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REVIEW

TRANSGENIC PLANTS, SOME CONSIDERATION AND PROSPECT FOR TROPICAL REGION

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ABSTRACT

Application of biotecgnology especially transgenic plants, probably hold the most promising in agricultural production in the first decades of the next millennium. However, the application of these technologies to the agriculture of tropical regions where the largest areas of low productivity are located, and where they are most needed, remains a major challenge. In this paper, some of the important issues that need to be considered to ensure that plant biotechnology is effectively transferred to the developing world and their prospect are discussed as an review.

INTRODUCTION

The world's population is expected to be double by the year 2050, making food security the major challenge for the next millennium. Food production will have increasing preferably tripled by the year 2050 to meet the needs of the expected 11 billion people, of whom ninety percent will reside in the developing world.

Agricultural research and technological improvements are, and will continue to be, required for increasing agricultural productivity. There are numerous ways in which agricultural productivity may be increased in a sustainable way, including the use of biological fertilizers, improved pest control, soil and water conservation, and the use of improved plant varieties, produced by either traditional or biotechnological means. Of these measures, biotechnological applications, especially transgenic plant varieties, probably hold the most promise for augmenting agricultural production and productivity, when properly integrated into traditional system [1,2,5,6].

How Does Classical Breeding Differ From Genetic Engineering?

To answer some of these questions, it is important to have an understanding of how the methods by which vegetable and fruit varieties have been traditionally developed differ from or are similar to the new genetic engineering techniques. This points out one of the main differences between the two technologies [1,3,4].

1. The outcome of genetic engineering is often more predictable because it was more precise.
2. Although not obvious from this example another difference is that the source of the genetic material with genetic engineering is any living organism; the donor and recipient organisms need not be related.
3. Another important difference with the two technologies is that in the molecular approach the expression of the introduced gene can be directed to occur only in specific tissues of the plant, for example only in the fruit, the seeds or the roots.

Genetically Engineered Plants.

The effectiveness of transgenic plant varieties in increasing production and lowering production cost has been demonstrated in the cases of virus, insect, and herbicide-resistant plants, in which an average increase in production of 5% to 10%, and a saving in herbicides of up to 40% and in insecticides of between $60 to $120 per acre, have been reported in 1996 and 1997 [7]. However, these increases in productivity, impressive as they are in terms of their economic and environmental value, will have a limited impact for global food supply. In fact, most of the developments in transgenic crops are aimed either at reducing production costs in agricultural areas that already have high productivity levels or at increasing the value added to the final product by improving, for instance, oil quality. This trend has been stimulated by the current policies of developed countries to limit production of key products such as cereals, meat, and dairy products because of the reductions in international prices of these products, and to reduce the intensive use of fertilizers and pesticides because of their deleterious effects on the environment.

In a global sense, a more effective strategy would be to increase productivity in tropical areas, where an increase in food

production is needed and where crop yields are significantly lower than those obtained in developed countries. In tropical areas, the losses caused by pests, diseases, and soil problems are happen by climatic conditions that favor high levels of insect pests and vectors and by the lack of the economic resources to apply insecticides and fertilizers and to purchase high-quality seeds.

In addition to low productivity levels, postharvest losses in tropical areas are very high, again because of climatic conditions that favor fungal and insect infestation and because of the lack of appropriate storage facilities. Despite efforts to prevent preharvest and postharvest crop losses, pests destroy over half of all world production. Preharvest losses caused by insects, the majority of which occur in the developing world, are calculated at around 15% of the world's production.

Using biotechnology to produce transgenic plants that better withstand diseases, insect attack, or unfavorable soil conditions, is not a simple task. There are an estimated 67,000 species of insects worldwide that damage crops and a similar or even higher number of plant pathogens. For instance, in the case of *Phaseolus vulgaris*, over 200 diseases and 200-300 species of insects can affect bean productivity. These numbers give an idea of the complexity of the task that scientists face in increasing productivity. There are of course a certain number of diseases and insect pests that can be singled out as the most important constraints for the production of each crop.

One of the major advantages of plant biotechnology is that it can generate strategies for crop improvement that can be applied to many different crops. In this sense, genetically engineered virus resistance, insect resistance, and delayed ripening are good examples of strategies that can benefit many different crops. Transgenic plants of over 20 plant species that are resistant to more than 30 different viral diseases have been produced by using different variations of the patnogen-derived resistance strategy. Insect-resistant plant varieties, using the endotoxin of *Bacillus thuringiensis*, have been produced for several important plant species including soybean, tobacco, tomato, potato, cotton, walnut, maize, sugarcane, and rice. Of these, maize, potato, and palm oil are already under commercial production. It is envisaged that these strategies can be used for many other crops important for developing countries. Genetically engineered delayed ripening, although tested only on a commercial scale for tomato, has an enormous potential application for tropical fruit crops, which suffer severe losses because they ripen rapidly, and in many developing countries there are neither appropriate storage conditions nor adequate transportation systems to allow their efficient commercialization.

To date, most of the developments in plant gene transfer technology and the different strategies for producing improved transgenic plant varieties have been driven by the economic value of the species or the trait. These economic values are in turn mainly determined by their importance to agriculture in the developed world, particularly the United States and Western Europe. This economical emphasis is understandable, because important investments are needed to develop, field test, and commercialize new transgenic plant varieties. However, in terms of global food production, it is necessary to ensure that this technology is effectively transferred to the developing world and adapted to the local crops and/or local varieties of crops for which it was originally developed.

Developing improved transgenic versions of local varieties or local crops is not a trivial issue; in most, if not all, cultures, the use of specific crops has a deep social and/or religious meaning. Cultural preservation is just as important as environmental preservation. Cultural aspects of technology transfer need to be considered because simply replacing crops to increase productivity could have an enormously negative effect for certain cultures, and new introductions may not be accepted easily for human consumption.

It is unfortunate that most developing countries do not have sufficient resources to implement the biotechnological capacity needed to solve the major problems that limit agricultural productivity, at least not in the time frame that is required to cope with the increasing demand for food. However, it is in the developing world that biotechnology could have its major impact in increasing crop production, especially in the areas of the world where yields are low because of the lack of technology [1,2,3].

Plant genetic engineering could be considered a neutral technology that in principle does not require major changes in the agricultural practices of farmers in developing countries. Perhaps more importantly, it has the potential to bring about great benefits to the small farmers who lack the economic resources to purchase agrochemicals or prevent postharvest losses because of the lack of storage facilities. Whether there is time to increase agricultural productivity in the developing world is a question with a complex answer, because there are many factors that need to be taken into account to make this happen. We need to identify and establish mechanisms of technology transfer from developed countries, from both academic

institutions and the private sector, to the developing world; there is a need to create a sufficient number of research centers with the capability of acquiring this technology, adapting it to local crops, and developing their own technologies. Seed production facilities must be improved and an effective mechanism implemented to reach subsistence farmers with this new technology. To meet these requirements, several economic, political, and social issues must be dealt with to ensure the general application of plant biotechnology to the agriculture of developing countries. The discussion of these issues goes beyond the scope of this article. However, it is my personal opinion that it will not be technological limitations but rather political and/or economic constraints that will determine how successful we are in supplying food to the hundreds of millions of people who will be malnourished in the next millennium.

Soil Acidity: A Problem for Agriculture in the Tropics.

Estimates of the world's potentially arable land resources indicate that only 10.6% of the total land area of the world is cultivated, and about 24.2% is considered cultivable or is potentially arable land . Of these 2.5 billion hectares of potentially cultivable land, 68% is located in the humid tropics. The acid soils of the tropics, remaining potential for future agricultural development [6,7].

There are problems limiting food production that are specific or more significant to the agriculture of tropical and subtropical regions, but that unfortunately have not been given sufficient importance to deserve being considered priorities in the research being done in developed countries. However, solutions to these problems could significantly contribute to food production in tropical areas. Because many of these problems are common to many developing countries and affect the productivity of a wide spectrum of crops, transgenic strategies to solve them that can be applied to different plant species are urgently needed.

Aluminum Toxicity.

Poor crop productivity and soil fertility in acid soils are mainly caused by a combination of aluminum and manganese toxicity and nutrient deficiencies (mainly deficiencies in P, Ca, Mg, and K). Among these problems, aluminum toxicity has been identified as the most important constraint for crop production in acid soils. Aluminum toxicity problems are of enormous importance for the production of maize, sorghum, and rice in developing countries located in tropical areas of Asia, Africa, and Latin America. Most maize, sorghum, and rice cultivars currently being used are susceptible to toxic aluminum in the soil, and decreases in yield of up to 80% resulting from aluminum toxicity have been extensively reported in the literature. [5,6,7].

Aluminum has a clear toxic effect on roots, disturbing plant metabolism by decreasing mineral nutrition and water absorption. The most easily recognized symptom of Al toxicity is the inhibition of root growth, and this has become a widely accepted measure of Al stress in plants. Although Al toxicity primarily restricts root growth, given sufficient exposure, myriad different symptoms appear on both roots and shoots that are often mistaken for soil nutrient deficiencies. Therefore, crop production in acid soils is, to a great extent, limited by nutrient uptake deficiency caused by the inhibition of root growth and function that results from the toxic effects of Al. Moreover, in some acid soils, plant growth is affected not only by aluminum toxicity but also by low availability of some essential elements such as P, Ca, Mg, and Fe, some of which form complexes with Al and consequently are not readily available for root uptake. It is well documented that many plant species exhibit significant genetic variability in their ability to tolerate Al. Although it is clear that certain plant genotypes have evolved mechanisms that confer Al resistance, the cellular and molecular basis for Al resistance is still poorly understood. Two basic strategies by which plants can tolerate Al have been proposed: (*i*) the ability to exclude Al entry into the root apex and root hairs, and (*ii*) the development of mechanisms that allow the plant to tolerate toxic concentrations of Al within the cell [5,7].

Several conceptually attractive hypotheses have been proposed to explain how plants could exclude Al from entering into the root. For example, mechanisms based on alteration in rhizosphere pH, low cell-wall cation-exchange capacity, or Al +3 efflux across the plasma membrane. However, experimental evidence from several research groups supports a mechanism that results in Al exclusion from the root apex via the release of Al-binding ligands such as malic and citric acids. When these ligands are released into the rhizosphere, they can effectively chelate Al^{+3} and prevent its entry into the root.

How Transgenic Plants Could Improve Productivity in Acid Soils.

The production of Al-tolerant transgenic plant varieties should be considered an important part of crop management strategies to increase agricultural production on acid soils and to protect forests around strongly acidified industrial regions.

Generation of metal-tolerant plants through genetic engineering has been demonstrated to be a valid approach. For instance, expression of the alpha domain of human metallothionine IA in transgenic tobacco plants confers cadmium resistance. The production of transgenic plants with an increased capacity to produce and/or excrete organic acids that chelate and detoxify Al in the rhizosphere is an appealing strategy to produce Al-tolerant plants.

Citrate overproduction, therefore, appears to be an ideal candidate to produce Al-tolerant transgenic plants. To test whether citrate overproduction could be achieved in transgenic plants and to assess the impact of elevated levels of citrate on aluminum tolerance. Some research team produced transgenic tobacco lines that overexpress the citrate synthase from *Pseudomonas aeruginosa* in their cytoplasm. The finding that in two different plant species an increased capacity to produce and excrete citrate led to Al tolerance suggests that this strategy might be useful in many different plant species [4,6,7].

Transfer of Technology to Developing Countries.

Most of the available technology for producing improved transgenic plant varieties could effectively be used to improve productivity in developing countries. Because most, if not all, of these technologies have been patented and belong to private corporations, a major challenge is to identify and establish the mechanisms to effectively transfer this technology to developing countries. Several way could be followed: one would be the training of scientists from developing countries in universities, research institutes, and companies in developed countries; a second one is to assist developing countries in establishing their own facilities for biotechnological research; and the third one is to transfer technology, by means of gene constructs or transgenic plants, from universities or companies to the existing research centers in the developing world.

In terms of training and capacity building, several foundations and government agencies have important programs. Good examples of successful programs of this kind are the rice and cassava programs of the Rockefeller Foundation, the program of the Biotechnology Action Council of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Cooperation (INCO) program of the European Commission, among others. In particular, the success of the Rockefeller rice biotechnology program can be highlighted, which in a few years stimulated biotechnological research for this crop in the U.S. and Europe and facilitated the establishment of rice molecular biology research in many laboratories in many countries in the developing world [1,2,4].

In the short term, the direct transfer of technology may be the most effective strategy to implement plant biotechnology to increase productivity in the developing world. Technology transfer can be done by using end products (transgenic seed) that have been developed for the agriculture of advanced countries. Transfer of end products in some cases will be done anyhow if the market is of value to the companies; however, the use of such seed will probably be limited to intensive agriculture of a nature similar to that for which the transgenic seed was originally developed. It would be more interesting if transgenic seeds were transferred to national breeding programs, which could be used as the basis for developing local varieties better suited to local environment and soil conditions.

Another possibility is to transfer gene constructs to research institutes that have the capacity to introduce this genetic material into local crops or varieties. How to achieve this is still not completely clear, but a number of mechanisms are beginning to be explored. Transferring this technology has some problems; for instance, when royalties can be paid and when not. Perhaps , approach would be to reach agreements in which the technology is donated or, a royalty-free basis if it will be used only for production aimed at internal markets of developing countries. In cases where export is possible, royalties should of course be paid; if the farmers can export their products, however, they should at least have certain capacities to share their increased income with the providers of the technology.

To be able to meet the needs of developing countries with technology available in public and private institutions in developing countries, a source of easily accessible information will be needed, which preferentially indicates which institutions or companies agree in principle to donate technology. Initial attempts in this direction have been carried out by the International Service for the Acquisition of Agrobiotech Applications (ISAAA). This nonprofit organization is attempting to play the role of an identifying needs in their target countries and assisting a national institution to reach an agreement with the companies that have the technology that can potentially solve the problem. An example of this is the agreement between the Centro de Investigación y Estudios Avanzados in Mexico and Monsanto to develop virus-resistant potatoes for the Mexican market.

Having a company as a partner makes it more likely that all the steps, from basic research to field evaluation, are carried out successfully. These still-limited initiatives should be significantly enhanced to make sure that plant biotechnology is transferred to developing countries at an adequate pace [1,2,4,5].

To ensure effective technology transfer, each recipient country must have a research center with the capacity to assimilate the technology and apply it to local crops or local varieties. Although several developing countries, such as Brazil, Argentina, India, and China, have at least some of this capacity, it is clear that not all developing countries have research institutes with sufficient infrastructure and trained personnel to effectively participate in this process. It is therefore urgent that the countries that do not have such capabilities give priority to the establishment of research groups, as well as the regulatory bodies required to assess and approve the use and commercialization of genetically modified organisms.

Even if technology is successfully transferred to developing countries and transgenic varieties are developed for local crops, the problem of getting this technology to the small farmer is still an important challenge. The government of each country needs to implement a system for producing and distributing transgenic seeds and any other input, at low or no cost, to the small farmer. Whether technology transfer to developing countries takes place will, of course, depend on the political will of each national government and the resources required.

PROSPECTS

Bioengineered Products Reach The Marketplace

Today Plant Biotechnology is a reality. Some crops are growing in the field that have been genetically engineered and the products in the marketplace that are being eaten by consumers. Beginning in 1994, the first wave of fruits and vegetables resulting from biotechnological applications were introduced into pilot test markets in the U.S [1,6,7].

These included:

1. Vine-ripe tomatoes concerning the potential that GMO technology has for improving the living conditions of the poor and underprivileged in developing countries.
2. Processing tomatoes with superior quality (higher solids content and deeper red color).
3. Resistance to several devastating viruses. Genetically engineered virus-resistant papaya from an area of Hawaii devastated by this particular virus and Potatoes, Soybean, Maize, are genetically modified to produce an insect-killing protein.
4. Vegetables such as nonbrowning lettuce, broccoli with enhanced cancer-fighting properties, and produce of all kinds that won't wrinkle, spoil or blemish. Indeed, Monsanto has already agreed to place in lettuce a gene that provides tolerance to the herbicide Roundup, allowing farmers to spray their crop to kill weeds without harming the lettuce.

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