CHAPTER 6

LEARNING FROM THE PAST: SUCCESSES AND FAILURES WITH AGRICULTURAL BIOTECHNOLOGIES IN DEVELOPING COUNTRIES OVER THE LAST 20 YEARS – AN E-MAIL CONFERENCE

6.1 INTRODUCTION

The FAO Biotechnology Forum is an e-mail-based mechanism which was launched in 2000 with the aim of providing access to quality balanced information and to make a neutral platform available for all interested stakeholders to openly exchange views and experiences on agricultural biotechnology in developing countries. It covers applications in the crop, forestry, livestock, fisheries and agro-industry sectors. The Forum covers the broad range of tools included under the general term "biotechnology". Some of these technologies, such as the use of molecular markers or genetic modification, may be applied to all food and agricultural sectors, while others are more sector-specific, such as tissue culture (in crops and forest trees), embryo transfer (livestock) or sex-reversal (fish).

Each conference takes one particular theme that is relevant to agricultural biotechnology in developing countries and opens it up for debate for a limited amount of time. From 2000 to 2008 the Forum hosted 15 moderated e-mail conferences, with messages coming roughly equally from participants living in developing and developed countries.

For each conference, two key documents are produced. Firstly, before the conference takes place, a Background document is prepared to give a good overview of the conference theme, in a balanced neutral way, and written in easily-understandable language so that people with little knowledge of the area may understand what the theme is about. The document also highlights any particular issues of special relevance to developing countries.

Secondly, after the conference, a Summary document is prepared to provide an overview of the main issues that were discussed based on the messages posted by the participants.

This Chapter presents these two documents from conference 16 of the Forum, entitled "Learning from the Past: Successes and Failures with Agricultural Biotechnologies in Developing Countries Over the Last 20 Years ", that took place from 8 June to 8 July 2009 as part of the build up to ABDC-10. As for other conferences of the Forum, it was moderated by John Ruane from the FAO Working Group on Biotechnology.

For ABDC-10, FAO prepared five sector-specific technical documents on biotechnology applications in crops, forestry, livestock, fisheries and aquaculture, and in food processing and food safety (presented in Chapters 1 to 5 respectively of these proceedings). Their aim was to document the current status of application of biotechnologies in developing countries in the relevant sector, provide an analysis of the reasons for successes/failures in the application of biotechnologies in developing countries, present some relevant case studies, and provide options for the future. To complement these documents, the Forum hosted this cross-sectoral e-mail conference to bring together and discuss relevant, often undocumented, past experiences of applying biotechnologies in developing countries, ascertain the success or failure (partial or full) of these experiences, and determine and evaluate the key factors that were responsible for their success or failure. The sector-specific documents were in draft form when the Background document was being prepared; it therefore benefited from the information already available in these drafts. The Background document is presented in Part 6.2. In turn, the drafts also benefited from the discussions and case studies that emerged from the e-mail conference. The Summary document is presented in Part 6.3.

6.2 BACKGROUND TO THE ISSUES

In this e-mail conference, as well as in the context of ABDC-10, the term "agricultural biotechnology" encompasses a variety of technologies used in food and agriculture for a range of different purposes such as the genetic improvement of plant varieties and animal populations to increase their yields or efficiency; genetic characterization and the conservation of genetic resources; plant or animal disease diagnosis; vaccine development; and the improvement of feeds. Note, the term "agriculture" here includes the crop, livestock, fisheries and aquaculture, forestry and food processing sectors, and so the term "agricultural biotechnologies" encompasses their use in any of these sectors.

This Background document aims to provide information that participants will find useful for the e-mail conference. In Part 6.2.1 an overview is provided of the different agricultural biotechnologies to be considered, while Part 6.2.2 presents some specific guidance about the e-mail conference.

6.2.1 Overview of agricultural biotechnologies in developing countries

A short overview is provided below of the main kinds of agricultural biotechnologies that have been used in developing countries over the past 20 years and that should be covered in the e-mail conference. They are described separately, although in practice more than one may be used in certain situations (e.g. in wide crossing programmes, see later). Note, new biotechnologies that are still at the research level, be it in the laboratory or at the field trial stage, but have not yet been applied (i.e. used for commercial production by farmers) in developing countries are not included.

This overview also indicates what the biotechnologies are used for, the food and agricultural sectors involved, and gives some examples of their applications in specific developing countries. Regarding the examples, their inclusion in the document does not imply that these applications have been a partial or complete success (or, conversely, that they have been any kind of a failure). Indeed, these are the kind of issues to be addressed by participants during this e-mail conference. Although not the subject of this conference, it should also be kept in mind that the path from research, for example in the laboratory, to the eventual application of a product in the field (e.g. farmers cultivating a new genetically improved plant variety or using a new vaccine against an animal disease) can be long, resource-demanding and unsuccessful. Many biotechnologies of seemingly high promise at the experimental stage have had limited applications in developing countries so far.

As many of the biotechnologies described below are related to molecular biology and genetic material, some basic terminology is introduced here. Living things are made up of cells that are programmed by genetic material called deoxyribonucleic acid (DNA). A DNA molecule is made up of a long chain of nitrogen-containing bases. Only a small fraction of this DNA sequence typically makes up genes, i.e. that code for proteins, which are molecules essential for the functioning of living cells, made up of chains of amino acids. The remaining and major share of the DNA represents non-coding sequences whose role is not yet clearly understood. The genetic material is organized into sets of chromosomes (e.g. five pairs in *Arabidopsis thaliana* – a model plant species; 30 pairs in cattle), and the entire set is called the genome. In a diploid individual (i.e. where chromosomes are organized in pairs), there are two alleles of every gene – one from each parent – transmitted by gametes (reproductive cells) that are normally haploid (having just one of each of the pairs of chromosomes). A typical genome contains several thousand genes, e.g. about 30 000 genes in grasses like rice and sorghum (Paterson *et al.*, 2009). Definitions of technical terms used below can be found in FAO (2001).

6.2.1.1 Molecular markers

Molecular markers are identifiable DNA sequences found at specific locations of the genome and transmitted by standard Mendelian laws of inheritance from one generation to the next. They rely on a DNA assay, and a range of different kinds of molecular marker

systems exist such as restriction fragment length polymorphisms (RFLPs), random amplified polymorphic DNAs (RAPDs), amplified fragment length polymorphisms (AFLPs) and microsatellites. The technology has improved in the past decade and faster, cheaper systems like single nucleotide polymorphisms (SNPs) are increasingly being used. The different marker systems may vary in aspects such as their technical requirements, the amount of time, money and labour needed and the number of genetic markers that can be detected throughout the genome.

Molecular markers have been used in laboratories since the late 1970s and are applied across all the food and agricultural sectors. They are very versatile and can be used for a variety of purposes. Thus, they are used in genetic improvement through so-called marker-assisted selection (MAS), where markers physically located beside (or even within) genes of interest (such as those affecting yield in maize) are used to select favourable variants of the genes (FAO, 2007a). MAS is made possible by the development of molecular marker maps, where many markers of known location are interspersed at relatively short intervals throughout the genome, and the subsequent testing for statistical associations between marker variants and the traits of interest. Marker maps are now available for a wide range of economically important agricultural species (see e.g. FAO, 2007a for details). Progress in the field of genomics (the study of an organism's entire genome) has also provided much useful information for MAS, enabling in some cases markers to be used that are located within the genes of interest.

Molecular markers are also used to characterize and conserve genetic resources where some of the approaches can be applied in each of the crop, forestry, livestock and fishery sectors (e.g. estimating the genetic relationships between populations within a species). Other uses are more sector-specific, such as their utilization to identify duplicate accessions in crop genebanks, monitor effective population sizes (N_e) in capture fish populations or carry out biological studies (e.g. of mating systems, pollen movement and seed dispersal) in forest tree populations (FAO, 2006a). They are also used in disease diagnosis to characterize and detect pathogens in livestock, crops, forest trees, fish and food (see later).

Molecular markers have been used in a number of developing countries. In livestock, for example, they have been used in four African countries for characterizing genetic resources and in eight Asian countries where six used them for genetic distance studies and two for MAS (FAO, 2007b). In Latin America and the Caribbean, most countries have used molecular techniques primarily for characterization purposes, while their use has been limited in the Near and Middle East (FAO, 2007b). In crops, several examples of new hybrids and varieties developed through MAS are available, and in progress, in different crops such as pearl millet, rice and maize, and in several developing countries such as Bangladesh, India and Thailand (Varshney, Hoisington and Tyagi, 2006). Different centres of the Consultative Group on International Agricultural Research (CGIAR) have been working with partners in developing countries to accelerate plant breeding practices through MAS.

6.2.1.2 Genetic modification

A genetically modified organism (GMO) is an organism in which one or more genes (called transgenes) have been introduced into its genetic material from another organism. The genes may be from a different kingdom (e.g. a bacterial gene introduced into plant genetic material), a different species within the same kingdom or even from the same species. For example, so-called "Bt crops" are crops containing genes derived from the soil bacterium *Bacillus thuriengensis* coding for proteins that are toxic to insect pests that feed on the crops. The issue of GMOs has been highly controversial over the past decade. Many countries have introduced specific frameworks to regulate their development, release and commercialization.

GM crops were first grown commercially in the mid 1990s. While the majority continues to be grown in developed countries, an increasing number of developing countries are reported to be cultivating them. Recent estimates (James, 2008) indicate that 10 developing countries planted over 50 000 hectares (ha) of GM crops in 2008: Argentina (21.0 million ha), Brazil (15.8), India (7.6), China (3.8), Paraguay (2.7), South Africa (1.8), Uruguay (0.7), Bolivia (0.6), Philippines (0.4) and Mexico (0.1). For comparison, in 1997 the only developing countries reported were Argentina (1.4 million ha), China (1.8) and Mexico (less than 0.1). Almost all GM crops grown commercially are genetically modified for one or both of two main traits: herbicide tolerance (63 percent of GM crops planted in 2008) or insect resistance (15 percent), i.e. Bt crops, while 22 percent have both traits (James, 2008).

The commercial release of GM forest trees has been reported in one country, China. In 2002, approval was granted for the environmental release of two kinds of Bt trees, the European black poplar (*Populus nigra*) and the hybrid white poplar clone GM 741, together representing about 1.4 million plants on 300–500 ha (FAO, 2004). Regarding GM livestock or fish, there has been no reported commercial release for food and agricultural purposes in any country.

Although documentation is generally quite poor, the use of GM micro-organisms (GMMs) in agro-industry and for animal feeds is routine in developed countries and is also a reality in many developing countries. In agro-industry, the use of enzymes (proteins that catalyze specific chemical reactions) is important. Many of the enzymes used in the food industry are commonly produced using GMMs. For example, since the early 1990s, preparations containing chymosin (an enzyme used to curdle milk in the preliminary steps of cheese manufacture) derived from GM bacteria have been available commercially (FAO, 2006b). Similarly, many colours, vitamins and essential amino acids used in the food industry are also from GMMs.

In animal nutrition, feed additives such as amino acids and enzymes are widely used in developing countries. The greatest use is in pig and poultry production where intensification has increased over the last decade, further accelerating the demand for feed additives. For example, most grain-based livestock feeds are deficient in essential amino acids such as lysine, methionine and tryptophan. For high-producing monogastric animals (pigs and

poultry) these amino acids are added to diets to increase productivity. The amino acids in feed, L-lysine, DL-methionine, L-threonine and L-tryptophan, constitute over half of the total amino acid market. The essential amino acids are produced in some cases by GM strains of *Escherichia coli* (Chapter 3).

In the dairy industry, recombinant bovine somatotropin (rBST), a protein hormone from an *Escherichia coli* K-12 bacterium containing the bovine somatotropin gene, has been used to increase milk production in a number of developing countries. Chauvet and Ochoa (1996) report that rBST was first used in Mexico in 1990 and has been sold in a number of other developing countries, including Brazil, Malaysia, South Africa and Zimbabwe.

6.2.1.3 Chromosome set manipulation

As mentioned earlier, genetic material is organized into sets of chromosomes and each plant and animal species has a characteristic number of chromosomes. Manipulation of whole sets of chromosomes is possible and is used for a range of different purposes in agriculture. For example, fish and shellfish have been extensively studied in relation to the manipulation of their chromosomes during the early stages of development. Using relatively simple techniques such as cold and heat shocks it is possible to produce triploid individuals (i.e. with three sets of chromosomes), leading to the production of almost completely sterile populations. Sterility may be desirable in conservation programmes where it can prevent the introgression of escaped individuals from commercial stocks into natural populations. It may also be of interest in commercial fish operations, e.g. when developing hybrid stocks or to prevent the side-effects of sexual maturation on carcass quality (Chapter 4). As in fish, induction of sterility in crops may be desirable in certain breeding programmes, e.g. to produce seedless fruits, and one of the most rapid and cost-effective approaches is to create polyploids (i.e. with more than two complete sets of chromosomes), especially triploids. Triploid varieties have been produced in numerous fruit crops including most of the citrus fruits, acacias and the kiwifruit (Chapter 1).

Another example of chromosomal set manipulation in fish is the production of haploid individuals after eggs are fertilized by sperm that do not contribute genetic material (a process called gynogenesis) or else when normal sperm fertilize eggs whose DNA has been deactivated (a process called androgenesis). In both cases the haploid chromosomes can then be duplicated using shocks. The importance of gynogenesis/androgenesis is that it is possible to develop inbred individuals, which may be useful in fish breeding experiments aimed at producing clonal lines for detecting genomic regions affecting quantitative traits (Chapter 4).

In crops, chromosome doubling is one of the most important technologies for the creation of fertile inter-specific hybrids (wide crosses). Wide crossing involves hybridizing a crop variety with a distantly related plant from outside its normal sexually compatible gene pool.

Its usual purpose is to obtain a plant that is virtually identical to the original crop except for a few genes contributed by the distant relative. The technique has enabled breeders to access genetic variation beyond the normal reproductive barriers of their crops (Chapter 1). For example, the New Rice for Africa (NERICA) hybrids are derived from crossing two species of cultivated rice, the African rice and the Asian rice, combining the high yields from the Asian rice with the ability of the African rice to thrive in harsh environments.

Wide-hybrid plants are often sterile so their seed cannot be propagated due to differences between the sets of chromosomes inherited from genetically divergent parental species that prevent stable chromosome pairing during meiosis. However, if the chromosome number is artificially doubled, the hybrid may be able to produce functional pollen and eggs and be fertile. Colchicine has been used for chromosome doubling in plants since the 1940s and has been applied to more than 50 plant species including most important annual crops. More recently, several additional chromosome doubling agents, all of which act as inhibitors of mitotic cell division, have been used in plant breeding programmes. To date, with the help of chromosome doubling technology hundreds of new varieties have been produced worldwide.

In crops and forest trees, chromosome doubling has also been used, as for fish, to generate "doubled haploids". The haploid plants can be produced using anther culture which involves the *in vitro* culture of immature anthers (i.e. the pollen-producing organs of the plant). As the pollen grains are haploid, the resulting pollen-derived plants are also haploid (FAO, 2009a). Doubled haploid plants were first produced in the 1960s using colchicine and today, thermal shock or mannitol incubation can be used. They may also be produced from ovule culture. Breeders value doubled haploid plants because they are 100 percent homozygous, so any recessive genes are readily apparent. The time required after a conventional hybridization to select pure lines carrying the required recombination of characters is thus drastically reduced. Since the 1970s, doubled haploid methods have been used to create new varieties of barley, wheat, rice, melon, pepper, tobacco and several Brassicas. In the developing world, a major centre of such breeding work is China where numerous doubled haploid crops have been released and many more are being developed. By 2003, China was cultivating over two million ha of doubled haploid varieties, the most important being rice, wheat, tobacco and peppers (Chapter 1).

6.2.1.4 Biotechnology-based diagnostics

Applications of biotechnology for diagnostic purposes are important in crops, forest trees, livestock and fish as well as for food safety purposes. Two main kinds of methods are used: those based on the enzyme-linked immunosorbent assay (ELISA) and those based on the polymerase chain reaction (PCR).

ELISA systems are antibody-based techniques to determine the presence and quantity of specific molecules in a mixed sample. They are used in a range of formats, both for the detection of pathogens and for the detection of antibodies produced by the host as a response to the pathogens, and a range of commercial kits are available, e.g. to detect fish and shrimp pathogens (Adams and Thompson, 2008). Some of the ELISA-based methods use monoclonal antibodies, produced by a cell line that is both immortal and able to produce highly specific antibodies, or polyclonal antibodies, produced by many cell lines. In livestock, ELISAs form the large majority of prescribed tests for OIE-notifiable animal diseases, and many diagnostic kits are available in developing countries (Chapter 3).

The PCR-based methods rely on the fact that each species of pathogen carries a unique DNA or ribonucleic acid (RNA) sequence that can be used to identify it. PCR allows the production of a large quantity of a desired DNA from a complex mixture of heterogeneous sequences. It can amplify a selected region of 50 to several thousand DNA base pairs into billions of copies. After amplification, the target DNA can be identified using techniques such as gel electrophoresis or hybridization with a labelled nucleic acid (a probe). Real-time PCR (or quantitative PCR) enables the quantification of DNA or RNA present in a sample. The genomes of certain viruses, such as the influenza A virus, are made of RNA instead of DNA. To identify RNA from these viruses, a complementary DNA (cDNA) copy of the RNA is first synthesized using an enzyme called reverse transcriptase. The cDNA then acts as the template to be amplified by PCR. This method is called reverse transcriptase PCR (RT-PCR).

PCR-based techniques offer high sensitivity and specificity, and diagnostic kits allow the rapid screening of viruses or bacteria and have a direct use in situations where individuals show no antibody response after infection. For example, molluscs do not produce antibodies, and therefore antibody-based diagnostic tests are limited in their application to pathogen detection in these species. In fisheries, PCR-related tools are increasingly being used in developing countries, although they require detailed knowledge of the genomics of the pathogen itself and extensive validation in practice (Chapter 4).

In livestock, public sector production of diagnostic kits for animal diseases in Asia and Latin America can be found in Brazil, Chile, China, India, Mexico and Thailand. Research capabilities for development, standardization and validation of diagnostic methods are also well advanced in these countries. PCR-based diagnostics are increasingly being employed in developing countries to back up findings from serological analyses. However, their use is largely restricted to laboratories of research institutions and universities and to central and regional diagnostic laboratories run by governments (Chapter 3). In aquaculture, there are some highly integrated companies

operating in developing countries (e.g. in shrimp production) and these companies commonly use PCR-based diagnostic systems where the analyses are either carried out by the laboratories of the companies themselves or are outsourced to specialized private laboratories.

Biotechnology-based diagnostics are also important in food analysis. Many of the classical food microbiological methods used in the past were culture-based, with micro-organisms grown on agar plates and detected through biochemical identification. These methods are often tedious, labour-intensive and slow. Genetic-based diagnostic and identification systems can greatly enhance the specificity, sensitivity and speed of microbial testing. Molecular typing methodologies, commonly involving PCR, ribotyping (a method to determine homologies and differences between bacteria at the species or subspecies/strain level using RFLP analysis of ribosomal RNA genes) and pulsed-field gel electrophoresis (a method of separating large DNA molecules on agarose gels), can be used to characterize and monitor the presence of spoilage flora (microbes causing food to become unfit for eating), normal flora and microflora in foods (FAO, 2006b). RAPD or AFLP molecular marker systems can also be used for comparing genetic differences among species, subspecies and strains depending on the reaction conditions used. The use of combinations of these technologies and other genetic tests allows the characterization and identification of organisms at the genus, species, subspecies and even strain levels, thereby making it possible to pinpoint sources of food contamination, trace micro-organisms throughout the food chain or identify the causal agents of food-borne illnesses (FAO, 2006b).

6.2.1.5 Vaccines developed using biotechnology

Immunization can be one of the most effective means of preventing and hence managing animal diseases. In general, vaccines offer considerable benefits for comparative low cost, a primary consideration for developing countries. In addition, the development of good vaccines for important infectious diseases can lead to reduced use of antibiotics, which is an important issue in developing countries.

As described by Kurath (2008), biotechnology has been used extensively in the development of vaccines for aquaculture, and is applied at each of the three main stages of vaccine development, as follows:

a) the identification of potential antigen candidates that might be effective in vaccines (where an antigen is a molecule, usually a protein foreign to the fish, which elicits an immune response on first exposure to the immune system by stimulating the production of antibodies specific to its various antigenic determinants. During subsequent exposures, the antigen is bound and inactivated by these antibodies);

b) the construction of a new candidate vaccine (where biotechnology tools can be used to produce different kinds of vaccines such as DNA vaccines, recombinant vaccines or modified live recombinant viruses. For example, a DNA vaccine is a circular DNA plasmid containing a gene for a protective antigenic protein from a pathogen of interest);
c) the assessment of candidate vaccine efficacy, its mode of action and the host response (where e.g. quantitative RT-PCR [see earlier] can be used to examine the expression of fish genes related to immune responses).

Of the countries that responded to a recent World Organisation for Animal Health (OIE) survey, four out of 23 and seven out of 14 African and Asian countries respectively indicated that they produce or use animal vaccines derived from biotechnology, including experimental use as well as commercial release (MacKenzie, 2005).

6.2.1.6 Reproductive biotechnologies (livestock and fish)

A number of reproductive biotechnologies have been applied in developing countries to influence the number (and sex) of offspring from given individuals in fish and livestock populations.

Artificial insemination

In artificial insemination (AI), semen is collected from donor male animals, diluted in suitable diluents and manually inseminated into the female reproductive tract during oestrus (heat), to achieve pregnancy. The semen can be fresh or preserved in liquid nitrogen and then thawed. The efficiency of AI can be increased by monitoring progesterone levels, e.g. using ELISA, to identify non-pregnant females, and/or by oestrus synchronization where females are treated with hormones to bring them into oestrus at the desired time.

AI is widely used in developing countries (Chupin, 1992; FAO, 2007b). For example, in India 34 million inseminations were carried out in 2007 while about eight million were carried out in Brazil (Chapter 3). For Africa, Asia and Latin America and the Caribbean regions, AI is mostly used for cattle production (dairy). Other species for which AI is used in all three continents are sheep, goats, horses and pigs. In addition, in Asia, AI is used for chickens, camels, buffaloes and ducks, and in Latin America and Caribbean regions for rabbits, buffaloes, donkeys, alpacas and turkeys. For the most part, semen from exotic breeds is used in local livestock populations. To a lesser extent, semen from local breeds is also used for this purpose. Most AI services are provided by the public sector but the contribution of the private sector, breeding organizations and NGOs is also substantial. In Africa and Asia, AI use is concentrated in peri-urban areas (FAO, 2007b). Progesterone monitoring and oestrous synchronization have been applied in a number of developing countries. Applications of oestrous synchronization have been limited to some intensively managed farms where AI is routinely used.

Embryo transfer

Embryo transfer (ET) involves the transfer of an embryo from a superior donor female to a less valuable female animal. A donor is induced to superovulate (produce several ova) through hormonal treatment. The ova obtained are then fertilized within the donor, the embryos are allowed to develop and then removed and implanted in recipient females for the remainder of the gestation period. Alternatively, the embryos can be frozen for later use.

FAO (2007b) reports that five, eight and twelve countries respectively in Africa, Asia and the Latin America and the Caribbean regions provided information on use of ET in their countries. In Latin America and the Caribbean, ET is increasingly used by commercial livestock producers and the species involved are cattle (in all twelve countries) and alpacas, donkeys, goats, horses, llamas and sheep (in one to three of the twelve countries). In Brazil and Chile, private sector organizations are involved in providing the technology.

Hormonal treatment in aquaculture

In the same way as female reproduction in livestock can be controlled by hormonal treatment, it is also an important tool in aquaculture where it is applied for two main purposes. The first is to control reproduction of fish and shellfish, primarily to induce the final phase of ova production in order to synchronize ovulation and to enable broodstock to produce fish early in the season or when environmental conditions suppress the spawning timing of females. The second is to develop monosex (single sex) populations, which can be desirable in many situations. This can be, *inter alia*, because one sex is superior in growth or has more desirable meat quality or to prevent sexual/territorial behaviour. For example, female sturgeons are more valuable than males because they produce caviar. Female salmon are more valuable because sexually precocious males die before they can be harvested, and salmon roe has an economic value. Male tilapia are more desirable than females because they grow twice as fast. In many fish and shellfish species, sex is not permanently defined genetically and can thus be altered in a number of ways, including through treatment with sexual hormones such as testosterone or estrogen derivatives in early stages of development. To develop all-male tilapia populations, methyltestosterone can be used, while monosex trout can be produced using androgens (Chapter 4).

Sperm/embryo sexing

In livestock, to obtain offspring of a desired sex (e.g. females are preferred for dairy animals, males for beef animals), the separation of X and Y sperm (e.g. based on staining DNA with a fluorescent dye) for AI and sexing of embryos (e.g. using specific DNA probes) can be used. These technologies are being developed and refined in a number of research institutions, but are not widely used by farmers or breeders in developing countries.

6.2.1.7 Cryopreservation

Cryopreservation – the preservation of germplasm in a dormant state by storage at ultra-low temperatures, usually in liquid nitrogen (-196 °C) – can be used to preserve biological material (e.g. seeds, sperm, embryos) of crop, livestock, forest or fish populations for potential use in the future (FAO, 2006a). The technology can be used for genetic improvement purposes and for the management of genetic resources. In livestock, cryopreservation is used in many developing countries and well-established genebanks exist in India and are being established in China and Vietnam (Chapter 3). In fish, the cryopreservation of embryos is not possible but sperm cryopreservation works for many species (FAO, 2006c) and has been used in carp, salmon and trout breeding, especially when the aim has been to "refresh" populations that have gone through a bottleneck.

Considering crops and forest trees, about 90 percent of the six million plant accessions in genebanks, mainly crops, are stored in seed genebanks. However, storage of seeds is not an option for crops or trees that do not produce seed such as banana, or that produce recalcitrant or non-orthodox seed (i.e. seed that does not survive under cold storage and/or the drying conditions used in conventional *ex situ* conservation) such as mango, coffee, oak and several tropical forest tree species. In these situations, as well as for long-term storage of seeds from orthodox species, cryopreservation offers an alternative strategy for *ex situ* conservation, although its routine use is still limited. Plants can be regenerated after plant cell, tissue or organ storage at low temperatures. For various herbaceous (i.e. non-woody plants), hardwood (i.e. broadleaf, deciduous trees) and softwood species (i.e. coniferous trees), cryopreservation of a wide range of tissues and organs has been achieved. There is large-scale application of shoot tip cryopreservation in fruit crop germplasm collections such as plum and apple. Seeds of most common agricultural and horticultural species can be cryopreserved (FAO, 2006a and 2006d).

6.2.1.8 Tissue culture-based techniques

Tissue culture refers to the *in vitro* culture of plant cells, tissues or organs in a nutrient medium under sterile conditions. It has been widely used for over 50 years and is now employed to improve many of the most important developing country crops (Chapter 1). There are a number of tissue culture-based technologies and they can be employed for a range of different purposes. Some of them, used with chromosome set manipulation, have been described earlier. Others include:

Micropropagation

Micropropagation is the laboratory practice of rapidly multiplying stock plant material to produce a large number of progeny plants using plant tissue culture methods. For instance, the shoot tips of banana or potato are excised from healthy plants and cultivated

on gelatinized nutrient media in sterile conditions (in test tubes, plastic flasks, or baby-food jars), so that contamination with pests and pathogens is avoided. The plantlets obtained can be multiplied an unlimited number of times by cutting them into single-node pieces and cultivating the cuttings in similar aseptic conditions. Millions of plantlets can be produced in this manner in a very short time. The plantlets are then transplanted in the field or nurseries where they grow and yield low-cost, disease-free propagation materials ready to be distributed to farmers (FAO, 2009a). Even if healthy plants are not available initially, specific *in vitro* techniques can also be applied to produce disease-free propagation material.

Today, micropropagation is widely used for a range of developing country subsistence crops including banana, cassava, potato and sweetpotato; for commercial plantation crops, such as oil palm, coffee, cocoa, sugarcane and tea; for niche crops such as cardamom and vanilla; and for fruit trees such as almond, citrus, coconut, mango and pineapple. Some of the many countries with significant crop micropropagation programmes include Argentina, Cuba, Gabon, India, Indonesia, Kenya, Nigeria, Philippines, South Africa, Uganda and Vietnam (Chapter 1).

In vitro slow growth storage

Micropropagation procedures have been developed for over 1 000 plant species, many of which are today micropropagated commercially. The procedures include rapid multiplication, involving rapid growth and frequent subculture (regeneration) which is generally the objective of commercial micropropagation. Instead, the basis of successful *in vitro* storage of stock cultures is to increase the interval between subcultures by retarding the growth without any deleterious effects on the plants in culture. The strategy is used to conserve plant genetic resources, and *in vitro* slow growth procedures can be used so that plant material can be held for 1–15 years under tissue culture conditions with periodic subculturing, depending on the species. Normally, growth is limited using low temperatures often in combination with low light intensity or even darkness. Temperatures in the range of 0–5 °C are employed for cold-tolerant species and 15–20 °C for tropical species. Growth can also be limited by modifying the culture medium and reducing oxygen levels available to the cultures (Rao, 2004; FAO, 2006a).

In vitro embryo rescue

Wide crossing (see Part 6.2.1.3) has become possible only by advances in plant tissue culture. A particular challenge was to overcome the biological mechanisms that normally prevent inter-specific and inter-genus crosses, as a high proportion of wide-hybrid seeds either do not develop to maturity or do not contain a viable embryo. To avoid spontaneous abortion,

embryos are removed from the ovule at the earliest possible stage and placed into culture *in vitro.* Mortality rates can be high, but enough embryos normally survive the rigours of removal, transfer, tissue culture, and regeneration to produce adult hybrid plants for testing and further crossing (Chapter 1).

First generation, wide-hybrid plants are rarely suitable for cultivation because they have only received half of their genes from the crop parent. From the other (non-crop) parent they have received both the small number of desirable genes and also thousands of undesirable genes that must be removed by further manipulation. This is achieved by crossing the hybrid with the original crop plant, plus another round of embryo rescue to grow up the new hybrids. This "backcrossing" process is repeated for about six generations (sometimes more), until a plant is obtained that is almost identical to the original crop parent except that it now contains a small number of desirable genes from the non-crop parent plant. Wide crossing programmes can take more than a decade to complete, although MAS and anther culture can be used to speed up the process (Chapter 1).

6.2.1.9 Mutagenesis

This involves the use of mutagenic agents such as chemicals or radiation to modify DNA and hence create novel phenotypes. Induced mutagenesis has been used in crop breeding programmes in developing countries since the 1930s. It also includes somaclonal mutagenesis, involving changes in DNA induced during *in vitro* culture. Somaclonal variation is normally regarded as an undesirable by-product of the stresses imposed on a plant by subjecting it to tissue culture. However, provided they are carefully controlled, somaclonal changes in cultured plant cells can generate variation that is useful to crop breeders (Chapter 1).

Almost 3 000 new crop varieties have been developed and released by countries using mutation-assisted plant breeding strategies and an estimated 100 countries currently use induced mutation technology (FAO/IAEA, 2008; IAEA, 2008). Case studies from Kenya (wheat), Peru (barley), sub-Saharan Africa (cassava) and Vietnam (rice) are described in IAEA (2008).

In the livestock sector, mutagenesis has also been used in developing countries**.** The sterile insect technique (SIT) for control of insects (e.g. screwworm and tsetse flies) relies on the introduction of sterility in the females of the wild population. The sterility is produced following the mating of females with released males carrying in their sperm dominant lethal mutations that have been induced by ionizing radiation. This method is usually applied as part of an area-wide integrated pest management (AW-IPM) approach and has been applied in developing countries in the livestock sector as well as for the control of crop pests. An estimated 30 countries use the SIT against insect pests, including Chile and Peru (FAO/IAEA, 2008).

Mutagenesis is also extensively used to improve the quality of micro-organisms and their enzymes or metabolites used in food processing. The process involves the production of mutants through the exposure of microbial strains to mutagenic chemicals or ultraviolet rays. Improved strains thus produced are selected on the basis of specific properties such as improved flavour-producing ability or resistance to bacterial viruses (Chapter 5).

6.2.1.10 Fermentation

Fermentation is the process of bioconversion of organic substances by micro-organisms and/or enzymes of microbial, plant or animal origin. During fermentation, various biochemical activities take place leading to the breakdown of complex substances into simple substances and resulting in the production of a diversity of metabolites including simpler forms of proteins, carbohydrates, fats, such as sugars, amino acids, lipids, as well as new compounds such as antimicrobial compounds (e.g. lysozyme, bactericins); organic acids (e.g. lactic acid, acetic acid, citric acid); texture-forming agents (e.g. xanthan gum); and flavours (esters and aldehydes). Apart from the various new products that are yielded during fermentation, the process is widely known for its preservative benefits (FAO, 2006b).

The new products that emerge following fermentation have been found to have potential for longer shelf-lives, and they have characteristics quite different from the original substrates from which they are formed. Fermentation is globally applied to preserve a wide range of raw agricultural materials (cereals, roots, tubers, fruit and vegetables, milk, meat and fish, etc.). Commercially produced fermented foods which are marketed globally include dairy products (cheese, yogurt, fermented milks), sausages and soy sauce (FAO, 2006b). Fermentation of sugars is also central to the production of bioethanol from agricultural feedstocks (FAO, 2008a).

Certain micro-organisms associated with fermented foods, in particular strains of the *Lactobacillus* species, are probiotic i.e. used as live microbial dietary supplements or food ingredients that have a beneficial effect on the host by influencing the composition and/or metabolic activity of the flora of the gastrointestinal tract (FAO, 2006b). They can also be used as feed additives for monogastric and ruminant animals, and have been applied for this purpose in China, India and Indonesia (Chapter 3).

In developing countries, fermented foods are produced generally at the household and village level using traditional processes that are uncontrolled and dependent on spontaneous "chance" micro-organisms from the environment. Modern fermentation processes employ the use of well-constructed vessels (fermenters/bioreactors), with appropriate mechanisms for controlling temperature, pH, nutrient levels, oxygen tension, among others, and also use selected micro-organisms and/or enzymes for their operations (FAO, 2006b; Chapter 5).

6.2.1.11 Biofertilizers

Soils are dynamic living systems that contain a variety of micro-organisms such as bacteria, fungi and algae. Maintaining a favourable population of useful microflora is important from a fertility standpoint. The most commonly exploited micro-organisms are those that help in fixing atmospheric nitrogen for plant uptake or in solubilizing/mobilizing soil nutrients such as unavailable phosphorus into plant-available forms, in addition to secreting growth-promoting substances for enhancing crop yield. As a group, such microbes are called biofertilizers or microbial inoculants. They can be generally defined as preparations containing live or latent cells of efficient strains of nitrogen-fixing, phosphate-solubilizing or cellulolytic micro-organisms that are applied to seed or soil with the objective of increasing the numbers of such micro-organisms and accelerating certain microbial processes to augment the availability of nutrients in a form that plants can assimilate readily (FAO, 2008b). Biofertilizers are used in a number of developing countries such as Kenya and Thailand, often involving nitrogen-fixing *Rhizobia* bacteria (FAO, 2009a).

6.2.1.12 Biopesticides

Living organisms that are harmful to plants and cause biotic stresses are collectively called pests, and they cause tremendous economic damage to plant production worldwide. Biopesticides are mass-produced, biologically-based agents used for the control of plant pests. They can be living organisms such as micro-organisms or naturally occurring substances such as plant extracts or insect pheromones. Micro-organisms used as biopesticides include bacteria, protozoa, fungi and viruses and they are used in a range of different crops (Chandler *et al.*, 2008).

For example, different biopesticides are available for controlling locusts. In one example of their application, a biopesticide containing spores of the fungus *Metarhizium anisopliae* was used to control a migratory locust infestation in 2007 in Timor-Leste, supported by FAO. Surveys revealed that an area of about 20 000 ha was infested with gregarious nymphs and that there was a serious threat to the rice crop. The target area was considered unsuitable for chemical spraying because of high density human settlement and many water courses. The infestation was therefore treated with the biopesticide which was targeted at flying swarms using a helicopter, with spraying in a time period of over one month (FAO, 2009b). Note that since biopesticides generally have a slower action than conventional chemicals, the latter are preferred if crops are under immediate threat.

6.2.2 Specific points about this e-mail conference

The general aim of the e-mail conference is to bring together and discuss relevant, often previously un-documented, past experiences of applying biotechnologies at the field level (i.e. used by farmers for commercial production) in developing countries, ascertain the

success or failure (whether partial or total) of their application, and determine and evaluate the key factors that were responsible for success or failure. The conference does not cover experiences in developed countries.

Issues to be addressed in the e-mail conference

For any one (or combination) of the biotechnologies described above, considering its application at the field level in one of the different food and agricultural sectors (crops, livestock, forestry, fishery or agro-industry), in any particular developing country or region, and in any specific time period over the past 20 years:

- provide an overall assessment of the experience of applying the biotechnology (i.e. whether it was a partial or full success or failure, and provide a justification for this assessment); based on this, describe some of the key features that determined its partial or complete success (or failure)
- indicate, where possible, how transferable these results might be to other, 1) developing countries/regions, 2) biotechnologies, and 3) food and agricultural sectors;
- indicate any lessons that can be drawn from this experience that may be important for applications of agricultural biotechnology in developing countries in the future.

Defining success and failure

When considering a given situation where a biotechnology was implemented in a specific developing country, sector and time period, and attempting to assess whether it was a full or partial success (or failure), a number of different aspects may be taken into consideration such as any potential impacts its application had of a socio-economic, cultural, regulatory, environmental, agro-ecological, nutritional, health and hygiene, consumer interest and perceptions, sustainable livelihoods, equity, technology transfer or food security nature. For example, if the use of a reproductive technology such as AI in a certain livestock species (e.g. dairy cattle) in a given developing country is considered, some of the factors that might influence whether the technology can be judged to be a success or failure might include the impact of the biotechnology on:

- milk production (the trait of main interest);
- other traits, such as cow fertility and health, that can be indirectly affected (often negatively) by improvements in milk production;
- trade (e.g. did use of the biotechnology result in surpluses that led to creation of new trade opportunities? Alternatively, did its use result in closure of some existing markets, e.g. due to regulatory issues?);
- economic returns to the farmer, considering the increased financial returns from increased milk yields as well as any additional costs from using the biotechnology, such as the cost of inseminating the cow, any additional feed or veterinary bills, etc;

- food security (e.g. was more milk produced, leading to greater food security?);
- equity (e.g. was use of the biotechnology restricted to already rich farmers or did its use also extend to the more food-insecure smallholders; also who gained from sale of the biotechnology itself ? [e.g. were the AI services provided by a foreign multinational company or by a local farmers' cooperative?])
- consumer interests (did use of the biotechnology produce a negative consumer reaction, resulting in reduced milk consumption?);
- genetic resources (e.g. if AI was used to cross local females with semen from bulls of developed countries, did it result in erosion of valuable genetic resources in developing countries?);
- technical aspects related to applying the biotechnology (e.g. did it work properly, was much training/equipment needed for people to use it?);
- any unexpected impacts of using the biotechnology.

The number of factors that could potentially influence the overall assessment of the biotechnology as a success or failure (partial or complete) is therefore quite large and for any given case, some factors might be negative and others positive. Thus, the fact that a certain biotechnology has been used (and perhaps continues to be used) does not in itself mean it has been a success, although in certain cases it may be considered as an indicator of success.

A major hurdle to determining fully whether a specific application of biotechnology has been a success or failure is that there is normally a lack of solid, scientifically sound data and documentation about the impacts of its application on people's livelihoods and their socio-economic conditions etc. (FAO, 2009a). Indeed, one of the aims of this e-mail conference is to try and get a better insight into and more information about such areas.

Coverage of GM and non-GM biotechnologies

The conference will be moderated. One of the Moderator's main tasks is to ensure that all of the biotechnologies as well as all of the food and agricultural sectors are adequately covered. As anyone following this area knows, the topics of genetic modification and GMOs are of major interest and have been the object of highly polarized debates, particularly concerning GM crops. One of the consequences of this is that the actual impacts and the potential benefits of the many non-GM biotechnologies have tended to be neglected. However, to learn from the past regarding applications of agricultural biotechnologies in developing countries, the entire range of biotechnologies should be considered as there may be many specificities related to any particular biotechnology tool regarding aspects such as its financial, technical and human capacity requirements, its purpose (e.g. genetic improvement, genetic resources management or disease diagnosis), its potential impacts

etc. For this reason, participants are asked to ensure that all the biotechnologies and all the food and agricultural sectors are covered adequately. In addition, regarding GMOs, discussion should not consider the issues of whether GMOs should or should not be used *per se* or the attributes, positive or negative, of GMOs themselves. Instead, the goal is to bring together and discuss specific experiences of applying biotechnologies (including genetic modification) in the past in developing countries.

6.3 SUMMARY OF AN INTERNATIONAL DIALOGUE

6.3.1 Executive summary

Participants in the e-mail conference shared a wealth of experiences regarding the use of agricultural biotechnologies across the different food and agricultural sectors in developing countries. They provided concrete examples where agricultural biotechnologies were benefiting smallholders. They also discussed at length why specific biotechnologies, as well as agricultural biotechnologies in general, had not succeeded in developing countries and they offered suggestions to increase their success in the future. The conference also indicated that there is no general answer to whether applications of a given agricultural biotechnology have succeeded or failed in the past, but that every application is different and its success depends primarily on the local context in which it is used.

A total of 834 people subscribed to the conference and 121 e-mail messages were posted, 74 percent of which were from people living in developing countries. Most contributions focused on whether applications of one or more biotechnologies had been a success or a failure in the crop, livestock, forestry or food processing sectors, as well as the factors that determined their success or failure. The remaining messages were cross-sectoral in nature, discussing agricultural biotechnologies in general without specifying a given sector, and focused on reasons for failures and suggestions for increasing their success in the future.

Of the different sectors, the greatest focus was on crops and here the use of genetic modification, in particular, as well as tissue culture, molecular markers, biofertilizers and induced mutagenesis were discussed. For GM crops, most of the messages focused on specific case studies, in particular Bt cotton in India and herbicide tolerant soybean in Argentina. For the former, it was considered a major success by some participants, while others indicated that the situation was more complex with performance depending on the hybrid background, growing conditions and institutional context, among others. For the latter, there seemed to be general agreement that GM soybean had resulted in substantial economic benefits in Argentina as well as some undesirable correlated environmental impacts which were not caused by the technology *per se* but by failures to incorporate appropriate planning and policy interventions. There was also considerable discussion about the impact

of regulation on the success or failure of GM crops in developing countries. The practical benefits of establishing a regulatory system for GM crops were underlined as it enabled commercial release. Many participants also argued that GM crops were over-regulated, which was negatively impacting their adoption in developing countries, imposing additional costs and delays.

Discussions on tissue culture focused on its use for micropropagation and numerous participants described how it had been applied successfully in different countries such as Sri Lanka, India, the Philippines and Venezuela, for banana, cassava, cocoa and ornamental plants among others. It was also argued that more could be done to make it accessible to farmers, and practical suggestions including low-cost micropropagation and creation of small regional micropropagation laboratories were proposed. Apart from micropropagation, other successful uses of tissue culture were also discussed, including the release of new wheat varieties in the Sudan and the well-known NERICA varieties.

For MAS, a number of MAS-derived crop varieties that have been released in developing countries were discussed including rice tolerant to submergence, released in the Philippines, and pearl millet hybrids with resistance to downy millet disease, released in India. Success of the latter was attributed to long-term donor support and collaborative partnerships as well as good linkages between the upstream biotechnology end and the downstream product development, testing and delivery ends. CGIAR centres were mentioned as often playing an important role in these MAS developments. Many messages addressed the issue of slow progress in the field and a key factor identified was the lack of collaboration/interaction between plant breeders and biotechnologists.

Biofertilizers have been applied successfully in a number of developing countries including Mexico, the Philippines, Honduras and Peru. Most of the messages emphasized the importance of communicating with the farmers, particularly concerning the relative advantages of biofertilizers. Successful examples of applications of induced mutagenesis were also described, leading to the release of new varieties of banana, groundnut and sesame in Sri Lanka and banana in the Sudan.

Participants indicated that application of biotechnologies in livestock and forestry was less advanced than in crops. Most livestock-specific messages focused on biotechnologies for genetic improvement, in particular AI as well as ET and the use of molecular markers. AI was considered to have had a substantial impact in only few developing countries and numerous explanations were proposed for this, including the lack of extension services, economic incentives and appropriate policies. The lack of proper animal recording systems in developing countries was identified as one of the major constraints to applying biotechnologies for genetic improvement. Successful use of a DNA test for a major gene to increase the fertility of Deccani sheep in India was described.

In forestry, most discussion was about micropropagation with the remainder dedicated to biofertilizers, biopesticides and molecular markers. Clear messages emanating from the contributions are that there is a big gap between research developments and their use in the field; and that enhancing collaboration and understanding between researchers in the laboratory and forestry professionals in the field will enhance the application of forestry biotechnologies.

Several contributions were dedicated to the production and importance of traditional fermented foods in developing countries. There was general consensus about the need to develop defined starter cultures for indigenous fermented foods and to transform fermentation from being an "art" to a "technology-driven process", and successful examples from Thailand were provided.

Cross-sectoral discussions covered four main reasons for failures of agricultural biotechnologies in developing countries. The first was the lack of funds, facilities and trained professionals, where their negative impacts were highlighted. The second was brain drain which weakened national capacities, although some participants argued that it should not always be considered in a negative light. The third was inappropriate research focus, where it was argued that researchers were increasingly focusing on basic rather than applied research. The fourth was the lack of political will, where it was considered that there was government apathy to research in general, as well as biotechnology research in particular, while the positive enabling roles that government policies could play was underlined.

Cross-sectoral discussions also included four main suggestions for increasing the success of agricultural biotechnologies in the future. The first was that research should be focused on the real problems of the farmers, where discussions included practical recommendations to make this possible. The second was that extension systems should be strengthened, as they can ensure that relevant R&D results actually reach the farmer. The third was that regional and sub-regional cooperation should be increased, and establishment of sub-regional centres of excellence was proposed. The fourth was that public-private partnerships (PPPs) be formed, and participants described some recent examples and discussed the potential advantages and disadvantages of PPPs.

6.3.2 Introduction

This Summary document presents a concise account of the major issues discussed by the participants. A total of 834 people subscribed to the moderated conference and 121 e-mail messages were posted by 83 participants from 36 different countries. Most contributors discussed whether applications of one or more biotechnologies had been a success or a failure in a given sector, including the factors that determined their success or failure. Greatest attention was given to crops and least to the fishery sector. Although each sector has its specificities, some of the discussions, especially on the features that determined success or failure, are also of general relevance.

In Part 6.3.3 to 6.3.6 the main sector-specific issues discussed during the conference are summarized. Parts 6.3.7 and 6.3.8 cover cross-sectoral discussions, where participants discussed successes and failures of agricultural biotechnologies in general, without specifying a given sector or biotechnology, with Part 6.3.7 covering discussions about the reasons for failures and Part 6.3.8 focusing on suggestions for increasing their success in the future. Specific references to messages posted, giving the participant's surname and the corresponding message number, are included[1]. Part 6.3.9 provides a summary of information on participation in the conference, including the area of work and geographic distribution of the participants as well as the names and countries of those who sent messages that are referenced in this document.

6.3.3 Biotechnologies in crops

Participants focused particularly on the use of genetic modification, as well as tissue culture, molecular markers, biofertilizers and induced mutations.

6.3.3.1 Genetic modification

There was considerable discussion about the success or failure of GM crops in developing countries. Most discussion focused on specific case studies (i.e. a single GM crop cultivated in a specific country) although a few messages considered GM crops in general. There was also discussion about regulation and its impact on the success or failure of GM crops.

Regarding GM crops in general, Ahmed (95), C.S. Prakash (107) and Giddings (118) referred to the 2008 figures from the International Service for the Acquisition of Agri-Biotech Applications (ISAAA), estimating that GM crops were cultivated on 125 million ha in 25 developed and developing countries. Giddings (118) emphasized that the figures show that genetic modification is not merely promise and potential, but increasingly is already delivering value to farmers on the ground in developing countries. C.S. Prakash (107) similarly argued that GM crops had demonstrated value in terms of economic returns and environmental and social benefits and thus farmers were buying the GM seeds. Falck-Zepeda (20) noted that commercial diffusion so far was mainly in four crops (maize, soybeans, cotton and canola) and two traits (insect protection and herbicide tolerance), although other products were in the regulatory pipeline (some examples were provided in the conference for Brazil (Souza, 102), India (Prakash, 28), Nigeria (Beach, 18) and the Philippines (Tababa, 67)).

Falck-Zepeda (20) presented the results from a set of case studies that he and his colleagues from the International Food Policy Research Institute (IFPRI) had carried out, examining the impact on farmers of the adoption of insect resistant maize in Honduras

[1] The messages are available at www.fao.org/biotech/logs/c16logs.htm

and the Philippines; insect resistant cotton in Colombia; and herbicide tolerant soybeans in Bolivia. Results showed that the impact of adopting GMOs in developing countries had been "overall positive, but it masks significant outcome variability between countries, regions, households, crops and traits. Furthermore, we have seen that the level of economic benefits tend to be more dependent on the institutional context than on the technology itself. In essence, issues such as access to credit and complementary inputs, availability of knowledge and information flows about using the technology and about markets; are critical for determining the level of benefits".

Regarding individual case studies, there was considerable discussion about the cultivation of Bt cotton in India, i.e. containing genes derived from the soil bacterium *Bacillus thuriengensis* coding for proteins toxic to insect pests that feed on the cotton plants. For Gupta (2), Banerjee (15) and Prakash (28), it was a clear success story. For example, Prakash (28) wrote: "since its introduction in 2002, Bt technology in cotton is a huge success in India. Looking at the speed of adoption of this technology, now India has become the second largest producer of cotton in the world". Gupta (2), similarly, described it as a "major success" and looked forward to other GM crops benefiting farmers in India.

Glover (51) felt that the situation was more complex. Based on his own research and that of IFPRI, he argued that the overall picture regarding Bt cotton was of broadly beneficial impacts but that the general overview masked considerable variation between farms, farmers, regions and seasons. He suggested that at the aggregate level there is good evidence that the overall productivity of cotton had increased following the introduction of Bt technology but that, at the microscale, the picture was much more complicated, as the performance of Bt cotton depended on favourable growing conditions especially good soils and reliable water, farmer skills and the presence/absence of supportive institutional frameworks. He concluded: "to label Bt cotton as a great success would be just as crude as to dismiss it as a disastrous failure. We also cannot assume that Bt cotton must be a success merely because it has spread rapidly".

Banerjee (53) agreed with Glover (51) that the rapid spread of a technology should not be considered as the sole factor for deciding its success or failure, but argued that it was an important factor. Banerjee (53), supported by Glover (58), also underlined that the performance of Bt cotton depended not only on the Bt gene but also on the performance of the hybrid background. Responding to the comment of Glover (51) about the dependence of Bt cotton performance on favourable growing conditions, Banerjee (53) stated that this was true for all crops. Glover (58) agreed with Banerjee's comments and concluded that it was important to "consider the specific local circumstances (bio-physical, social and institutional) under which biotechnologies need to perform and to evaluate the positive and negative outcomes in developmental terms (e.g. their effects on labour, incomes,

equity, empowerment etc.) - recognizing that these impacts will be different for different people in different places and circumstances. This last observation applies to all kinds of biotechnologies, of course, not just to GM crops".

Zambrano (59) followed up on this thread by reporting on the results of their IFPRI study on Bt cotton in Colombia where, overall, farmers benefited from the technology but that the results, nevertheless, were not generalized for all cotton growing regions or for all farmers in the country. The most successful results were seen in areas that had irrigation, better lands and more farmer-friendly associations which provided farmers with inputs and credit. Zambrano (59) also reported that results from herbicide tolerant cotton in Colombia seemed much less successful and that the lack of, or incorrect, information about crop management and herbicide application appeared to be implicated in losses[2].

There was also ample discussion about GM crops in Argentina, most of which are herbicide tolerant soybean and where the majority of soybeans planted is GM. Discussions highlighted that the technology could provide substantial benefits and that appropriate planning and policy interventions were needed to prevent undesirable impacts.

Trigo (33, 47) argued that GM crops had meant a "real agricultural production revolution" in Argentina and referred to a report he had co-authored in 2006, which estimated that the total accumulated benefit from 10 years cultivation of herbicide tolerant soybeans was about US$20 billion and that they may have contributed to the creation of almost one million jobs. Similarly, Sharry (25) noted that Argentina was one of the world's leading exporters of GM crops; that several GM and non-GM products had been developed; and that these developments usually start in the public sector and then the private sector develops and markets them. She (25) argued that this had been made possible by the development of a strong and transparent biosafety regulatory system; government support, including financial, communication and information aspects; support for the creation/hosting of companies that use or produce biotechnology inputs; and good interaction between government, scientists and producers.

Escandon (39) also underlined the role that the Technical Co-operation Network on Agricultural Biotechnology in Latin America and the Caribbean (REDBIO) had played in Argentina regarding acceptance of GMOs by the public, as public perception is one of the most important factors for the success of GM products (a point also made by Tababa (67) concerning the experience of Bt corn in the Philippines). The network had organized symposia, workshops and courses, which had facilitated the exchange of ideas between people. Escandon (39) proposed that it was an example that could be followed

[2] Presentations by Zambrano and by Fonseca & Zambrano on GM cotton in Colombia were given at ABDC-10, available at www.fao.org/fileadmin/templates/abdc/documents/zambrano.pdf and www.fao.org/fileadmin/templates/abdc/documents/fonseca.pdf respectively.

in other countries. Indeed, Tchouaffé (75), in the context of dissemination of low-cost micropropagation, underlined the role that fora to exchange views between researchers and local populations could play and that governments could act as a facilitator in establishing such fora. Sharry (25) also pointed out the importance of REDBIO's role in communication in Argentina.

Echenique (41, 64, 73) agreed with Trigo (33) about the economic benefits of GM soybean in Argentina, stating: "it is a highly profitable extremely recent technology which has been widely accepted by farmers in a very short time period" (64). However, she also highlighted the need to consider environmental and social aspects related with adoption of the technology, focusing on two main issues. The first is the move towards soybean monocultures, strongly accentuated in some provinces, leading to nutrient loss and soil fertility problems unless appropriate measures are taken (such as crop rotation and application of fertilizers to replace nutrients taken from the soil). The second is the expansion of land areas dedicated to soybean cultivation at the expense of forest areas, horticulture, milk production, cattle and forage (41).

Echenique's comments evoked a number of responses, most of which generally agreed with her while arguing that the problem was not the technology *per se* but the related policy environment. Thus, Trigo (47) and Parrott (52) both pointed out that there were more economic incentives for farmers to grow soybean than maize, which triggered the monoculture problem, and that the social and environmental impacts in Argentina would be totally different if the incentives were different (52). Escandon (70) agreed in general terms with Echenique (64) and called for government policies to encourage farmers to practise crop rotation. Parrott (52) also noted there was growing recognition among farmers that current practices were not sustainable and that there was now a strong movement to implement more sound agronomic practices such as crop rotation. Regarding deforestation, Trigo (47) noted that while availability of herbicide tolerant soybeans may have contributed to the process and even sped it up, the problem existed before GM soybeans were released and was the result of policy failure in terms of forest protection and land use planning and was independent of GMOs. Echenique (73) concluded by stating that the problem was not the technology, but that planning of agriculture was needed when any new technology was introduced.

There was also discussion about the success or failure of two GM crops that had not been commercialized. The first was GM sweetpotato in Kenya, resistant to the feathery mottle virus, where GMOs developed in the United States were imported by the Kenya Agricultural Research Institute in 2000 for field testing, but they were not later commercialized. For Gurian-Sherman (26), the project was a failure as it involved substantial financial and scientific inputs over a decade without resulting in any product, whereas there had been a reported

success in Uganda with conventional breeding. Kamanga (45) did not agree, saying instead that it had been a great success, as it had allowed GMO trials to be carried out in accordance with international standards; facilitated capacity building and building of partnerships in GMOs; led to development of an institutional framework in GMOs/biosafety in Kenya and, indirectly, to the passing of the national biosafety law. Bett (49) agreed, giving her personal testimony that the project had allowed her to get training in biotechnology and to get direct experience of carrying out GMO field trials.

The second was GM cassava resistant to the cassava mosaic virus disease (CMVD), where GM varieties of cassava developed by the Danforth Center were later found to have lost their resistance to the virus. Anderson (46) from the Danforth Center noted that the problem referred to experimental work carried out at their laboratories and that to speak of success or failure during the experimental phase of this or other research projects was not appropriate as meeting problems and solving them was a normal part of the scientific process. Usman (37) confirmed that the varieties had never been field tested in Nigeria, and stated that the development of improved cassava varieties was critical to Nigeria's food sustainability and agricultural development, a project in which the Danforth Center was a partner (Anderson, 46). Egesi (13) said it was important to avoid hype and propaganda and that this case did not mean that virus resistance cannot be acquired by genetic modification. Nassar (7) reported that CMVD resistant cassava cultivars had been produced by non-GMO methods from inter-specific hybridization with the wild species *Manihot glaziovii,* and estimated that they were cultivated on four million ha in Nigeria.

In addition to the many messages discussing specific examples of GM crops, there was considerable discussion about the impact of regulation on the success or failure of GM crops in developing countries. As noted by Nzeduru (27), the aim of regulation is to ensure that the benefits of GM crops can be harnessed without compromising human/animal health or environmental sustainability. Specific aspects of national regulatory frameworks were described by participants, for Kenya (Kamanga, 45), Nigeria (Usman, 86) and Brazil (Souza, 102). Pathirana (110) mentioned the difficulties involved in establishing a biosafety framework in Sri Lanka, including the fact that five government departments were involved in the process. Ahmed (95) noted that biosafety legislation had not yet been approved in most African and Arab countries and urged that it should be done.

The practical benefits of establishing a regulatory system for GM crops were underlined by some participants, with Roca (74) describing the establishment of a science-based biosafety regulatory framework in Honduras as a success since it had allowed the country to "deploy and legally commercialize herbicide tolerant and insect resistant GM maize since 2001". Similar sentiments were expressed by Sharry (25) and Tababa (67) for Argentina and the Philippines respectively.

Many participants also argued that GM crops were over-regulated, which was negatively impacting their adoption in developing countries. In India, Gupta (2) and Dudhare (24) considered that the regulatory process was too slow, discouraging work in this area (Gupta, 2), and was very costly (Gupta, 2; Keshavachandran, 82). Sharry (25) warned about the dangers of "excessive bureaucratic delays", which can limit investment and technology transfer. Van der Meer (115), noting the challenges of preparing and conducting GM crop field trials, proposed that a support network for public researchers be established so that they could help each other in this work. Roca (74, 119) wrote that regulation is often not science-based, which had dire consequences for public sector research. Trigo (71) argued that there was a very thin red line between "being careful" and over-regulation; that these were "the most watched-over technologies in agricultural history"; and that regulation should evolve based on the accumulation of scientific evidence. C.S. Prakash (107) agreed, and concluded that over-regulation was leading to excessive costs and needless delays in commercialization of GM crops for both the private and public sectors. Similarly, Giddings (118) argued that "scientifically unsupportable regulatory burdens" were blocking wider dissemination of GM crops.

6.3.3.2 Tissue culture

As described earlier, tissue culture refers to the *in vitro* culture of plant cells, tissues or organs in a nutrient medium under sterile conditions. There are a number of tissue culture-based technologies and they can be employed for different purposes. They include micropropagation, involving the rapid multiplication of stock plant material to produce disease-free propagation materials for dissemination to farmers; *in vitro* embryo rescue to enable wide crossing; anther culture and ovule culture to produce haploid plants; and *in vitro* slow growth storage to conserve plant genetic resources.

Discussions on tissue culture focused on its use for micropropagation, although its use for wide crossing, creation of doubled haploids and conservation of genetic resources were also briefly considered. The messages illustrated that application of micropropagation has been successful in realizing substantial benefits in countries such as Sri Lanka, India, the Philippines and Venezuela, although in some other cases it was seen to have failed. Important factors which influenced its success or failure included the degree of involvement of the extension system or the private sector.

Pathirana (81) informed participants that micropropagation together with the technique of mutation induction had resulted in successful development of early flowering, high-yielding banana clones in Sri Lanka, which were also free of banana bract mosaic virus, which significantly reduces yield in infected plants. An estimated 25 percent increase in annual income had been attributed to intensification of the production cycle through use of the early maturing mutant banana cultivars and Pathirana (81) stated that micropropagated bananas

were now common and popular among farmers and encouraged by governmental authorities. He noted that a key component for success of the project was that the scientists involved in the project held many field days to inform farmers how to care for the micropropagated plants in the early period of growth.

After giving a brief history of commercial micropropagation in India, Dinesh Kumar (87, 101) estimated that over 135 million plants are currently produced by 300 tissue culture laboratories in India; production of tissue culture bananas was rising fast and nearing 100 million plants; and 30-35 million ornamental plants were exported annually. He noted that the Government of India had set up a committee to accredit all the commercial tissue culture laboratories in the country and had prescribed a detailed standard procedure for them. He concluded that commercial tissue culture production in India was "poised for a big leap forward" (87). Interest of the private sector for this biotechnology was also indicated by Pathirana (110) who noted that apart from micropropagation, the private sector in Sri Lanka had yet to play an important role in contributing to biotechnology development or research. The important work carried out by Indian public funded institutions in tissue culture was highlighted by Seshadri (113).

Tababa (67) wrote that in the Philippines, mass propagation through tissue culture, supported by both public and private institutions, had contributed to making large-scale banana plantations economically viable and led to the introduction of new varieties of flowers in the cutflower industry. Both the private sector and the backyard plant growers had benefited. Mass production of mutant coconuts through embryo rescue had, however, been less successful as production costs were high and productivity was relatively low (67).

Infante (38) wrote about successful cassava and cocoa micropropagation programmes in Venezuela. He noted that a key feature which allowed the cassava research results to reach the farmers was the creation of "transfer" laboratories, where small micropropagation laboratories were established in several regions, whose personnel were trained in the main research facility in Caracas. People in the regional laboratory were thus able to act as a two-way communication link between the research facility and the farmers so that farmers could receive inputs and provide eventual feedback. Muralidharan (63) commended this approach. He also argued that too little had been done around the world to harness the full potential of micropropagation, except perhaps by the ornamental plant industry. He highlighted the scope for simple "low cost micropropagation" in several crop species, noting that the orchid industry in Thailand was a good example, where micropropagation was carried out in small household laboratories (63).

Orellana (62) described the long history and wide range of tissue culture activities on potato, sugar cane and hybrid coffee in his institution's laboratory in El Salvador, and reported that the disease-free plants had been provided to farmers. Roca (74) also noted

that there was a well established structure for tissue culture work in Honduras. Caesar (121) reported that in Guyana, successes had been achieved in tissue culture of pineapple, sweetpotato and plantain among others.

For Tonjock (9), the provision of tissue cultured seedlings at low cost was a success in Cameroon, although she noted that some farmers were still unable to afford them. Similarly, Loquang (97) argued that the production of disease-free banana planting material by tissue culture could be considered a success in Uganda as the clean planting material boosted food and income security. In Nigeria, micropropagation had also been used for the production of disease-resistant varieties of crops but doubts were expressed about its success (Chikezie, 48; Echereobia, 78; Oselebe, 57). Chikezie (48) argued that disease-resistant varieties of staple root crops resulting from research in Southeast Nigeria had not benefited many farmers in that part of the country, which could be because of inadequate funding to enable large-scale micropropagation of these staple root crops or the lack of well-developed agricultural extension networks. Echereobia (78) also mentioned the need for training and provision of technical support to sustain the technology.

Oselebe (57) reported on progress with micropropagation in plantains and bananas, noting also its potential as it could lead to rapid multiplication of disease-free plantlets for farmers. However, she concluded: "it is highly technical, can only be employed in very few research institutes (in most cases for other crops) and is not amenable to the resource-poor farmers who are the main producers of plantain and banana". Infante (85) noted that research activities may be carried out without focusing on eventual applications, reporting that some laboratories in Venezuela had carried out micropropagation work for years without it ever resulting in the release of plant materials to farmers.

In the Sudan, Gama (54) wrote that a tissue culture laboratory had been established under a long-term project and it had been extensively used for banana tissue culture and wheat doubled haploid production. He noted that the laboratory had been able to provide banana planting materials during critical times of post-flood devastation of banana plantations along the Nile banks and that anther culture techniques for production of doubled haploid wheat had yielded good results leading to the release of several cultivars.

Also in Africa, Manneh (35) described the successful combination of conventional breeding and biotechnology to produce the NERICA varieties by crossing Asian (*Oryza sativa*) with African rice (*Oryza glaberrima* Steud.), mentioning in particular the role of anther culture to create doubled haploids and fix desirable genotypes. While noting that upland NERICAs are now widely cultivated (over 200 000 ha) by farmers in Africa, he argued that one of the major impediments to the widescale use of these biotechnological products is the weak seed system in many developing countries especially those in Africa and that the present demand for NERICA seeds in developing countries surpassed their

supply. He concluded by urging that to enable wider usage of these rice biotechnologies and their products "there is a need to reinforce national capacities especially those involved in the seed sector such as the national research and extension systems as well as farmers, farmers' organizations and the private sector"[3].

Tissue culture has also been used to conserve plant genetic resources in developing countries. Cruz (32) reported that in the Philippines, tissue culture was used in the national genebank to preserve a backup collection of banana and yam. Pathirana (116) also described the numerous activities of the Plant Genetic Resources Centre which is the focal point for promoting and facilitating the conservation and sustainable utilization of plant genetic resources in Sri Lanka. He reported that *in vitro* conservation protocols had been established for about 15 different species and that some accessions of cassava, sweetpotato, potato, yams, colocasia, innala and banana were maintained in storage under normal or minimal growth conditions.

6.3.3.3 Molecular markers

Several messages dealt with the use of molecular markers for genetic improvement in crops. It was suggested that marker-assisted selection (MAS) has been used with reasonable success in countries such as India and the Philippines. Using this technology, a number of improved varieties of crops such as pearl millet, rice, maize and wheat have been developed and are in use in some countries in Asia and Africa. The CGIAR institutions have often played an important role in these developments.

Banerjee (15) stated that MAS is becoming increasingly popular in India and that both public and private sectors are investing in it. Hash (44) provided a detailed overview of the successful development and adoption of "HHB 67 Improved", a pearl millet hybrid with resistance to downy mildew disease which was approved for release in India in 2005. In 2008, F_1 hybrid seed was produced to sow at least 300 000 ha with HHB 67 Improved, while he predicted that the 2009 area could exceed 500 000 ha, if sowing conditions are favourable (Hash, 44). He noted that the research product development and testing chain for the hybrid was long and had many partners in India and the United Kingdom, and estimated that economic benefits to farmers were substantial. To him, the success story had clearly demonstrated how research partners with widely disparate interests could come together, each contributing something for which they have a comparative advantage, to deliver an appropriate research product targeted to meet the needs of the poor. In conclusion, he felt that the most important factors for its success were long-term donor support (over

[3] A presentation of the NERICA case study was given at ABDC-10, www.fao.org/fileadmin/templates/abdc/documents/nerica.pdf and further details on NERICA are given in Chapter 1.5.1.

15 years); long-term collaboration of the partners; and reasonably strong linkage of the "upstream" biotechnology end of the projects to the more "applied" plant breeding product development, testing and delivery ends.

In India, Gupta (2) maintained that MAS had been used successfully in crop improvement, with the development of products that were already commercially available or being field tested, namely superior hybrids of pearl millet and quality protein maize, high protein wheat cultivars, wheat resistant to rust, rice resistant to bacterial blight and rice tolerant to submergence. Nevertheless, he felt that the pace of work and adoption of marker technology was slow, attributing this to lack of expertise and motivation among those involved in breeding, lack of cooperation between molecular biologists and plant breeders and high costs of the technology compared with conventional plant breeding. Singh (60) agreed, arguing that the lack of interest of plant breeders had meant that few populations for molecular mapping and tagging had been developed for field crops in India. Predeepa (111) agreed that a lack of collaboration/interaction between breeders and molecular biologists was a hurdle in India. Murphy (100) felt it was not just an Indian phenomenon but also applied to developed countries to some extent although his impression was that it was much more serious in developing countries, possibly due to the more recent development/introduction of some biotechnologies there. Indicating that he had experienced the same phenomenon in Malaysia, he concluded: "it needs to be addressed by improved education of agricultural science graduates in ways that emphasize the unity of the discipline and especially the role of biotechnology as the servant of breeders and agronomists rather than their master" (100).

Based on his own experience, Jordan (83) argued that marker technology works well if breeders have the appropriate skills, understand the technology well and are involved in developing the technology for a particular application; biotechnologists have some understanding of plant breeding; there is appropriate balance between investments in traditional disciplines and marker technologies; skills in statistics and informatics are sufficiently advanced to support the use of molecular technology by breeders; and rational decisions are made regarding resource allocation in applied programmes based on true costs and returns. From his limited experience of plant breeding programmes in developing countries, he suggested that investments in conventional plant breeding and related disciplines often seem insufficient to allow technologies like markers to be used effectively and that, in many cases, much greater genetic improvements could be made by enhancing the conventional breeding programme rather than investing in markers. Trigo (93) agreed with Jordan (83) that appropriate and intelligent investment is essential. However, he argued: "molecular biology applications are the way of the future to make breeding more efficient and effective and we should push in that direction" and that strengthening conventional breeding alone "is not the solution even when we accept that there is still a lot to be achieved through conventional breeding" (93).

In the Philippines, Cruz (32) noted that molecular markers had been used to develop disease resistant rice varieties, analyse the purity of hybrid rice seeds and to study collection diversity and manage germplasm in the national genebank. Manneh (35) described some of the biotechnology work carried out on rice by two CGIAR institutes, the International Rice Research Institute (IRRI) and the Africa Rice Center. He noted that they and other research institutes were using MAS to introduce a number of traits (such as tolerance to salinity and low temperature, resistance to rice yellow mottle virus disease, and grain quality) into rice varieties already adopted by farmers. He reported that MAS had been used by IRRI to transfer submergence tolerance into stress-tolerant improved varieties such as Swarna and IR64, which are very widely cultivated in Asia and have already been tested and released in some Asian countries. Rigor (42) from the Philippine Rice Research Institute confirmed that through collaboration with IRRI, they had recently recommended release of IR64 with submergence tolerance. Using MAS and anther culture, they had also released rice varieties suited to irrigated lowland conditions and varieties tolerant to salinity. In his institute, Rigor (42) noted that the technical aspects of using DNA markers had not yet been optimized, so it was not possible to fully use markers in their breeding programme, and that the high rate of staff turnover was negatively impacting the sustainability of certain biotechnology projects.

Roca (74) wrote that biotechnologies have been successfully used in Honduras for the past 20 years and listed various examples including a strong regional MAS breeding programme for beans. Singh (76) underlined the role that markers could play in inter-specific hybridization, where markers could be used to accelerate transfer of novel genes for important traits such as disease resistance from related/wild species of field crops. He reported that these techniques had been used in wheat in India where genes for resistance to leaf rust, stripe rust, Karnal bunt, powdery mildew and cereal cyst nematode had been transferred. He concluded by highlighting the need for capacity building in developing countries on this subject, especially for crops that are solely/largely cultivated in developing countries (76).

6.3.3.4 Induced mutations

A small number of successful applications of induced mutagenesis were described in the conference. Thus, Pathirana (108) reported that its application (using gamma rays) in Sri Lanka had led to release of the "Malee" variety of sesame (resistant to fungal diseases, mainly *Phytophtera nicotianae* var. *parasitica*) and he suggested that its release had halted the decline in the area cultivated with sesame (which had been declining because of the disease). Mutation breeding had also resulted in release of the "Tissa" variety of groundnut (more drought resistant, early maturing and high yielding), which was in popular demand

by the farmers (108). He reported that they were the only mutant cultivars of oilseed crops released in Sri Lanka and that they had been cultivated for almost two decades (108). Both Pathirana (81) and Gama (54) reported on the successful application of mutation breeding in bananas in combination with tissue culture in Sri Lanka and the Sudan respectively. The projects were supported by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and led to the release of new varieties in both countries.

6.3.3.5 Biofertilizers

The application of biofertilizers has met with some success. For example, Tababa (67) stated that in the Philippines, biofertilizers for corn and rice had been successful, which could be attributed to the farmers' education on their use and benefits, inclusion of their use in the package of technologies adopted by the National Corn Programme, and the government's uninterrupted financial support to their production. Peralta (22) reported that in Mexico a *Rhizobium*-based biofertilizer for the common bean (*Phaseolus vulgaris*) had been developed by the university and was now successfully commercialized by a private company. Initial efforts to involve government agencies in promoting and using the product were unsuccessful. The biofertilizer is used mainly in central and northern Mexico (Peralta, 50) and he (22) felt that "this is the beginning of the common bean fertilizer era in Mexico". He pointed out that much educational/promotional work is required (22) and that the farmers who bought the biofertilizers also received access to printed material, sessions with agronomists and further assistance (50)[4]. Sangar (56) appreciated this example from Mexico and wondered whether biofertilizers had helped poor farmers in India, which suggests that documentation of such cases in India is weak.

Roca (74) stated that in Honduras, biofertilizers had also been used successfully, with strong programmes for *Rhizobium* and mycorrhizal fungi. Listing a selection of ongoing biofertilizer programmes in her country, Dávila (109) noted that biofertilizers are increasingly being used in Peru. She emphasized the need for training and that farmers need to have evidence that biofertilizers enhance crop performance, are more economical than chemical fertilizers, and are environmentally-friendly. Seshadri (113) argued that, despite long-term research and the fact that many products are already on the market, much more could be done regarding biofertilizers and biopesticides in India. Farmers were seldom convinced by them, primarily due to issues of profitability, and he urged that, with concerted efforts, biofertilizers and biopesticides could be presented in a better way. He highlighted that there was room for improvement in areas such as formulation, shelf-life, number of cells, packaging quality and price (113).

[4] A presentation of this case study was given by Peralta at ABDC-10, www.fao.org/fileadmin/templates/abdc/documents/peralta.pdf.

6.3.4 Biotechnologies in forestry

Several participants wrote about forestry biotechnologies. Their main focus was on micropropagation, although biofertilizers, biopesticides and molecular markers were also mentioned. Clear messages emanating from the contributions are that there is a big gap between research developments and their use in the field; and that enhancing collaboration and understanding between researchers in laboratories and forestry professionals in the field will enhance the application of forestry biotechnologies.

Muralidharan (89) thought it was important to draw attention to the subject of biotechnology in forestry, noting that any benefit from using technology in tropical forests would have a great impact on the environment and people's livelihoods. Similarly, Sharry (106) underlined the important role that forest biotechnology could play, but observed that the understanding of tree biology is poor compared with that of agricultural crops and that individual trees remain much longer in the landscape than short-lived agricultural crops, meaning they are subject to a much wider range of environmental stresses.

Sharry (106) summarized some results from FAO (2004) which indicated that most non-GMO biotechnology activities in forestry were still largely confined to the laboratory, although the application of micropropagation in field plantings was becoming more common. Indeed, most discussions about forest biotechnology in the conference focused on micropropagation. Sharry (106) wrote that it was the most applied forest biotechnology in Argentina. Muralidharan (89) also reported on the successful use of micropropagation and molecular markers for clonal propagation of teak in Malaysia, yielding superior quality planting materials for both the local market and export[5].

Muralidharan (89), however, was critical of the fact that, despite the availability of laboratory protocols for almost all of the important tree species in India, micropropagation had been rarely used in the field. He attributed this failure to the situation where biotechnologists worked in isolation instead of joining forces with the practising forest managers, i.e. the State Forest Departments. He quoted the example of teak, the most important and widely planted timber species, where almost three decades after they succeeded in cloning mature trees the technique was still barely used in practice although micropropagated plantlets would be better than conventional grafts for establishing clonal seed orchards (89). In addition, he argued that in the few cases where large scale micropropagation of a forestry species had actually been undertaken, it was done with insufficient scientific backing. He underlined that unless there was proper selection and testing of the material to be propagated, the technology would not disseminate material superior to plantlets raised from seed (89). Similarly, Rajalakshmi (104) felt that the application of forest biotechnologies such as

[5] The Malaysian case study was presented at ABDC-10, www.fao.org/fileadmin/templates/abdc/documents/teak.pdf

micropropagation still had a long way to go in India and that key issues to be addressed were the existing gap between research and the field; limited funds and inadequate infrastructure; and the lack of trained professionals.

From his own experience, Muralidharan (63) indicated that low-cost and simple micropropagation technology for bamboo, teak and several medicinal plants now appeared feasible and he was looking at the possibility of training small groups, consisting mainly of rural women, and setting up small production units. In response to Muralidharan's (63) request for information on aspects to consider when transferring such technology to the field, Tchouaffé (75) suggested that it could be disseminated and transferred through capacity building and networking with communicators and the local population.

Regarding more advanced biotechnologies, Sharry (106) indicated that Brazil and Chile have developed a strong forest industry and are using all available biotechnologies including genomics. In her own country, Argentina, she reported that genetic maps and molecular markers had been developed to support eucalyptus breeding programmes; molecular markers had been used to identify areas of protection for native forest species; and research on GM poplar was ongoing. However, she argued that compared with the crop sector, these biotechnologies had not yet had a major impact at the forest chain level in Argentina. Similarly, Muralidharan (89) noted that molecular markers were increasingly used in studying the provenances and the breeding behaviour of some of the important tree species of India, but the results were not assimilated into ongoing breeding programmes.

Regarding microbial-based biotechnologies, Caesar (121) noted that the use of biofertilizers for inoculation of seedlings of the local forest species *Eperua grandiflora* ssp. *guyanensis* had met with partial success in Guyana. Rajalakshmi (104) also mentioned the importance of biofertilizers in India as they could boost agriculture and reduce the debt burden on farming communities. Muralidharan (114) presented a case study of the development of a biopesticide for the biological control of a serious insect pest of teak, the teak defoliator (*Hyblaea purea*). Based on a virus isolated from natural populations of the insect larvae, a biopesticide was successfully developed in India after nearly two decades of research, culminating in an "elegant solution to a serious problem" (114). However, the technology had not yet been applied in the State Forest Departments, and he underlined that biotechnology research had a much better chance of producing results when conceived, developed and implemented in a broader framework consisting not just of scientists and technologists but also involving at every stage the forestry professionals who work at the field level and, also at some level, the policy-makers who eventually have to give the green signal.

6.3.5 Biotechnologies in livestock and aquaculture

The majority of livestock-specific messages focused on biotechnologies for genetic improvement including AI, ET and the use of molecular markers. In the conference, only one message was dedicated specifically to the fishery sector and it is summarized at the end of this section.

For AI, Cruz (32) reported that in the Philippines its application in the genetic improvement programmes of local buffalo was a good example. He said that although also introduced for cattle and swine, AI had led to a more organized governmental genetic improvement scheme in buffaloes. Loquang (97) reported that AI had made significant contributions to the livestock industry in Uganda through its impact on milk and beef production and the emerging milk processing industry, which had created many jobs.

Traoré (88) observed, however, that AI is practised at a level that substantially impacts livestock production in only very few developing countries. Looking at the past, he felt that apart from some technical constraints (such as its relatively high costs, poor heat detection and nutrition), a major reason for the less successful development of AI in Mali in the 1970s and 1980s was that there were insufficient economic incentives for farmers to use it. Nevertheless, he was more optimistic about the future as he noted that the situation had changed drastically with the emergence of new market opportunities for milk and milk products in urban areas and subsequently the rise in demand for crossbred cattle. He argued that the main current constraint to AI development was the lack of infrastructure and appropriate policy. From his experience of dual-purpose cattle in Mexico, Moro (14) wrote that the reasons why farmers failed to adopt a technical package (including practices such as AI, record keeping, mineral supplements and generation of value-added products such as cheese) were the lack of trained extension agents; low income and/or limited access to credit; and poor documentation of the economic returns of adopting the technology package.

Apart from AI, another reproductive technology discussed in the conference was ET, where participants reported that it had been used successfully in Honduras (Roca, 74), was approaching the commercial stage in Pakistan (Ali, 77) and that embryos from the British Texel breed had been successfully transferred to local Blackbelly sheep in Guyana (Caesar, 121).

Ali (77) was upbeat about the potential benefits of applying biotechnologies to the livestock sector in Pakistan. He reported that molecular markers had been used for genetic characterization of the Nili, Ravi and Nili-Ravi buffalo breeds and that DNA fingerprinting had been successfully used in legal proceedings for paternity confirmation to resolve an issue regarding animal ownership. Nimbkar (55) described the successful introgression of the FecB mutation allele for fecundity from the small prolific Garole sheep into the larger Deccani sheep in Maharashtra in India, resulting in Deccani sheep that were more prolific

while retaining their larger size, local adaptation and meat-producing ability. The FecB mutation increases ovulation rate considerably and a PCR-RFLP test was used to detect the mutation while backcrossing. She concluded (55) that the gene had provided farmers with the opportunity for moderate and sustainable intensification of production, which was a step towards raising the efficiency of resource use. She noted that it was possible to use the patented gene and DNA test without paying a royalty because those patents were not valid in India[6].

Lack of proper animal recording systems in developing countries was seen as one of the major constraints to using biotechnologies for genetic improvement. Moro (40) highlighted the importance of keeping accurate records and based on his experiences with dual-purpose cattle in Mexico, he stated that the lack of phenotypic recording was a reason for failure of the research/technology transfer programmes for genetic improvement (involving AI, planned crossbreeding, genetic selection). For farmers that might eventually join a milk recording scheme, he underlined the importance of enabling them to make quick and practical use of the records, e.g. to assist them with daily management issues (Moro, 40). In a similar vein, Satish Kumar (31) bemoaned the fact that in India good-quality phenotypic performance records are lacking and was critical of the fact that in this situation most of the animal breeding researchers "have gone high-tech". Unless some basic animal genetics experiments were carried out and there was collection of quality data, he argued that research into molecular markers would have no impact, concluding: "let us count our sheep before worrying about genes!"

For Africa, Adebambo (72) also highlighted the difficulties of animal improvement. Rather than importing poorly adapted exotic breeds, he urged that more attention be give to African livestock, and that issues of description and census of African livestock needed to be addressed first. Like Adebambo (72), Kumarasamy (29) argued that the use of biotechnology in the animal sector was far behind the crop sector. The reasons he cited for this included the lack of coordination between agencies and between the laboratory and the field; excessive bureaucracy and lack of encouragement from the administration; and short-term project funding (3–4 years), which is too short for animal breeding schemes because of the long generation intervals in animals (29).

A small number of messages were dedicated to biotechnologies applied to animal health. Pathirana (110) noted that R&D in biotechnology had progressed at a very slow pace in Sri Lanka, and that only plant micropropagation, AI in cattle and ELISA techniques for disease diagnosis in cattle and buffalo had made any impact at the field level. Roca (74)

[6] The Deccani sheep case study was presented by Nimbkar at ABDC-10, www.fao.org/fileadmin/templates/abdc/documents/chanda.pdf and further details are given in Chapter 3.6.1

also noted that good progress had been made on the use of immunological and molecular approaches for diagnosis of animal pathogens in Honduras. Ali (77) noted the major potential of producing indigenous recombinant DNA vaccines against highly prevalent livestock diseases (such as foot-and-mouth disease and hemorrhagic septicaemia), but indicated that the facilities were not yet available for this in Pakistan.

For aquaculture, Zidana (98) wrote about the use of hormonal treatment to generate single sex populations in tilapia, where males are more desirable as they grow faster than females. He reported the production of YY males in indigenous tilapias with improved growth rates as a success at the technical level in Malawi. However, due to the high cost of importing hormones from Asia, its use at the field level was not economically feasible and farmers had reverted to producing mixed sex tilapia. He also mentioned that it had not been possible to produce or buy the hormones locally or regionally or to get any collaborators to support the project (98).

6.3.6 Biotechnologies in food processing

Several messages were dedicated to the production and importance of traditional fermented foods in developing countries. There was general consensus regarding the need to develop defined starter cultures for indigenous fermented foods and to transform fermentation from an "art" to a "technology-driven process".

Raheem (1) pointed out that many developing countries, especially those where cold storage is lacking, rely on fermentation to preserve food. Edema (79) argued that fermentation could be regarded as a success in Nigeria as virtually every household depends on fermented food for its daily meals. In addition, some of the fermented foods and their by-products are used as medicines, such as Omidun, the liquid derived from the fermented cereal gruel called Ogi, used to treat childhood diarrhoea. In a similar vein, Loquang (97) highlighted the importance of traditional fermentation in indigenous food processing among pastoralist communities in Uganda. He described how fermented milk was used to produce ghee and listed many of this product's important functions, both food and non-food, in the communities. He concluded that since such techniques have sustained the livelihoods of pastoralists for generations, it is only fair to say they have been successful. Sivakumar (112), writing about Nepal, advocated applying biotechnology for fermented products, also because it could be an effective use of limited financial and infrastructural investments. The successful use of novel enzymes and micro-organisms for agro-industrial processes in Honduras was noted by Roca (74).

Olusegun (17) highlighted the importance of cassava-based fermented foods such as gari, fufu and lafun in Nigeria and said there was an urgent need to apply biotechnologies to these popular foods. He noted, however, that most research findings in this area had not

led to anything concrete and concluded by advocating the production of starter cultures for traditionally fermented foods in Africa. Raheem (1) commended recent initiatives to diversify the industrial utilization of cassava such as the production of dried yeast, alcohol, L-lactic acid and phytase through fermentation, and wrote that cottage industries should be established to commercialize them.

Edema (79) argued that fermentation could also be considered a failure in Nigeria because more advanced biotechnologies had not been applied, as back-slopping (rather than application of defined starter cultures) was used at the household level. Highlighting the need to move production of indigenous fermented foods in developing countries from an "art" to a "technology-driven process", Olusegun (61) noted that starter culture development is one of the steps in this transition, mentioning the successful use of starter cultures in production of fermented pork sausage (nham) and soy sauce in Thailand[7].

Nevertheless, Olusegun (61) noted that although important micro-organisms for fermentation might have been identified, starter cultures had not been developed for most indigenous fermented foods in Africa and for some in Asia. He argued (61) that one of the reasons was that the industry was still at the household level and manufacturers view starter culture technology as a burden to the cost of production.

To improve traditional fermentation processes and products in developing countries, Olusegun (61) concluded that the way forward involved more research on process standardization and controls and on the nutritional benefits of fermented foods; capacity building in biotechnology, especially in starter culture technology; development of fermenters (bioreactors) with control parameters (to overcome the tedious and time consuming nature of traditional processing); and promoting public awareness of the potential of biotechnology and the need to improve traditional food biotechnology with modern knowledge.

6.3.7 Cross-sectoral discussions: Reasons for failures of agricultural biotechnologies in developing countries

In Parts 6.3.3 to 6.3.6, summaries were provided of messages that discussed the successes or failures of specific biotechnologies in specific sectors. A large number of messages were also posted which considered agricultural biotechnologies in general without specifying any sectors or biotechnologies. In this part, these cross-sectoral discussions about the reasons for failures in applying agricultural biotechnologies in developing countries are summarized.

[7] A presentation of the soy sauce case study was given at ABDC-10, www.fao.org/fileadmin/templates/abdc/documents/soysauce.pdf and further details are given in Chapter 5.5.1

Lack of funds, facilities and trained professionals

Chikezie (4) thought that a major reason for the failure of agricultural biotechnologies in developing countries was the lack of funds, facilities and properly trained personnel to use them. As a follow-up to this message, Oyewole (8) added that many scientists in developing countries who work in the field of agricultural biotechnologies have also limited possibilities to disseminate the outcomes of their research to the people who could benefit from them. Additionally, he noted that the lack of funds and facilities meant that much of the agricultural biotechnology research carried out by developing country scientists was done in advanced institutions in developed countries (8). Tonjock (9) also described the negative impacts that the lack of funding, facilities and training had on the use of agricultural biotechnologies to fight against plant diseases in Cameroon.

Apart from Chikezie (4), lack of availability of funds was reported in many messages as one of the reasons for the failure (e.g. Tchouaffé, 10; Moro, 11; Sharry, 15; Muchadeyi, 16; Oyewole, 36; Roca, 74; Pathak, 96; Ubi, 120). Van der Meer (115) also noted that the funding levels for biotechnology were far inferior to the levels promised in the past. However, Yongabi (19) cautioned that even if funds were available for biotechnology, the improvement of agricultural productivity might not be significant in developing countries unless sustainable locally-adapted technologies were used, concluding: "agriculture can be improved in developing countries if appropriate technologies are developed simply and accessible to everyone rather than the over reliance on high-tech which is usually expensive!". Moro (40) agreed that some failures of biotechnologies may be due to lack of appropriate (local) solutions aimed to solve local problems and that lack of funds was not necessarily the main problem.

The negative impacts of poor research facilities were mentioned in several messages. Ajambang (30), supported by Oyewole (36), noted some of the routine challenges that many researchers face in developing countries were high customs duties for importing scientific equipment; difficulties in getting spare parts for broken scientific equipment; and power failures. Ubi (120) also named inadequate power supply as one constraint to their research in Nigeria. Pathak (96) noted that in Nepal there was no local industry producing the reagents and chemicals required for biotechnology work so they had to be imported which meant that prices were high, thus discouraging investments in this area. Oselebe (57) indicated that apart from the International Institute of Tropical Agriculture (IITA), a CGIAR institute, there were few laboratories in Nigeria equipped with facilities to assist with molecular markers. Edema (79) noted that many scientists who visited advanced laboratories abroad often had problems continuing their work when they returned home due to limited facilities.

Several messages, including Sharry (25), Rajalakshmi (104) and Pathirana (110) pointed to the lack of trained professionals. For example, Manneh (35) stated that the lack of sufficient trained manpower was "most acute in Africa where there is a serious shortage of breeders and biotechnologists in many national research programs". For sub-Saharan Africa, Danquah (99), supported by Gama (103), emphasized the importance of education, stating: "we have to go back to basics and develop not only the post-graduate schools in sub-Saharan Africa but the entire plant science programmes in institutions of higher learning. Today, a number of universities in Africa are struggling and many cannot run a good practical class for science students and many people graduate without the necessary skills to confront the challenges of any workplace. It's important for us to recognize that many of these half-baked students are those who end up in higher offices, some as politicians who never appreciate the application of science to development". Similarly, Driss (117) concluded that training should be the priority, while both Chikezie (48) and Oselebe (57) urged that donors provide funding for training. Caesar (121) proposed that a global biotechnology capacity building project be established, possibly spearheaded by FAO and UNEP.

Brain drain

Another important reason cited for failures of biotechnology was brain drain. For example, Yifru (23) reported that in the past decade or so, a number of prominent African agricultural researchers and policy analysts had left their respective national agencies, which had weakened the capacity of national agricultural research organizations and created knowledge gaps. For Caesar (121), human capacity sustainability and brain drain in developing countries were a threat to effective biotechnology development. Specific examples of brain drain were mentioned with Caesar (121) naming two key professionals that had migrated from his country, Guyana, in the past decade and Rigor (42) reporting that many trained biotechnology staff in his institute in the Philippines stayed only a short time before migrating/moving, which normally led to their projects being suspended or prematurely terminated.

Some participants felt, however, that brain drain need not be only negative, and that the professionals who migrated from developing countries could still contribute to solving problems back home. Thus, Murphy (100) felt that brain drain was "real but need not be catastrophic". He cited the case of the 2009 World Food Prize winner, Gabisa Ejeta, an Ethiopian-born scientist who worked in the United States and who developed Striga-tolerant sorghum hybrids that were widely disseminated in Africa, noting that he had been able to leverage know-how from the United States for the direct benefit of subsistence farmers in Africa. Caesar (121) noted that this model of brain gain could be explored as a way to lever the knowledge and support of citizens of developing countries who are fully established in developed countries. Predeepa (111) thought that brain drain was a necessary evil, which made it possible to learn about science, share resources and transfer

technologies between countries. Gama (103) agreed that the story of Gabisa Ejeta was inspiring, but argued that Africa needs to build its own expertise at home, a point which echoed Yifru's (23) conclusion: "at the end of the day, there will be no effective substitution for national capacity".

To act against brain drain, Caesar (121) proposed that scholarship programmes for developing country trainees in developed countries should be complemented by a subsequent home-country sustainability/support programme. C.S. Prakash (107) advocated government-sponsored building of a science-based infrastructure to prevent the problems of high staff turnover rates mentioned by Rigor (42).

Inappropriate research focus

Muralidharan (43) argued that, unlike some African countries, there was no lack of funds, facilities or expertise in biotechnology research in India, and yet agricultural biotechnology had hardly produced any benefits so far. He attributed this to excessive duplication of research; the lack of a clear objective or perspective in terms of eventual application; and over-emphasis in most organizations on purely academic aspects of research. The need to consider the end user was also emphasized in other messages such as Adebambo (72) and Tchouaffé (5), with the latter urging that national research should be re-oriented towards addressing practical problems in the country based on the farmers' needs and should be demand-driven, which was not the case currently. Murphy (80) argued that one of the reasons for the lack of capacity and focus on practical areas of agricultural research in developing countries was the general worldwide trend for scientists to shift from applied to basic research which is perceived as being more prestigious. He noted that this issue had been of concern to Norman Borlaug, the "father of the green revolution", who insisted that his staff focus on projects relevant to increasing production and discouraged "researches in pursuit of irrelevant academic butterflies". Both Jordan (83) and Yifru (84) agreed with Murphy (80), although Trigo (93) was not convinced that such a trend was seen in reality, explaining that his experience in national agricultural research systems in the Latin America and the Caribbean region was that the bulk of research was dedicated to more applied, problem solving efforts.

On a related issue, Kojo (21) argued that international donors had undue influence on the research agenda, supporting research projects in their own commercial interest and "leaving the problems facing Africa and the other developing countries still unattended to", calling it "indirect brain drain".

Lack of political will

Kojo (21) argued that another pressing issue which had contributed immensely to the failure of agricultural biotechnologies in developing countries over the last 20 years was the lack of political will in most developing countries, especially in Africa, to support

research in general. Oyewole (36) also highlighted the challenge in developing countries of governmental apathy towards research including biotechnology research, as did Gama (103) who wrote that development of indigenous biotechnology capacity was damaged by the lack of awareness or willingness of policy-makers to support biotechnology projects.

Yifru (23) noted that Africa was still far behind in the development and dissemination of appropriate agricultural technologies and products and urged that governments should give utmost priority to reinvigorating their educational systems and institutions and creating a conducive environment for biotechnology R&D in agricultural colleges and universities. The positive enabling role that government policies could play for application of biotechnologies was mentioned in several messages (Tchouaffé, 5; Olusegun, 61; Edema, 79: Traoré, 81; C.S. Prakash, 107; Muralidharan, 114). Danquah (99) also emphasized the importance of policy development, mentioning that most countries in sub-Saharan Africa did not have a science policy or a biotechnology policy, and that international organizations such as FAO needed to place policy development high on their agenda. Some developing countries have, nevertheless, prepared national biotechnology policies, including Nigeria (Usman, 37) and Sri Lanka (Pathirana, 110).

6.3.8 Cross-sectoral discussions: Suggestions for increasing the success of agricultural biotechnologies in developing countries

In the conference, many participants also suggested ways to ensure that applications of agricultural biotechnologies would be successful in developing countries in the future. These discussions are summarized below.

Research should be directed to the real problems of farmers

To enhance the benefits of applying biotechnologies in developing countries, one of the key suggestions made by participants was that research should be directed to address the real practical problems of farmers in developing countries. For example, Kumarasamy (29) stated that for biotechnology to be more effective in the future, problems from the field should be identified, the research should be results-oriented and it should lead to applications in the field. Similar views were expressed by Tchouaffé (5), Satish Kumar (31), Muralidharan (43) and Infante (85). Nimbkar (55) agreed with Satish Kumar (31) and Muralidharan (43) that biotechnology research should fit into a comprehensive improvement programme for the given sector and be focused on applicability. Otherwise, she said, it would use scarce financial resources without delivering the expected progress (55).

To encourage researchers to focus on applied, more practical research than basic, more academic research, Murphy (80) suggested that the status of applied researchers should be boosted and they should be rewarded equally compared with their more academic colleagues;

the public sector in all countries should shift the emphasis to socially valuable applied R&D; and resource-strong bodies like the European Union should channel collaborative funding with developing countries towards such areas. Jordan (83) agreed, and advocated increasing the funding and status of the applied disciplines so that the potential gains from applying biotechnologies can actually be realized. Yifru (84) also agreed, stating that "national governments in developing countries and their international partners need to work towards revitalizing applied research in the public sector". To arrive at a successful application of biotechnology, however, Infante (85) and Trigo (93) argued that both basic and applied research are needed, with Infante (85) giving an example of his work in sequencing the cocoa genome to indicate why this was true, and Trigo (93) arguing that an examination of success stories indicates that most of them had both research components.

Strengthened extension services

As stated eloquently by Murphy (100): "R&D is like a hosepipe - there is little point in filling it with water if the outlet remains blocked!". Having directed R&D towards the real problems of the farmers, to ensure that these results actually reach and benefit farmers in developing countries, participants suggested that extension systems be strengthened (Tonjock, 9; Moro, 14; Cruz, 32). Tababa (67) reported that one of the factors that facilitated adoption of biotechnologies in the Philippines was strong agricultural extension. For rice biotechnologies and their products, Manneh (35) concluded that to enable their wider use there was a need to reinforce national capacities such as the national research and extension systems. The importance of providing appropriate and timely information to farmers was also highlighted by Falck-Zepeda (20) and Zambrano (59) in their IFPRI studies on adoption of GM crops in South America.

Increased regional and sub-regional cooperation

Several participants suggested that increased regional and sub-regional cooperation would increase the benefits of applying biotechnologies. For sub-Saharan Africa, Danquah (99) concluded that biotechnologies had failed to deliver on their promise in the past and to change this he highlighted the importance of education, capacity building and close collaboration between institutions and universities in sub-Saharan Africa. He also proposed the establishment of sub-regional centres of excellence and innovations in sub-Saharan Africa to train the next generation of African biotechnologists. Gama (103) agreed with this proposal as did Hash (105) who, however, underlined that the centres should be linked with agencies involved in technology delivery to ensure that research products were delivered and accessible to farmers. Hash (105) noted that for breeding programmes wishing to use molecular markers it would be very useful if service laboratories providing

high quality and cost-effective marker data could be established at sub-regional hubs. Agreeing with Danquah (99), Caesar (121) stressed the need for capacity building and outlined the key features of a potential global biotechnology capacity building project, building on regional and sub-regional groupings of developing countries and including a comprehensive scholarship/fellowship programme for developing countries. Commenting on the many messages describing the lack of facilities and capacity for biotech R&D in developing countries, Murphy (100) felt it might be unrealistic for each country, however small, to have its own research programme and he advocated increased collaboration with neighbouring countries and with centres in developed countries. Gama (103), however, disagreed that it was unrealistic to have a national programme.

Regional collaboration can be promoted through South-South cooperation programmes and a number of UN and non-UN international organizations provide assistance for South-South cooperation. McGrath (69) described one such example from the Academy of Sciences for the Developing World (TWAS), which supports young scientists from developing countries to carry out research in centres of excellences in other developing countries.

Public-private partnerships (PPPs)

Several participants suggested strengthening collaboration between the public and the private sectors as, following Roca (74), it "can create a win-win outcome in addressing local problems". Some recent examples of PPPs were described, including the water efficient maize for Africa project, a PPP led by the African Agricultural Technology Foundation (AATF), involving five African national agricultural research systems, two donor foundations, the International Maize and Wheat Improvement Center (a CGIAR institute) and Monsanto (C.S. Prakash, 107). Launched in 2008, its goal is to produce drought-tolerant maize varieties and make them available to small-scale farmers in sub-Saharan Africa. Echenique (41, 64) also described the WheatBiotech project launched in 2008 and developed by 12 partners including seven private breeding companies in Argentina. Its goal is to exploit biotechnological tools to improve the competitiveness and sustainability of the Argentinean wheat chain.

The private sector is playing a significant role in commercializing products resulting from agricultural biotechnologies in various developing countries, and numerous messages in the conference documented this. Examples were provided for biofertilizers in Mexico (Peralta, 22, 50); genetic modification in the Philippines (Cruz, 32) and India (Banerjee, 15; Prakash, 28); MAS in India (Hash, 44; Banerjee, 15); and tissue culture in El Salvador (Orellana, 62), the Philippines (Tababa, 67) and Sri Lanka (Pathirana, 110). Both national and multinational companies are involved (e.g. Priyadarshan, 6; Moro, 11; Banerjee, 15; Prakash, 28).

Hash (68) underlined that use of biotechnology tools needed to be strongly linked to applied product development, testing and delivery systems that address any relevant regulatory, multiplication and marketing issues. He therefore concluded: "this means that public sector biotechnology research will generally need to have strong links to the private sector if it is to have a high likelihood of delivering successful applied products within a reasonable time frame". For species that are already the target of large-scale private sector research investments, he did not, however, exclude investments by the public sector, but advised that they be focused. Similarly, Trigo (93) argued that because of the lack of management capacities and resources most public sector institutions had difficulties in handling many of the downstream issues such as biosafety (for GMOs) and intellectual property rights, and so they often ended up making agreements with private companies to handle those stages. Hash (68) noted, however, that it may then be difficult to apply biotechnology in situations where there are very small markets or where much of the product delivery and dissemination occurs via informal or traditional technology exchange systems. In many African countries, more than 80 percent of seeds used in agriculture are supplied by the informal system (Manneh, 35).

Yifru (84) argued that when commercialization was dominated by the private rather than the public sector, the crops or traits of critical importance for poor farmers (such as "orphan crops") received less attention and there was an increasing shift in research/funding from food crops to export-oriented crops. To overcome these kinds of hurdles, he and others (e.g. Trigo, 93) called for increased public sector investments and to focus them on applied research so that the public sector can ensure that biotechnologies "are employed for the common good as well as for private profit" (Murphy, 100).

6.3.9 Participation in the conference

A total of 834 people subscribed, of whom 83 (i.e. 10 percent) submitted at least one message. Of the 121 messages that were posted, 33 (27 percent) came from people living in Asia; 32 (26 percent) from Africa; 24 (20 percent) from Latin America and the Caribbean; 16 (13 percent) from North America; 10 (8 percent) from Europe; and 6 (5 percent) from Oceania. The messages came from people living in 36 different countries, the greatest number coming from India (27 messages), Nigeria (12), Argentina (11), United States (9) and Cameroon (5). A total of 90 messages (i.e. 74 percent) were posted by participants living in developing countries.

Forty eight messages (40 percent) came from people working in universities; 34 (28 percent) from people working in research centres (28 in national institutes and 6 in CGIAR centres); 12 (10 percent) from people in the private sector; ten (8 percent) from participants from non-governmental organizations; eight (7 percent) from people working as independent consultants; six (5 percent) from people in Governments; two from the UN and one from a development agency.

Here below, the names are provided of participants with referenced messages, as well as the country in which they are living:

Adebambo, Ayotunde
Nigeria

Ahmed, Kasem Zaki
Egypt

Ajambang, Walter
Indonesia

Ali, Ahmad
Pakistan

Anderson, Paul
United States of America

Banerjee, Partha
India

Beach, Larry
United States of America

Bett, Bosibori
Kenya

Caesar, John
Guyana

Chikezie, Uche
Nigeria

Cruz, Von Mark
The Philippines

Danquah, Eric
Ghana

Dávila, Doris Zúñiga
Peru

Driss, Sadok
Tunisia

Dudhare, M.S.
India

Echereobia, Christopher
Nigeria

Echenique, Viviana
Argentina

Edema, Mojisola
Nigeria

Egesi, Chiedozie
Nigeria

Escandon, Alejandro
Argentina

Falck-Zepeda, José
United States of America

Gama, Peter
The Sudan

Giddings, Val
United States of America

Glover, Dominic
The Netherlands

Gupta, P.K.
India

Gurian-Sherman, Doug
United States of America

Hash, Tom
India

Infante, Diógenes
Venezuela

Jordan, David
Australia

Kamanga, Daniel
South Africa

Keshavachandran, R.
India

Kojo, Agyemang
Ghana

Kumar, Dinesh
India

Kumar, Satish
India

Kumarasamy, P.
India

Loquang, Thomas
Uganda

Manneh, Baboucarr
Senegal

McGrath, Peter
Italy

Moro, José
Canada

Muchadeyi, Farai
South Africa

Muralidharan, E.M.
India

Murphy, Denis
United Kingdom

Nassar, Nagib
Brazil

Nimbkar, Chanda
India

Nzeduru, Chinyere
Nigeria

Olusegun, Obadina Adewale
Nigeria

Orellana, Mario Antonio
El Salvador

Oselebe, Happiness
Nigeria

Oyewole, Olusola
Nigeria

Parrott, Wayne
United States of America

Pathak, Dhruba
Serbia

Pathirana, Ranjith
New Zealand

Peralta, Humberto
Mexico

Prakash
India

Prakash, C.S.
United States of America

Predeepa, Rachel
Australia

Priyadarshan, P.M.
India

Raheem, Dele
United Kingdom

Rajalakshmi, K.
India

Rigor, Alex
The Philippines

Roca, Maria Mercedes
Honduras

Sangar, Sunita
India

Seshadri, S.
India

Sharry, Sandra
Argentina

Singh, Harjit
Canada

Sivakumar, S.
India

Souza, Lúcia de
Brazil

Tababa, Sonny
Singapore

Tchouaffé, Norbert
Cameroon

Tonjock, Rosemary
Cameroon

Traoré, Adama
Mali

Trigo, Eduardo
Argentina

Ubi, Benjamin
Japan

Usman, Raheef Ademola
Nigeria

Van der Meer, Piet
The Netherlands

Yifru, Worku Damena
Canada

Yongabi, Kenneth Anchang
Cameroon

Zambrano, Patricia
United States of America

Zidana, Hastings
Malawi

6.4 REFERENCES

Adams, A. & Thompson, K.D. 2008. Recent applications of biotechnology to novel diagnostics for aquatic animals. *Rev. Sci. Tech. Off. Int. Epiz.,* 27: 197–209.

Chandler, D., Davidson, G., Grant, W.P., Greaves, J. & Satchel, G.M. 2008. Microbial biopesticides for integrated crop management: an assessment of environmental and regulatory sustainability. *Trends Food Sci. Technol.,* 19: 275–283.

Chauvet, M. & Ochoa, R.F. 1996. An appraisal of the use of rBST in Mexico. *Biotechnol. Dev. Monitor,* 27: 6–7. (available at www.biotech-monitor.nl/2703.htm).

Chupin, D. 1992. Résultats d'une enquête sur l'état de l'insémination artificielle dans les pays en développement. *Elevage et Insémination,* 252: 1–26.

FAO. 2001. *Glossary of biotechnology for food and agriculture*, by A. Zaid, H.G. Hughes, E. Porceddu & F. Nicholas. FAO Research and Technology Paper 9. (also available at www.fao.org/docrep/004/y2775e/y2775e00.htm).

FAO. 2004. *Preliminary review of biotechnology in forestry, including genetic modification*. Forest Genetic Resources Working Paper FGR/59E. Rome. (also available at www.fao.org/docrep/008/ae574e/ae574e00.htm).

FAO. 2006a. Background document to the e-mail conference on the role of biotechnology for the characterization and conservation of crop, forest, animal and fishery genetic resources in developing countries, by J. Ruane & A. Sonnino. *In* J. Ruane & A. Sonnino, eds. *The role of biotechnology in exploring and protecting agricultural genetic resources*. pp. 151–172. Rome. (available at www.fao.org/docrep/009/a0399e/A0399E09.htm#ch4.1).

FAO. 2006b. *Results from the FAO biotechnology forum: Background and dialogue on selected issues*, by J. Ruane & A. Sonnino. FAO Research and Technology Paper 11. Rome. (available at www.fao.org/docrep/009/a0744e/a0744e00.htm).

FAO. 2006c. The potential of cryopreservation and reproductive technologies for animal genetic resources conservation strategies, by S.J. Hiemstra, T. van der Lende & H. Woelders. *In* J. Ruane & A. Sonnino, eds. *The role of biotechnology in exploring and protecting agricultural genetic resources*. Rome. (available at www.fao.org/docrep/009/a0399e/A0399E06.htm#ch2.1).

FAO. 2006d. Status of cryopreservation technologies in plants (crops and forest trees), by B. Panis & M. Lambardi. *In* J. Ruane & A. Sonnino, eds. *The role of biotechnology in exploring and protecting agricultural genetic resources*. pp. 61–78. Rome. (available at www.fao.org/docrep/009/a0399e/A0399E06.htm#ch2.2).

FAO. 2007a. *Marker-assisted selection: Current status and future perspectives in crops, livestock, forestry and fish*. E.P. Guimarães, J. Ruane, B.D. Scherf, A. Sonnino & J.D. Dargie, eds. Rome. (also available at www.fao.org/docrep/010/a1120e/a1120e00.htm).

FAO. 2007b. The state of capacities in animal genetic resources management: Reproductive and molecular biotechnology. *In* B. Rischkowsky & D. Pilling, eds. *The state of the world's animal genetic resources for food and agriculture*. Chapter 3.D. Rome. (also available at ftp://ftp.fao.org/docrep/fao/010/a1250e/a1250e13.pdf)

FAO. 2008a. *The role of agricultural biotechnologies for production of bioenergy in developing countries*. Background document to conference 15 of the FAO biotechnology forum (10 November to 14 December 2008). Rome. (available at www.fao.org/biotech/C15doc.htm).

FAO. 2008b. *Guide to laboratory establishment for plant nutrient analysis*, by M.R. Motsara & R.N. Roy. FAO Fertilizer and Plant Nutrition Bulletin 19. Rome. (also available at www.fao.org/docrep/011/i0131e/i0131e00.htm).

FAO. 2009a. Assessing the socio-economic impacts of non-transgenic biotechnologies in developing countries, by A. Sonnino, Z. Dhlamini, L. Mayer-Tasch & F.M. Santucci. *In* A. Sonnino, Z. Dhlamini, F.M. Santucci & P. Warren, eds. *Socio-economic impacts of non-transgenic biotechnologies in developing countries: The case of plant micropropagation in Africa*. Rome. (also available at www.fao.org/docrep/011/i0340e/i0340e00.htm).

FAO. 2009b. Report of the 39th Session of the FAO Desert Locust Control Committee, Rome, Italy, 10-13 March 2009. Rome. (available at www.fao.org/ag/locusts/common/ecg/1665/en/DLCC39e.pdf).

FAO/IAEA. 2008. *Atoms for food: A global partnership*. (available at www.iaea.or.at/Publications/Booklets/Fao/fao1008.pdf).

IAEA. 2008. *Nuclear science for food security*. IAEA press release. (available at www.iaea.org/NewsCenter/PressReleases/2008/prn200820.html).

James, C. 2008. *Global status of commercialized biotech/GM crops: 2008*. ISAAA Brief 39.

Kurath, G. 2008. Biotechnology and DNA vaccines for aquatic animals. *Rev. Sci. Tech. Off. Epiz.,* 27: 175–196.

MacKenzie, A.A. 2005. *Applications of genetic engineering for livestock and biotechnology products*. Paper presented at the 73rd OIE General Session. Paris, OIE. (available at ftp://ftp.fao.org/codex/ccfbt5/bt0503ae.pdf).

Paterson, A.H., Bowers, J.E., Bruggmann, R. et al. 2009. The *Sorghum bicolor* genome and the diversification of grasses. *Nature,* 457: 551–556.

Rao, N.K. 2004. Plant genetic resources: Advancing conservation and use through biotechnology. *Afr. J. Biotechnol.,* 3: 136-145. (also available at www.academicjournals.org/AJB/PDF/Pdf2004/Feb/Rao.pdf).

Varshney, R.K., Hoisington, D.A. & Tyagi, A.K. 2006. Advances in cereal genomics and applications in crop breeding. *Trends Biotechnol.,* 24: 490–499.