Can Agricultural Biotechnology Make A Difference In Africa?

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There has been much recent discussion on the potential impact of biotechnology on development in Africa. Can agricultural biotechnology make a significant difference, or would a strategy combining conventional breeding with good crop management, farmer participatory research, and the provision of disease-free planting material be sufficient to increase yields in Africa?

Key words: Africa, biosafety, biotechnology, root crops, training.

There has been much published on the burgeoning population growth in developing countries, where this constitutes 97% of the global population increase (Swaminathan, 1995). In Africa there are the concomitant problems of food shortages, a burdened economy, political instability and poor environmental sustainability. These problems have contributed to Africa lagging behind in reaping the benefits of the "Green Revolution", as well as the "Gene Revolution". Africa therefore needs to implement strategies to increase the efficiency of food production as well as broadening their food base to address problems of nutritional deficiencies. With dwindling arable land, the challenge is to increase yields on current fields. Pests and diseases account for about 30% yield losses and, therefore, transgenic crops would offer an approach which developing countries cannot be excluded from (Vasil, 1998). The introduction of transgenic crops, perhaps combined with a more conventional approach using traditional breeding, good management of soil fertility, and crop protection facilitated by participatory extension approaches, could go a long way to improving the yields obtained by African farmers.

A previous review has highlighted the status of biotechnology in Africa, as well as constraints that may have to be considered during the implementation of biotechnology strategies in Africa (Brink, *et al*., 1998). In this review, some examples of initial applications of biotechnology in Africa will be highlighted, and the potential for development in Africa discussed.

Biotechnology For Africa

Africa has several centers with a long-standing history of applied agricultural research on crops important to Africa. These centers include the International Institute of Tropical Agriculture (IITA) in Nigeria, the Kenyan Agricultural Research Institute (KARI) in Kenya, and the Agricultural Research

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Council (ARC) in South Africa. More recently, the Agricultural Genetic Engineering Research Institute (AGERI) in Egypt was established. In addition, there are many other smaller research organizations and universities with well established biotechnology facilities. Generally, tissue culture techniques are easiest to implement initially, and micropropagation is a valuable and much-used technique in Africa for the multiplication of many vegetatively propagated food crops such as cassava, sweet potato, yam, potato, banana and plantain.

Sweet Potato

Virus elimination techniques have been used for the last 20 years at ARC-Roodeplaat in a scheme for the production of disease-free sweet potato planting material. This disease-free material is used for all the commercial planting of sweet potato in South Africa, and has been an efficient way of suppressing the level of disease present in the field (Van Zijl & Botha, 1998).

In addition, transgenic approaches are being developed for sweet potato cultivars important to resource-poor farmers in Africa. Transgenic sweet potato resistant to sweet potato feathery mottle virus has been produced at KARI in a program funded by the United States Agency for International Development (USAID), and Monsanto (Wambugu, 1999). Another program involves the engineering of resistance to weevil in sweet potato, which is a collaboration between American and African laboratories. At Tuskegee University, South African sweet potato cultivars are being transformed by a South African researcher (as part of an international team of researchers), with a gene to increase essential amino acid levels in the tubers. With other sweet potato cultivars this research has shown to be extremely successful (Egnin *et al*., 1999), with transgenic sweet potatoes containing up to five times the normal protein levels. There is enough evidence to show that transgenic technologies could be successfully transferred to African laboratories, if certain constraints can be overcome. There is also every reason to believe that there can be a smooth and sustainable transfer of the technology to the field, and that farmers will be able to benefit from these crop-protection transgenic strategies (Wambugu, 1999). Existing channels for the distribution of planting material, such as the Sweetpotato Vine Grower's Association in South Africa, could provide an efficient means of making transgenic plants available to farmers in a form that is familiar to them.

Potato Biotechnology - From North And South Africa

In two separate programs, field trials of transgenic potatoes have been carried out since 1997 in Egypt and in South Africa. The Egyptian program, sponsored by USAID involves research agreements between AGERI, Michigan State University (MSU), and several other U.S. institutions. Field trials of potato engineered to express the *Bacillus thuringiensis* CryV protein, which is toxic to the potato tuber moth, were carried out at AGERI in Egypt in 1997 and are now entering their third year of assessment.

At the same time, in South Africa at ARC-Roodeplaat local potato cultivars which had been engineered in-house with the coat protein of the potato leaf roll virus (Murray *et al.*, 1998) were planted in the first field trial of transformed potatoes in South Africa (Berger *et al.*, 1998). Potatoes South Africa (PSA), the potato commodity organization of South Africa, funded this program. Current research is focussing on transforming potato cultivars important for resource-poor farmers. Potatoes containing the viral coat protein gene to control potato virus Y, and lines with increased expression of a CuZn superoxide dismutase gene for increased tolerance to abiotic stress, are also ready for field-testing. Potatoes South Africa also fund the maintenance of the national *in vitro* potato cultivar collection located at ARC-Roodeplaat (Van Zijl & Botha, 1998).

A Minor Root Crop "Re-Introduced"

At ARC-Roodeplaat in South Africa, the Biotechnology Division has shown that it is possible to use tissue culture techniques to benefit resource-poor farmers. In a project funded by UNESCO's University-Industry Science Partnership Program in Africa (UNISPAR), an indigenous crop, once part of the diet of rural communities in the Northern Province, was re-introduced into the area. The "Wild" or "Livingstone" potato (*Plectranthus esculentus* N.E.Br) is an indigenous, semi-domesticated plant (Allemann & Coertze, 1996). In the past, the crop was planted by resource-poor farmers in the Northern Province and, although popular, planting material became neglected and was eventually lost to the community.

Tissue culture provided a way of rapidly producing planting material where field propagation is very slow. Planting material was provided to 18 members of the "Matetlwa Farmers" Association for re-establishment of the crop. The popularity of the Wild potato is borne out by the fact that this year almost 60 farmers have indicated that they would like to plant the crop. This nutritious crop, which contains high levels of protein (around 7%) and several essential amino acids, could make a significant contribution to household food security and the broadening of the food base of this community. This crop has been incorporated, together with maize, in a program of participatory extension (Hagmann *et al*., 1998) funded by GTZ and the Northern Province Department of Agriculture in South Africa. The aim of this participatory scheme, which has been very successful in Zimbabwe, is to assist farmers in setting and fulfilling their own developmental goals.

Maize Genetic Engineering In Africa

Genetic engineering of maize in South Africa was partly pioneered by the Food Science and Technology Division (Foodtek) of the CSIR, as well as the Department of Microbiology of the University of Cape Town (UCT). CSIR-Foodtek reported on Hi-II maize transformation in 1998 (O'Kennedy, *et al*., 1998). A collaborative project to engineer maize for fungal resistance was embarked upon in 1995 by the ARC-Roodeplaat and CSIR-Foodtek. This program, funded by maize producer organizations in South Africa, used a polygalacturonase-inhibiting protein (*pgip*) gene isolated from bean to confer fungal resistance to the serious fungal pathogen, *Stenocarpella maydis*, which causes severe yield losses and quality downgrading in maize in South Africa (Van Rensburg & Ferreira, 1997).

The problem of Maize Streak Virus (MSV) in Africa is being addressed in a collaborative research program to produce engineered maize resistant to MSV. This program is funded by the United States Rockefeller Foundation and Novartis, and involves the International Service for the Acquisition of Agri-Biotech Applications (ISAAA), KARI, the International Center for Insect Physiology and Ecology in Kenya, UCT in South Africa, and the John Innes Center in the United Kingdom (Wambugu, 1999).

Applications Of Biotechnology To Vegetatively Propagated Crops In Africa

In vitro propagation of vegetative crops is a second-generation biotechnology activity that can be successfully applied in developing countries. Cassava, yam, bananas, and plantains are important crops in Africa, and biotechnology has made significant contributions to their improvement. At IITA, biotechnology has been used for the last ten years as a tool for improvement of these crops. An extensive *in vitro* genebank of cassava and yam is maintained here for distribution worldwide. Tissue culture methods and cryopreservation techniques have been developed for these crops. In the case of yam, a molecular genetic linkage map has been developed, and putative transgenic shoots obtained.

A polymerase chain reaction (PCR) test for yam virus II has been developed in a collaborative project with the Natural Resources Institute (NRI). This sensitive test has been useful in the program to distribute improved varieties to farmers.

In the case of banana, RAPD markers linked to A and B genome sequences have been identified and tissue culture used for mass propagation. Several diagnostic tests have also been developed for detecting banana streak virus, in collaboration with the John Innes Center and the World Bank. Research on regeneration and transformation techniques in cassava are being carried out at ARC-Roodeplaat in South Africa and IITA in Nigeria. Here, techniques of organogenic regeneration (Li *et al*., 1998), developed in Switzerland, have been successfully applied in both laboratories through a technology transfer activity.

Training Of African Scientists

Training of African scientists has taken place at two main training centers in Africa. One is at IITA, where training is a major activity of the Biotechnology Unit. Between 1990 and 1995 about 50 African scientists were trained and six students completed Ph.D. degrees. The training activities included three annual workshops on the use of monoclonal antibodies for the detection of crop viruses, which were attended by 35 scientists from 19 countries.

The Life Science Program of UNESCO has been very active in developing countries through their Microbial Resources Centers (MIRCENs) and Biotechnology Education and Training Centers (BETCENs) (Brink *et al*., 1999). These programs are providing training to scientists in Africa, enabling biotechnology to be applied to solve local problems. In 1995, the Biotechnology Action Council (BAC) of UNESCO established a BETCEN, at the ARC-Roodeplaat in Pretoria. Since 1995, a total of 180 scientists from 23 countries have been trained in basic and advanced tissue culture techniques, and applications of molecular markers. In addition to these short-term courses, 11 fellowships were provided for training periods of 2 to 3 months. The International Atomic Energy Agency (IAEA) and the African Regional Co-operative Agreement (AFRA) have also been involved in supporting regional training initiatives in Africa.

One of the more serious problems with training of African scientists is the lack of opportunities for African graduates once they return to their home-countries, and particularly after obtaining degrees in developed countries. Training gained in developed countries using hi-tech equipment to study esoteric topics does often not equip African scientists to return and contribute to growth in their own countries. Some countries in Africa are now sending students for training at South African universities in the hope that graduates will be more willing to return to their home-countries once their studies have been completed.[1]

Field Trials Of Transgenic Crops And Commercial Releases Of GMO's

In the period between 1990 and 1995 there were 25 field trials of transgenic crops in Africa (James & Krattiger, 1996). These involved a variety of crops and introduced traits. Of the field trials, 22 were performed in South Africa, 2 in Egypt and 1 in Zimbabwe. Africa has performed relatively few field trials of transgenic crops compared to the numbers of trials in the rest of the world for the time period 1986-1995. These are, North America (2,438 trials), Western Europe (796 trials), Asia-industrialized (86 trials), Asia-developing (62 trials), Latin America (204 trials), and Eastern Europe and Russia (36 trials) (James & Krattiger, 1996). Since this time, however, several other countries, for example, Kenya, Uganda, Namibia, and Cameroon, have introduced National Biosafety laws and regulations, and discussions are also being conducted in Mauritius, Zambia, Tanzania, Ethiopia, Nigeria, Ghana and Côte d'Ivoire. As a result, the number of field trials has also increased, and in South Africa between 1996 and 1999, there were 90 applications for transgenic field trials (M. Koch, personal communication). Field tests of transgenic crops have taken place since 1989 in South Africa under strict compliance of the South African Committee on Genetic Experimentation (SAGENE) guidelines. The GMO bill (Act 15 of 1997) has since replaced SAGENE.

In 1998 in South Africa, there were commercial releases of two insect resistant yellow maize varieties. About 1000 hectares of transgenic maize resistant to the local stem borers, *Busseola fusca* and *Chilo partellus,* were planted in the 1998/1999 season. Another release of a genetically modified crop in South Africa has been in cotton. A recent trial release of insect resistant Bt-cotton showed a significant decrease in insecticide use and increases in yield between 17 and 24% for commercial farmers, and 28% for a group of resource-poor farmers. One woman farmer from a rural area in KwaZulu Natal said that she had made $5,000 more profit than she expected (Koch, October 1999).

Gene Discovery For Developing Countries

Over 50 years ago, Nicolai Vavilov alerted the scientific community to the value of conserving plant genetic resources to identify useful genes for breeding programs. More recently, Tanksley and McCouch (1997) highlighted the usefulness of molecular tools to plant breeders. In developing countries there is a need to build capacity in gene discovery, where in the absence of such programs, many of the crop genetic engineering projects are "copycat" applications using existing genes from developed countries. These may not necessarily provide the most effective solutions to local problems in developing countries. In addition to this, Africa contains an abundance of untapped, indigenous knowledge and genetic wealth, which could benefit developed and developing countries. There has also been concern expressed that the Biodiversity Convention does not clearly entrench adequate intellectual property right (IPR) protection for indigenous knowledge (Noiville, 1996). There is also a school of thought that IPRs are inappropriate when applied to plant genetic resources in developing countries, since this benefits industrialized countries (Mooney, 1996). A more practical approach, however, would be to build local capacity in developing countries, in collaboration with developed countries, in order to identify local genetic wealth, and then use this to address specific local problems.

Conclusion

The application of plant biotechnology techniques, in conjunction with conventional plant breeding and good crop management, can play a major role in ensuring food security and adequate nutrition in Africa. In this paper we have provided examples of initial successes in the application of plant biotechnology techniques. Strong leadership, effective priority-setting, and adequate working opportunities for scientists are, however, required to provide incentives for the establishment of capable biotechnology groups. Participatory extension approach programs could be an ideal channel for the implementation of biotechnology products, as well as endowing resource-poor farmers with the confidence to develop and apply solutions to some of their problems.

Africa's advantage is its valuable biodiversity, which can earn revenue for its people not only through tourism, but also through bioprospecting, if the value-addition remains in Africa. Programs to build capacity in African laboratories to identify, classify, and utilize the continent's biochemical and genetic diversity will go a long way towards bringing the promise of biotechnology to Africa.

Endnotes

[1] For a comprehensive review on biotechnology activities in South Africa see Rybicki (1999).

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