CHAPTER 21

Marker-assisted selection as a potential tool for genetic improvement in developing countries: debating the issues

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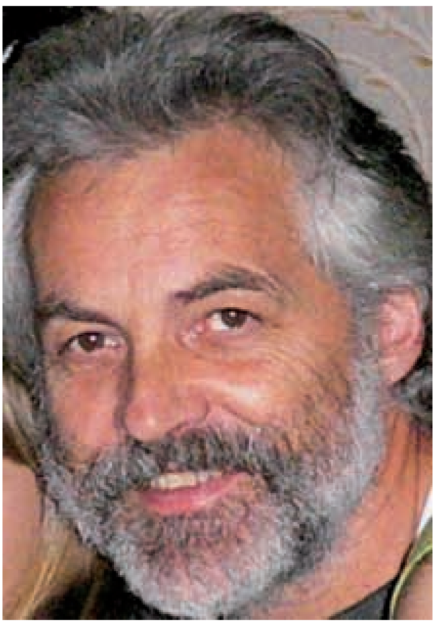

SUMMARY

Marker-assisted selection (MAS) is a complementary technology, for use in conjunction with more established conventional methods of genetic selection, for plant and animal improvement. It has generated a good deal of expectations, many of which have yet to be realized. Although documentation is limited, the current impact of MAS on products delivered to farmers seems small. While the future possibilities and potential impacts of MAS are considerable, there are also obstacles to its use, particularly in developing countries. Principal among these are issues relating to current high costs of the technology and its appropriateness, given that publicly funded agricultural research in many developing countries is suboptimal and development priorities do not necessarily include genetic improvement programmes. Other potential obstacles to the uptake of MAS in developing countries include limited infrastructure, the absence of conventional selection and breeding programmes, poor private sector involvement and lack of research on specific crops of importance in developing countries. Intellectual property rights may also be an important constraint to development and uptake of MAS in the developing world. It is hoped that through partnerships between developing and developed country institutions and individuals, including public–private sector collaboration, MAS costs can be reduced, resources pooled and shared and capacity developed. With the assistance of the Consultative Group on International Agricultural Research (CGIAR) and international organizations such as FAO, developing countries can benefit more from MAS. These were some of the outcomes of a moderated e-mail conference, entitled “Molecular Marker-Assisted Selection as a Potential Tool for Genetic Improvement of Crops, Forest Trees, Livestock and Fish in Developing Countries”, that FAO hosted at the end of 2003. During the four-week conference, 627 people subscribed and 85 messages were posted, about 60 percent coming from people living in developing countries. Most messages (88 percent) came from people working in research centres (national or international) or universities. The remainder came from people working as independent consultants or from farmer organizations, government agencies, non-governmental organizations (NGOs) or United Nations (UN) organizations.

INTRODUCTION

FAO, an intergovernmental organization with 189 Member Nations and one Member Organization, was founded in 1945 with a mandate to raise levels of nutrition and standards of living, to improve agricultural productivity, and to better the condition of rural populations. One of FAO's primary roles is to serve as a knowledge network sharing information on agriculture. It uses the expertise of its staff, agronomists, foresters, fisheries and livestock specialists, nutritionists, social scientists, economists, statisticians and other professionals, to collect, analyse and disseminate data that aid development. The information is made available using a number of different strategies, e.g. providing documents on the FAO Web site that can be freely downloaded, publishing hundreds of newsletters, reports and books, and hosting dozens of electronic fora. In this context, FAO has also been playing an active part in disseminating information and promoting information exchange regarding biotechnology. For example, in 2000 it established the FAO Biotechnology Forum (www.fao.org/biotech/forum.asp), with the aim of providing quality balanced information on agricultural biotechnology in developing countries and making a neutral platform available for people to exchange views and experiences on this subject.

At the end of 2003, the FAO Biotechnology Forum hosted a four-week long e-mail conference entitled "Molecular Marker-Assisted Selection as a Potential Tool for Genetic Improvement of Crops, Forest Trees, Livestock and Fish in Developing Countries". The conference was open to everyone and 627 people subscribed. Each of them received a ten-page document providing easily understandable background information on the conference theme, so that those with little knowledge of the area could understand what the theme was about. The conference was moderated (by John Ruane) and participants were requested to introduce themselves briefly in their first posting to the conference and to limit their messages to 600 words. During the conference, 85 messages were posted, each numbered in chronological order. Of the 627 subscribers, 52 (8 percent) submitted at least one message. Messages were received from each of the different world regions, 28 of the 85 messages (33 percent) were posted from Asia, 26 percent from Europe, 14 percent from Latin America and the Caribbean, 9 percent each from Africa and Oceania and 8 percent from North America. Messages were posted from people living in 26 different countries, the largest numbers from India (25 percent), followed by Australia (9 percent), United States of America (8 percent), United Kingdom (7 percent) and Peru (6 percent), with the remainder from Argentina, Austria, Benin, Brazil, Chile, Cyprus, Egypt, Finland, France, Germany, Ireland, Israel, Kenya, Madagascar, Mexico, Netherlands, Nigeria, Philippines, Spain, Syrian Arab Republic and Turkey. Fifty messages (59 percent) were contributed from people in developing countries and 35 (41 percent) in developed countries. The majority of messages came from people working in research centres (52 percent), including Consultative Group on International Agricultural Research (CGIAR) centres, and in universities (37 percent). The remainder worked as independent consultants or for farmer organizations, government agencies, NGOs or UN organizations.

This chapter summarizes the main issues that were discussed during the conference, based on the messages posted by the participants. These included some general topics regarding MAS (such as its costs, its actual impact to date on products delivered to farmers, whether it should be a priority in developing countries and whether it was necessary to have an established breeding programme in place before introducing MAS), as well as some MAS-related issues that were more technical, such as which traits are suitable for MAS and the importance of tight marker-gene linkages. Other kinds of issues raised included intellectual property rights, public–private sector linkages, the differences in capacity between developing countries with respect to MAS and the role of the CGIAR and international organizations. Throughout the chapter, specific references to messages posted are provided, giving the participant's surname and message number. All the individual messages are available at www.fao.org/biotech/logs/c10logs.htm.

During the conference, contributions were not evenly spread across the four agricultural sectors of the conference. MAS for crop and livestock genetic improvement dominated the discussions, with issues relating to forest trees and aquaculture mentioned much less, possibly indicating differences in uptake of this relatively new technology among the four sectors. Nonetheless, many of the issues and concerns raised were general in nature and applicable across sectors. These issues included considerations of costs and gains, intellectual property rights and the benefits of partnerships to allow developing countries greater opportunities for developing and using MAS.

Murphy (1) began the conference with a request that MAS be viewed dispassionately as a potential tool for crop improvement to be deployed alongside conventional methods. Sokefun (64) referred to conventional selection methods as "soft" technologies and the newer technologies, such as MAS, as "hard" technologies, and suggested that the hard would not replace the soft technologies and that a fusion of both would achieve the best results. In contrast to more upstream technologies (including genetic modification, mutagenesis and protoplast fusion), which generate additional variation in plant populations, Murphy (1) described MAS as a "downstream technology" that, like conventional phenotypic selection, can be used to select the optimal variants in a population.

The conference discussion was balanced and the topic of the potential of MAS did not evoke a strong reaction among the participants, although many had reservations about it. There was consequently little indication of a substantial dichotomy of opinion whereby participants could be put into pro- and anti-MAS camps. This is in sharp contrast to many debates that have been held about genetic modification. As stated by Muralidharan (7), MAS differs from genetic modification in being more widely acceptable.

There was considerable agreement among the participants on the perceived opportunities and constraints associated with MAS and the usefulness and applicability of the technology in developing countries. Olori (21) thought that successful application of MAS in a well structured breeding programme in any developing country would yield the same benefits as in developed countries. However, as suggested by Montaldo (18) for genetic improvement in animals, it would be necessary to make case-by-case studies, taking into account not only biological issues, but also social, political and economic ones, before making recommendations on application of MAS.

MAIN THEMES DISCUSSED

Whether MAS should be a priority in developing countries

The general opinion was that MAS could be usefully applied for genetic improvement of plants and animals in developing countries, but that it would not necessarily represent a priority. Gianola (6) pointed out that in order for MAS to be taken up in developing countries, because of the scarcity of resources the returns to investment should be far superior compared with those for a developed country, given the significant opportunity costs. Africa was mentioned as facing major constraints to agricultural production, including drought stress, low soil fertility and pests, which were not easily and economically amenable to MAS. Koudandé (68) and Seth (26) stressed the importance of priority-setting in the context of national agricultural economies. Crop diversification and research on underutilized species were also mentioned as other possible priorities for addressing problems of the expanding human population (Priyadarshan, 11 and 71). Murphy (1) suggested that tremendous gains could be made in agricultural development without resorting to applications of biotechnology, by addressing issues of management and infrastructure. For example, in the case of Brazil, a priority might be improvements in the road system to facilitate export crops reaching the ports (Murphy, 1).

Costs of MAS

The cost associated with MAS was a common theme during the conference and several participants, including Collard (9), considered it to be the most important issue for developing countries. It was pointed out (e.g. De Koning, 13) that although costs associated with MAS can be high, conventional genetic improvement programmes can also be expensive. Gianola (2) called for an economic analysis of MAS in comparison with conventional methods, specifically requesting estimates of internal rates of return. He (6) also warned that there was a risk that some investments in MAS might be wasted given the advances being made in post-genomics. For Weller (4), "with respect to the economic questions, MAS is no different from any other technology that increases rates of genetic gain, but also increases costs", concluding that the investments required for MAS could be massive, but so also could the long-term economic gains. However, as pointed out by Montaldo (18), the economics of MAS is based on the value of the selected traits and most importantly, each case should be looked at individually. De Koning (13) highlighted the major economic benefits that could be gained by breeding livestock for resistance to trypanosomiasis.

Various stages in the MAS development and application process were regarded as being costly. Labour and DNA extraction were viewed by Williams (37) as representing the major costs, but Collard (45) considered equipment, consumables and infrastructure to be among the most costly items in a MAS programme. Genotyping (Toro, 67), marker development (El Ouafi, 77; Wallwork, 59) and patenting (Ganunga, 69) were other areas that represented large costs that might constrain MAS use in developing countries. It was suggested that farmers in the developing world could not be expected to pay for MAS (Chávez, 33), while Muralidharan (74) suggested that costs in a country like India would eventually be a lot cheaper than in developed countries.

Participants, including Buijs (58), pointed out that technologies become cheaper as knowledge accumulates and capacity is built up, citing the example of tissue culture. Buijs (22) also felt that the costs of MAS should be put in perspective with those from other related research areas, pointing out that plant varieties or animals bred by MAS do not require costly safety regulations, in contrast to those bred using genetic modification. Toro (50) and Muralidharan (74) suggested that MAS would become cheaper due to automation/robotics, and Varshney (82) reported that microsatellite marker development has become cheaper as a result of bioinformatics. Many participants suggested that developing countries could make the best use of MAS through collaborative ventures (Olori, 21, 65; Acikgoz, 66; Saravanan, 73), formation of multidisciplinary teams (Sridhar, 76; William, 70; Muchugi, 49) and within national and regional frameworks (Montaldo, 18). Collaboration would spread resources and reduce costs.

Figures for the costs of genotyping mentioned in the conference ranged from US$4 per marker for MAS in pigs (Toro, 79) to under US$0.2 for durum wheat (El Ouafi, 77). Discussion of such exact figures for costs is at best indicative in the face of continuous changes in the world economy, particularly in exchange rates and purchasing power. Suffice to say that as costs are reduced, the value of MAS rises and it possibly becomes more widely applicable.

Putting MAS in context

Although MAS has generated a good deal of expectations, leading in some cases to over-optimism and in others to disappointment because many of the expectations have not yet been realized, participants in the conference aimed to consider MAS rationally and to put it in the context of the whole agricultural picture. As Murphy (1) wrote, MAS "should be viewed dispassionately as a potential tool for crop improvement to be usefully deployed alongside conventional phenotype selection for certain crops and for certain characters".

Good genetic improvement strategies were considered by many to be among the most important prerequisites for successful implementation of MAS. Montaldo (18) said that, with respect to livestock improvement, MAS would not substitute for choosing the right breeding objectives and the starting point of a programme incorporating MAS should be a sound breeding strategy founded on traditional selection methodology. Wallwork (59) thought that many of the criticisms of MAS (e.g. see De Lange, 57) stemmed from poor research and development strategies and not necessarily from shortcomings in the technology. El Ouafi (77) stated plainly that if a successful conventional breeding programme could not be established, MAS would not help, and Olori (21) suggested that the absence of "any real sense of the need for a genetic improvement programme" in developing countries would hinder application of MAS. Such practical strategic considerations balance the hyperbole and over-optimism that has sometimes been associated with MAS. De Lange (57) argued that because of its high costs and relatively moderate results to date, MAS seemed to be "yet another over-hyped gene technology" and questioned, like Ackigoz (66), whether MAS should be a primary consideration for developing countries. Bhatia (8) was among several participants to comment on this issue and believed that the hyperbole to some extent reflected fashion and vendor bias, as for all new technologies.

MAS in relation to conventional breeding programmes

The need for an established breeding programme to be in place for MAS to be usefully introduced represented one of the main points debated in the conference. Many participants (e.g. Montaldo, 18) explicitly stated the need for a conventional programme to be operational prior to implementation of MAS and others inferred it. Notter (25), on the other hand, suggested that animal recording need not precede implementation of MAS, and he proposed they could be implemented together.

Referring to animal trypanosomosis in Africa, De Koning (13) commented that lack of routine recording of production and health traits, with limited national molecular research facilities, presented a structural problem to implementing a breeding programme using MAS. De Koning (20) also said that when livestock were mainly kept by smallholders, each with a handful of animals, there would be no routine recording. Makkar (52) too suggested that in the low input systems that characterize many developing countries, phenotype and pedigree information were often not available, and this would make it difficult to realize the value of MAS. Notter (25) proposed, however, that MAS (or related technologies) could act as a lever to promote implementation of animal recording. He also noted that "MAS without recording is unlikely to be very beneficial for most traits".

For crops, Singh (61) suggested that MAS should be an integral part of the breeding strategy, but Acikgoz (66) was critical of situations where scientists without any experience of traditional plant breeding programmes entered directly into MAS. Sridhar (76) and El Ouafi (77), while acknowledging the importance of MAS, both suggested that meaningful breeding programmes were necessary to make progress with MAS and Dulieu (23) doubted that traditional selection methods could easily be replaced by MAS. Priyadarshan (11) also believed that more basic biological knowledge about the intricacies of nature was needed to improve selection procedures for plants and Montaldo (18) pointed out that knowledge of genetic control of some important traits remained incomplete.

MAS in aquaculture in developing countries was only briefly discussed in the conference, although Priyadarshan (71) argued that aquaculture merited more emphasis. Martinez (63) suggested that, for aquaculture, application of DNA technologies and MAS was scarce even in developed countries because of the lack of integration between quantitative and molecular genetics, and that the only successful application in aquaculture was that described by Toro (50), who said that molecular markers could be used to assist classical genetic improvement programmes by constructing pedigrees needed for genetic evaluation in trees and fish where pedigree information was otherwise lacking. Martinez (63) noted, however, that economic analysis of this strategy compared with individually identifying fish using electronic devices was scarce. Krause (75) gave an example where molecular marker information could be used to reduce the costs of a fish breeding programme. Normally, electronically tagged back-up copies of nucleus breeding populations of fish are made as an insurance against loss of a deployed population. This is an expensive process that can be avoided by taking tissue samples from sires and dams that are analysed for the presence of established molecular markers if a nucleus stock is destroyed. This allows a nucleus stock to be regenerated relatively easily and cheaply, if and when necessary.

While the merits of applying MAS to genetic improvement of trees in developing countries were appreciated (e.g. Muralidharan, 7), participants suggested there are many problems that detract from its usefulness. Principal among these is the poor state of current tree breeding in general, and in developing countries in particular. Simons (28) listed a number of problems concerning genetic improvement of tropical trees, including dioecy, undocumented origins and uncertainty of genetic control of traits. However, Galvez (10) mentioned that MAS had been used to assist in selection of coconut parents for breeding. Priyadarshan (11) considered MAS to be helpful for rubber improvement, at least theoretically, and Badr (47) seemed to be looking forward to MAS reducing the time needed for evaluation of fruit trees in Egypt, obviating the need for grafting to see the products of breeding efforts. Forest trees, perhaps more than other genetic resources used by humans, are at, or still very near, their wild state (Muralidharan, 7), which indicates that tremendous improvement can probably be made quite rapidly based on selection among existing genotypes. Muchugi (49) recognized the potential of MAS for tree species improvement, seeing it as a technique best placed to help select and upgrade tropical tree species where the first fruiting may take as long as twenty years.

Technical details of MAS use

There were several contributions to the conference regarding technical aspects of MAS, and how to use MAS effectively in genetic improvement programmes. Mota (14) raised the issues of molecular markers located far from the target gene, increasing the probability of recombination taking place between them, resulting in reduced efficiency of MAS and, secondly, of false positive marker-gene associations. Dulieu (23) also emphasized the importance of tight marker-gene linkage to minimize losses through recombination. Weller (15) acknowledged the importance of both issues raised by Mota (14) and proposed that the best solution to the problem of false positives is to employ the false discovery rate, to get an idea about the expected number of false positives. De Koning (16) supported the use of the false discovery rate and also referred to recent research results suggesting there were benefits in MAS from using a relaxed threshold for QTL (quantitative trait loci) detection. Mota (36) concluded that developing countries should only use MAS in their breeding programmes when there is complete linkage between the marker and the gene of interest, to avoid wasting precious resources. Dulieu (42) commented on this, pointing out the advantages of using flanking markers (i.e. where markers are located on either side of the gene of interest) in MAS.

Singh (44) described the usefulness of MAS in backcrossing programmes, by growing large BC1 populations (BC1 is the first backcross generation), rejecting 50–60 percent based on phenotype (conventional screening) and analysing the remainder with MAS. This could be repeated in the second backcross population, saving considerable time and resources. The usefulness of this approach was confirmed by Dulieu (53), and Sridhar (54) explained how three genes for rice bacterial blight resistance were pyramided into adapted germplasm using MAS in a backcrossing programme.

Which traits for MAS?

Referring to crop improvement, Murphy (1) noted that not all crops and traits were amenable to MAS. A Dutch perspective on the type of traits amenable to MAS to date was provided by De Lange (57), who indicated that single gene controlled traits had received most attention, but little progress had been made with multiple gene traits. Makkar (52) stated that many MAS studies had adopted a single trait approach, pointing out that with a multitrait breeding objective, response for one trait often goes at the expense of another. He also suggested the utility of MAS when heritability for the trait was low. Singh (41) indicated that "breeders are not much thrilled about MAS for simply inherited traits, and not many QTL (especially the productivity related ones) with tightly linked markers are available".

Several other participants mentioned traits that would be amenable to MAS, including Priyadarshan (11) working with rubber trees, Williams (37) who provided the case of root nematodes and William (70) who mentioned work being done on barley yellow dwarf virus resistance in cereals, rust diseases, nematode resistance and root health. Rakotonjanahary (78) also suggested that MAS be used when conventional approaches to selection were difficult or impossible. For example, Reddy (62) proposed MAS be used for traits where it is difficult to get phenotypic data, like quality traits, and William (70) indicated that protein assays to develop quality protein maize were expensive compared with marker assays. Slaughter traits in livestock were also considered to be amenable to MAS as the desired traits are otherwise difficult to measure without killing the animal (Makkar, 52). Muchugi (49) suggested the potential usefulness of MAS in selecting for medicinal traits and growth rate in tropical trees.

Introgression of genes from wild into cultivated germplasm was proposed to be a good use of MAS (Bhagwat, 46). Notter (25) also commented on the opportunities molecular markers provide for screening populations of animals with favourable or unfavourable genotypes, giving as an example scrapie in sheep. Krause (75) mentioned other genetic examples, such as a sperm defect in pigs and the halothane gene implicated in low pork quality, that could be screened out using MAS. Sex-linked traits were also mentioned as being suitable for MAS (Makkar, 52).

Galvez (10) suggested that molecular markers could be also useful for work with transgenic crops, for characterizing GM plants and tracking movement of the transgene in the gene pool. William (70) also mentioned the use of MAS for transferring a desirable transgene, such as a gene from *Bacillus thuringiensis*, from one cultivar to another.

In addition to discussing traits considered amenable to MAS, brief mention was made of traits not considered amenable to MAS. It was realized that more progress had been made with single genes that were relatively easily transferred, but that there was potential for facilitating QTL transfer, although this was still relatively undeveloped. Traits that are highly influenced by the environment or production system, including crop yield (Priyadarshan, 11), were not considered easily amenable to MAS. Williams (37) pointed out that a major problem associated with MAS was lack of polymorphism at the DNA level, which would render a trait not amenable to MAS. Inadequate coverage of the genetic map with molecular markers was viewed by Dulieu (23) as an obstacle to applying MAS. He also detailed other conditions relating to the nature of the trait that should be considered for MAS to be efficient: single versus multigene, additive versus dominant, expressivity and penetrance.

Practical applications of MAS

Some participants considered the actual impact of MAS on genetic products delivered to farmers. Although documentation was limited, the current impact seemed small while the future impact was likely to be far more substantial.

Priyadarshan (11) indicated that biotechnology research had been supported actively for over 17 years in India, but was doubtful about the impact on varieties released to farmers. He believed that research on MAS and other biotechnologies had remained largely in journal articles and had not significantly boosted conventional plant breeding efforts on the ground. Kirti (12) lamented that there was no comprehensive documentation regarding the successful use of MAS for breeding new crop varieties or developing breeding material, as this information would be important for evaluating the technology. Collard (45), while noting that MAS had been successful in cereal crops in his country, Australia, said he was not aware of many examples of MAS-derived cultivars grown in Australia despite the wealth of publications from Australian institutions on the technology. Sridhar (48) suggested that, in India, most products of MAS are still in the hands of research institutions undergoing evaluation. He suggested that MAS products require a "fast track" evaluation system to expedite the release of promising germplasm.

According to Makkar (52), success in demonstrating genetic gain in the laboratory did not always equate with success under field conditions. However, some real successes were reported, including transfer of important resistance genes into adapted rice germplasm for Indian farmers (Sridhar, 35 and 54), indicating that more successes might be in the pipeline. Williams (51) said that molecular markers had been used for at least five years in Australia in some wheat and barley improvement programmes and that "it is likely that in Australia all breeding programmes with industry funding and probably also the private breeding companies are currently using MAS to some extent". However, the potential of the new technology has to be weighed against the success achieved using traditional methods. Acikgoz (66) pointed out that the Turkish rice cultivar Tokak was still being sold despite having been released in 1937, and questioned how much impact population genetics studies, popular 20–30 years ago, had on cultivar development, let alone the impact of biotechnology applications.

Buijs (58) mentioned tissue culture, once regarded as a modern, relatively expensive technology, which is now relatively inexpensive and widely used in developing countries. It will only be known retrospectively whether MAS evolves similarly to become a standard tool of the plant and animal breeder in developing countries.

Intellectual property rights issues

Some participants felt that intellectual property rights (IPRs) were an important constraint to development and uptake of MAS in the developing world. Corva (29) raised the issue of the use of licensed genomic technology by public institutions in developing countries, mentioning that many useful cattle markers were becoming available, but which were patented, and that there was therefore a demand for practical information about IPRs and violation of IPRs. Weller (30) pointed out that patents are only valid in the country where they are granted, that research tends to be exempted from patent restrictions and that there can be long delays between filing of patent claims and their eventual granting. Saravanan (31) argued strongly for the freedom of researchers to use patented biotechnology tools. Storlie (32) argued that farmers in the developing world should be concerned about being constrained by "corporate patents on particular genes, which may require a company's authorization for possession and use". William (70) noted that development of useful markers for MAS was already a significant challenge in developing countries and felt that if their use was restricted due to IPRs "their use would be really limited". Both Williams (51) and Sarla (80) stressed that new genetic information has to be kept as much in the public domain as possible to ensure that there is equal access to it.

Fairbanks (60) described a case demonstrating how some of the limitations imposed by IP issues, including transfer of germplasm across international boundaries, could be overcome, while also avoiding some of the economic obstacles faced by scientists in developing countries. Microsatellite markers for quinoa were being developed at an American university in a joint programme with a Bolivian foundation, to be then sent to Bolivia for use by Bolivian scientists in their quinoa breeding and conservation programmes.

Differences in capacity between developing countries

From the conference it was clear that there is enormous diversity in terms of capacity, opportunities and constraints among developing countries that would have a bearing on development and application of MAS. There are substantial differences in factors including the state of public sector research, the involvement of the private sector in research, development and marketing capabilities, perceived priorities for development, the social and agricultural systems of the country, the state of educational systems and the degree to which information and technology remain in the public domain.

Many participants, including Buijs (22) and Corva (29), commented on developing countries lagging behind developed countries in uptake of new technologies, and Sokefun (3) expressed concern that a lack of resources should not result in the developing world being bypassed. Davila (81) suggested that developing countries like Brazil, where MAS can be used relatively easily, could help other developing countries with MAS development, through south-south cooperation. Roughly a quarter of messages posted in the conference came from India, and it was apparent that this is another developing country that has invested substantially in MAS, among other biotechnologies. Such are the trends in capacity and infrastructure there that it was indicated that Indian institutions might be able to provide MAS services more cheaply than in developed countries (Muralidharan, 74). This is an important consideration, as Bhatia (8) suggested that breeders should ask whether MAS-related analytical work could be outsourced. Reddy (62) believed that MAS would only be economical in developing countries like India.

Role of the CGIAR and international organizations

Collaboration between the developing and developed world was inferred to be the only way for the developing world to participate realistically in the development of MAS and avail itself of the opportunities it represented (Sokefun, 3; Galvez, 38). Fasoula (84) expressed the need for developing countries to play an active role in developing MAS, particularly in making the associations between markers and traits, although Koudandé (68) considered that for economic reasons developing countries could simply import required technology. Many other participants voiced the need for international cooperation. One demonstration of the extent to which scientists from developing countries are contributing to research on, and application of, MAS is that many participants were from developing countries but studying and/or working abroad. Contributions came from national institutions hosting foreign researchers and also from centres of the CGIAR that promote collaborative research and training. Olori (65) described the many ways that developing country individuals and institutions are contributing to the development of MAS by participating in international agricultural research. Gianola (24), however, questioned the apparent altruism of developed countries in sponsoring collaborative MAS efforts, fearing that it might hide motives for developing biomedical applications from the results.

Partnerships between the CGIAR and national researchers led to some successes in MAS mentioned in the conference. Sridhar (35) reported on the collaboration between an Indian rice research institute and the International Rice Research Institute, and Wallwork (59) on cooperation between an Australian institution, the International Center for Agricultural Research in the Dry Areas and the International Maize and Wheat Improvement Center.

There was a strong call from many participants for the CGIAR and international organizations such as FAO to play an active role in the area of MAS development and application. For example, Murphy (1) suggested that the CGIAR and FAO should facilitate international collaboration in this area, while Priyadarshan (11) suggested that the CGIAR might manage a centralized facility for routinely doing MAS. Acikoz (66) envisaged a role for FAO in addressing issues of classical plant breeding at regional and national levels, which he saw as being more of a priority than MAS, while Muralidharan (74) thought FAO to be suited to playing the role of coordinator for MAS research among laboratories working on the same crop. Rakotonjanahary (78) proposed a similar role for FAO and the CGIAR as facilitators in the exchange of information and genetic material obtained from MAS. Sarla (80) suggested that FAO could play a catalytic role in marker-aided allele mining and facilitate capacity building for applying MAS, especially for crops of regional importance.

Public–private sector linkages

Various additional constraints to using MAS in plant and animal improvement programmes in developing countries were discussed in the conference. Notter (25) stated that the history of public funding in developing countries was not good and Fairbanks (60) commented that agricultural research in developing countries was not well coordinated. Australia has invested heavily in MAS in its breeding programmes but, as pointed out by Collard (45) regarding plant breeding, the major target crops have been cereals produced for export. Moreover, there has been considerable support from private industry for research and development of MAS. For example, the Grains Research and Development Corporation (GRDC) of Australia was set up to serve farmers and is maintained through a levy collected from them. In contrast, in the developing world, most important crops are usually produced for subsistence and there is often little private–public cooperation (Murphy, 1). Developing country farmers are unlikely to be able to support the activities of a dedicated research and development organization equivalent to the GRDC (Collard, 45). Similarly, Notter (25) pointed out that there was a scarcity of private animal breeding initiatives in developing countries and little or no commercial sector. MAS, in his opinion, would not change this situation. Nicol (19) highlighted the importance of extension agencies in assisting uptake of commercially available DNA marker tests.

Koudandé (68) noted that in developed countries, most of the applied MAS in breeding is undertaken by companies, and wondered which companies in Africa would be wealthy enough to support MAS development and application. An additional factor is that MAS requires that molecular markers are available for particular crops and important traits, but most of the publicly available markers are for the major crops (Collard, 9), which are not necessarily of primary importance in developing countries. Some crops are also very region specific, such as black gram mentioned by Gopalakrishna (72), and are unlikely to be the target of research leading to development of MAS technologies. There seemed to be general support for a collaborative approach to MAS research and application, including public–private sector linkages, which would represent the best opportunity to facilitate development of, and access to, MAS in developing countries. Unfortunately, private sector contributions to this e-mail conference were limited and the discussion would have benefited from inputs by more of them.

REFERENCES

The author, number and title of messages referenced in the chapter – all messages are available at www.fao.org/biotech/logs/c10logs.htm

Acikgoz, N. (66). Is MAS a little luxurious for developing countries?

Badr, A. (47). Tropical fruit breeding

Bhagwat, A. (46). Polyploid crops

Bhatia, C.R. (8). Indicators of utility of MAS in plant breeding

Buijs, J. (22). MAS and other ongoing research

Buijs, J. (58). Locally adapted technology

Chávez, J. (33). MAS and animal breeding

Collard, B. (9). Cost of MAS - the biggest barrier

Collard, B. (45). Investment makes MAS feasible in developed countries

Corva, P. (29). Use of licensed genomic technology

Davila, A. (81). MAS and bioinformatics for developing countries

De Koning, D-J. (13). MAS for livestock in developing countries

De Koning, D-J. (16). Re: Crossing-over // false-positive markers

De Koning, D-J. (20). Re: MAS for livestock in developing countries

De Lange, W. (57). Experiences with MAS so far - Netherlands, plants

Dulieu, H.L. (23). Genetic conditions for MAS efficiency

Dulieu, H.L. (42). Re: When the marker is the gene

Dulieu, H.L. (53). Re: marker assisted backcrossing

El Ouafi, I. (77). Some of the main topics for discussion

Fairbanks, D. (60). Collaborative international research on MAS

Fasoula, D. (84). Re: Integration of molecular markers with plant breeding

Galvez, H. (10). MAS for tree crop improvement and transgenics

Galvez, H. (38). Re: When the marker is the gene

Ganunga, R. (69). Flanking markers/ Patenting

Gianola, D. (2). Economic impact of MAS
Gianola, D. (6). Re: economic impact of MAS
Gianola, D. (24). International collaborative efforts - MAS
Gopalakrishna, T. (72). MAS technology
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