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# 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)

## Guadalajara, Mexico, 1 – 4 March 2010

# Synthesis: Current status and options for forest biotechnologies in developing countries

### Introduction

Forests and other wooded areas perform key economic and ecological functions. Not only do they provide goods and livelihoods but they also protect soils, regulate water and absorb carbon. Forests also shelter much of the world's biodiversity. The world has slightly less than 4 billion hectares of forests, covering about 30 percent of the world's land area. The production of wood and non-wood forest products is the primary function for 34 percent of the world's forests. More than half of all forests are used for wood and non-wood production in combination with other functions such as soil and water protection, biodiversity conservation and recreation. Only 5 percent of forests in the world are in plantations, with the balance found in natural or semi-natural, largely unmanaged and undomesticated forest stands. Planted forests are expanding, and their contribution to global wood production is approaching 50 percent of the total. More than half of the wood biomass consumed globally – and well over 80 percent in developing countries – is burned as fuel. About 1.6 billion people rely heavily on forest resources for their livelihoods. The 60 million indigenous people who live in the rain forests of Latin America, Southeast Asia and West Africa depend heavily on forests. A further 350 million people who live in or next to dense forests rely on them for subsistence or income, while 1.2 billion people in developing countries use trees on farms to generate food and cash.

Forest and tree resources are managed in different types of systems that are characterized by varying management intensity and range from primary natural forests to productive industrial plantations. A number of factors shape global opportunity, condition investment decisions and drive research priorities for forest biotechnology - they also underline important ways in which uses of biotechnologies in forestry differ from crops or livestock. The factors consist of the following: forest trees are highly heterozygous, long-lived perennials with late sexual maturity and a lengthy regeneration cycle, which places high priority on retaining genetic diversity as an insurance policy against rapid change; most forest tree species have narrow regional adaptation, so the numbers of species used for planting are orders of magnitude higher than those for food crops; forest trees serve as keystone species in dynamic ecosystems, so managing against loss translates into more than tree survival; forest trees are largely undomesticated although a few species have had some population-level improvement for one to four generations.

This document synthesizes the key elements of document ABDC-10/4.1 that evaluates the use of forest biotechnologies in developing countries, and considers the extent of their current use, the reasons for their success or failure in the past, emerging challenges and future options both for developing countries and for the international community (FAO, UN organizations, NGOs, donors and development agencies).

**Stocktaking – Learning from the Past**

In recent decades, forest biotechnology has grown into a dynamic portfolio of tools, moving beyond research into global trade and development. Forest biotechnology applications have historically been developed for the benefit of planted forests. But today, forests are still planted from undomesticated reproductive material. A few forest tree species are in the early stages of domestication but even so, they are semi-domesticated at most. Regarding conventional technologies, forest tree improvement spread as a concept in the twentieth century well after the advent of quantitative genetics, and its primary goal was to identify and select wild seed sources suitable for planted forests. Only a few recurrent breeding programmes developed from this. Breeding cycles were lengthy, in part because population-level improvement was essential. Recurrent tree breeding refers to the application of Mendelian genetics principles within a given silvicultural system for the purpose of improving the genetic quality of the forest. Its goal is to *improve the genetic value of the population while maintaining genetic diversity*. Genetic diversity is seen as an insurance policy against catastrophic loss beyond a single generation. This advanced-generation or recurrent breeding programme refers to population-level improvement, not to the development of breeds or inbred lines. Few of the many forest tree species planted today have even been subjected to a single generation of population-level improvement. This is a subtle but important point when comparing forest biotechnology advances with those for crop or livestock biotechnology. Forest tree breeders weigh the importance of genetic gain against the importance of sufficient genetic diversity, the avoidance of inbreeding depression and long-term uncertainty.

**Management of naturally regenerated forests:** DNA-based and biochemical markers are available for a growing number of tropical species. Today, findings are available to guide operational forest management plans in developing countries, but only for a very limited number of the hundreds of tree species that are managed in naturally regenerated tropical forests. This area of forest biotechnology continues to expand, moving from tools development into more hypothesis-driven knowledge acquisition. Such research inquiry is a powerful source of pertinent knowledge for protecting tropical forests. This research is also moving from molecular markers into genomics. The availability of DNA sequencing data brings a distinct advantage to worldwide research on tropical forests. Genomics data are yielding new insights into comparative biology for tropical forests. Perhaps the application of most immediate use is an international plant barcoding project. This emerging use of genomics has been applied to several areas of inquiry including phylogeny.

Biotechnology tools such as molecular markers and genomics can therefore provide important knowledge about naturally regenerated tropical forests and provide important insights into the nature of the entire tropical forest ecosystems, including the relationship between the forest trees and the microbial communities with which they interact, which can influence the strategies employed for managing tropical forests.

**Planted forests:** Although there is some overlap, the range of biotechnologies used for planted forests is generally quite different from that used for naturally regenerated forests. Plantations can have different types of management systems (e.g. intensive, semi-intensive) and use different types of genetic material (e.g. wild material, genetically improved trees). Depending on the level of management intensity and the genetic material used in the planted forest, different groups of biotechnologies can be used. For simplicity, three different groups of biotechnologies can be identified according to the type of planted forests, ranging from the least sophisticated to the most advanced.

A first group of biotechnologies is suitable for the least intensively managed planted forests, and includes a range of vegetative propagation methods, including micropropagation based on tissue culture, biofertilizers and genetic fingerprinting using molecular markers. Forest biotechnologies in this first stage of planted forests contribute to health and quality of forests planted with indigenous as well as exotic species. Vegetative propagation covers a wide range of techniques which are useful for rapid multiplication of genotypes. This has been useful for species which produce few or recalcitrant seeds and for multiplying selected genotypes in a short period of time. While a large number of tree species have been used for micropropagation research in developing countries, most of the work reported (94%) is still at the laboratory stage, while relatively little has entered the field-testing stage (5%). Less than just 1% of the reported micropropagation activities in developing countries have reached the commercial application stage. The use of biofertilizers has yielded positive results for indigenous forest species as well as for exotic forest species, including eucalypts, acacia and cypress. Symbionts that are being considered include nitrogen-fixing bacteria such as *Rhizobium* and *Azolla*, blue-green algae and mycorrhizal fungi. In addition to the least intensively managed planted forests in developing countries, biofertilizers have also proved useful in those with more intensive management. Different types of molecular and biochemical markers have also been used for decades in these early-stage tree improvement programmes. They have been used, for example, to measure genetic diversity of breeding population, test paternity contributions to offspring grown in field tests and to verify genetic identity during vegetative propagation.

The second group of biotechnologies is suitable for planted forests that provide industrial raw materials on a large planting scale. The single species used for plantations may be indigenous or exotic, but these plantations are intensively managed. This group of biotechnologies includes somatic embryogenesis, molecular markers and quantitative trait locus (QTL) analyses, whole genome sequencing and functional genomics. Although successes have been reported using somatic embryogenesis (a tissue culture technique) in some of the commercial species, there are still major obstacles to its large scale operational application to forest trees in developing countries. Breeding and selection in the recurrent breeding programme can be improved by localizing QTLs which influence the trait (or traits) of interest and using them for marker-assisted selection. Finding QTLs for forest trees is more costly and more computationally demanding than for most crop and livestock species, because forest tree pedigrees are outcrossing and highly heterozygous. Gene-based or reverse genomics can be used to identify and characterize genes of interest. For hardwood species such as *Eucalyptus* spp. or *Populus* spp., genome sizes are in the same range as those for rice, tomato and Arabidopsis. The poplar genome was the first forest tree species to be sequenced in its entirety. The *Eucalyptus* genome initiative for whole-genome sequencing is an even larger effort that is being coordinated among 130 scientists in 18 countries including Brazil and South Africa.

The third and most sophisticated group of biotechnologies includes backward and reverse genomics approaches, whole-genome sequencing, low-cost vegetative propagation and genetic modification of forest trees. To date, the only report of commercial plantings with genetically modified (GM) trees is for poplar, in China. However, most tree species used in planted forests have been successfully transformed at the experimental level, and traits that have been the subject of extensive research include stem shape, herbicide resistance, flowering characteristics, lignin content, insect and fungal resistance. Many developing countries currently have biosafety regulations for agricultural crops, including fruit-trees, although many others lack such frameworks and the capacity to implement them. There are no regulations, however, specific to the use of GM forest trees. Although policies and regulations adopted for agricultural crops are also likely to be used for forest trees, they present special challenges (long time frames and life spans, wild resource, major constituents of an ecosystem). Forests are not only trees, and forest ecosystems are more fragile, longer-lived and less closely controlled than crop fields. Decision-making is complicated by the fact that while agriculture is primarily viewed as a production system, forests are generally viewed as a natural system, important not only for the conservation of biodiversity but also for social and cultural values. Thus the use of GM forest trees is viewed more as a political and environmental issue than as a technical or trade issue.

Considering the overall application of forest biotechnologies in developing countries in the past, the analysis indicates that their use has been beneficial only at very advanced stages of selection and improvement programmes. For most species and most forest tree management systems, advances registered in developing countries until now have been made without any incorporation of biotechnologies. There are very good examples of advanced tree breeding programmes using biotechnology tools also in developing countries, but they concern only a small part of the forest area (although their relative share of timber production is higher). One main reason for failure is that an inadequate assessment has been made of the real costs and benefits of using biotechnology tools in given conditions (the level of improvement and intensity of management), often following an offer-driven approach. As a result, expectations are not met and unjustified costs are high. This is a common risk in the early stages of the development of new technologies. Much still needs to be done to upgrade the skills of researchers by ensuring that they receive higher education and/or appropriate higher level training to plan, develop and execute proper tree improvement programmes. Sufficient financial resources also need to be committed at the national level to ensure that such programmes are carried out successfully, with the final aim of the producing improved reproductive material. The effective integration of biotechnologies in broader programmes – including programmes based on conventional technologies such as tree improvement and recurrent breeding – is a common feature in case studies of successful applications.

**Looking Forward – Preparing for the Future**

If used within a proper framework, forest biotechnologies can contribute to improving productivity and reducing the vulnerability of forest ecosystems to disease, degradation and human disturbance. Looking forward, biotechnologies can be useful for addressing some key issues.

Forests, particularly tropical forests, play a central role regarding the key issue of climate change, which is expected to shape forest biotechnology research in new ways. At the heart of the matter is how to facilitate forest adaptation to climate change. Forest adaptation is the foundation for all other forestry policy solutions aimed at slowing climate change. With regard to the biotic and abiotic stresses expected in climate change scenarios, the development of biotechnology tools to assist with resistance to pests, tolerance to climatic extremes, bioremediation and carbon sequestration will be more relevant in the near future both for naturally regenerating and for planted forest tree species.

Another key issue is the management of forest genetic resources (FGR). Genetic diversity provides the fundamental basis for evolution of forest-tree species that has enabled forests and trees to adapt to changing conditions for thousands of years. Fires, deforestation, new pests and diseases, and other factors are increasingly threatening FGR. The vast majority of FGR remain unknown and underutilized, although the sustainable use of forest genetic diversity can contribute much towards addressing new challenges and maintaining economic, social and cultural values as well as environmental services and benefits. Emerging uses of FGR must be assessed to achieve sustainable use of these resources. Advances in biotechnology are rapidly enabling the improved use of genetic resources, and potentially greater economic and social contributions resulting from FGR. Biotechnology developments will also provide improved tools to enhance the effectiveness of conservation and development measures (knowledge about life-history traits and genetic diversity is lacking or inadequate for most tree species to define and implement conservation strategies).

Based on the stock-taking exercise that has been central to this document, a number of specific options can be identified for developing countries to help them make informed decisions regarding adoption of biotechnologies in the forestry sector in the future. First, biotechnologies should be integrated with conventional technologies. Second, public-private partnership is an important option to be considered by developing countries and should be promoted at a national level. Third, information and communication strategies for biotechnologies should be improved. Public access to good and updated information on forest biotechnologies is very important for developing countries. Consolidated information and education mechanisms should be put in place to allow communication between concerned sectors in society. Issues relevant to the meaningful adoption of biotechnologies, including their socio-economic implications, efficiency, costs and benefits and environmental implications, among others, should be covered.

The international community can play a key role in supporting developing countries by providing a framework for international cooperation and funding support for the generation, adaptation and adoption of appropriate biotechnologies.

1. The international community can improve access to peer-reviewed scientific information about forest biotechnologies in developing countries. Even with internet access, peer-reviewed journal and books continue to be central sources of information for scientists.

2. The international community can assist in building capacity for understanding forest biotechnology issues at all levels. Most policymakers, scientists and even students regard forest biotechnology as a form of agriculture. As discussed earlier, this is not the case. Forest biotechnology requires capacity-building that is separate from that applied in crop and livestock biotechnology. Capacity-building initiatives in forest biotechnologies from the international community should be strengthened, considering this important point.

3. The international community can continue reviewing the status and potential of forest biotechnologies for developing countries. The forestry sector in developing countries is in a very dynamic situation and is facing a number of important challenges and opportunities in which biotechnologies can play a significant role. Global surveys are important and the international community should continue to provide periodic reviews regarding the status and potential of forestry biotechnologies in developing countries.

4. The international community should encourage North-South collaboration. Application of forest biotechnologies has advanced faster in developed countries than originally predicted. As much of the research carried out there is on processes and/or tree species that are relevant to developing countries, these advances are therefore of major potential relevance to developing countries as well. The international community should act to ensure that the results of research and application in forest biotechnologies in developed countries are made accessible to developing countries.