August 2024 CGRFA/WG-MIGR-1/24/3 Rev.1

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联合国粮食及农业组织 Food and Agriculture Organization of the United Nations | Organisation des Nations Unies pour l'alimentation et l'agriculture | Продовольственная и сельскохозяйственная организация Объединенных Наций | Organización de las Naciones Unidas para la Alimentación y la Agricultura | منظمة الأغذية والزراعة للأمم المتحدة

COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

Item 3 of the Provisional Agenda

INTERGOVERNMENTAL TECHNICAL WORKING GROUP ON MICROORGANISM AND INVERTEBRATE GENETIC RESOURCES FOR FOOD AND AGRICULTURE

First Session

Rome, 25–27 September 2024

MICROORGANISMS USED IN FOOD PROCESSING AND AGRO-INDUSTRIAL PROCESSES

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I. INTRODUCTION

1. The Commission on Genetic Resources for Food and Agriculture (Commission), at its Seventeenth Regular Session, adopted its Work Plan for the Sustainable Use and Conservation of Micro-organism and Invertebrate Genetic Resources for Food and Agriculture (Work Plan).[1] The Work Plan addresses microorganisms and invertebrates as functional groups[2] and foresees that the two functional groups considered by the Commission at its Twentieth Regular Session will be (i) edible fungi and invertebrates used as dietary components of food/feed and (ii) microorganisms used in food processing and agro-industrial processes.[3] In the case of the latter of these functional groups, it notes that work should build on Background Study Papers 64[4] and 65.[5]

2. The Work Plan foresees that each functional group will be addressed on the basis of:

- a summary of the status and trends of conservation, use and access and benefit-sharing, based on previous work of the Commission, existing literature and, as appropriate, an open survey that may also compile best practices with respect to their sustainable use and conservation;
- a mapping of regional and international organizations and other institutions most relevant for the functional group and the identification of strategic areas of possible collaboration; and
- an analysis of the gaps and needs, and possibilities for the Commission and its Members to address them.[6]

3. In response to the Work Plan, FAO commissioned the preparation of a study on the sustainable use and conservation of microorganisms used in food processing and agro-industrial processes. As some of the agro-industrial processes covered in Background Study Paper 64, notably those related to nutrient cycling, biological control and biostimulation, have been addressed in other background study papers recently prepared under the Work Plan, the current study focuses on the use of microorganisms in food processing and in the processing of agro-industrial materials into non-food value-added products. The draft study is contained in the document *Draft study on the sustainable use and conservation of fermentation associated microorganisms within the agrifood system*.[7]

4. It should be noted that the multifaceted nature of the study has made it difficult to organize a comprehensive expert review of the draft within the time available. The intention is therefore, in addition to addressing any recommendations made by the Working Group regarding the further development of the study, to subject the draft to further expert reviews before a revised version is made available to the Commission at its next session.

5. This document draws on the findings of the draft study to present an overview of the sustainable use and conservation of microorganisms used in food processing and agro-industrial processes, and seeks the Working Group's guidance regarding future work on these groups of microorganisms.

II. ROLES OF MICROORGANISMS IN FOOD PROCESSING AND AGRO-INDUSTRIAL PROCESSES

6. The use of microorganisms in food processing and agro-industrial processes is an important component of agrifood systems. Traditional fermentation processes have long been vital to the food security and livelihoods of many people around the world. More recent and ongoing developments in

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1 CGRFA-17/19/Report, Appendix E.
2 CGRFA-17/19/Report, Appendix E, paragraphs 8–14.
3 CGRFA-17/19/Report, Appendix E, paragraph 14
4 Chatzipavlidis, I., Kefalogianni, I., Venieraki, A. & Holzapfel, W. 2013. *Status and trends of the conservation and sustainable use of microorganisms in agro-industrial processes*. Commission on Genetic Resource for Food and Agriculture. Background Study Paper No. 64. Rome, FAO. https://www.fao.org/4/mg339e/mg339e.pdf
5 Alexandraki, V., Tsakalidou, E., Papadimitriou, K., Holzapfel, W. 2013. *Status and trends of the conservation and sustainable use of micro-organisms in food processes*. Commission on Genetic Resources for Food and Agriculture. Background Study Paper No. 65. Rome, FAO. https://www.fao.org/4/mg309e/mg309e.pdf
6 CGRFA-17/19/Report, Appendix E, paragraph 7.
7 CGRFA/WG-MIGR-1/24/3/Inf.1.

these fields are creating new options that potentially have major significance for efforts to improve food security while also addressing the climate and biodiversity crises.

7. Where food processing is concerned, applications involving the use of microorganisms can broadly be grouped into the following categories: the production of fermented foods (FFs) through traditional fermentation processes; the production of fermentation-derived foods (FDFs) using biomass; and the production of FDFs using precision fermentation.

8. Food processing through traditional fermentation pre-dates agriculture and involves the transformation of a plant or animal substrate through the activity of microorganisms to improve its preservation, safety, nutritional value and flavour. It remains integral to many cultures worldwide, with an estimated one-third of the human diet being composed of fermented foods globally. Examples include the fermented milk drink kefir, which studies have found to have various health-promoting benefits, including potential as an intervention strategy for diet-related non-communicable diseases via its effect on the gut microbiome, and which has been included as a recommended dairy component in some national dietary guidelines. Biomass fermentation makes use of microbial biomass as a direct source of protein and other nutrients. Precision fermentation utilizes "microbial cell factories" to manufacture useful compounds, for example micronutrients.

9. Key advantages of FF and FDF production include the following: shorter timelines because of the speed at which microorganisms grow; reduced land and water use; potential to valorise agricultural by-products and food waste and; and (because of reduced dependence on climatic/weather conditions feature) stability in supply and flexibility in the site of production. For example, the production of dairy protein β-lactoglobulin from a fungal cell factory has the potential to eliminate the need to use pastureland to meet the demand currently met by whey protein, although the carbon footprint of the process is highly dependent on the energy source used.

10. The more than 5 000 different varieties of fermented food produced across the world reflect the diverse range of microorganisms (bacteria and yeasts and other fungal species) utilized in traditional fermentation. The genetic resources of these microorganisms are a product of traditional knowledge, as the composition and structure of a fermentation-associated microbial community are linked to the chosen substrate and the design of the fermentation process, which selects for the microbial strains that define the qualities of the final food product.

11. Although information on the status of this biodiversity is limited, the loss of traditional practices means the loss of the associated microbial communities. Globalization and industrialization are accompanied by the increasing use of starter cultures composed of one to three well-characterized domesticated microbial strains rather than the complex microbial communities emerging from traditional practices. Characterization of the latter microbial communities allows the identification of microbial species with attractive properties that can be used in the design of other bioprocesses.

12. Where non-food processes are concerned, there are also some well-established uses of fermentation within agrifood systems, for example in silage making. Precision fermentation is now creating new opportunities to utilize a variety of materials derived from agrifood systems, often by-products or materials otherwise regarded as wastes, as a basis for alternatives to petrochemical-based systems for the supply of a range of different products.

III. STATE OF USE

13. Production of FFs currently takes place at several scales, ranging from the household level, where fermentation serves as a low-cost technique for preserving raw materials such as milk, to large industrial operations designed to meet increasing consumer demand. To enable the standardization of products, increase control over the microbial community and lower the risk of contamination, extensive efforts are being put into the design of starter cultures, including through the identification of key strains in natural communities, the use of non-conventional strains and the assembly of semi-synthetic communities containing genetically engineered or evolved organisms.

14. Traditional fermentation is also being explored as a processing technique for overcoming bottlenecks in the development of plant-based alternative proteins, including those related to sensory

properties (e.g. taste, texture and smell), bioavailability of micronutrients, allergenicity and the prevalence of antinutritional compounds.

15. Because of concerns over the environmental impacts of producing animal-derived proteins, providing alternative sources of proteins is also a key goal in FDF production. Biomass fermentation circumvents many of the constraints associated with livestock production while providing products with high protein quality, low energy density and low total and saturated fats.

16. Given the diversity of edible microorganisms, microbial protein can be produced using a variety of different feedstocks, ranging from inedible plant biomass to direct CO_2 capture. Currently, however, microbial proteins for human consumption generally rely on sugars. The use of a bioreactor (a large vertical vessel) allows flexibility in terms of where protein can be produced. The primary needs are access to a feedstock, water, air and electricity.

17. A number of precision fermentation-based products are already on the market, including substances intended as alternatives to various animal-derived proteins (e.g. egg and dairy) as well as various essential nutrients, food ingredients and additives that are too complex, costly or environmentally damaging to manufacture via conventional means.

18. Innovation in FDF production strives to address challenges in economic feasibility, sustainability, and consumer acceptance using engineering biology tools[8] and/or bioprocess design.[9] This is exemplified by carbon-capture-based production systems, which provide the possibility of decoupling food production from land, biophysical conditions and photosynthesis.

19. The potential of engineering biology at different scales, ranging from the enzyme to the cell to the microbial community-level, with co-culture designs, is being used not to only expand the range of food products that can be feasibly produced by microorganisms but also to enable this to be done through the valorisation of agrifood system wastes and by-products such as lignocellulosic biomass.

20. Despite the potential significance of FFs in efforts to promote food security, they currently receive limited policy attention. Constraining factors include a lack of knowledge of their health benefits and of how food safety and the standardization of products can be achieved in artisanal set-ups.

21. Where FDFs are concerned, technical barriers to expansion include the pressing need for an increase in global fermentation capacity, especially in resource-limited regions. The lack of facilities to scale-up bioprocesses is one of the key factors limiting the transfer of technologies from laboratory to industry. Economic barriers, energy-requirements and resource use (carbon and nitrogen in particular) are also critical in determining the feasibility, competitiveness and sustainability of FDF production. The feedstock, which supplies the essential nutrients carbon and nitrogen, substantially impacts the land- and water-use efficiency, the carbon footprint and the circularity of the process. Although currently most bioprocesses rely on sugar derived from high-yielding sugar crops, for some food and feed applications the use of agricultural by-products, food processing wastewater and direct carbon capture have been proven at scale.

22. Investment, legislative action and technical innovation are all necessary for the development of the sector. Fundamentally, however, realizing the potential of fermentation technologies to improve the capacity, resilience and sustainability of food production hinges on consumers' trust in products, manufacturers and regulatory bodies.

23. Precision fermentation involving the use of one or more natural or engineered microorganisms has been extensively explored to produce non-food products. These includes biofuels, platform and bulk chemicals with extensive applications (e.g. organic acids, such as lactic and succinic acid, amines and short chain diols), biomaterials, bio-based solvents and pharmaceuticals.

24. Fermentation technologies hold the potential to play a role in the shift towards a circular economic framework in the chemical industry, which currently relies heavily on non-renewable fossil

[8] Engineering biology consists in the design and construction of biological systems (e.g. proteins, metabolisms, whole cells and microbial communities) via the application of engineering principles to biology.
[9] Bioprocess design deals with the techniques involved in the manufacturing of products using living cells or their components. This encompasses preparation, production and purification steps.

fuels. To ensure a sustainable and economically viable production system, agro-industrial by-products and wastes have been investigated as feedstock for such bioprocesses. Examples include non-edible lignocellulosic biomass residues, such as stalks, straws and bagasse, non-food crops, such as silvergrass, forestry residues, fruit waste, such as peels, and food-processing wastewater.

25. Biomanufacturing fuelled by agro-industrial materials has reached commercial scale for some applications and is being piloted in biorefinery plants around the world, not only as a more sustainable chemical production platform but as an effective method of waste treatment. However, the cost of production still exceeds that of petrochemical alternatives, posing a challenge to the expansion of this alternative. Innovation in integrated biorefinery models, where a single processing facility converts biomass into power, heat and value-added products, holds promise for improved efficiency and lower environmental impact.

IV. STATE OF CONSERVATION

26. The conservation of microbial diversity is vital to the future development of food-processing and agro-industrial microbial applications and hence to the development of a sustainable bioeconomy. Culture collections are a key resource in this regard, as they allow the long-term storage of microorganisms, whether isolated from nature or engineered. These collections can be large public repositories accessible in accordance with international agreements, research collections in academic institutions or industrial research laboratories.

27. Numerous culture collections have been established around the world: the Culture Collections Information Worldwide repository records 859 culture collections, based in 80 countries, storing more than 4 million microorganisms. However, in many parts of the world shortages of funding (especially for meeting high, long-term operating costs), infrastructure and expertise restrict opportunities to identify, characterize and store isolates relevant to fermentation applications. Technical challenges surrounding the preservation of microbial communities as a whole are another major constraint.

V. STATE OF POLICY, LEGAL AND INSTITUTIONAL FRAMEWORKS

28. Given that the genetic resources of fermentation-associated microorganisms are products of traditional knowledge that have great potential for commercialization, ensuring fair and equitable arrangements for access to them and for the sharing of benefits arising from their use for research and development is a significant policy issue. As with other components of biodiversity, the global legal framework for this is provided by the Convention on Biological Diversity and the Nagoya Protocol. However, as with several of the other functional groups of microorganisms and invertebrates addressed by the Commission over recent years, unintended consequences of the application of these instruments include constraints to the expansion of culture collections and microbial biological resource centres (mBRCs) because of the complex bureaucratic bilateral negotiations required for sampling and collaborative characterization efforts. This has an impact on both academic researchers and biotechnological companies, potentially hampering the use of promising microbial strains.

29. Questions remain about the ownership status of microorganisms that are prevalent around the world and not closely linked to a particular geographic location. Furthermore, in the case of microbial cell factories designed using sequences from multiple sources and with lengthy value chains, there are ambiguities as to how benefit-sharing should be pursued.

30. Harmonized international standards are essential for streamlining regulatory processes and facilitating market entry for FFs and FDFs. Current frameworks are often fragmented and out of step with industry developments. In the case of labelling in particular, this can have marked effects on consumer acceptance.

31. Policy surrounding the equitable integration of novel technologies and products into the agrifood system is another pressing issue. Scaling-up of FDF products has the potential to disrupt current food production methods, causing concern over how this may affect food sovereignty, rural communities and landscapes, the labour force associated with livestock production, and the industries that supply the agricultural sector and depend on non-food animal-derived products, such as leather. Responsible innovation and just transitions require the development of effective policy and legal

frameworks, and this would greatly benefit from the effective engagement and involvement of multiple stakeholders.

32. A number of global and regional research and industrial networks relevant to FFs, FDFs and conservation of related microorganisms are emerging worldwide. The following is a non-exhaustive list of significant players among these: the International Scientific Association for Probiotics and Prebiotics,[10] the Good Food Institute,[11] Precision Fermentation Alliance,[12] Food Fermentation Europe,[13] the International Dairy Federation,[14] the Lactic Acid Bacteria Industrial Platform,[15] Future Food Asia,[16] European Food and Fermentation Cultures Association,[17] the UK Research and Innovation[18] Microbial Food Hub, the Bezos Centre for Sustainable Protein, the COST (European Cooperation in Science and Technology) Action PIMENTO (Promoting Innovation of ferMENTed fOods),[19] DOMINO (a European network on fermented foods),[20] the Swedish South Asian Network for Fermented Foods,[21] World Federation for Culture Collections,[22] Global Biological Resource Centre Network,[23] Global Microbiome Conservancy[24] and the Microbiota Vault.[25]

VI. GAPS NEEDS AND POTENTIAL ACTIONS

33. Based on the conclusions of the draft study, the following gaps, needs and potential actions to address them can be identified.

- There is a need to establish frameworks for the provision of long-term financial support for culture collections and mBRCs. One avenue could be to promote the involvement of private industry in the maintenance and funding of culture collections and mBRCs. Another would be funding via international organizations for centralized collections, with clear and simple paths for access to resources in line with relevant international agreements.
- In parts of the world where such capacity is currently weak or non-existent, there is a need to build the infrastructure and skills needed to preserve and characterize the microbial communities behind local fermented foods – as well as microbial strains from various environmental niches that may have potential for use in the production of platform chemicals and high-value compounds from non-food agro-industrial materials – and enable the development of starter cultures.
- Better documenting traditional knowledge related to fermented foods would help to promote food security, the preservation of cultural heritage and the identification of novel microbial strains with industrial potential. Where traditional practices are in decline, opportunities to revitalize them need to be explored and, where relevant, supported.
- There is a need to establish legal and policy frameworks that a) safeguard the rights of Indigenous Peoples and local communities over the microbial genetic resources associated with the food-processing techniques they have developed, b) facilitate fair and equitable international research collaborations, and c) minimize constraints to access caused by unclear guidelines and lengthy bureaucratic procedures. Multilateral solutions could be explored. Especially in light of developments in engineering biology applications, there is need to

[10] https://isappscience.org
[11] https://gfi.org
[12] https://www.pfalliance.org
[13] https://www.foodfermentation.eu
[14] https://fil-idf.org
[15] https://labip.com
[16] https://futurefoodasia.com
[17] https://effca.org
[18] https://www.ukri.org
[19] https://www.cost.eu/actions/CA20128
[20] https://www.domino-euproject.eu/about/m4sf
[21] https://fermented-foods.net.in
[22] https://wfcc.info
[23] https://www.bionity.com/en/associations/69535/global-biological-resource-centre-network-gbrcn.html
[24] https://microbiomeconservancy.org
[25] https://www.microbiotavault.org

determine how to deal with digital sequence information related to fermentation-associated microorganisms.

- Constraints to the expansion of commercial fermentation capacity to meet forecasted demand for the production FDFs need to be overcome.
- Harmonization of definitions related to fermentation technologies, such as precision fermentation, could be an initial step towards harmonizing policies governing their use, including with regard to labelling, which has a substantial impact on consumer understanding of novel food products.
- Fermentation needs to be integrated into agricultural practice as a means of *in situ* valorising by-products and waste, promoting circularity in production systems and addressing concerns over how FDF production may impact food sovereignty. Exploring opportunities and frameworks for partnerships between agricultural and FF/FDF producers could further support these objectives.
- Research on the role of fermented foods as part of healthy diets needs to be strengthened, as do science communication and awareness raising on fermentation technologies and FF and FDF products. Accompanied by appropriate quality-control and certification procedures, better understanding of the components of FFs that confer health benefits can ensure that consumers are well informed about the health and nutritional value of the wide array of products entering the market. New evidence emerging from microbiome science may provide the basis for further refinement of food-based dietary guidelines to include the consumption of a range of FFs.
- To effectively realize the potential of non-food product biomanufacturing from agro-industrial materials, especially as an alternative to petrochemical-based production, concerted efforts need to be made to direct resources, including both public and private investments, towards the compounds that hold the greatest potential for economically feasible and sustainable production. This requires effective communication between industry and academia. Improving technology transfer terms at universities and public institutions could also help to lower barriers to commercialization.

VII. GUIDANCE SOUGHT

34. The Working Group may wish to review the draft study and make recommendations concerning its further development:

35. It may also wish to make recommendations to the Commission concerning what can be done to:

(i) strengthen the technical and human capacity needed to characterize and improve the use of the microbial communities behind local fermented food products and other microorganisms with potential for application in food processing or in non-food agro-industrial processes;
(ii) improve the documentation of traditional knowledge associated with fermented foods;
(iii) address shortages in fermentation capacity to meet demand for FDFs;
(iv) improve the integration of fermentation processes into agrifood systems;
(v) ensure adequate funding for the long-term storage of microorganisms of relevance to food processing and agro-industrial processes in culture collections;
(vi) improve arrangements for access to the genetic resources of microorganisms of relevance to food processing and agro-industrial processes, as well as digital sequence information associated with them, and the fair and equitable sharing of benefits arising from their use;
(vii) harmonize terminology related to the use of microorganisms in food processing and agro-industrial processes;
(viii) improve research, awareness-raising and scientific communication related to the use of microorganisms in food processing and agro-industrial processes; and
(ix) overcome barriers to the commercialization of beneficial food processing and agro-industrial technologies involving the use of microorganisms.