocoa, etc.), nuts and spices;

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[9] Background Study Papers No. 54 and No. 57.
[10] Background Study Papers No. 62 and No. 63.
[11] Goals of the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity as laid out in the Initiative's Framework for Action (CBD COP Decision VIII/23 section B):
1. Promote awareness-raising, knowledge and understanding of key roles, environmental services, functional groups and impacts of diverse soil management practices, including those performed by indigenous and local communities, in different farming systems and agro-ecological and socio-economic contexts;
2. Increase understanding of the role of soil biodiversity in agricultural production, traditionally applied land management practices and ecosystem and environmental health;
3. Promote the understanding of the impacts, ownership, and adaptation of all land use and soil‑management practices as an integral part of agricultural and sustainable livelihood strategies; and
4. Promote the mainstreaming of soil biodiversity conservation into land and soil‑management practices.
[12] Gallai, N., Salles, J.M., Settele, J. and Vaissière, B.E. (2009) Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological Economics 68, 810–821.

most of these are critically important for nutrient security and healthy diets. Crop pollination provided by wild pollinators spilling over from natural and semi-natural habitats close to crop fields has generally been free and therefore has received little attention in agricultural management. If wild pollinators are lacking or additional pollination is required, as is the case in many intensive agricultural production systems, some farmers (particularly in developed countries) buy or rent managed honeybees or other pollinator species (e.g. bumblebees, alfalfa leafcutter bees and alkali bees). The global population of managed honeybee hives has increased by 45 percent during the last half century. However, with the much more rapid (more than 300 percent) increase in the fraction of agriculture that depends on animal pollination during the last half century, global capacity to provide sufficient pollination services may be stressed, and more pronouncedly in the developing world than in the developed world (Aizen and Harder, 2009).[13] Over the last decades, both options – i.e. use of wild species and use of managed pollinators – have come under severe pressure from, *inter alia*, habitat loss, degradation and fragmentation; pollution, including the use of pesticides; the introduction of non-native species and diseases; and climate change; a development that is sometimes referred to as the "pollination crisis".[14]

33. Recognizing the urgent need to address the issue of the worldwide decline in pollinator diversity, the Conference of the Parties to the CBD (COP) established the cross-cutting International Initiative for the Conservation and Sustainable Use of Pollinators (IPI) in 2000.[15] FAO plays the leading role in facilitating and coordinating the IPI, and reports biennially to the COP on the progress of the Initiative. The last progress report was submitted to the eleventh meeting of the COP, which was held in Hyderabad, India, in October 2012.[16] It provides an update of the main activities and findings of the global community concerned with the conservation and sustainable use of pollinators.

IV. GUIDANCE SOUGHT

34. The Commission may wish to:

i. reiterate the importance of microbial and invertebrate diversity for sustainable agriculture and for food and nutrition security, particularly in the light of global environmental and health challenges; and

request FAO to:

ii. undertake, subject to the availability of funds, focused targeted assessments on the status and trends in the conservation and use of soil micro-organisms, biological control agents and plant pathogens for additional major food crops, such as wheat and maize, with a special emphasis on good agricultural practices favouring the delivery of ecosystem services by beneficial micro-organisms and invertebrates,;

iii. report on developments in the use and conservation of micro-organisms in ruminant digestion, agro-industrial processes and food processing, where relevant;

iv. present new developments in the use and conservation of micro-organisms and invertebrates of relevance to food and agriculture, if applicable, at the Commission's Fifteenth Regular Session, when it will review the work of the Intergovernmental Technical Working Groups on the application and integration of biotechnologies for the conservation and sustainable utilization of genetic resources for food and agriculture; and

v. address, where relevant, the contribution of micro-organisms and invertebrates to the delivery of ecosystem services for food and agriculture in *The State of the World's Biodiversity for Food and Agriculture*.

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[13] Aizen, M.A. and Harder, L.D. (2009) The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. Current Biology 19, 1–4.
[14] BSP 54.
[15] CBD COP Decision V/5.
[16] UNEP/CBD/COP/11/INF/29