The role of modern biotechnology in developing country agriculture

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‘The 20th Century’s unprecedented gains in advancing human development and eradicating poverty came largely from technological breakthroughs.’ (UN Human Development Report 2001).

‘Foods can be produced through the use of GM technology that are more nutritious, stable in storage and, in principle, health promoting – bringing benefits to consumers in both industrialised and developing nations.’ (Transgenic plants and world agriculture; Royal Society 2001).

‘The impact of GM crops for people in poverty, particularly in developing countries, could be negative. GM crops and related technologies are likely to consolidate control over agriculture by large producers and agro-industrial companies, to the detriment of smaller farmers.’ (Oxfam 1999).

‘Golden Rice has been presented as a quick fix for a global problem. It isn’t, and the cash-driven propaganda about the product is swamping attempts to enforce existing effective solutions, and carry out further work on other sustainable, reliable methods to address the problem.’ (Greenpeace 2001).

Introduction

Modern biotechnology, genetic modification, genetic engineering: call it what you will, this is a controversial subject for many in Europe. Since it is a new tool with the capability to produce more food for the developing world, you would think that its use for such markets would be relatively uncontroversial. But not a bit of it: the last two quotes above gives the reader an idea of the opposition from some groups.

This paper attempts to review the subject and put forward some personal conclusions about the future.

How genetic modification differs from conventional breeding

The term ‘conventional breeding’ covers a wide range of techniques. In each case, the aim is to produce a sexual cross between two parent lines and to select promising varieties from the progeny. The parent plants will have been chosen to have desirable traits; for example one with high yield, the other with resistance to a particular disease. Crossing them mixes the two genomes completely and the genes then segregate in a random way in individual progeny. The result, in the second generation, is hundreds of thousands of genetically unique individual plants, and the skill of the breeder lies in selecting and multiplying those with potential to give improved varieties. In the early stages, this can be done only by eye, and is indeed an art.

The simple crossing of sexually compatible parent plants has been supplemented more recently by other techniques still regarded as ‘conventional’. Mutagenesis, either radiation- or chemical-induced, has given a number of plant varieties with one or more mutated genes, not previously existing in that species (examples include thornless blackberries and some popular disease-resistant barley varieties). Wide crossing and embryo rescue are further techniques which allow the generation of viable plants from species which are normally sexually incompatible.

Marker-assisted breeding is the latest tool for the breeder. In this case, knowledge of the link between a

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given trait and a particular gene allows individual progeny to be biochemically screened for the presence of the gene, so that only plants likely to demonstrate the trait in question will be multiplied and tested.

All these techniques are invaluable, and have given us the wide variety of cultivated plants in use today.

What we normally call genetic modification is more correctly termed recombinant DNA technology. Essentially, this allows the isolation of genetic material from one organism and its insertion into the genome of another. The receiving organism is said to have been 'transformed', even if the added gene is from the same species. If the transformation is successful, the organism will develop as normal and express the trait encoded by the inserted gene. For example, soyabeans tolerant to the environmentally benign broad spectrum herbicide glyphosate are produced by insertion of a single gene from a bacterium.

In one sense, this is a natural extension of modern plant breeding: rather than trying to introduce one desirable trait without other negative effects, breeders are now able in principle to change individual genes, without affecting any other characteristic of the plant. However, its use also enables the movement of genes between very distant species; from bacteria to legumes, for example.

Why use genetic modification?

The simple answer to this perfectly reasonable question is that some desirable traits are just not available within the gene pool of a particular crop plant or sexually compatible species. For example, no-one has found cassava varieties resistant to viruses which cause major yield losses, so breeding for such resistance is not an option.

Of course, there are options other than genetic modification, including growing different crops or using pesticides to kill the insects which act as the disease vector. The first of these is normally just not sensible in terms of what will grow and give a potential high yield; the second generally not a practical proposition in subsistence agriculture (nor necessarily desirable). If the appropriate gene conferring virus resistance can be found in another species, then transferring it to cassava by means of recombinant DNA technology is the only current practical route.

The arguments against

Like virtually any technology, genetic modification is intrinsically neutral: it is how it is applied that results in good or bad outcomes. In a similar way, engineers can build roads and refrigeration, but also military hardware. To take a parallel example in the nutrition field, Vitamin D in an appropriate amount is vital to proper development and good health. However, in excessive amounts it is poisonous. Almost nothing is essentially good or bad.

Nevertheless, there is strong opposition to genetic modification from some quarters, and such criticisms have to be taken seriously.

This is not the place to do anything other than list some of the major questions raised, which include:

- *Is it natural?*
- *Is it safe?*
- *What about the environment?*
- *Isn't it controlled by multinational corporations?*
- *This isn't accepted by Europeans: why should it be forced on the developing world?*

For a detailed review of some of the arguments, see, for example, the report by the Nuffield Council on Bioethics, published in 1999.

The challenge of food security

The problem of food security in the developing world is many faceted. Clearly, no amount of food production will feed the hungry if they cannot afford to buy food or there are no effective means of distribution. Additionally, in most countries, there are two distinctly different groups who must be fed: rural dwellers, dependent on subsistence farming, and the rapidly increasing urban population.

However, ultimately everyone is dependent upon productive agriculture, and the basic problems are the same for all farmers: soil quality, water availability, pests and diseases in particular. Some crops are naturally more tolerant of harsh conditions than others, or may be resistant to particular diseases, but all are susceptible to some degree.

Conventional plant breeding has, for many decades, given continuing real and significant increases in agricultural productivity. For developing countries, the so-called 'Green Revolution' was a major step forward. Norman Borlaug, working at the International Maize and Wheat Improvement Center in Mexico, received the Nobel Peace Prize in 1970 for his work in breeding dwarf varieties of rice and wheat, suitable for tropical agriculture. The key principle here is that cereals will produce a similar amount of total biomass under particular growing conditions. If more of this is present as grain, because there is a lower proportion of straw, then the yield of food can be greatly increased.

Varieties from this programme have transformed agricultural productivity in many countries. For example, in the 1960s, India was still subject to recurrent famines; today, with a much increased population, the country is basically self-sufficient in cereals, and is now the largest producer of wheat in the world. Of course, this has not been a complete panacea: high inputs of nitrogen fertiliser are needed to produce high yields, in some places constant irrigation has increased soil salinity considerably, and yields may still be severely reduced by pests and diseases. In addition, this programme did very little for sub-Saharan African agriculture, based on staples such as cassava, sweet potato and bananas.

There are those who argue that food production is not an issue; that there is already sufficient food to go round if it was to be distributed equitably. The same people suggest that 'organic' agriculture is the way forward (see, for example, Vananda Shiva 2000). Unfortunately, these views are somewhat short-sighted, as the present global population of six billion is likely to increase by a further 50% by 2050 before finally stabilising. The productivity of organic agriculture is limited purely by the amount of nitrogen it is possible to apply: best estimates suggest that global organic agriculture could not support a world population of more than four million.

The situation becomes even more challenging when we realise that most of the extra mouths to feed will be outside the industrialised Western world. Not only will there be pressure on the amount of arable land as settlements expand, but increasing prosperity will lead to a significant increase in meat consumption. The net result of providing enough food for the 800 million people who currently go hungry, feeding an extra three billion people and providing a higher proportion of animal products in the diet is a requirement to double or even triple global food production in the next half century.

Mankind must and will meet this challenge, but we will need to use all the tools available to us, including recombinant DNA technology.

Appropriate applications of modern biotechnology

Already, there are good examples of how to use this tool well:

Golden rice

Rice is a very widely consumed staple, and yet is a poor source of some vitamins. This is exacerbated by the normal polishing process, used to remove the bran and hence increase the storage life of the grain. In particular, rice is not a source of Vitamin A, and lack of this during development is a major source of childhood blindness. Even worse, there is a higher than normal mortality rate among those afflicted.

Accordingly, a team of scientists, led by Professor Ingo Potrykus of the Swiss Federal Institute of Technology has produced transformed rice which does indeed express beta-carotene, a Vitamin A precursor (for a fascinating personal account of this and related work, see for example Potrykus 2000). The presence of this results in the characteristic 'golden' colour. This work has been done with funding from the Rockefeller Foundation, and the complex intellectual property issues arising have been resolved satisfactorily so that farmers in developing countries will be able to receive seed without royalty payments being necessary. There is still some way to go before this is out in the field: transformed rice has been made available to the International Rice Research Institute and other developing country public institutions for use in breeding programmes for locally adapted varieties.

Although an exciting and eminently worthwhile development, golden rice alone will not solve the problems of malnutrition in the Third World. It is capable of delivering sufficient Vitamin A to avoid deficiency disease, but not the full recommended daily allowance (RDA). Nevertheless, in the absence of any demonstrable progress in alternative approaches such as distribution of high-dose tablets, or improvement of the overall diet, this surely has to be welcomed as a possible step in the right direction.

Virus-resistant cassava

Most of the advances in crop breeding have, unfortunately, completely by-passed sub-Saharan Africa, and it is this region – wracked by political strife and periodic drought and floods – which has some of the greatest need for advances in agriculture. Part of the problem is that many of the staple crops are not shared with other regions to any great extent.

In particular, cassava is widely grown in tropical Africa. It gives high yields in the local soils, but is susceptible to a variety of diseases. It also needs careful preparation before consumption: if not, the natural cyanide content makes it poisonous (another target for the molecular biologists). Fortunately, there are programmes of work under way to produce virus-resistant cassava, which will give consistent high yields.

Similar work to increase the reliable yield of other tropical staples – sweet potato, bananas, sorghum, etc. – is also in progress. For a recent, if somewhat partisan, account of work on a variety of crops in Africa, see Wambugu 2001.

Maize tolerant to acidic soils

Many subtropical regions have highly acidic soils, which most plants cannot tolerate successfully. Maize is the major staple in some areas, particularly Latin America, and yields can be extremely low.

The primary reason for this effect is that the low pH makes aluminium in the soil available, and this has a negative influence on the plant's metabolism. Fortunately, a group in Mexico, led by Prof Luis Herrera-Estrella, have developed a way to overcome this; maize plants have been genetically modified to express citric acid in their roots. The effect of this is to complex aluminium ions so that they are unavailable to the plant, which then develops in much the same way as on less acidic soils. For more background on this and other uses of genetic modification in tropical agriculture, see for example Herrera-Estrella 1998.

Ways forward

First the bad news: it is indisputable that, despite all efforts to improve food security, over 800 million people in the world still have an inadequate supply of food. Now the good news: In the time that the world population has increased from four to six billion, the number of the chronically under-nourished has decreased by approximately 200 000. So, in the last few decades, we have managed to feed adequately an extra 2.2 billion people.

The coming, and greater, challenge is to feed adequately the further three billion likely to be added to the population over the next 50 years, while eliminating chronic under-nutrition. This is probably the greatest challenge the human race has ever had to face, and the consequences of failure would be famine on an unimaginable scale: the Malthusian nightmare widely predicted in the 1960s would indeed come to pass.

Homo sapiens is a uniquely resourceful species, and I believe is equal to the challenge. But, to succeed, we must use all tools at our disposal to produce better yielding crop varieties, improve agricultural practices, reduce storage losses and set up better distribution systems. We simply cannot ignore a powerful tool such as rDNA technology because of concerns expressed in the developed world. What has been called 'the arrogance of affluence' must not be allowed to dictate the development agenda of those less fortunate.

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