Summary document of the FAO e-conference “Learning from the past: Successes and failures with agricultural biotechnologies in developing countries over the last 20 years"

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Executive Summary

This document summarizes the major issues discussed by the participants of a moderated e-mail conference hosted by the FAO Biotechnology Forum from 8 June to 8 July 2009, entitled "Learning from the past: Successes and failures with agricultural biotechnologies in developing countries over the last 20 years". It took place as part of the build up to the FAO international technical conference on Agricultural Biotechnologies in Developing Countries (ABDC-10), that was held in Guadalajara, Mexico on 1-4 March 2010 (www.fao.org/biotech/abdc/).

Participants in the 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 in developing countries. 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 genetically modified (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, resulting in release of new wheat varieties in the Sudan and the well-known new rice in Africa (NERICA) varieties.

For marker-assisted selection (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 end. Consultative Group on International Agricultural Research (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 issue 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 artificial insemination (AI) as well as embryo transfer 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 regarding 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 only 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 role 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.

1. Introduction

The title of the 16th e-mail conference of the FAO Biotechnology Forum, which took place from 8 June to 8 July 2009, was "Learning from the past: Successes and failures with agricultural biotechnologies in developing countries over the last 20 years". The aim of this e-mail conference was to bring together and discuss relevant, often previously un-documented, past experiences of applying biotechnologies used by farmers in developing countries; ascertain the success or failure, partial or total, of their application; determine and evaluate the key factors that were responsible for their success or failure; ascertain the transferability of the results to other developing countries, biotechnologies and sectors; and draw lessons that might be important for applications of agricultural biotechnologies in developing countries in the future.

This cross-sectoral e-mail conference was hosted to complement a series of five technical sector-specific documents, on biotechnology applications in crops, forestry, livestock, fisheries and aquaculture, and food processing and food safety, that were prepared for the FAO international technical conference on "Agricultural biotechnologies in developing countries: Options and opportunities in crops, forestry, livestock, fisheries and agro-industry to face the challenges of food insecurity and climate change" (ABDC-10, www.fao.org/biotech/abdc/) that was held in Guadalajara, Mexico on 1-4 March 2010. Some of the specific examples discussed in the e-mail conference were later presented as case studies at ABDC-10 and links to these presentations are included in this document.

As for all other conferences of this Forum, a Background Document (www.fao.org/fileadmin/user_upload/abdc/documents/emailconf.pdf) was prepared before the conference. This document provided a description and overview of the main kinds of agricultural biotechnologies that have been used in the five different sectors in developing countries over the past 20 years (e.g. use of molecular markers, genetic modification, chromosome set manipulation, biotechnology-based diagnostics, development of vaccines using biotechnologies, reproductive biotechnologies in livestock and aquaculture, cryopreservation, tissue culture-based techniques, mutagenesis, fermentation, biofertilizers and biopesticides). It also gave some examples of their applications in specific developing countries and some guidance about the e-mail conference, which included a description of the issues participants should address as well as potential factors to consider when assessing whether specific applications of a biotechnology have been a partial or complete success or failure.

This Summary Document presents a concise account of major issues discussed by the participants. A total of 834 people subscribed to the conference and 121 e-mail messages were posted by 83 participants from 36 different countries. The conference was moderated by John Ruane, from the FAO Working Group on Biotechnology. 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 Sections 2 to 7 of this document, the main issues discussed during the conference are summarized. Sections 2 to 5 deal with sector-specific discussions. Section 6 and 7 cover cross-sectoral discussions, where participants discussed successes and failures of agricultural biotechnologies in general, without specifying a given sector or biotechnology. Section 6 covers discussions about the reasons for failures of agricultural biotechnologies in developing countries and Section 7 focuses 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 (all messages are available at www.fao.org/biotech/logs/c16logs.htm). Section 8 provides a summary of information on participation in the conference – including the area of work and geographic distribution of the participants. Section 9 lists the names and countries of those who sent messages that are referenced in this document.

2. Biotechnologies in crops

In their messages, participants focused on the use of genetic modification, in particular, as well as tissue culture, molecular markers, biofertilizers and induced mutation.

2.1 Genetic modification

There was considerable discussion in the conference about the success or failure of genetically modified (GM) crops in developing countries. Most of the discussions 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 were also some 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) all referred to the 2008 figures from the International Service for the Acquisition of Agri-Biotech Applications, estimating that GM crops were cultivated on 125 million hectares 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 [and 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 and the Philippines; insect resistant cotton in Colombia; and herbicide tolerant soybeans in Bolivia. Results showed that the impact of adopting genetically modified organisms (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 complimentary 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 a lot of 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. [Presentations by Zambrano and by Fonseca & Zambrano on GM cotton in Colombia were given at ABDC-10, at www.fao.org/fileadmin/templates/abdc/documents/zambrano.pdf and www.fao.org/fileadmin/templates/abdc/documents/fonseca.pdf respectively].

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 20 billion US dollars 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 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 practice 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 a lot of 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 hectares in Nigeria.

In addition to the many messages discussing specific examples of GM crops, there was also considerable discussion during the conference 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 sector. Similarly, Giddings (118) argued that “scientifically unsupportable regulatory burdens” were blocking wider dissemination of GM crops.

2.2 Tissue culture

As described in the Background Document, 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 doubled haploid individuals; 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 India 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 the 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 South-East 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 new rice for Africa (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 hectares) by farmers in Africa, he argued that one of the major impediments to the wide-scale 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". [A presentation of the NERICA case study was given at ABDC-10, www.fao.org/fileadmin/templates/abdc/documents/nerica.pdf].

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, reporting 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.

2.3 Molecular markers

Several messages dealt with the use of molecular markers for genetic improvement in crops. From the contributions, it was suggested that marker-assisted selection (MAS) has been used with reasonable success in countries such as India and 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 Consultative Group on International Agricultural Research (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, F1 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 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 end.

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 to 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 that it 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 turn-over 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 program 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).

2.4 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 got access to printed material, sessions with agronomists and further assistance (50). [A presentation of this case study was given by Peralta at ABDC-10, www.fao.org/fileadmin/templates/abdc/documents/peralta.pdf]. 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 are 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).

2.5 Induced mutation

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.

3. Biotechnologies in livestock and aquaculture

The majority of livestock-specific messages focused on biotechnologies for genetic improvement, including artificial insemination (AI), embryo transfer 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 practiced 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 embryo transfer, 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 DNA 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. [The Deccani sheep case study was presented by Nimbkar at ABDC-10, www.fao.org/fileadmin/templates/abdc/documents/chanda.pdf].

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 (enzyme-linked immunosorbent assay) techniques for disease diagnosis in cattle and buffalo had made any impact at the field level. Roca (74) also noted that good progress had been made on the use of immunological and molecular approaches for diagnostics 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 septicemia), 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 production of 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).

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 the 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 a 2004 FAO report 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. [The Malaysian case study was presented at ABDC-10, www.fao.org/fileadmin/templates/abdc/documents/teak.pdf].

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 practicing 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 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 to 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 behavior 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.

5. 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 in Nigeria 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 "Ogi", used to treat childhood diarrhea. 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. [A presentation of the soy sauce case study was given at ABDC-10, www.fao.org/fileadmin/templates/abdc/documents/soysauce.pdf].

Nevertheless, Olusegun (61) noted that, even though 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 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 day knowledge.

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

In Sections 2 to 5, 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 Section, these cross-sectoral discussions about the reasons for failures in applying agricultural biotechnologies in developing countries are summarized.

6.1 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 manpower 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 as one of the reasons for the failure in many messages (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, such as high custom 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, 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, that could be spearheaded by FAO and UNEP.

6.2 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 a lot of 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 that 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 turn-over rates mentioned by Rigor (42).

6.3 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”.

6.4 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).

7. 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 here.

7.1 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 result 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 to 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.

7.2 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.

7.3 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 African, 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 co-operation programmes and a number of UN and non-UN international organizations provide assistance for South-South co-operation. 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.

7.4 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 in the conference, including the water efficient maize for Africa project, a PPP led by the African Agricultural Technology Foundation, 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).

8. 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; 10 (8 percent) from participants from non-governmental organizations; 8 (7 percent) from people working as independent consultants; 6 (5 percent) from people in Governments; 2 from the UN and 1 from a development agency.

9. Name of participants with referenced messages and 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. 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

ABBREVIATIONS: AI = Artificial insemination; Bt = Bacillus thuringiensis; CGIAR = Consultative Group on International Agricultural Research; CMVD = Cassava mosaic virus disease; FAO = Food and Agriculture Organization of the United Nations; GMO = Genetically modified organism; IAEA = International Atomic Energy Agency; IFPRI = International Food Policy Research Institute; MAS = Marker-assisted selection; NERICA = New rice in Africa; PPP = Public-private partnership; REDBIO = Technical Co-operation Network on Agricultural Biotechnology in Latin America and the Caribbean

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