Public research in plant biotechnology

PRRI Briefing Paper
- **Background and history**
- **Potential applications**
- **Public research in modern plant biotechnology**
- **Why mainly four GM crops with only two traits are available to farmers today despite the massive research efforts**

PRRI
Science 4 BioReg
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1. INTRODUCTION

Global developments such as growth of the world population, loss of arable land, environmental pollution and climate change pose enormous challenges for sustainable agricultural production of food, feed, fibre and fuel. Governments and international organizations invest massively in public plant biotechnology research to help finding solutions for these challenges.

This briefing paper provides background on modern plant biotechnology, describes areas of ongoing public research in it and discusses reasons for the fact that, despite massive research efforts over many years, the genetically modified crops made available to farmers today are mainly four crops with only two new features or "traits".

2. BACKGROUND AND HISTORY

Some 10.000 years ago man changed from hunting animals and gathering fruits in the wild to keeping animals and growing plants near the places where he lived – from a nomadic, hunter-gatherer to a settled agriculturalist.

Since then and in a long process, humans have dramatically changed the animals and plants they originally found in nature. Domesticated cattle, sheep, cats, and dogs are well recognized, but people are sometimes unaware that similar domestication has occurred with virtually all plants and trees we grow as crops both in developed and developing societies, such as maize, wheat, rice, and soybeans. For many thousands of years humans have selected and crossed plants and animals that had characteristics they wanted such as higher yield or better taste.

This approach made a major leap forward when in the 19th century the monk Mendel discovered the 'rules' by which characteristics were inherited from one generation to the next. Later, scientists discovered that the code for the characteristics of plants, animals and micro-organisms are contained in so-called 'genes', and that genes consist of genetic material, which we call DNA.

In the early 20th century, plant breeders discovered that mutations in plants do not only occur spontaneously, but can also be induced by exposing plant material to radiation or chemicals. This has become a widely used technique, and many of the crops we consume every day were obtained originally with the help of mutations induced by chemicals and ionizing radiation although these are also typically carcinogenic or toxic in higher doses.

While cross-breeding and induced mutations are, and will continue to be, extremely important tools for plant breeding, they also have a number of limitations.
1. For some plants cross breeding is extremely difficult or even impossible. Cultivated bananas, for example, are sterile and have no seeds. Banana palms are multiplied 'asexually', which means that to make new banana palms, parts of an existing palm are used and all the resulting bananas are therefore genetically identical or clones of the original palm.
2. Cross breeding only works between plants that are genetically related. A gene for disease resistance in tomato cannot be crossed into maize, for example, because maize and tomatoes do not cross breed.
3. Cross breeding can take a very long time. For example, it took apple breeders over 50 years to cross breed resistance against scab, which is a major disease of apple trees that requires many sprays with pesticides each season, into other varieties.
4. Cross breeding not only brings the desired genes from plant A into plant B, which is usually a variety that is well adapted to the local environment and/or already has other desirable traits, but also brings the tens of thousands of other genes from plant A with it. This so-called 'linkage drag' forces plant breeders to carry out a long process of 'back crossing' with plant A to regain its desirable characteristics.
5. Similarly, while inducing mutations by radiation and chemicals is an extremely useful technique that has had impressive results, it is very undirected and unpredictable, and also often has effects on the other genes of the plants.

INFORMATION

The Public Research and Regulation Initiative (PRRI) is an independent world wide organisation established in 2004 with the objective of offering public researchers involved in modern bio-technology a forum through which they are informed about and involved in international discussions pertaining to biotechnology.

PRRI produces briefing papers on various areas of regulation, providing back-ground and current status, and identifying specific issues that require researchers' attention. These papers provide general introductions and overviews with references to more detailed information rather than being exhaustive legal documents.

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To overcome these limitations of cross breeding and induced mutation, in the 1970s scientists developed techniques that made it possible to:

1. identify a specific gene responsible for a trait in an organism,
2. isolate that gene, and
3. bring it into plant cells through a process called "transformation".

Compared with traditional breeding, this technique, usually now called "genetic modification", is faster, more specific and is not limited to exchanging genes from related plants but can make use of any gene from any micro-organism, plant or animal and transfer it into any other of these.

The reason that in principle any gene from any organism can be made to function in any other organism, is because the genetic code is a universal code. In fact many genes found in one organism can also be found in another. For example many genes of humans are also found in bacteria, plants, fruit flies, mice and of course our near relatives, the apes.

3. POTENTIAL APPLICATIONS

To understand the potential uses of the technique of genetic modification in agriculture, it is important to understand the challenges for food production that the world community faces today:

- The current world population is approximately 6.75 billion and far too large a number of these people are undernourished, either in terms of quantity or quality of food, or both, while the world population is expected to grow to around 9 billion by 2040.
- The area of land that can be used for agriculture is shrinking because of erosion, pollution, and land being used for other purposes such as buildings and roads, as well as other causes.
- There is increasing shortage of fresh water for drinking and irrigation.
- Climate change will increase the need for keeping pace with well-adapted crop plants, especially those capable of growing in more arid conditions.
- Increasing demand for fuels and chemicals from renewable sources as oil reserves become depleted and oil-based commodities more expensive.
- 80 % of the world's calorific intake comes from only four crops.

These developments create crucial, immense challenges for the world community to, among other things:

- produce more crop per hectare,
- produce more crop per litre of water,
- produce on hitherto non-arable land,
- produce on arid and/or saline land,
- enhance the nutritional value of crops,
- enhance crop diversity,
- reduce dependence on pesticides and fertilizers,
- reduce post-harvest losses during storage and transport,
- reduce soil erosion.

No single technology can solve these immensely complex challenges by itself. The future of the agriculture is not a matter of "either this or that technology" but rather of combining the most suitable approaches of each available technology, tailored to specific needs and situations.

Since 1992 Governments and international organisations with the United Nations Conference on Environment and Development (UNCED), Agenda 21 have repeatedly acknowledged that modern biotechnology – although not a 'silver bullet' - can contribute significantly to finding solutions for these challenges. This has been repeated in the outcome of the World Summit and the Johannesburg Declaration.

4. PUBLIC RESEARCH IN MODERN PLANT BIOTECHNOLOGY

Over the years governments and international organisations have invested, and will continue to invest, billions of euros in research and development in modern biotechnology.

The types of "traits" or characteristics in current and planned public plant biotechnology research are:

1. "Biotic stress" resistance
   a. disease resistance
   - *fungus resistance* in banana (black sigatoka), wheat, yams
   - *virus resistance* in banana, cassava (cassava brown streak virus, cassava mosaic virus), yam (yam mosaic virus), papaya (papaya ringspot virus), groundnut (tobacco streak virus), tomato (tomato yellow leaf curl virus), maize, rice, potato
   - *bacterial resistance* in rice (bacterial late blight), cassava (bacterial blight), banana (bacterial wilt), potato (late blight)

   b. pest resistance:
   - *pests in the field*: cowpea (pod borers), maize, cotton, potatoes (nematodes), yams (nematodes), vegetables (sucking insects), chickpea (borers), banana (borers, weevils, nematodes), egg plants (fruit and shoot borer), sweet potatoes (insects)
   - *storage pests*: grains (borers), potatoes (tuber moths)
2. "Abiotic stress" tolerance
   a. *drought tolerance*: wheat, maize (water efficient maize for Africa - WEMA project), rice, sorghum, potato, groundnut, cowpea and watermelon
   b. *saline tolerance*: wheat (nitrogen use efficiency), maize, sorghum, tobacco
3. Enhanced nutrition: rice (provitamin A, iron, zinc, vitamin E, and high-quality protein), wheat (iron), mustard (provitamin A), maize (protein quality), potatoes (protein quality), cassava (protein, provitamin A, vitamin E, iron and zinc), sorghum (digestibility, protein quality, zinc, iron, and provitamin A), and banana (provitamin A and iron).
4. Other: enhanced Nitrogen Use Efficient & Salt –Tolerant (NUE-ST). [1] Changing available phosphorus by reducing phytates. Reducing existing levels of cyanogenic compounds in cassava.

Overviews with background information can be found on several web sites, such as:

- CGIAR Challenge Programs Harvest Plus for micro-nutrient enrichment: http://www.harvestplus.org
- Generation Challenge Programme: http://www.generationcp.org for drought adaptation
- *'The global pipeline of new GM crops'* – JRC database: http://ftp.jrc.es/EURdoc/JRC50946.xls
- AATF: www.aatf-africa.org
- NGICA: www.entm.purdue.edu/NGICA
- CSIRO: www.csiro.au/resources/Cowpeas.html
- IITA:r4dreview.org/2009/03/designer-cowpea-plants

5. WHY MAINLY FOUR GM CROPS WITH ONLY TWO TRAITS ARE AVAILABLE TO FARMERS TODAY DESPITE THE MASSIVE RESEARCH EFFORTS

The genetically modified crops that are currently available to farmers are primarily soy beans, maize, cotton and rapeseed with improved insect resistance and/or herbicide tolerance. In 2008, these crops were grown on 125 million hectares by over 13 million small and large farmers in 25 developed and developing countries.[2] While the performance of these GM crops varies from case to case, the aggregated impact on farm level incomes amounts to $US billions. The environmental benefits include a decrease of hundreds of millions of kilograms of pesticides as well as significant reduction of soil erosion and fossil fuel use due to low-till farming practices made possible by herbicide tolerant crops. In addition, the health and livelihoods of farmers, particularly in developing countries, have been improved through reduced exposure to toxic chemicals and the adoption of more environmentally-benign chemicals.[3]

A study by the Joint Research Centre of the European Commission concluded after thorough research of the published data:

"…. Published research analysing ex post the impacts of GM crops adoption at farm level is now abundant. The picture emerging is that adoption of GM crops has taken place at a rapid rate and driven by a number of reasons including on-farm and off-farm benefits. On-farm benefits are derived from reducing production costs (weed control costs for HT crops and pest control costs for Bt crops). For some crops there are also yield increases (particularly in the case of Bt cotton), affected in some regions by the fact that GM traits have not yet been introduced in all local varieties. The net economic benefits for farmers are variable in regional terms…." [4]

"….Ex post analyses also show that adoption of dominant GM crops and on-farm economic gains have benefited both small and large farmers. Small farmers have shown no difficulty in adopting the technology and adoption rates are not related to farm size. Moreover, detailed analyses (for example of Bt cotton in China) show that increases in gross margin are comparatively larger for smaller and lower income farmers than for larger and higher income farmers…."

"…Ex post analyses provide data on the effects of GM crop adoption on the use of agricultural inputs. Bt cotton adoption has resulted in a significant decrease in the use of insecticides in all cases studied (25% of all insecticide used in agriculture world wide is for cotton cultivation). Bt maize adoption has induced only a little decrease in insecticide use since the pests Bt maize is designed to resist were not usually controlled by insecticide applications. The adoption of HT soybean has resulted in the displacement of several herbicides by one single product that is considered to be less toxic than the herbicides it replaces. Use of this herbicide has increased. HT soybean adoption has been associated with reduced fuel consumption per hectare and with the adoption of reduced soil tillage practices…."

However, despite decades of massive and often successful research efforts with many crop plants, particularly in the public research sector, very few GM crops have actually been made available to farmers.

One of the biggest hurdles to developing GM crop plants is that complying with regulations has become unnecessarily difficult, lengthy and costly, and therefore inhibits public research institutions with small budgets. Traits or crops that cannot create enough return on investment to recoup the huge regulatory investment necessary, make it almost impossible for public projects to go ahead unless a project is recognised as a national or international priority and receives additional funding for regulatory purposes. This poses a huge problem for the whole public research funding community; as such R&D projects usually receive funds in the range of hundreds of thousands of euros for the whole project, while regulatory costs lie in the millions of euros.

Since the introduction of modern biotechnology, national and international biosafety regulations have been established in order to allow policymakers to make informed decisions based on an evaluation of potential benefits and potential risks. However, the general feeling of many researchers is that regulatory decisions for field trials or placing on the market are often either unnecessarily delayed, or denied without balanced, science based assessment. There are believed to be three main reasons why decisions are delayed:

1. In some cases there is uncertainty about the legal framework. This is particularly the case with transboundary movement of GMOs from one country for field testing in another country that does not yet have biosafety regulations in place. For these cases the Cartagena Protocol on Biosafety has been established. One of the main purposes of the Protocol is to allow decision makers in countries that do not yet have biosafety regulations in place to make informed decisions on the import of genetically engineered organisms for field testing, based on a procedure called AIA (Advanced Informed Agreement). The fact that over five years after coming into force of the Protocol there have been no such AIA decisions, either positive or negative, indicates that research institutes and Governments may not be aware of the possibilities that the Protocol offers. It is for these reasons that PRRI conducts several activities to educate researchers about the functioning of the Protocol.

2. Decision makers often find it difficult to come to decisions under the current public or political pressure and therefore delay decisions. This seems to be the case, for example, in the European Union where certain dossiers remain undecided for years.

3. Many researchers believe that there are too many cases where authorisations are denied without adequate assessment. The impression is that the key factor in this is an unbalanced evaluation of environmental risks and environmental benefits, whereby the "risk" factor receives disproportionate weight despite scientific evidence and advice, and that the "benefit" factor is under-valued or ignored.

REFERENCES:

[1] Economic Impact of Dominant GM Crops Worldwide a Review, see: http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=1458 . Institute for Prospective Technological Studies, at the Joint Research Centre of the European Commission. See also: http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=1580.

[2] http://www.isaaa.org/Kc/cropbiotechupdate/online/default.asp?Date=2/13/2009#3741

[3] Source: Brookes, 2008.

[4] http://ipts.jrc.ec.europa.eu/publications/pub.cfm?prs=1458

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