Small farmers need a basket of options to meet their site-specific requirements Photo: Bert Lof

Biotechnology
a basket of options

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From traditional to modern biotechnologies

The brewing of beer from barley or bananas, wine making, the fermentation of milk into various products such as yoghurt and cheese as well as of soybean into curd, the combination of cereals and pulses to improve nitrogen availability, the use of ethnoveterinary vaccines to protect cattle are all examples of traditional biotechnology. According to the Convention on Biological Diversity (1992) biotechnology is defined as 'any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use'. The keywords in this definition are living, technological, and products. Biotechnology that has been developed and utilised by humans over the ages falls within the parameters of this definition. However, it is not this traditional use of biotechnology that has brought it into the focus of current global debate.

Recent sharp increase in the knowledge of biological science (biochemistry, molecular biology, genetics) has complemented these traditional forms of biotechnology with modern applications. Not only are modern biotechnologies based on new scientific knowledge, they also depend largely on the availability of capital and skilled human resources. This makes biotechnology a specialised affair and takes it into the realms of private research funded by multinational corporations. And it is this trend in biotechnology and the perceived risks that has aroused the present debate.

Much of the debate is centred on two questions: (a) who determines which applications to develop and where to apply? (b) who benefits from those applications? To widen the public debate and to render the discussions productive, a basic knowledge of major modern biotechnologies amongst a larger public is indispensable. The aim of this article is to describe four major modern biotechnologies, their applications and the inputs they require, i.e. *in vitro* technologies, detection technologies, genomics and genetic modification. Although the last application is discussed in more detail, care should be taken not to equate biotechnology to genetic modification of living organisms.

In-vitro technologies

The meaning of the Latin words *'in vitro'* is 'in glass'. In-vitro technologies separate parts of living organisms in closed containers to manipulate and maintain this material. Several well-known and relatively older applications belong to this category.

Plant tissue culture became established in the 1970s. It involves the maintenance of plant material (complete plants, specific organs or cells) under sterile conditions and in the presence of nutrients. Plant tissue culture allows the rapid multiplication of crop plants at a small scale in comparison to *'in vivo'* (living) conditions. Starter material for crops can thus be supplied in large quantities, solving bottle-necks in supply to farmers. Particularly for crops that are propagated vegetatively (not through seed), plant tissue culture forms a useful instrument to multiply starter material. Plant tissue culture also allows for the cleaning of virus-infected starter material. A third use of plant tissue culture is to conserve useful crop genetic resources in a less vulnerable environment than in the field. Finally, plant tissue culture, done in-vitro, can be used to transfer useful traits from wild relatives into crop varieties by crossing sexual barriers that do not take place under normal (in vivo) conditions.

Nowadays, more than a thousand plant species are being propagated in tissue culture. The costs of plant tissue culture are modest. A new banana plant of a desired variety can be produced and made available at less than one US dollar. This option also offers the added benefit of providing healthy planting material. Oil palm, cassava, potato and ornamentals are also propagated in-vitro. The only facilities required are two rooms: one in which the material can be handled under sterile conditions, and the other a growth room with the necessary light, temperature and humidity. Basic training is adequate to teach the principles of sterile handling of material. Local communities who have been trained to do so and have access to the facilities can manage in vitro growth. In-vitro technologies are also used in animal husbandry. Artificial insemination of cattle is a rather old application, in which sperm is stored under sterile conditions at low temperatures for large-scale insemination. Modern extensions of this technology are: "in vitro fertilisation", in which a sperm and an egg cell are made to fuse, thus speeding up the generation of new breeds; "embryo transfer", which allows the use of carrier animals for the new offspring to develop; and "cryopreservation", the storage of valuable starter material at very low temperatures. Evidently, these applications are being used both in animal breeding, and for the conservation of animal diversity. Except for artificial insemination, which is a low-cost application, the costs here are much higher than for plant tissue culture and require more advanced facilities.

Detection technologies

Detection technology has been developed to detect the presence or absence of specific traits in individual organisms. A major part of this technology is the use of an array of DNA marker techniques. These marker techniques make use of patterns of specific DNA sequences (the building blocks of all genetic information) that reveal the genetic difference between two individual organisms. This technology has considerably increased the speed of plant and animal breeding. If DNA marker sequences are linked to specific traits, such sequences can be used to search for the presence these traits in the offspring of a cross breeding, long before the trait is actually expressed. A major aspect of these techniques is that they do not alter the DNA (the genes, the traits). Instead they just allow a fast appraisal of what can be found in the offspring of a breeding programme. Various forms have been developed over the last fifteen years that differ in robustness, costs, facilities needed, and the type of information provided.

In comparison to in-vitro technologies, costs in this case are higher and the facilities required are more advanced. Until now, the extent to which this technology is applied in plant and animal breeding and its impact is much larger than that of genetic modification (see below), because it requires less time and financial investments. These techniques are being applied in small-scale agriculture as in a maize-breeding project aiming to increase the drought tolerance in local maize germplasm in Kenya and Zimbabwe. Markers have also been used to better understand farmers' selection of local rice varieties in the Philippines and Vietnam, and to more efficiently maintain the genetic diversity in enset, a staple crop of small-scale farmers in Ethiopia.

Monoclonal antibodies constitute another biotechnological detection technology. Cells derived from the immune system that produce specific antibodies are maintained and multiplied in-vitro for the production of large amounts of antibodies that can

Tissue culture can be useful for small farmers. Photo: AgroIndia

be used to search for specific material. Apart from main applications in health care, the technology is being used in agriculture to detect pathogens (agents causing pests and diseases) in plants and animals, thus allowing accurate pest and disease management. These technologies are used to provide the pest/disease free import guarantees on products as required by many countries, facilitating cross-border exchange of plants and animals. Whereas the costs for the development of monoclonal cells producing specific antibodies are high and specialist expertise is needed, the use of such monoclonal cells and their antibodies is relatively simple and requires only modest facilities.

Genomics

Genomics is a field of biology that has developed very rapidly over the last decade. It involves the large-scale sequencing of DNA, including entire genomes (all the DNA of a single individual), and the comparative analysis of the resulting sequences across species barriers. Major highlights in this field are the sequencing of the total DNA of man, but also of a substantial number of micro-organisms (model organisms, pathogens and organisms used in traditional biotechnology), of plants (including rice) and of animals. Genomics produces enormous datasets and a complete new science, bio-informatics, has been developed to handle these databases and to allow retrieval and analysis of the information they contain. The costs of genomics research are high and only a few specialised institutions worldwide, located almost exclusively in developed countries, are able to contribute to this newly-evolving science. Although no immediate spin-off for agricultural applications should be expected in the next 5-10 years, a detailed knowledge of plant and animal genomes will, in the long run, speed up breeding, also in tropical agriculture.

Genetic modification

Genetic modification, also termed genetic manipulation, concerns the transfer of genetic information - in the form of DNA sequences - across sexual barriers between species, which under normal conditions would not exchange DNA. The resulting organisms are called genetically modified organisms (GMOs) or transgenics. Genetic modification is currently used only to introduce a single new trait, which might be based on the activity of a single gene, or a small number of genes. The number of genes with known functions that has been isolated is still too small to allow for more complicated traits or combinations of traits to be introduced using genetic modification. In agriculture, genetic modification has been applied in a number of major crops. The majority of these applications involve the introduction of resistant traits, particularly to herbicides and insects. A smaller number of applications involve the quality of the resulting product, e.g. the shelf life of tomatoes, or the production of alternative sweeteners in sugarbeet. Whereas farmers mainly deal with the former type of agronomic applications, the processing industry and consumers are confronted with the latter. Transgenic animals have been produced under laboratory conditions, but up to now have not been released for industrial application.

In all cases, the costs of developing GMOs are high, and the technology is dependent on very expensive facilities and highly skilled experts. The cost of the development and commercialisation of a GMO crop variety was recently estimated at US$30 million. In an increasing number of countries, legislation and regulations to contain GMOs and their products during the development and extensive testing phases before release are strict and costly. Although 70 transgenic crop varieties were registered for commercial cultivation in 1999, as of now international agricultural biotechnology companies have focussed their activities on a few crops, including the seed companies' cash earners such as cotton, rapeseed, maize, soybean, and wheat.

Impact on tropical agriculture

In developed countries agriculture has been industrialised over the course of the twentieth century. Breeding has developed from a farmer's activity into a specialist's affair. The conditions of the farmers' fields have been adjusted to the new breeds by extensive application of fertilisers and pesticides. Crops have become increasingly uniform to facilitate mechanised cultivation, harvesting and processing. Because of the more capital-intensive nature of agriculture, the size of an average economically sustainable farm has increased several times over the last century. Agricultural biotechnology will certainly enhance this trend by increasing the dependence of the entire production chain on a very limited number of crops and varieties with new traits. Modern agriculture will continue to be high-input dependent and become even more uniform. Genetic modification will allow the production of the same raw materials (e.g. plant oils) in different crops. The negative impact of modern agriculture on agrobiodiversity might be worsened by the wide-scale introduction of genetically modified crops and farm animals.

Tropical agriculture, however, is still dominated by small-scale systems. Often, farmers' access to external inputs is low. Therefore, international companies developing GM crops do not consider small-scale agriculture as an important market. Besides, GM crops would not cater to the diverse agro-ecological conditions encountered in farmers' fields and would be of little benefit to them.

The field release of GMOs is generally heavily regulated and major short-term effects on the crops and the agro-system environment are expected to show up in the test phase. Yet, small-scale systems may well have to face the environmental risks of GMOs. In the long term it is difficult to imagine how the appearance of GMO traits in non-GMO crops can be avoided as a result of uncontrolled crossing, particularly in cross-fertilising species. The question is whether we regard this an unacceptable tinkering of nature, a risky development in terms of food safety and environmental and genetic pollution, or simply as a new harmless step in the interference of humans on the plants and animals that provide our food. In any case, it will certainly pose problems to the organic agriculture sector that is devoted to the maintenance of a GMO-free chain.

Although GMOs may currently have little or no direct relevance to small-scale tropical agriculture, this reality does not follow from the biological nature of biotechnological applications but from the socio-economic context in which biotechnological applications are developed. This leads us to the question of whether and under what conditions other appropriate biotechnologies for small-scale farmers are feasible.

Appropriate biotechnologies: a reality or fantasy?

Biotechnology has the potential to serve all farmers, including small-scale farmers in tropical production systems. Appropriate biotechnologies may be developed on the basis of demand and in consultation with farmers and/or their representatives (community-based organisations, supportive NGOs, dedicated extension services). It can be expected that modern biotechnologies that require relatively few investments and that can be applied in-country or even in the community stand the best chance of being appropriate. In particular, this could apply to plant tissue culture technology to produce healthy, much valued varieties in large enough quantities. Also the use of monoclonals may in time allow farmers and extension services to monitor for specific pests and diseases. The use of artificial insemination could be extended also to well-adapted indigenous breeds. Cryopreservation and tissue culture of valuable plant and animal varieties and breeds might also serve the small-scale farming sector in providing a back-up for their genetic resources maintained in the field. All these applications form a potential reality.

However, it can be doubted whether genetic modification has anything to offer to small-scale farmers other than a growing dependence of farmers on the seed industry. It can be doubted whether and to which extent the lack of interest by the private sector will be compensated for by increased public breeding efforts that should prevent a widening technology gap between a rather small number of commercial crops and crops of regional or local importance. On the other hand, it should be realised that for any application in the public domain aimed at benefiting small-scale farmers, co-operation with the private sector will be absolutely indispensable since the private sector owns all the key patents needed to develop GMOs. The case of Golden Rice forms an interesting one as it represents an exceptional effort in the public domain to alleviate problems of low-income groups including many small-scale farmers in developing countries (vitamin A deficiency) through the application of genetic modification. However, many patent exemptions in the form of licences had to be obtained to allow Golden Rice to be developed for farmers in developing countries, and whether Golden Rice will fit social and cultural patterns will have to be awaited. Also, it is yet too early to predict how often such patent exemptions will be granted to allow the development of public sector initiatives to benefit the small-scale sector.

In my opinion, more than the risks of monster organisms, food safety problems and environmental pollution, the real threat of GMOs might be the socio-economic dependence it creates for its users from the companies selling such GMOs.

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