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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

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STATUS AND TRENDS OF BIOTECHNOLOGIES APPLIED TO THE CONSERVATION AND UTILIZATION OF GENETIC RESOURCES FOR FOOD AND AGRICULTURE AND MATTERS RELEVANT FOR THEIR FUTURE DEVELOPMENT

Summary

This document aims to present an overview of the current status of biotechnology applications as applied to the characterization, conservation and utilization of genetic resources for food and agriculture, as well as the comparative advantages that biotechnologies can provide over conventional technologies. The document also provides an update of developments in fields which the Commission, at its Tenth Regular Session, identified as most appropriate for further work. This document has been revised following comments received from the Intergovernmental Technical Working Groups and seeks the Commission's advice regarding future activities in relation to biotechnologies and the conservation and utilization of genetic resources.

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I. INTRODUCTION

1. At its Twelfth Regular Session, the Commission on Genetic Resources for Food and Agriculture (the Commission) considered the document, *FAO's policy and technical assistance on biotechnology for food and agriculture, and matters relevant to codes of conduct, guidelines, or other approaches*.[1]

2. The Commission noted the trend for increased use of biotechnology tools in the conservation and sustainable use of genetic resources for food and agriculture (GRFA) over the past 15 years, and underlined FAO's role in providing advice, technical assistance, capacity building and information to developing countries in the consideration of the application and integration of relevant biotechnologies, and in providing a neutral forum to its Members.[2]

3. The Commission requested FAO to prepare a scoping paper describing the range of biotechnologies being applied to the conservation and utilization of GRFA, the current status of application of these technologies and matters relevant for their future development, including relevant policy developments in other international forums, for consideration at its next regular session.[3] As indicated in the *Strategic Plan 2010-2017 for the implementation of the Multi-Year Programme of Work*, the Commission requested that the scoping paper be reviewed by its Working Groups.[4]

4. The Working Groups on animal, forest and plant genetic resources reviewed the document and provided a number of suggestions and recommendations that are available in the respective reports of their sessions.[5] Based on these reviews, the document has been revised.

5. This document provides an overview of biotechnologies relevant for the conservation and utilization of GRFA, and an update of developments in areas which the Commission, at its Tenth Regular Session, identified as most appropriate for further work for consideration by its Working Groups. This document also seeks the Commission's advice with regard to future activities in relation to biotechnologies, especially in the context of the major output of the Multi-Year Programme of Work to "review ways and means of considering the application and integration of biotechnologies in the conservation and utilization of genetic resources".[6] The document, *Biotechnologies for the Management of Genetic Resources for Food and Agriculture,*[7] supplements the sector-specific technical information provided in this document.

II. BACKGROUND

FAO's policy and technical activities related to biotechnology

6. FAO has an integral role in assisting its Member States harness the potential of science and technology to improve agriculture[8] and people's access to food, while ensuring that the

[1] CGRFA-12/09/17; CGRFA-12/09/Report, paragraph 70.

[2] CGRFA-12/09/Report, paragraph 71.

[3] CGRFA-12/09/Report, paragraph 72.

[4] CGRFA-12/09/Report, Appendix G, page 31.

[5] CGRFA-13/11/8; CGRFA-13/11/12; CGRFA-13/11/14.

[6] CGRFA-13/11/20.

[7] Background Study Paper No. 52.

[8] In this paper, agriculture includes crops, livestock, fisheries and aquaculture and forestry.

implications and risks in doing so are adequately addressed. FAO plays its role as a multilateral catalyst through its policy and technical assistance on biotechnology for food and agriculture by providing:

- advice to Member States on areas such as development of national biotechnology strategies and biosafety frameworks;
- technical assistance for capacity development of Member States;
- high-quality, updated, balanced science-based information; and
- a forum for nations to facilitate development of international standards and agreements[9] as well as hosting major conferences, technical meetings and expert consultations.[10]

7. In 2010, FAO organized an *International Technical Conference on Agricultural Biotechnologies in Developing Countries* (ABDC-10) in Guadalajara, Mexico. A major objective of the conference was to take stock of the application of biotechnologies across the different food and agricultural sectors in developing countries, in order to learn from the past and to identify options for the future to face the challenges of food insecurity, climate change and natural resource degradation. Reference is made to its comprehensive documentation, including the report[11] and proceedings[12] of the Conference.

Biotechnology and the Commission

8. In addition to sector-specific themes, the Commission addresses cross-sectoral matters such as biotechnologies as they relate to GRFA. In 1989, at its Third Regular Session, the Commission requested FAO to draft a Code of Conduct for Biotechnology, as it effects conservation and use of plant genetic resources[13], and the request was endorsed by the FAO Council in 1991. At its Fourth Regular Session, the Commission considered the document, *Biological and Plant Genetic Resources and Elements of a Code of Conduct for Biotechnology,*[14] and agreed on the objectives of the Code.[15]

9. A preliminary draft of the Code of Conduct,[16] prepared in consultation with a wide range of relevant stakeholders, was considered by the Commission at its Fifth Regular Session. The Commission suggested that FAO further develop Articles 5-10 of the Code (dealing with maximizing the positive effects and minimizing the negative effects of biotechnology) and recommended that, to avoid duplications and inconsistencies, the “biosafety and other environmental concerns” component of the Code should constitute an input to the biosafety protocol being developed by the Convention on Biological Diversity (CBD).[17]

10. At its Sixth Regular Session, the Commission received a report on *Recent international developments of relevance to the draft Code of Conduct for Plant Biotechnology*[18] and agreed to

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[9] Particular mention should be made here to the Codex Alimentarius Commission, the International Plant Protection Convention (IPPC), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and the FAO Code of Conduct for Responsible Fisheries.

[10] CGRFA-12/09/17.

[11] CGRFA-13/11/Inf.8.

[12] Biotechnologies for agricultural development: Proceedings of the FAO international technical conference on Agricultural biotechnologies in developing countries: Options and opportunities in crops, forestry, livestock, fisheries and agro-industry to face the challenges of food insecurity and climate change (ABDC-10).

[13] CPGR/89/REP, paragraph 54.

[14] CPGR/91/12.

[15] CPGR/91/REP, paragraph 93 and 96.

[16] CPGR/93/9.

[17] CPGR/93/REP, paragraph 67 and 68.

[18] CPGR-6/95/15.

postpone any further development of the draft Code until after the ongoing negotiations for the revision of the International Treaty were over.[19]

11. Subsequent to the broadening of its mandate in 1995, the Commission, at its Ninth Regular Session reviewed the document, *The Status of the Draft Code of Conduct on Biotechnology as it Relates to Genetic Resources for Food and Agriculture: Report of surveys of FAO Members and stakeholders*.[20] While the Commission agreed that the focus should be on biotechnologies related to GRFA, there were divergent views expressed as to whether the best way to address the challenges and opportunities was through the revision and updating of the draft Code, or through a phased approach, with consideration of additional options.[21] As such, it was requested that a study be prepared in order to identify what was done in other forums, what remained to be done on the issues raised in the document, and which issues were relevant to FAO and in particular its Commission.[22]

12. At its Tenth Regular Session, the Commission considered the document, *Progress on the draft Code of Conduct on Biotechnology, as it relates to genetic resources for food and agriculture: policy issues, gaps and duplications*[23] and identified the following fields, amongst those listed in the document, as the most appropriate for further work:

- Conservation of GRFA in the centres of origin and *ex situ* collections;
- Appropriate biotechnologies that apply to GRFA;
- Access and benefit-sharing issues related to biotechnologies that apply to GRFA;
- National capacity building and international cooperation;
- Biosafety and environmental concerns;
- Genetic use restriction technologies (GURTs);
- GMO gene flow and the question of liability; and
- Incentives to promote appropriate biotechnologies[24].

13. The Commission referred this document to its Eleventh Regular Session and decided that the identified fields be taken into consideration when designing the MYPOW.[25] At its last Session, the Commission agreed to review at its Thirteenth Regular Session, as one of the cross-sectorial matters within the Commission's MYPOW, ways and means of considering the application and integration of biotechnologies in the conservation and utilization of genetic resources.

III. THE CURRENT STATUS OF BIOTECHNOLOGIES AS APPLIED TO THE CONSERVATION AND UTILIZATION OF GENETIC RESOURCES FOR FOOD AND AGRICULTURE

14. Biotechnology applications can provide comparative advantages over, or can increase the effectiveness of, traditional technologies for the characterization, conservation and utilization of GRFA. Indeed, both the *Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture* and the *Global Plan of Action for Animal Genetic Resources* identify a direct or indirect role for agricultural biotechnologies in some of their priority areas.

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19 CPGR-6/95/REP, paragraph 35.

20 CGRFA-9/02/18.

21 CGRFA-9/02/REP, paragraph 64.

22 CGRFA-9/02/REP, paragraph 65.

23 CGRFA-10/04/13.

24 CGRFA-10/04/REP, paragraph 80.

25 CGRFA-10/04/REP, paragraph 82.

15. This section presents a brief overview of the current status of biotechnology applications relevant for the characterization, conservation and utilization of GRFA. In this document, the following definition of biotechnology is used: "*any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use*".[26]

16. Issues such as the health or environmental risks of any biotechnology product are beyond the scope of this paper. Conventional breeding is also not discussed in detail. Nonetheless, it should be recognized that conventional breeding has provided enormous benefits for the crop and livestock sectors in the past and will continue to do so in the future. On the other hand, for many aquatic species controlled reproduction and domestication have not been achieved so far. In general, they have not been genetically improved to the same extent as crop and livestock species, and thus can benefit considerably from the potential that selective breeding offers. This is also true for forestry, a sector dealing with long-lived organisms, characterized by high diversity between and within populations, whose phenotypic plasticity is crucial for the ability to respond and adapt to future environmental conditions, in particular related to climate change.

CHARACTERIZATION OF GRFA

17. Characterization is a prerequisite for identifying and prioritizing the genetic resources to be conserved, and is fundamental for optimizing appropriate allocation when resources are limited. Characterization also links conservation and utilization as it allows the identification of unique and valuable traits of conserved genetic resources, both *in situ* and *ex situ*, for incorporation into breeding programmes.

18. Genetic resources can be characterized with respect to phenotypes, morphological traits, genetic diversity, population size and structure, geographical distribution, degree of endangerment, etc. Biotechnology applications for characterization include molecular markers and the so-called 'omic'[27] technologies.

Molecular Markers

19. Molecular markers are heritable, identifiable DNA sequences that are found at specific locations within the genome and can be used to detect DNA polymorphism. The first widely used markers were isozymes[28] and they are still being applied (e.g. to characterize forest trees). However, isozymes show low levels of polymorphism, relatively low abundance and, in many instances, have been replaced by more sensitive techniques.

20. Different kinds of molecular marker systems are available, such as restriction fragment length polymorphisms (RFLPs), random amplified polymorphic DNAs (RAPDs), amplified fragment length polymorphisms (AFLPs), single nucleotide polymorphisms (SNPs) and microsatellites. They are not affected by environmental conditions and require only small amounts of biological material that can be easily transported and stored. They can also be used at any growth stage, which is especially advantageous for long-lived species such as forest trees.

21. Molecular markers can be used to characterize GRFA in a variety of different ways, namely for the:

- assessment of intraspecific genetic diversity (e.g. in capture fisheries to identify units between which limited gene flow occurs and hence may need to be managed as different stocks);

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[26] http://www.cbd.int/convention/articles.shtml?a=cbd-02.

[27] Omics is a general term for a broad discipline of science and engineering for analyzing the interactions of biological information objects in various omes, such as genome, proteome, etc.

[28] An isozyme is a genetic variant of an enzyme. Isozymes for a given enzyme share the same function, but may differ in level of activity, as a result of minor differences in their amino acid sequence.

- assessment of genetic distances to identify wild populations most closely related to domesticated species as well as to study the putative centers of origin (e.g. teosinite as the progenitor of maize);
- detection of interspecific variation when species are difficult to identify morphologically (particularly significant for the forestry and fisheries sectors);
- estimation of effective population size (Ne), a key indicator for determining the degree of endangerment of a population, especially when information such as pedigree data, censuses, etc. is difficult to obtain (e.g. for wild populations);
- investigation of gene flow between domesticated populations and their wild relatives; and
- identification of quantitative trait loci (QTLs)[29].

22. Moreover, molecular markers are of considerable value in developing sampling strategies for gene banks (e.g. determining if the greatest diversity is found within or between populations can impact the choice of individuals for collection). Markers also assist in the efficient management of gene bank operations, by:

- identifying both gaps (missing/under-represented populations) and redundancies (duplicate accessions as opposed to safety duplicates) in collections to guide future acquisition and increase cost-effectiveness. Currently, less than 30% of the 7.4 million plant germplasm accessions held in gene banks are estimated to be distinct. It has been calculated that the additional cost of identifying a duplicate using molecular characterization (once passport data has been checked) is approximately 12 times less than the cost of conserving and distributing the material as a different accession;
- assessing genetic integrity following periodic regeneration and multiplication. Markers can be employed to verify accession identity, detect inadvertent seed mixtures and monitor changes in alleles/allele frequencies; and
- developing core collections i.e. subsets that consist of a small percentage of the entire collection but represent a broad spectrum of genetic variability.

23. Molecular marker systems differ with respect to technical requirements, the amount of time, money and labour needed, level of polymorphism detected, and the number of genetic markers that can be detected throughout the genome. Irrespective of the kind of molecular marker used, technical infrastructure and know-how, as well as relatively expensive consumables are necessary, although multiplexing for polymerase chain reaction (PCR)-based markers can significantly improve the speed and efficiency of genotyping leading to reduced costs and labour. For QTL identification, an additional challenge is the technical sophistication associated with creating mapping populations, recording meaningful phenotypes and compiling genetic maps. However, since marker development costs are higher than running (i.e. typing using known markers) costs, research and development, including in developing countries, may benefit from the large number of markers already available for many species.

24. Molecular marker information should be used in conjunction with other information sources (e.g. phenotypic traits and population data), to assist decision-making regarding conservation, particularly since molecular markers are typically not useful for revealing adaptive variation.

'Omic' technologies

25. Genomics refers to the study of an organism’s genome at the DNA level. To date, the genomes of more than 1,000 organisms, including plants, animals, fish[30], forest trees, micro-organisms and invertebrates, have been sequenced. Outputs from genome sequencing can be

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[29] A quantitative trait locus is a locus where allelic variation is associated with variation in a quantitative trait, such as yield, tolerance to abiotic stresses, etc.

[30] The term also includes aquatic invertebrates e.g. molluscs, echinoderms and crustaceans.

further enhanced by elucidating patterns of gene expression and gene function through functional genomic technologies such as transcriptomics, proteomics and metabolomics, thus providing a thorough gene inventory. This information, analyzed in conjunction with bioinformatics, can be exploited to characterize and utilize GRFA in novel ways, since entire networks of genes (as opposed to single genes) can be analyzed spatially and/or temporally and in a much speedier manner compared to conventional technologies.

26. Genomic information has greatly accelerated the generation of molecular markers throughout the genome and aided in creating high-density linkage maps[31] in addition to identifying markers within genes controlling the traits of interest, leading to more effective selection strategies. Advances in microbial genomics have shed light on plant-microbe interactions, mycorrhizal symbionts in forest trees as well as rumen microbial processes in livestock.

27. Specialized fields of genomics are integrating information from numerous sources to benefit from the immense amount of genomic data available. For example, comparative genomics has facilitated the prediction of candidate genes in close relatives following the availability of the sequences of model/key species (especially important for utilizing the genetic diversity of under-resourced and orphan crop species and less-common livestock species).

28. High levels of financial investments and expertise are required for the set-up and maintenance of laboratories/centers capable of providing 'omic' facilities. Further, trained scientists, good internet access and computer facilities are vital to take advantage of the publicly available sequence information and bioinformatic tools. Consequently, these technologies are being used only in some cases across the different agricultural sectors in developing countries. Nevertheless, genomic sequencing is becoming steadily cheaper.

CONSERVATION OF GRFA

29. Two major strategies exist for conservation.[32] *In situ* conservation allows continued evolution and adaptation of a species in response to the environment. Albeit more dynamic, it is exposed to habitat destruction by natural calamities and/or human interference. *Ex situ* conservation can be used to ensure easy and ready accessibility of reproductive material. The methods described in the preceding section are of utility in monitoring conserved species and/or populations, both *in situ* and *ex situ*.

30. An effective link between both strategies is critical. For example, *ex situ* collections can be used for *in situ* population enhancement, or even to reintroduce rare/extinct species in the wild. Effective conservation strategies often incorporate elements of both, to devise the best strategy taking into account the biology of the species to be conserved, technical and financial aspects as well as infrastructural and human resources available.

Cryopreservation

31. Cryopreservation involves the storage of germplasm at ultra-low temperatures (usually in liquid nitrogen at -196°C) whereby all biological activities are suspended. It is a cost-effective option that allows for long-term storage, reduces the risk of loss, requires limited space and minimal maintenance, and offers extinct/selected genetic material for improved breeding in the future.

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[31] A linkage map is a linear or circular diagram that shows the relative positions of genes on a chromosome as determined by recombination fraction.

[32] According to the CBD and the ITPGRFA, *in situ* conservation means the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties. *Ex situ* conservation means the conservation of components of biological diversity outside their natural habitats.

32. Cryopreservation is a useful method for long-term storage of animal germplasm and for vegetatively propagated crop and tree species, as well as species that produce recalcitrant seeds[33]. Nonetheless, the routine use of cryopreservation is restricted in developing countries since reliable electricity supplies and the availability of economically priced liquid nitrogen are particular constraints.

33. Cryoconservation may have practical advantages, even for plant species for which other options are available. A recent study on the comparative costs of maintaining a large coffee field collection with those of establishing a coffee seed cryo-collection at the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) showed that cryopreservation costs less per accession than conservation in field gene banks, with the accession costs further decreasing with increasing number of cryopreserved accessions.

34. Cryoconservation of animal genetic resources has been carried out in a number of developing countries, though the technology is well-developed only for a few species. In fish, cryopreservation of ova and embryos remains a challenge (primarily due to the biochemical composition of female gametes) while sperm cryopreservation has been successful for many cultured finfish and shellfish species, though its application is still limited in developing countries. The choice of genetic material for cryopreservation depends upon the generation interval and reproductive rate of a species and costs must also be considered. For example, embryo collection and freezing in livestock is much more expensive than for semen but regeneration using embryos is quicker and cheaper than for semen.

In vitro slow growth storage

35. For crop and forest genetic resources, the majority of the accessions are maintained as seeds in gene banks. A significant number of crop and forest species that do not produce orthodox seeds[34] or that are vegetatively propagated can be preserved in field gene banks or *in vitro*.

36. Field gene banks are expensive to maintain, require more space and are not very secure. Hence, short to medium term conservation of vegetatively propagated crops and forest trees is best achieved with *in vitro* slow growth storage i.e. as sterile tissue/plantlets on nutrient gels. Growth is usually limited by reducing temperature and/or light intensity, by modifying the nutrients in the culture medium and reduction of oxygen levels.

37. Advantages of this method include reduced storage space for maintaining a large number of explants in an aseptic environment, decreased need for frequent subculturing, the potential for high clonal multiplication rates, and reduced need for quarantine during germplasm movement and exchange. However, *in vitro* maintenance is time and labour intensive, requires specialized equipment and has an increased risk of somaclonal variation[35] as well as losses due to contamination or mislabeling. Several developing countries have reported having *in vitro* slow growth storage facilities.

Reproductive biotechnologies

38. Reproductive biotechnologies have considerable potential for conserving livestock and fish by facilitating the storage, and eventual multiplication and dissemination, of genetic resources and reducing the risk of disease transmission. In livestock, both artificial insemination (AI) and embryo transfer (ET) can be applied for the future use of cryopreserved GRFA. Currently, however, the main use of these technologies is not for this purpose but as tools to increase animal production, generally with the most productive commercial breeds. This focus can lead to the loss of indigenous breeds.

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[33] Seeds that are unable to survive drying and subsequent storage at low temperature.

[34] Seeds which can be dried to a low moisture content and stored at low temperatures without losing their viability over long periods of time.

[35] The term refers to epigenetic or genetic changes induced during the callus phase of plant cells cultured *in vitro*.

39. In developing countries, AI is the most widely used reproductive technology, with most of the AI services being provided by the public sector, though it is still unavailable in many countries in Africa and the Southwest Pacific. AI is generally not very expensive and can be carried out by trained farmers. ET, on the other hand, is expensive and requires highly skilled personnel. For example, a recent study on ET in Mexico showed that the technology is profitable for farmers only when substantial subsidies are provided.

40. Another reproductive technology that can be used for conservation purposes, particularly when a breed is nearly extinct, is that of cloning. Although cloned animals have been produced in a few developing countries, it is still at the experimental stage due to the high costs and skills required. Nevertheless, developments in animal cloning have made realistic the conservation of animal genetic resources through cryopreservation of somatic cells rather than germ cells. This strategy can significantly decrease the costs and the level of technical expertise required to collect and bank the genetic material, but relies, for most species, on the assumption that the use of the material for regeneration of new animals will not be necessary until future technological advances have increased the efficiency and reduced the cost and animal welfare implications of creating clones.

UTILIZATION OF GRFA

41. Genetic resources are the raw material for agricultural development and for the continued survival of natural populations. Therefore their sustainable use is crucial for global food security and economic well-being. Biotechnologies are increasingly being applied for the enhancement of GRFA and, as listed below, have had a profound impact on their effective utilization.

Reproductive biotechnologies

42. In addition to the reproductive technologies described earlier, sperm and embryo sexing permits the preferential production of one sex in livestock (e.g. females are desired as dairy animals). Successful application of sperm sexing has been limited due to the high cost of sexed semen as well as low sperm viability and fertility rates. In aquaculture, hormonal treatment is used for controlling the time of reproduction (e.g. to synchronize ovulation when environmental conditions suppress the spawning timing of females) and for developing monosex populations (e.g. male tilapia are more desirable than females because they grow faster). Chemically synthesized hormones are relatively inexpensive and practical to use.

Biotechnologies for disease diagnosis and prevention

43. Diseases are a major impediment to the sustainable utilization of GRFA. Biotechnologies, based on the enzyme-linked immunosorbent assay (ELISA)[36] and on PCR, for pathogen screening and disease diagnostics are important in all agricultural sectors and can contribute to improved plant and animal disease control and food safety. Biotechnologies have also been extensively used in the development of vaccines for preventing diseases in livestock and fish.

Chromosome set manipulation

44. Chromosome set manipulation is used for a range of different purposes in agriculture. In fish, this technique has been used to create triploid sterile organisms (advantageous in production as they do not devote energy to gamete production, and in conservation programmes to prevent introgression of escaped individuals from commercial stocks into natural populations). Chromosome set manipulation can be useful for detecting QTLs.

45. In plants, a rapid and cost-effective approach for inducing sterility (e.g. to produce seedless fruit) is the creation of triploids. Doubled haploid plants, produced using *in vitro* anther

[36] An immunoassay i.e. an antibody-based technique for the diagnosis of the presence and quantity of specific molecules in a mixed sample.

culture and chromosome doubling, are valuable in breeding programmes since they are 100% homozygous (i.e. recessive genes are readily apparent) and considerably shorten the time needed to select desired lines. However, skilled labour is required to test large populations leading to increased costs.

Tissue culture-based techniques

46. Inter-specific hybridization (wide crossing) is used to obtain hybrids that display good degrees of heterosis[37], but significant amounts of time and scientific expertise need to be invested. Biotechnology approaches are crucial to overcome sexual incompatibility and to speed up the process. For example, *in vitro* embryo rescue and anther culture have been vital in the creation of New Rice for Africa (NERICA) varieties, which have been released in 30 African countries and have played a key role in enhanced rice harvests.

47. Micropropagation is a fast and low-cost method to overcome the accumulation of infectious agents in vegetatively propagated plants and has been used for mass clonal propagation of true-to-type, disease-free material in more than 30 developing and transition countries. Socio-economic impact studies, carried out in a few developing countries, have shown that the use of micropropagated material led to increased productivity and enhanced rural livelihoods.

Molecular marker-assisted selection (MAS)

48. An alternative to conventional phenotypic selection is MAS, which can greatly accelerate genetic improvement by enhancing the accuracy of selection and reducing the time needed (particularly when phenotype screening is difficult). It has been especially useful in plant breeding for developing new varieties but, in spite of its high potential, MAS is still applied in relatively few breeding programmes in developing countries. This is because an effective MAS strategy requires adequate laboratory capacity and data management, trained personnel and operational resources. Although the relative costs of applying MAS are higher than conventional approaches, MAS is becoming progressively cheaper. A recent *ex ante* impact analysis from the Consultative Group on International Agricultural Research (CGIAR) concludes that MAS in rice and cassava results in significant incremental benefits over conventional breeding.

Mutagenesis

49. Chemical, radiation or somaclonal mutagenesis can be used to accelerate the process of spontaneous mutation to create novel phenotypes. Mutagenesis is one of the few biotechnologies that is employed more in developing countries than elsewhere, with the FAO/International Atomic Energy Agency (IAEA) partnership being instrumental in technology transfer of irradiation technology approaches. Almost 3,000 improved crop varieties in about 170 species have been developed and released in an estimated 100 countries generating economic benefits for farmers. In the livestock sector, this technique is generally not applied. However, the sterile insect technique for the suppression/eradication of several livestock pests has been used by 30 countries. Mutagenesis has also been extensively used to improve specific qualities of microorganisms and metabolite yield in food processing applications.

Genetic engineering

50. One biotechnology, genetic engineering, has been at the centre of a highly polarized debate worldwide in recent years. Genetically modified (GM) crops are estimated to have been cultivated on 148 million hectares in 2010, with the United States, Brazil, Argentina, India and Canada accounting for 45, 17, 16, 6 and 6 percent respectively of the total GM crop area. Seventeen countries, including 13 developing countries, planted over 50,000 hectares each. GM soybean, maize, cotton and canola comprised an estimated 50, 31, 14 and 5 percent respectively

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[37] Heterosis (hybrid vigour) is the extent to which a hybrid individual outperforms both its parents with respect to one or many traits e.g. increased size, yield, fertility, growth rate, etc.

of the GM crops. GM forest trees (poplars) are reported to be grown on roughly 400 hectares in China. GM livestock and fish have been developed but have not been commercialized. Genetic engineering, though common in developed countries for microbial strain improvement, is only now beginning to be applied for this purpose in developing countries.

OUTLOOK

51. Developments in biotechnology have been quite substantial in the last two decades and, as reviewed here, biotechnologies have made significant contributions and hold great promise for the management of GRFA. Molecular markers can be used in a variety of ways to characterize genetic resources, to identify priority genetic resources for conservation and to more effectively manage *ex situ* collections; *in vitro* technologies offer complementary techniques to conventional conservation methods; and technologies like tissue culture provide the means to overcome reproductive barriers. While some biotechnologies such as artificial insemination and micropropagation have been widely adopted and applied in developing countries, uptake of other biotechnologies has been slower. Usually the successful application of a given biotechnology depends on the presence of complementary factors (e.g. training and extension services), rather than on the effectiveness of the biotechnology *per se*.

52. Developing countries are often endowed with a wealth of genetic resources. Agriculture is frequently an integral component of the economy and harvest of wild populations as in capture fisheries, forests, and bushmeat is economically and culturally important. Yet they have not been able to harness this diversity of genetic resources to their full potential due to many reasons, among them the lack of appropriate policy, limited human and institutional capacity, low R&D capacity and investment, inadequate infrastructure, and low level of financial investments. The challenge, therefore, remains to manage GRFA effectively so as to conserve and enhance genetic diversity and at the same time sustainably utilize it for increased agricultural productivity as well as to ensure food security for the future.

IV. MATTERS RELEVANT FOR THE FUTURE DEVELOPMENT OF BIOTECHNOLOGIES

53. As mentioned earlier,[38] the Commission, at its Tenth Regular Session, identified a number of fields in the area of biotechnology as the most appropriate for further work. This section reviews developments in those eight fields to allow the Commission to review the application and integration of biotechnologies in the conservation and utilization of GRFA at its Thirteenth Regular Session.[39]

Conservation of GRFA in the centres of origin and *ex situ* collections

54. Global policy instruments and forums for the conservation of GRFA include the CBD, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and the Commission. In 2002, the Conference of the Parties of the CBD (CBD COP) adopted the Global Strategy for Plant Conservation (GSPC) with 16 targets to be implemented by 2010, which has now been updated for the period 2011-2020. Targets 3 and 8 of the GSPC include priorities for developing and sharing methods for *ex situ* conservation, and the conservation of threatened plant species in accessible *ex situ* collections, preferably in the country of origin, respectively.

55. With regards to conservation of GRFA in the centres of origin, the Commission called for the establishment of a network on *in situ* conservation areas for both plant (including crop wild relatives) and animal genetic resources in 1989[40], and a background study paper[41] was prepared for the Twelfth Regular Session.

[38] See paragraph 12.

[39] CGRFA-12/09/Report, Appendix G.

[40] CPGR/89/REP, paragraphs 32-37.

56. The Global Crop Diversity Trust, launched in 2004 by FAO and Bioversity International (on behalf of the CGIAR), is an essential element of the ITPGRFA's funding strategy and supports crop *ex situ* conservation with two sets of complementary and mutually reinforcing strategies (regional and crop).

57. The largest plant *ex situ* collections are held by the CGIAR centres in the public domain, under the framework of the ITPGRFA and assuring the genetic integrity of these accessions is of paramount importance. In this regard, the CGIAR adopted the *Guiding Principles for the development of CGIAR Centres' policies to address the possibility of unintentional presence of transgenes in ex situ collections*[42] in 2005 and since then, crop-specific guidelines have been developed for maize, potato and rice.

58. Genebank Standards exist for the conservation of orthodox seeds and a few crop-specific regeneration guidelines have been developed by the CGIAR.[43] In addition, Bioversity International has developed technical guidelines for the management of field and *in vitro* crop germplasm collections. Draft technical guidelines for cryoconservation of animal genetic resources have also been developed by FAO and are presented as an information document.[44]

59. While the establishment and maintenance of gene banks may be an important element for the conservation of GRFA, it must be coupled with the ability to identify useful genes and utilize the genetic diversity with much greater efficiency. To facilitate the generation and exchange of standardized molecular marker data for plant germplasm held in gene banks, a list of descriptors has been developed by Bioversity International although, in general, the degree of characterization data is quite low. The situation is further exacerbated in developing countries, where the percentage of accessions characterized using molecular markers is less than 12%, with the exception being 64% in the Near East. This lack of adequate characterization is a major impediment to the sustainable use of GRFA (even though the number of accessions deposited is continuously growing), hence characterizing the extensive collections maintained in gene banks must be prioritized.

Appropriate biotechnologies that apply to GRFA

60. No internationally agreed criteria exist specifically to evaluate and identify appropriate biotechnologies. Non-GMO biotechnologies are often overshadowed by the debate on GMOs and there is a paucity of information/accurate assessments related to the application and potential socio-economic effects of non-GMO biotechnologies.

61. There is no one-size-fits-all solution, since there are substantial differences between sectors, species, regions and countries. Moreover, within developing countries, there is considerable variation regarding funding and agricultural research capacities. Hence, decisions about what biotechnologies are appropriate and their subsequent development and adoption should be made carefully, based on reliable *ex ante* (e.g. sector-specific requirements and relevance to smallholders' needs) and *ex post* (e.g. adoption rate and genetic impact assessments) analyses, as well as suitability within existing development strategies.

Access and benefit-sharing issues related to biotechnologies that apply to GRFA

62. To date, two international legally binding instruments regulate access and benefit-sharing (ABS) for genetic resources: the CBD and the ITPGRFA. The CBD aims to conserve and

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41 Establishment of a network for the *in situ* conservation of crop wild relatives: status and needs, Maxted, N. and Kell, S. (2009), Background Study Paper 39.

42 CGRFA-11/07/14 Rev.1.

43 The Commission, at its Twelfth Regular Session, requested its Intergovernmental Technical Working Group on Plant Genetic Resources for Food and Agriculture to review the Genebank Standards (CGRFA-12/09/Report, Appendix G, page 11). Draft revised Genebank Standards are presented in document, CGRFA-13/11/9.

44 CGRFA-13/11/Inf.21.

sustainably use biodiversity and share the benefits from using it, and the main objectives of the ITPGRFA complement those of the CBD. The Ad Hoc Open-ended Working Group on ABS of the CBD COP developed the *Bonn Guidelines on Access to Genetic Resources and Fair and Equitable Sharing of the Benefits Arising out of their Utilization* that were adopted in 2002. In October 2010, the CBD COP-10 adopted the *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity*.

63. At its Twelfth Regular Session, the Commission considered the current policy environment for ABS for GRFA and requested its Secretariat to work closely with the negotiators of the International Regime and report on the results.[45]

National capacity building and international cooperation

64. A number of international agreements are in place concerning biotechnologies and the management of GRFA. Since many developing countries are signatories to these agreements, they need to give considerable attention to regulation, intellectual property rights (IPR) and ABS in their national biotechnology policy/strategy frameworks in coherence with the global legislative architecture. FAO has had a pivotal role in providing advice and sharing expertise with Member States for strengthening national capacities for priority-setting and policy formulation in biotechnologies for food and agriculture, but significant capacity deficits still remain. Indeed, one of the key conclusions from ABDC-10 was that "*FAO and other relevant international organizations and donors should significantly increase their efforts to support the strengthening of national capacities in the development and appropriate use of pro-poor agricultural biotechnologies, and that they be directed to the needs of smallholders, consumers, producers and small biotechnology based enterprises in developing countries*".[46]

65. The CGIAR and the International Centre for Genetic Engineering and Biotechnology (ICGEB) have contributed considerably towards enhancing human capacities in biotechnologies through training activities and partnerships with the National Agricultural Research and Extension Systems (NARES). Several UN agencies such as the UN Environment Programme (UNEP), the UN Conference on Trade and Development (UNCTAD), the UN Development Programme (UNDP), the UN Industrial Development Organization (UNIDO), etc. have also carried out capacity-development activities.

Biosafety and environmental concerns

66. Numerous efforts have been made and are ongoing to harmonize international biotechnology regulatory frameworks. The CBD Cartagena Protocol on Biosafety, the Aarhus Convention, the World Trade Organization (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures (SPS), the WTO Agreement on Technical Barriers to Trade (TBT) and the International Plant Protection Convention (IPPC) are legally binding instruments addressing biosafety issues. For the SPS agreement, the relevant standard setting organizations are the FAO/WHO Codex Alimentarius Commission for food, the IPPC for plant health and the World Organization for Animal Health (OIE) for animal health. Relevant non-binding codes, guidelines and documentation include the FAO Code of Conduct for Responsible Fisheries and the Organisation for Economic Co-operation and Development (OECD) consensus documents among others. Biosafety capacity-development initiatives for developing countries have also been undertaken by various UN organizations, including FAO.

67. International instruments addressing invasive alien species (IAS) include the CBD, IPPC and the OIE among others. The CBD COP-9 Decision IX/4 invited the FAO Committee on Fisheries to note the lack of international standards covering IAS and to consider further ways and

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[45] CGRFA-12/09/Report, paragraph 11, 12 and 13, for the report on the outcome of the negotiations see document, CGRFA-13/11/5.

[46] CGRFA-13/11/Inf.8, paragraph 38.

means to address this gap as it applies to the introduction, for fisheries and aquaculture, of alien species.

Genetic use restriction technologies (GURTs)

68. GURTs have been addressed by the CBD COP in the context of agricultural biodiversity, and the Commission has contributed substantially to the COPs' discussions on policy issues related to GURTs.[47] There are no known commercial examples of GURTs, in part due to the CBD COP-5 Decision V/5, that established what is widely interpreted as a *de facto* moratorium on the use of GURTs. An Ad Hoc Technical Expert Group on GURTs was established at COP-6 to further analyze their potential impacts on smallholder farmers, indigenous and local communities, and on farmers' rights. Decision V/5 was later reaffirmed at COP-8.

GMO gene flow and the question of liability

69. Gene flow from genetically modified organisms and the issues of liability/redress are addressed by the Cartagena Protocol. The first meeting of the COP serving as the meeting of the Parties to the Cartagena Protocol (COP-MOP 1) established an Ad Hoc Open-ended Working Group of Legal and Technical Experts on Liability and Redress to negotiate international rules and procedures on the issue. Subsequently, a Group of the Friends of the Co-Chairs was established by COP-MOP 4 to continue the process. The Nagoya - Kuala Lumpur Supplementary Protocol on Liability and Redress to the Cartagena Protocol on Biosafety was adopted by COP-MOP 5 in October 2010. The new treaty is currently open for signature and will enter into force 90 days after the deposit of the fortieth instrument of ratification, acceptance, approval or accession.

70. An overview of the effects of transgene flow on the conservation and sustainable use of GRFA can be found in the background study paper[48] prepared for the Commission in 2007.

Incentives to promote appropriate biotechnologies

71. An enabling environment, with sound policies in place, is necessary to facilitate the application of appropriate biotechnologies. Incentives to promote appropriate biotechnologies include proper IPR management, facilitation of public-private sector partnerships, improved market access, and the sharing of technologies through collaboration platforms and initiatives.

72. Pertinent to biotechnology and GRFA, the globally negotiated legal frameworks that govern IPR include the International Union for the Protection of New Varieties of Plants (UPOV) and the WTO Agreement on Trade-Related aspects of Intellectual Property Rights (TRIPS). Additionally, the World Intellectual Property Organization (WIPO) Intergovernmental Committee on Intellectual Property and Genetic Resources, Traditional Knowledge (TK) and Folklore is conducting negotiations regarding the protection of TK, traditional cultural expressions/folklore and genetic resources.

73. At its Eleventh Regular Session, the Commission requested the Secretariat to provide information related to policy developments in IPR and genetic resources on a regular basis[49], and a background study paper[50] on the subject was prepared for the Twelfth Regular Session. The study *Trends in Intellectual Property Rights*[51] reports on further updates in this area.

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[47] CGRFA-9/02/17; CGRFA-9/02/17 Annex.

[48] A typology of the effects of (trans)gene flow on the conservation and sustainable use of genetic resources, Heinemann, J.A. (2007), Background Study Paper 35, Rev.1.

[49] CGRFA-11/07/Report, paragraph 72.

[50] Trends in Intellectual Property Rights relating to Genetic Resources for Food and Agriculture, Correa, C.M. (2009), Background Study Paper 47.

[51] Background study paper 58.

V. GUIDANCE SOUGHT

74. The Commission, in light of the guidance received from its Working Groups, may wish to request FAO to:

i) Increase its efforts to strengthen the national capacities of developing countries for priority-setting, policy formulation and the use of biotechnologies for the characterization, conservation and utilization of GRFA;

ii) Strengthen its activities for the regular dissemination of updated factual information on the role of biotechnologies for the characterization, conservation and utilization of GRFA through its existing databases, networks and newsletters, emphasizing also communication of biotechnology developments to the public;

iii) Explore mechanisms for future cooperation with relevant international organizations, including for fostering North-South and South-South cooperation, for harnessing the benefits of biotechnologies for the characterization, conservation and utilization of GRFA.

75. The Commission, in light of the guidance received from its Working Groups, may also wish to request FAO to:

i) Develop draft sector-specific standards and technical protocols, for selected sectors, for the molecular characterization of GRFA[52] in order to generate reproducible and comparable data, for consideration by the ITWGs;

ii) Prepare sector-specific analyses, for selected sectors, on the investments, returns and socio-ecological impacts of biotechnologies for GRFA.

76. With regards to its future work on the application of biotechnologies for the conservation and utilization of genetic resources for food and agriculture, as a cross-sectoral matter, the Commission may wish to:

i) Note with *appreciation* the FAO international technical conference on *Agricultural biotechnologies in developing countries: Options and opportunities in crops, forestry, livestock, fisheries and agro-industry to face the challenges of food insecurity and climate change* (ABDC-10);

ii) Consider whether/ how to proceed with the draft Code of Conduct for Biotechnology;

iii) Propose the inclusion of any biotechnology-related issues in the MYPOW.

[52] Draft guidelines on molecular genetic characterization of animal genetic resources are presented as an information document, CGRFA/-13/11/Inf.20.