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Agricultural biotechnologies in developing countries and their possible contribution to food security

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ABSTRACT

Latest FAO figures indicate that an estimated 925 million people are undernourished in 2010, representing almost 16% of the population in developing countries. Looking to the future, there are also major challenges ahead from the rapidly changing socio-economic environment (increasing world population and urbanisation, and dietary changes) and climate change.

Promoting agriculture in developing countries is the key to achieving food security, and it is essential to act in four ways: to increase investment in agriculture, broaden access to food, improve governance of global trade, and increase productivity while conserving natural resources. To enable the fourth action, the suite of technological options for farmers should be as broad as possible, including agricultural biotechnologies. Agricultural biotechnologies represent a broad range of technologies used in food and agriculture for the genetic improvement of plant varieties and animal populations, characterisation and conservation of genetic resources, diagnosis of plant or animal diseases and other purposes. Discussions about agricultural biotechnology have been dominated by the continuing controversy surrounding genetic modification and its resulting products, genetically modified organisms (GMOs). The polarised debate has led to non-GMO biotechnologies being overshadowed, often hindering their development and application.

Extensive documentation from the FAO international technical conference on Agricultural Biotechnologies in Developing Countries (ABDC-10), that took place in Guadalajara, Mexico, on 1–4 March 2010, gave a very good overview of the many ways that different agricultural biotechnologies are being used to increase productivity and conserve natural resources in the crop, livestock, fishery, forestry and agro-industry sectors in developing countries. The conference brought together about 300 policy-makers, scientists and representatives of intergovernmental and international non-governmental organisations, including delegations from 42 FAO Member States. At the end of ABDC-10, the Member States reached a number of key conclusions, agreeing, *inter alia*, that FAO and other relevant international organisations 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.

1. Introduction

In this paper, one of the most important issues for humankind – food insecurity – is addressed, as well as the increasing challenges that the world is facing to achieve global food security. The possible contribution that agricultural biotechnologies can make in helping to face these challenges is also considered. FAO recently organised the 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), and the paper also provides an overview of the conference and reports on its major outputs.

2. Defining food security and quantifying food insecurity

For FAO, food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 1996; Schmidhuber and Tubiello, 2007). There are four dimensions of food security: the availability of food; access to food; utilisation of food; and food system stability. For food security objectives to be realised, all four dimensions must be fulfilled simultaneously.

The first dimension covers the availability of good quality and nutritious food from local, regional and international sources. It

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therefore includes issues of food production and processing; trade imports and exports; availability of food stocks and food aid. For example, in a region like Latin America and the Caribbean, countries possess large capacity for the production, export and import of food, so availability of food is not the main problem for food security in the region (FAO, 2008).

The second dimension covers physical and economic access to food for an active, healthy life. This includes marketing and transport infrastructure, food distribution systems and markets; purchasing power or having the money to buy the right food; social programmes to ensure access to nutritious food; and school meals which are nutritious and appealing to children. If food is available but people do not have the money to access it, they are food insecure.

The third dimension covers the safe and healthy utilisation of the food. This includes good health status, since healthy individuals can make proper use of food; having nutritious food choices for all age groups; food safety and quality; and access to clean water and sanitation.

The fourth dimension covers the fact that to be food secure, a population, household or individual should have access to adequate food at all times and should not risk losing access to food as a consequence of sudden shocks (e.g. an economic or climatic crisis) or cyclical events (FAO, 2006). This dimension is increasing in importance with the economic and climate change related challenges facing the world, especially developing countries.

Having described the four dimensions of food security, the other side of the coin is food insecurity, a situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life. It may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution, or inadequate use of food at the household level. Each year, FAO publishes a flagship report entitled “The State of Food Insecurity in the World” and figures from the 2010 report, jointly published with the UN’s World Food Programme, estimate that a total of 925 million people (19 million in developed and 906 million in developing countries) are undernourished in the world in 2010 (FAO and WFP, 2010). These figures mark an improvement compared to 1023 million people of the previous year. The decline, which was expected, is primarily a result of better access to food as the global economy recovers and food prices remain below their peak levels of mid 2008. However, there is no cause for complacency whatsoever. There are close to 1 billion people who live in hunger and this terrible situation is not acceptable.

These new figures were released in advance of the UN Summit in New York on 20–22 September 2010, that was called to accelerate progress towards achievement of the eight Millennium Development Goals, the first of which is to eradicate extreme poverty and hunger. FAO and WFP (2010) estimate that developing countries account for 98% of the world’s undernourished people; that two-thirds live in seven countries (Bangladesh, China, the Democratic Republic of the Congo, Ethiopia, India, Indonesia and Pakistan); and that over 40% live in China and India. The region with the highest number of undernourished people is Asia and the Pacific, where 62% of the world’s hungry live. The region with the highest proportion of undernourished people is sub-Saharan Africa, at 30%.

A target of the first Millennium Development Goal is to halve, between 1990 and 2015, the proportion of people who suffer from hunger. FAO and WFP (2010) indicate that some progress has been made towards achieving this target, as the prevalence of hunger in developing countries has declined from 20% undernourished in 1990–1992 to 16% in 2010. However, with the world population still increasing, a declining proportion of hunger people conceals an actual increase in numbers. In fact, the number of hungry people in developing countries has risen from 827 million in 1990–1992 to 906 million in 2010.

Using 2005–2007 data, FAO and WFP (2010) also show that, in sub-Saharan Africa, the Congo, Ghana, Mali and Nigeria had reached the hunger target of the first Millennium Development Goal, and Ethiopia and others were close to doing so. In Asia, Armenia, Myanmar and Viet Nam had achieved the target reduction and others were coming close, including China. In Latin America and the Caribbean, Guyana, Jamaica and Nicaragua had reached the target while Brazil, among others, was approaching this objective.

3. Challenges of the future

Currently, more than enough food is produced to feed the world’s population of nearly 7 billion inhabitants. However, still about one in six people in developing countries suffers from chronic hunger. Looking to the future, there are, in addition, some major challenges ahead that can drastically worsen this already unacceptable situation.

The first is the rapidly changing socio-economic environment. The world’s population is projected to increase to over 9 billion people by the year 2050, and nearly all of this increase will occur in developing countries (UN Population Division, 2011). In addition, the ongoing migration from rural to urban areas is expected to continue, so that by 2050 about 70% of the world’s population will be urban (compared to 50% today). Incomes are also expected to rise in the future in developing counties, resulting in dietary changes where the proportion of grains and other staple crops in diets will decline, while the proportion of vegetables, fruits, edible oil, meat, dairy and fish will increase. With this larger, more urban and, on average, richer population, it is estimated that the global demand for food in 2050 may be 70% higher than today (FAO, 2009a).

The second major challenge is climate change, which affects the frequency of extreme weather events, alters agricultural growing patterns as well as the distribution patterns of pests, weeds and diseases that threaten crops and livestock. Frequencies of natural disasters have increased in recent decades and global warning will likely lead to more natural disasters. The overall impacts of climate change on agriculture and food security are expected to be increasingly negative, especially in areas already vulnerable to climate-related disasters and food insecurity.

As the UN organisation with the global mandate of ensuring that all people everywhere have enough to eat, FAO is aware that the war against hunger is far from being won. This is in spite of its ongoing and concerted efforts to create a broad united front against hunger by working with its Member States and the international community in support of policies and programmes that promote food security. Because of the major challenges of the future, these efforts will have to be greatly intensified.

4. How to achieve global food security

Although the challenges are great, there are solutions and agriculture is the key. This is because:

- Agriculture accounts on average for about 30% of the GDP in agriculture-based countries, and for 50% of employment in the developing world.
- Developing countries, which represent over 80% of the world’s population, are home to about 500 million small farms, supporting around two billion people.
- Three out of every four poor people live in rural areas, and most depend on agriculture for their daily livelihoods.

Promoting agriculture in developing countries is therefore the key to achieving food security and, following FAO (2009a), four areas can be prioritised for action.

4.1. *Increase investment in agriculture*

FAO continues to underline that the root cause of hunger and malnutrition is under-investment in agriculture in developing countries. The part of total official development assistance going to agriculture, including forestry and fisheries, has decreased from 19% in 1980 to around 5% presently (FAO, 2009a). In developing countries, the share of total government expenditure on agriculture has also fallen. For example, for the period 1980–2002, it fell from 14.8 to 8.6% in Asia; from 8.0 to 2.5% in Latin America and the Caribbean; and from 6.4 to 4.5% in Africa (Akroyd and Smith, 2007). In Maputo in 2003, African leaders committed themselves to raising the share of agriculture and rural development in their budget expenditures to at least 10%. By 2008, eight countries had succeeded, nine devoted 8–10% while the majority of African countries devoted just 3–6% (FAO, 2009b). So, much more can be done.

4.2. *Broaden access to food*

An important option for ensuring that everyone can enjoy adequate access to food is to create targeted social protection or safety net programmes, which target resources to the poor and vulnerable. The most important safety net policies include cash-transfers, in-kind transfers (such as school meals and take home rations), food price subsidies, public works programmes, fee waivers (for healthcare, schooling or transport) and food stamps. This option was used successfully by a number of developing countries, such as Brazil and Ethiopia, during the 2007–2008 food crisis (FAO, 2009c).

4.3. *Improve governance of global trade*

The 2007–2008 food crisis provided a clear reminder that the global food and agricultural system, including agricultural trade, is highly vulnerable. Price volatility is a key concern for policy-makers and the needs of low-income import-dependent countries have to be addressed. For example, new and innovative arrangements are needed to ensure that levels of worldwide food stocks are adequate and that poor and import-dependent countries have access to them, especially at times of extraordinary scarcity. The rapid increase in cereal prices in 2010 has again brought the issue of food price volatility into the limelight and experts from 75 FAO Member States met in Rome in September 2010 to discuss the issue. In their report they recognised that unexpected price hikes and volatility are among the major threats to food security and that their root causes needed to be addressed (FAO, 2010a). One month later, the Committee on World Food Security, which was recently reformed to make it the cornerstone of the global governance of agriculture and food security, met in Rome. At the meeting, the Committee requested its high-level panel of experts to take a close look and make recommendations regarding causes and consequences of food price volatility, including market distorting practices and links to financial markets, and appropriate and coherent policies, actions, tools and institutions to manage the risks linked to excessive price volatility in agriculture (CFS, 2010).

4.4. *Increase productivity and conserve natural resources*

Increasing the productivity of smallholders, fishers and foresters through appropriate application of good practices and improved technologies should be a priority for developing countries wishing to achieve food security. This was also underlined at the UN Summit in New York on 20–22 September 2010, when Heads of State and Government committed themselves to accelerating progress in order to achieve Millennium Development Goal 1 through a series of actions, including “Increasing the growth rate of agricultural productivity in developing countries through promoting the development and dissemination of appropriate, affordable and sustainable agricultural technology, as well as the transfer of such technologies on mutually agreed terms, and supporting agricultural research and innovation, extension services and agricultural education in developing countries” (UN, 2010).

Increasing productivity can improve food security in two ways. First, the increasing demand for agricultural products in low- and middle-income countries provides an opportunity for the rural poor to increase their incomes and to improve their livelihoods. Second, increased productivity can also lead to reduced food prices, benefiting many poor people in both urban and rural areas (the rural landless) as poor households typically spend a large proportion of their income on food.

Increased productivity should be achieved while simultaneously conserving the natural resource base upon which future productivity increases depend. In this way, the farmer’s income growth can be combined with truly sustainable resource use. The importance of productivity increases is especially clear if it is considered that increases in food production for the future may only come in part from further expansion of agricultural lands and that the majority should come from increased yields per unit of land. This challenge is made more difficult by climate change, which is expected to have significant impacts on agriculture and food production patterns, and the fact that reduced investments in agriculture have led to a slowdown in productivity growth compared to previous decades. It is therefore necessary to substantially increase investments in international and national public agricultural R&D, strengthening, in particular, the Consultative Group on International Agricultural Research (CGIAR) and the national agricultural research systems.

Technologies must be appropriate and adapted to the local needs of poor farmers and they must be accessible to them. Even at current levels of technology, large gaps between potential and realised yields remain in many places. Extension services play an essential role in closing these gaps and ensuring that farmers have access to the benefits of R&D. Lack of information and skills are a big hurdle in smallholder farmer systems, constraining adoption of technologies and reducing their efficiency if eventually adopted. When not in place, investing in functional demand-driven pluralistic extension systems is essential. Another important related issue is that of participation, as it is now generally recognised that the potential beneficiaries of R&D and extension services should have a say in, and be able to influence, priorities and strategies, as it ensures that these services respond to their needs and priorities. Several kinds of participatory approaches can be used and there are many examples of their application in developing countries (e.g. Puente-Rodríguez, 2007).

To increase productivity, the suite of technological options for farmers should be as broad as possible, including those used to improve water management in irrigated and rainfed production systems; save labour; reduce post-harvest losses; improve natural resource management, including conservation agriculture, increasing soil fertility and integrated pest management. Preference should be given to technologies promising win–win combinations of enhancing productivity and conserving natural resources.

The suite of technological options should also include agricultural biotechnologies, and the paper will now focus on the use of agricultural biotechnologies to increase productivity and conserve natural resources.

5. Agricultural biotechnologies to increase productivity and conserve natural resources

The subject of biotechnology is often accompanied by strong emotions and controversies. So, it is important to first define the term biotechnology. FAO traditionally uses a broad definition, based on that contained in Article 2 of the Convention on Biological Diversity, which states that biotechnology is "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use".

The term agricultural biotechnology (or agricultural biotechnologies) therefore covers a broad range of technologies used in food and agriculture. They are used for a number of different purposes, such as the genetic improvement of plant varieties and animal populations to increase their yields or efficiency; diagnosis of plant or animal diseases; and vaccine development. They are also used to characterise and conserve agricultural biodiversity and Professor M.S. Swaminathan, in his keynote address to ABDC-10 (FAO, 2011a), noted that biodiversity has been the feedstock for sustainable food and health security and that it can play a similar role in the development of climate resilient farming and livelihood systems, although it is rapidly being lost. Agricultural biotechnologies, including the use of molecular markers, cryopreservation and reproductive technologies, can all play an important role in the characterisation and conservation of crop, livestock, forestry, aquatic and microbial genetic resources for food and agriculture and they are currently being used in developing countries for this purpose (FAO, 2011b).

The strong controversy about the subject of agricultural biotechnology relates to one single biotechnology, genetic modification, and its resulting products, genetically modified organisms (GMOs). Indeed, the term biotechnology is often used synonymously for genetic modification (hence the need for a definition earlier). The debate about the advantages and disadvantages, real or perceived, of GMOs began over a decade ago and it still continues today without showing significant signs of abating. The positions of different parties regarding GMOs have often become firmly entrenched in what has been called a 'global war of rhetoric' (Stone, 2002).

In the past, and still today, there has been too much emphasis on GMOs and too little focus on the potential merits and benefits of non-GMO biotechnologies and the positive role that they can play for food security and sustainable development in developing countries. The polarised debate has led to non-GMO biotechnologies being overshadowed and it has often hindered their development and application.

There are many non-GMO biotechnologies and they are very diverse. Some of them may be applied to all the food and agricultural sectors, such as the use of molecular markers, while others are more sector-specific, such as tissue culture (in crops and forest trees), embryo transfer (livestock) or sex-reversal (fish). They can also be roughly classified into different groups depending on whether they can be considered as 'low technology' (such as biofertilisers, biopesticides or tissue culture in crops/trees; artificial insemination in livestock; fermentation and use of bioreactors in food processing), 'medium technology' (such as use of PCR-based disease diagnostic tools or marker-assisted selection) or 'high technology' (such as genomics or *in vitro* fertilisation in livestock). An important feature they have in common is that, compared to GMOs, these biotechnologies, and any eventual products arising from them, do not normally require specific regulatory approval, meaning they can be quickly adopted by farmers and that the costs of release are low.

Here, a brief overview is provided of the ways that agricultural biotechnologies are being used to increase productivity and conserve natural resources in the crop, forestry, livestock, fishery and agro-industry sectors in developing countries, following the sector-specific documents prepared by FAO for ABDC-10 (Chapters 1–5 respectively in FAO, 2011a).

5.1. Crops

Crop biotechnologies have developed incrementally over the past century, but progress has accelerated greatly over the last two decades, leading to many important scientific achievements and impressive technological advances. As with other maturing technologies, there have been mixed experiences with crop biotechnologies in developing countries. Genetic modification has had limited but real success in modifying a few simple input traits in a small number of commercial commodity crops, adopted also in some developing countries.

However, the major breeding and crop management applications to date have come from non-GMO biotechnologies encompassing the full range of agronomic traits and practices relevant to developing countries' farmers. For example, mutagenesis is widely used in developing countries and more than 2700 mutation-derived crop varieties have been obtained worldwide in the last sixty years, mainly in developing countries (FAO and IAEA, 2008).

Interspecific hybridisation allows the combination of favourable traits from different species and has been used successfully in, for instance, the development of New Rice for Africa (NERICA) varieties, by crossing high-yielding Asian rice with African rice which thrives in harsh environments, using embryo rescue and anther culture techniques. NERICA varieties are estimated to be cultivated annually on about 200,000 ha of upland areas in sub-Saharan Africa (Wopereis et al., 2008) and, while they are not miracle varieties or a silver bullet (Orr et al., 2008), numerous studies indicate their positive impacts on yield and people's livelihoods (e.g. Obilana and Okumu, 2005; Wopereis et al., 2008). Analysis of NERICA adoption in upland areas of Uganda also shows how their profitability is influenced by other factors, such as extension services (e.g. to prevent NERICA varieties being cultivated in areas that are not suitable for rice production) and market development policies (Kijima et al., 2011). Interspecific hybridisation programmes can be slow and require a great deal of scientific expertise and skilled labour.

Marker-assisted selection is still at a relatively early stage in its application for key subsistence crops in many developing countries, although it has begun to produce some significant results, such as the development of a pearl millet hybrid with resistance to downy mildew disease in India (Dar et al., 2006) and flood-resistance rice in Asia (Septiningsih et al., 2009). The costs and technical sophistication required for marker-assisted selection, however, remain major challenges for developing countries.

Micropropagation is used for the mass clonal propagation of elite lines or disease-free planting material. Many developing countries have significant crop micropropagation programmes and are using it in a wide range of subsistence crops. The socio-economic impacts of biotechnologies are seldom evaluated, but can be substantial, as shown by the study of micropropagated sweetpotato in the Hwedza District (Zimbabwe), where the technology was adopted by 97% of the farmers, including both poorer and better-off farmers, and it contributed to household food security (Sonnino et al., 2009).

Biotechnology also offers important tools for the diagnosis of plant diseases of both viral and bacterial origin, and immuno-diagnostic techniques as well as DNA-based methods are commercially applied for this purpose in some developing countries (e.g. Miller et al., 2009). Additionally, biotechnologies such as molecular markers, cryopreservation and *in vitro* slow growth storage are extensively used for the characterisation and conservation of plant genetic resources in developing countries (FAO, 2011b).

Microbial-based biotechnologies are also important in the crop sector. Biofertilisers are used in developing countries both to augment the nutritional status of crops and as alternatives to chemical supplements (e.g. Sharma et al., in press). Although still tiny compared with synthetic pesticides, the market for biopesticides is increasing worldwide, with developing countries responsible for under 20% of global biopesticide production (Thakore, 2006). For example, biopesticides formulated with the spores of the fungus *Metarhizium anisopliae* var. *acridum* have been used successfully to control migratory locusts in countries such as Timor-Leste and Tanzania (FAO, 2011a).

5.2. Livestock

Livestock contribute directly to livelihoods worldwide, providing not only food, but also non-food products, draught power and financial security. They contribute 40% of the global value of agricultural output (FAO, 2009d), and this proportion is expected to increase. The rapidly increasing demand for livestock products, known as the "livestock revolution", has created opportunities for improving the welfare of at least some of the nearly one billion poor people who depend on livestock for their livelihoods. However, land degradation, environmental pollution, global warming, the erosion of animal genetic resources, water shortages and emerging diseases are all expected to present challenges to the growing global livestock sector.

Conventional technologies and biotechnologies in livestock have contributed immensely to increasing productivity, particularly in developed countries, and can help to alleviate poverty and hunger, reduce the threats of diseases and ensure environmental sustainability in developing countries. A wide range of biotechnologies are available and have already been used in developing countries in different sectors of animal science.

In animal reproduction and breeding, artificial insemination (AI) has perhaps been the most widely applied animal biotechnology, particularly in combination with cryopreservation, allowing significant genetic improvement for productivity, as well as the global dissemination of selected male germplasm. It is applied at some level in most developing countries, primarily in dairy cattle and peri-urban areas where complementary services including milk marketing are available. The high cost of liquid nitrogen for the cryopreservation of semen often restricts AI use far from cities.

The lack of a system for the identification of superior animals limits, along with lack of technical capacity, the use of more advanced technologies, such as embryo transfer or marker-assisted selection (e.g. Nimbkar and Kandasamy, 2011). Molecular biotechnologies in the area of animal reproduction and breeding in developing countries have generally been limited to genetic characterisation studies, usually through international cooperation.

In animal nutrition, biotechnologies are often based on the use of micro-organisms, including those produced through genetic modification. Fermentation technologies are used to produce nutrients (such as particular essential amino acids or complete proteins) or to improve the digestibility of animal feeds. Although data are scarce, amino acids and enzymes appear to be the most prominent and widespread nutrition-related biotechnology products used in developing countries. For example, India and China have developed local industries to produce them. Microbial cultures are used to increase the quality of silage for animal feed or to improve digestion, when fed as probiotics or prebiotics. Probiotics are live micro-organisms which, when administered in adequate amounts, confer a health benefit on the host (Pineiro and Stanton, 2007). They are used in animal nutrition in a number of developing countries, mostly in monogastrics. Prebiotics are non-viable food components that confer a health benefit on the host associated with modulation of the microbiota (FAO, 2007) and they are expected to play an increasing role in animal nutrition in the future.

In animal health, molecular-based serological techniques are widely used in developing countries. PCR-based diagnostics are increasingly used to allow early diagnosis of diseases, although their use is mainly restricted to the laboratories of research institutions and larger governmental diagnostic laboratories. Vaccination has been widely used as a cost-effective measure to control infectious diseases, as exemplified by the case of rinderpest, an infectious viral disease of cattle, buffalo, yak and numerous wildlife species that has caused devastating effects throughout history. For example, in the 1890s, rinderpest destroyed nearly 90% of all cattle in sub-Saharan Africa and millions of wild animals. The progress towards eradication, through large-scale vaccination and surveillance campaigns, has been a remarkable triumph for veterinary science (Roeder, 2011). The last known outbreak was reported in Kenya in 2001, the last use of vaccine was recorded in 2006 and the disease is now officially declared to be eradicated (FAO, 2011c), which is only the second time that a disease has been eradicated worldwide, following smallpox in humans.

5.3. Fisheries and aquaculture

In 2007, more than 113 million tonnes of food fish were supplied by aquaculture and capture fisheries globally, providing an estimated 17 kg per capita. Aquaculture contributed nearly half (44%) of this total, and is the fastest growing food-producing sector in the world (FAO, 2011a). It is expected that, in the near future, aquaculture will produce more fish for direct human consumption than capture fisheries.

Aquaculture started primarily as an Asian freshwater food production system and has now spread to all continents, encompassing all aquatic environments and utilising a range of aquatic species. From an activity that was principally small-scale, non-commercial and family-based, it now includes large-scale commercial or industrial production of high value species that are traded at the national, regional and international levels.

Compared with livestock and crop production, aquaculture is a novel production system in many developing and developed countries, and it has made less use of conventional technologies, such as traditional genetic selection, and biotechnologies to increase production than these other sectors. Nevertheless, a number of biotechnologies have been used in aquaculture systems in developing countries. These include the manipulation of sex in fish using hormonal treatment to generate single sex populations, for example in tilapia (Cnaani and Levavi-Sivan, 2009). Hormonal treatment has also been used successfully to control the timing of reproduction in fish and shellfish, for example in salmon and trout farming in Chile.

Extensive research has also been carried out on other biotechnologies relevant to genetic improvement and reproduction, such as induction of triploidy to create sterile populations (e.g. Flajshans et al., 2010); use of androgenesis and gynogenesis to produce individuals with genetic material from a single parent; and use of molecular markers for parental analysis and genetic selection (e.g. Herlin et al., 2008). However, they have had little practical application so far in developing countries.

Disease outbreaks are a serious constraint to aquaculture development. Better management of intensive systems is needed, and biotechnologies are assisting in this task. Immunoassay and DNA-based diagnostic methods are currently applied for pathogen diagnosis in developing countries. For example, twenty years ago in the shrimp sector, which is the most valuable aquaculture commodity sector in the world, there was hardly any accurate molecular-based pathogen detection system available in any part of the world. Now, PCR detection of viruses of broodstock and post-larvae in both *Penaeus monodon* and *Penaeus vannameii* is practised in all countries producing commercial shrimp (FAO, 2011a).

Vaccines are used against diseases causing severe mortalities in cultured fish and shellfish. Biotechnology tools have been used widely in their development, where they have facilitated antigen discovery; construction of new candidate vaccines; and the assessment of vaccine efficacy, mode of action and host response (Kurath, 2008). As molecular-based vaccine production procedures rely heavily on biotechnological tools, vaccines are produced mainly in developed countries.

Reducing the environmental impacts of aquaculture is a significant task. Aquaculture is often accused of being unsustainable and not environmentally friendly. Reducing the impacts of effluent discharge, improving water quality and responsible use of water are key areas to be considered in aquaculture development. Some biotechnologies are being used to address these areas, including bioremediation for the degradation of hazardous wastes (Chávez-Crooker and Obreque-Contreras, 2010) and use of DNA-based methodologies for the early detection of toxin-producing algae.

In capture fisheries, the sustainable management and conservation of fisheries is a priority. Better understanding of the population structure of fisheries is therefore of paramount importance. The use of molecular markers and the principles of population genetics have proved very effective for assessing the actual levels of genetic variability within single populations and for measuring the extent of differentiation between populations. Some of the main ways in which molecular marker data have been applied for conservation decision-making in fish populations include characterising the genetic structure of the populations being harvested; detecting changes/falls in population size; and estimating the effective population size (Primmer, 2006).

5.4. Forests

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 31% of the world's land area (FAO, 2010b). 30% of the world's forests are primarily used for production of wood and non-wood products. Only 7% 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 industrial wood production is approaching 50% of the total. Close to 1.6 billion people rely on forest resources for their livelihoods and most of them (1.2 billion) use trees on farms to generate food and cash.

For 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, including 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 (e.g. Kindt et al., 2009; Muchugi et al., 2008).

For planted forests, although there is some overlap, the range of biotechnologies used is generally quite different from that used for naturally regenerated forests. Plantations can have different types of management systems (e.g. intensive and semi-intensive) and use different types of genetic material (e.g. wild material and genetically improved trees). Depending on the level of management intensity and the genetic material used in the planted forest, different groups of biotechnologies are being used, including tissue culture for micropropagation, biofertilisers, genetic fingerprinting, whole genome sequencing and genetic modification (FAO, 2011a).

5.5. Agro-industry

Agro-industries provide a means of converting raw agricultural materials into value added products while generating income and employment and contributing to overall economic development. Food processing converts relatively bulky, perishable and typically inedible raw materials into more useful, shelf-stable and palatable foods or potable beverages. Processing contributes to food security by minimising waste and loss in the food chain and by increasing food availability and marketability. Food is also processed to improve its quality and safety.

Biotechnology as applied to food processing uses fermentation and microbial inoculants to enhance properties such as the taste, aroma, shelf-life, texture and nutritional value of foods (e.g. FAO, 2011a; Liu et al., 2011). Traditional methods of genetic improvement such as classical mutagenesis and conjugation can be applied to improve the quality of microbial cultures. Hybridisation is also used for the improvement of yeast strains. Genetic modification is widely employed in R&D for strain improvement (e.g. Olempska-Beer et al., 2006). While these techniques are common in developed countries, they are only now beginning to be applied in developing countries for the improvement and development of starter cultures.

Biotechnology is widely employed as a tool in diagnostics to monitor food safety, prevent and diagnose food-borne illnesses and verify the origins of foods. Biotechnological developments have led to the widespread availability of methods of identification that are more rapid and less costly than those based on conventional techniques. PCR-based and enzyme-linked immunoabsorbent assay methods are now applied for the detection of major food-borne pathogens (Velusamya et al., 2010).

6. ABDC-10

To meet the tremendous challenge of achieving food security in the future, developing countries and the international community need to act on several fronts. One of these is to increase agricultural productivity, while conserving the natural resource base, using the tools of science and technology, including agricultural biotechnologies. To highlight this issue, FAO organised the international technical conference on Agricultural Biotechnologies in Developing Countries (ABDC-10) that took place in Guadalajara from 1 to 4 March 2010, hosted by the Government of 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.

Partnership has always been a central component of FAO's work and both the build-up and organisation of the conference were hallmarked by a highly participatory approach. A large international Steering Committee was established, chaired by Professor M.S. Swaminathan. The Committee included individuals invited in their personal capacity, selected on the basis of their scientific expertise in one or more areas of agricultural biotechnologies, as well as those representing relevant stakeholder groups, including intergovernmental organisations, civil society organisations and private sector organisations.

ABDC-10 was co-sponsored by the International Fund for Agricultural Development, while the CGIAR, the Global Forum on Agricultural Research, the International Centre for Genetic Engineering and Biotechnology and the World Bank were all major partners. In addition to plenary sessions, the conference programme included 27 parallel sessions which were sector-specific, regional or of cross-sectoral interest, most of which were organised by different intergovernmental and non-governmental organisations and regional fora.

The conference brought together about 300 policy-makers, scientists and representatives of intergovernmental and international non-governmental organisations, including delegations from 42 FAO Member States. At the end of the four days, the Member States reached a number of key conclusions,[1] i.e. they acknowledged that agricultural biotechnologies can help to alleviate hunger and poverty, assist in adaptation to climate change and maintain the natural resource base; that agricultural biotechnologies have not been widely used in many developing countries, and have not sufficiently benefited smallholder farmers and producers and consumers; and that more R&D should be focused on the needs of smallholder farmers and producers. They also acknowledged that governments need to develop their own national vision and policy for the role of biotechnologies; that effective communication and participation strategies with the public are necessary; and that stronger partnerships among and within countries will facilitate the development and use of biotechnologies.

The Member States also agreed that effective and enabling national biotechnology policies and regulatory frameworks can facilitate the development and use of appropriate biotechnologies in developing countries and that developing countries should significantly increase investments in capacity building and the development and use of biotechnologies to support, in particular, smallholders, producers and small biotechnology based enterprises.

Finally, the countries also agreed that FAO and other relevant international organisations 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. In this area, FAO already collaborates with a range of partners for capacity development of Member States in biotechnology and related issues through technical co-operation and training. This technical assistance is provided by FAO in three ways.

The first is provision of technical assistance directly to Member countries, where one of the main instruments is the Technical Cooperation Programme, launched in 1976 to enable FAO to respond rapidly to urgent needs for technical and emergency assistance in Member countries and to contribute to their capacity development. By the end of 2006, Technical Cooperation Programme projects on biotechnology and biosafety had been completed or were under implementation in several countries, including Argentina, Bangladesh, Benin, Bolivia, Grenada, Kenya, Malaysia, Nicaragua, Paraguay, Swaziland and Tanzania. The second is provision of support for the establishment of biotechnology networks or acting as a catalyst for their establishment in different parts of the world. The third is through partnerships with international agricultural research centres and other institutions, where FAO has provided extensive technical assistance in co-operation with research centres supported by the CGIAR and/or with national agricultural research systems.

Following ABDC-10, FAO stands ready to work with its UN and non-UN partners to greatly step up these efforts to assist its Member States, on their request, to ensure that they can strengthen their capacities to develop and use pro-poor agricultural biotechnologies for the benefit of the food insecure in their countries.

[1] Paragraphs 37–38 of the ABDC-10 report, available at http://www.fao.org/biotech/abdc/.

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