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Plant biotechnology in agricultural research systems : FAO approach

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SUMMARY - Global population explosion combined with extreme climatic conditions and environmental degradation are taking a heavy toll on agricultural production. Therefore it is imperative to increase the production and productivity and that considerable attention be paid to new technologies and possible new breakthroughs. Biotechnology in food and agriculture presents both opportunities and challenges and it has also a potential to be an "appropriate technology" that may provide such breakthroughs and support sustainable agricultural development. Over the past four decades FAO has been supporting various projects in the fields of plant genetic resources, crop production and protection and seed improvement and development. During 1982-1991, FAO budget for conservation and use of crop genetic resources amounts to US$ 368 million and this is roughly distributed into : plant production and protection (45%), seed development (35%) and germplasm conservation (20%). Plant biotechnology projects were supported under all these categories. Following the 25th Session of FAO Conference in 1989 a specific budget item on plant biotechnology was initiated to support activities related to this field. The paper describes the role of plant biotechnologies in crop improvement and development, especially the FAO programme on plant biotechnology.

Key words: Biotechnologies - Agro-food - Plant breeding - NARS (National Agricultural Research Systems) - CGIAR (Consultative Group on International Agriculture Research) - IARC (International Agricultural Research Center) - FAO - Micropropagation - Tissue culture - Recombinant DNA - In vitro collection.

RESUME - "La biotechnologie végétale dans le cadre des systèmes de la recherche agronomique : l'approche de la FAO". L'explosion de la population mondiale combinée aux conditions climatiques extrêmes et à la dégradation de l'environnement sont des sujets préoccupants en production agricole. En conséquence il est impératif d'augmenter la production et la productivité et une très grande attention doit être portée aux nouvelles technologies et aux possibles nouvelles percées. Aussi bien en ce qui concerne l'alimentation que l'agriculture, les biotechnologies représentent des opportunités et des défis, qui potentiellement peuvent conduire au développement de "technologies appropriées" pouvant permettre des avancées et le développement d'une agriculture durable et viable. Durant les quatre dernière décades la FAO a soutenu un certain nombre de projets dans le domaine des ressources génétiques, de la production et de la protection des plantes et dans celui de l'amélioration et du développement des semences. De 1982 à 1991, le budget de la FAO pour la conservation et l'utilisation des ressources génétiques s'est élevé à 368 millions de dollars US répartis entre : production et protection des plantes (45%), développement des semences (35%) et conservation de germoplasme (20%). Des projets concernant les biotechnologies ont été conduits dans tous ces domaines. A la suite de la 25ème Conférence de la FAO en 1989 un poste budgétaire spécifique concernant les biotechnologies a été mis en place pour supporter les activités dans ces différents domaines. Cet article décrit le rôle des biotechnologies dans l'amélioration et le développement des cultures et plus particulièrement le programme de la FAO en ce qui concerne la biotechnologie des plantes.

Mots-clés: *Biotechnologies - Agroalimentaire - Amélioration des plantes - NARS (Systèmes Nationaux de Recherche Agronomique) - CGIAR (Groupe Consultatif sur la Recherche Agronomique Internationale) - IARC (Centre International de Recherche) - FAO - Micropropagation - Culture de tissus - ADN recombinant - Vitrothèques.*

Introduction

Crop improvement is as old as agriculture itself, and the earliest agriculturists were engaged in a simple form of plant breeding. Out of each year's harvest, farmers selected seed from those plants with the most desirable traits. Over thousands of years the slow but steady accumulation of such desirable traits (or genes) resulted in more productive cultivars. Following the rediscovery in 1900 of Mendel's work illustrating the hereditary transmission of traits, the simple form of plant selection was augmented by the systematic crossing of plants by scientists with the specific purpose of producing new varieties with desirable characteristics.

The evolution of conventional plant breeding methods in conjunction with advances in other fields of science and knowledge helped to shape the current status of world agriculture. Since the beginning of the 20th century plant breeders developed breeding, hybridization and backcrossing techniques, and these have led to the development of more productive modern cultivars. Cultivation of such higher yielding varieties brought great gains in the fight against world hunger.

However, the successes of plant breeding were relatively limited and the increments in production advanced in small steps, not in great leaps and bounds. Since 1920, through breeding the yields of most crops increased by approximately 1 percent per year.

Following the unveiling of the genetic code, scientists have been able to make major advances in their understanding of genetics. With the appearance over the last decade of a set of new and uniquely powerful genetic technologies, viz., recombinant DNA (rDNA), transfer (gene splicing), protoplast fusion and improved tissue culture techniques (cloning), which permit the modification of living organisms with an unprecedented specificity and allowing at the same time qualitatively different degrees of genetic transformation. Such transformations are not the result of randomly occurring changes but are the product of conscious and direct human intervention, of human engineering and design. Genetic engineering is an undertaking with far-reaching economic and social implications. Biotechnology promises to enhance significantly the human power to create and reproduce the material conditions of our existence.

Biotechnology in food and agriculture presents both opportunities and challenges. The new biotechnologies can help, both directly and by complementary conventional research and development, in the improvement of agriculture, in the increased production of food and non-food commodities, in the handling, storage and processing of most agricultural commodities and in the conservation of genetic diversity. Biotechnology has also a potential to be an "appropriate technology" that can support sustainable development, based on renewable natural resources. Plant and animal production, rainfed and irrigated farming systems, food and non-food crops, agriculture in favoured and marginal zones, fuel wood and fruit trees are all potential beneficiaries.

This is even more important as new breakthroughs in agricultural production are needed since the benefits of the green revolution are running out especially in times of increase in population in Developing Countries. The conventional technologies based on intensive energy and high production inputs have not benefitted all crops, nor all farmers, especially the resources of the poor peasants.

Agricultural Research and Agro-food Sector Outlook

With the understanding that agriculture needs to be looked at taking into consideration what is involved before as well as after-production on the farm, which means (pre...) correlating technological inputs, industrial inputs and managerial inputs for food, essential oils and fibre production, with (post...) agro-industry demands and food industry demands, including quality standards, packing materials, recycling and wastes affecting sanitary and environmental conditions, it is up to agricultural research systems - national and international - to see to these interrelated issues which culminate in the criticism of consumer preference.

Agricultural production and processing technologies clearly require preconditions which are easily found in many Developed Countries, but which hardly exist in most Developing Countries. The preamble to the FAO Constitution requires that the Organization should "work for raising levels of nutrition and standards of living of all people, secure improvement in the efficiency of the production and distribution of all food and agricultural products, bettering the condition of rural populations and thus contributing toward an expanding world economy". It does not differentiate between developed and Developing Countries. It is therefore our major task to ensure that the benefits of the application of biotechnology will be shared by people in the North and the South, in the small and the large countries, in the rich economies and in the poor countries.

FAO, as an intergovernmental organization, has a mandate for agricultural research and development. Research and development is one of its major roles; FAO not only provides technical assistance, guidelines on important matters, but also serves as a forum for Member Countries discussions on controversial issues. On the agricultural research side, taking into consideration the improved capacities and capabilities

of some national agricultural research systems (NARS), and following the creation of international agricultural research centres of the CGIAR, research on some major crops seems to be reasonably well supported. However, in FAO the importance is given not only to major crops but also to many underutilized crops, as well as crops of local social and economic importance.

The International Undertaking on Plant Genetic Resources, guiding principles for the unrestricted availability of germplasm and its information, emphasizing the need for conservation and utilization of plant genetic resources, represents the main policy mechanism for the Member Countries to decide where and how to approach future activities. The major important users of plant genetic resources are national and international plant breeding programmes.

National Agricultural Research Systems - NARS

Even in the industrialized countries there are always questions raised regarding fundamental changes to be accomplished with the evolution of science. These reflect farmers' and countries' needs to perform both at the domestic level and in international markets. It is often said that what is needed is a very well-defined role, a focus on quality research, and strong leadership in line with today's requirements and perspectives.

Due to the emergence of large numbers of private agricultural biotechnology companies, petrochemical and pharmaceutical groups among the seed and agro-food sectors, and the increasing use of new genetic engineering technologies by established firms, the role between governments, non-governmental organizations (NGOs) and private institutions must be defined anew.

Overhauling the systems is no easy task. The agricultural research programmes are very diverse, including preservation of germplasm and creation of hybrid crop plants, animal disease, nutrition and reproduction, control of crop pests and human nutrition. These activities and many others related are conducted in a multitude of laboratories and field stations located under different site-specific conditions.

The discussion on technology development encompasses both the capacity within a given country to produce improved technology and the inherent transferability of the technology. The producers have an interest in facilitating "transfer-in" or "spill-in" of technologies from other regions or countries. They also have an interest in inhibiting "transfer-out" or "spill-out" of technologies to producers perceived as competitors. In general, investment in research capacity in the region helps to produce location-specific technologies for the region and to facilitate spill-in. Competition or complementarity between regions then may take the form of research investment.

The NARS need to be redefined according to the kind or nature of their work. The patenting of inventions is another problem to be faced. Inventions are classified under the headings of mechanical, electrical, chemical, biochemical, biotechnological and managerial. Some Developing Countries do release patents but patent protection is not uniformly widespead.

Traditional patent protection is an open case to the first three classes. More recently, certain countries have introduced a new legal instrument, the Plant Variety Protection Certificate, and this has had a significant effect on the organization of plant breeding activities. The Chakrabarty decision providing patent protection to living organisms has extended traditional patent systems protection to much of the modern biochemical or biotechnological inventions.

NARS - government, NGOs and private companies, have to pick up new scenarios from the invention stage to consumers' preferences, and review priorities and strategies in the agricultural research programmes.

For biotechnologies alone, the DERWENT - International Patent Data, within the definition of 13 technology fields related to agriculture, releases four patents on: (i) mutation and genetic engineering; (ii) microorganisms and tissue culture; (iii) enzymes, and (iv) apparatus and equipment respectively.

International Agricultural Research Centres - IARCs

Each IARC plans and carries out research programmes according to the mandate established by the CGIAR - Consultative Group on International Agriculture Research, related to one or more commodities. In this framework biotechnology is considered as an approach to research that yields new information or techniques to help solve difficult problems.

The issue of biotechnology, however, is affecting IARCs in many senses. The 1984 Plant Breeding Forum participants agreed that biotechnology is expected to aid plant breeders by: (i) identifying and locating useful genes; (ii) allowing potentially unlimited transfer of genes; (iii) increasing understanding of the genetic and physiological processes in plants; (iv) improving diagnosis of plant diseases; (v) providing a better understanding of how genes regulate production of storage proteins; (vi) creating new methods for producing and selecting plants; and (vii) releasing new basic knowledge that will make possible genetic transformation, better control of gene expression and the construction of entirely new genes via DNA technology.

However, even having breeding as their main scope, it is felt that IARCs are probably not becoming major players in this new area. Except for ILRAD and a few centres, which have formed small units, this is the reason why cooperation among IARCs and other institutions must continue to be important in the refinement of new techniques and the exchange of shared basic knowledge.

The IARCs could play an important role in adapting the tools of modern biotechnology to the needs of Developing Countries agriculture.

Future of the Food System

Biotechnologies potentially transform the organizational linkage "agricultural inputs - final food production". Although traditional biotechnologies have been an essential part of the food system since the beginning of time, revolutionary techniques in modern biotechnologies are now being developed in chemical/petrochemical and pharmaceutical industries. These sectors are also becoming more and more involved in the seed areas.

It is, therefore, fundamental to understand, both backward and forward, the relationship between these industries and the food sector. A gradual introduction to the issue is strategic, although there is an urgent need for the establishment of a Programme on Plant Biotechnology for Developing Countries.

Role of Biotechnologies in Plant Improvement and Crop Development

In its publication, "the State of Food and Agriculture 1987-88", FAO stated that "in Developing Countries as a whole, agricultural production and productivity growths remain a top research and technology priority. However, higher yielding cultivars depending on large inputs of mineral fertilizers, other off-farm inputs and reliable water supplies, are unlikely to be all that is needed to provide the necessary increase in production. Priorities have to be extended to include development of stress-resistant, high yielding cultivars, well suited to local, mostly rainfed conditions, but less dependent on often cost-prohibitive or unavailable off-farm inputs.

Further, in Developing Countries acute population pressure combined with extreme climatic conditions and environmental degradation, such as desertification, salinity and uncontrolled deforestation are taking a heavy toll on agriculture production. Therefore, it is imperative that attempts be made to increase the production and productivity and that considerable attention be paid to new technologies and possible new breakthroughs. Plant biotechnologies might be such a breakthrough if, indeed, they can provide answers to the changing requirements and if they can offer possibilities to gradually arrive at the additional production increases. The results so far achieved in biotechnology research and development have indicated that these new tools offer opportunities for improved agricultural production. However, to ensure these agricultural benefits to Developing Countries proper choices have to be made and actions to be taken. It is also necessary that new initiatives be carried out successfully with the relatively limited means available in Developing Countries.

From the recent World Bank Study (1990), six issues of particular relevance have emerged:

(i) the possible impact of biotechnology on agricultural production, productivity and international trade;

(ii) the institutional and social issues likely to be associated with biotechnology in the Developing Countries;

(iii) the changing role of public and private sector investments in agricultural research;

(iv) the ecological implications of the environmental release of genetically engineered microorganisms, plants, and animals;

(v) the influence of patent law, plant variety protection and other means of intellectual property management on national biotechnology activities, and

(vi) possible ways to facilitate greater international assistance to biotechnology in the Developing Countries.

Given the fact that biotechnology is potentially relevant to a broad sectorial range and that the application of certain technologies requires relatively small investments, it represents a very attractive tool for food and agricultural development. At the same time, there are a number of factors that may limit the potential of this new set of technologies, including gaps in the knowledge on biological aspects of species and ecosystems that are essential for progress in biotechnology.

Some of the potentials of biotechnologies in plant improvement and crop development are as follows:

- fixing of hybrid vigour through apomixis or other means for certain crops like maize, rice, wheat, sorghum and possibly legumes;
- incorporation genes for nitrogen fixation into the major cereals; and photosynthetic C4 metabolism into C3 cereals;

- better adaptation to climate and season including cold tolerance, heat tolerance, drought tolerance and water use efficiency, and salt tolerance etc.
- improvements in resistance to pests and diseases;
- quality improvements;
- cleaning of planting/grafting material;
- plant propagation using tissue culture techniques;
- improved diagnostics for diseases and pests; and
- conservation of genetic resources.

There are a number of limitations to the application of plant biotechnologies. In particular, it has to be realized that it is not a goal in itself, nor a panacea, but a useful tool which might accelerate the improvement of productivity. There are a number of factors that strongly limit the application of these new technologies in Developing Countries. These are:

(i) biotechnology cannot be developed and applied in isolation. It needs to be applied to disciplines such as plant pathology and plant breeding. Unless these disciplines are already strong, little can be expected from the development and application of biotechnologies;

(ii) developing country expertise is generally very limited and the training of staff should be given high priority;

(iii) modern capital intensive laboratories are required. Long-term commitments for spare parts and reagents are necessary; and

(iv) the sheer number of problems and crops are beyond the capabilities of nearly all Developing Countries. Most of the current research is in temperate crops, more attention to the problems of tropical crops is necessary. Therefore, collaboration between Developing Countries and with Developed Countries' institutions is essential.

FAO Programme on Plant Biotechnology

The Plant Production and Protection Division of FAO has, almost since its inception, been supporting various projects in the areas of genetic resources, crop production and protection and seed production and some of these projects have components, such as tissue culture, micro-propagation, disease indexing, *in vitro* conservation of genetic resources etc., which fall under the category of biotechnology. For the years 1982-1991 the FAO budget allocation for conservation and utilization of plant genetic resources is approximately US$ 368 million (see Table 1) and this amount is roughly distributed into crop production (45%), seed development (35%) and conservation (20%). In all these three categories the projects included elements related to plant biotechnology work.

With the evolution of modern techniques such as recombinant DNA, protoplast fusion, cell and tissue culture etc., and their potential impact on world agriculture, FAO Conference in 1989 gave priority to plant biotechnology and allocated budget specifically to support activities in Developing Countries. In order to plan its role FAO has initiated the process of formulating a comprehensive policy towards plant biotechnology.

FAO, in close cooperation with CTA of the EEC and through generous funding by the Government of the Netherlands, organized a symposium in Luxembourg in June 1989 to take stock of the possibilities of plant biotechnology for plant improvement. The symposium reviewed the current status of plant biotechnology with specific reference to Developing Countries in five workshops. These concerned plant protection and the identification of pathogens, cereals, root and tuber crops, plantains and bananas, tree crops, legumes, vegetable crops and oil seeds. The Symposium defined elements that need to be addressed in relation to these subjects. A full account of the results of the Symposium is to be published soon.

In general, FAO would seek to promote the best use of appropriate biotechnologies to accomplish sustainable agricultural production. Since biotechnology promises both considerable benefits as well as the possibility of significant dislocations for Developing Countries, FAO will be interested in promoting those technologies leading to agricultural development and to a sustainable solution of the problems of hunger and malnutrition in the Developing Countries. FAO policy recognizes that biotechnology's ultimate impact will be a function of the research priorities that are being developed and pursued now and in the immediate future. FAO will encourage priorities directed towards those technologies which are of most benefit to Developing Countries. In the main, this will involve approaches and to give due attention to traditional food crops and to research priorities such as stability and tolerance to the climatic and environmental stresses of marginal areas.

Biotechnology research requires high levels of technical expertise and facilities in their R & D and FAO will assist member countries to define their needs and to identify and mobilize resources to meet them for institutional and manpower development. FAO will encourage cooperative networks in order to make optimal use of scarce resources.

FAO will continue to develop strategies to maximize the degree to which private sector research results can be made available to developing country-oriented biotechnology researchers. A relatively free flow of information and materials among the scientists in the developed and Developing Countries is essential to achieve desired goals.

Both national and international agencies are concerned with regulating biotechnology product testing, release and patenting and an active debate is on-going in several fora on this subject. In FAO the member countries requested the Organization to prepare a "Code of Conduct for Biotechnology" as it affects conservation and use of Plant Genetic Resources. Such a Code will obviously include regulatory issues such as intellectual property rights, field testing and release of genetically modified organisms and substitution of traditional agricultural products. Such a Code is currently being prepared and will be a subject for negotiations between parties concerned. We believe that the preparation of such a Code is a prerequisite to future implementation of technical cooperation between developed and Developing Countries.

In addition, FAO will develop guidelines for member countries to avoid major environmental costs arising from the application of new technologies used in agriculture.

Another task of the Organization is to advise its member governments on the merits of these new techniques and their socio-economic impact and, furthermore, to assist particular Developing Countries; it will monitor developments, including those related to privatization and genetic information, such as patenting of genes and living plants. It is envisaged that, in future, periodical assessments on the current status of biotechnology will be carried out under FAO's biotechnology programme and these will be made available to researchers in Developing Countries.