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Lesson: Biosafety Concerns in Plant Biotechnology

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Learning outcomes

After reading this Chapter, the reader should be able to understand:

- The importance of biotechnology
- Applications of various branches of biotechnology
- Concerns related to biotechnology
- Need for biosafety
- The principles of biosafety
- Different levels of biosafety
- National and international regulations of biosafety.

Chapter: Biosafety Concerns in Biotechnology

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Introduction

Biotechnology can be simply defined as technology based on biology. It uses living systems and organisms to develop technologies and products which are useful to our lives and improve the health of our planet. This term was coined by a Hungarian engineer, Karl Ereky, in 1919. As per the UN convention on biological diversity, biotechnology is defined as, "any technological application that uses biological system or living organisms to make or modify the process or products for specific use". In the modern times, biotechnological advancement is contributing in almost all aspects of human life, including development of breakthrough products and technology to fight rare diseases, production of plant resources with either higher nutritional values (such as golden rice) and/or enhanced ability to thrive in unfavorable environmental conditions (such as drought resistant plants) to alleviate the pressing need for more food, production of cleaner energy fuels (such as bioethanol from lignocellulosic waste using biocatalysts such as enzymes, yeast in fermentation process) and also development of cleaner, safer and better industrial manufacturing processes (such as use of biopulping instead of thermomechanical pulping in paper making can reduce consumption of electrical energy by 30 per cent). The contribution of biotechnology to our day-to-day life can be estimated by the facts that currently over 250 health care products/vaccines are available in the markets world over, over 13 million farmers use agricultural biotechnology tools/products for increasing yields, preventing losses from insects/pests and minimizing impact of farming on environment etc. Although, it has tremendously supported the human survival, some biosafety concerns are also associated with it. In this chapter, we will first briefly discuss the applications of biotechnology and its branches followed by the issues/concerns on biotechnological tools/practices and the biosafety measures.

Applications of biotechnology

Although biotechnology plays an integral part in our lives in innumerable ways, it received the much needed attention only in the last three decades when new and environmental friendly alternative methods were explored to help human survival. Initially the use of biotechnology were confined to a few processes such as , conversion of milk to yogurt or cheese is facilitated by involvement of bacteria or the process of fermentation which is used to bake breads and make wine involves biological activity of single celled microorganism called yeast. However, in the last three decades notable advancement in the biotechnological tools has been observed and there are innumerable examples of use of these tools in producing the breathtaking products. Some of the

recent path breaking achievements in biotechnology are – development of genetically modified bacteria (*Pseudomonas putida*) by Anand Chakrabarty (http://en.wikipedia.org/wiki/Diamond_v._Chakrabarty) and another oil eating bacteria (*Alcanivorax borkumensis*) has been sequenced (http://www.ncbi.nlm.nih.gov/pubmed/14651863) and now conditions are being optimized for its best growth on oils for cleaning the oil spills and keep up the environment clean; in medical science the tumor seeking immune system cells have been created to fight cancer (http://phys.org/news198170671.html). Additionally, scientists have found a way to improve the oil content in tobacco plant leaves with an aim to use such plants for biofuel generation (http://www.sciencedaily.com/releases/2009/12/091230174128.htm). Further, one of the most significant breakthroughs of recent biotechnological advancement is reduced cost of genome sequencing.

Availability of the genetic information of genome sequence is critical to the personalized medicines. The information facilitates the correct diagnosis and targeted treatment of a particular disease. Moreover, culturing of human stem cells without the use of animal substances has also been achieved and this is a significant breakthrough as now new cells can be created and used to test for different diseases.

Besides all these breakthrough advancement, biotechnological tools have also contributed for the development of antibiotics such as penicillin, pharmaceutical drug discovery and production, genetically modified crops with improved agronomic traits such as resistance to certain pests (Bt cotton), diseases, stressful environmental conditions (AtNHX1 lines), resistance to herbicide (soyabean), prolonged shelf-life tomatoes (FlavrSavr), improved nutrition (golden rice), genetically modified organisms such as Dolly (sheep). Since the chapter deals with the Biosafety concerns in plant biotechnology, a few benefits offered by the genetic engineering techniques to agricultural biotechnology are covered first. The advantages include:

- increased crop productivity such as in case of transgenic papaya varieties (SunUp and Rainbow) resistant to papaya ringspot virus, enhanced crop protection as pest resistant crops such as corn, cotton, and potato with *Bacillus thuringiensis* CRY genes,
- improvements in food processing as the genetically engineered bacteria produced *chymosin,*
- improved nutritional value such as golden rice with high beta-carotene,
- better flavor as in case of transgenic peppers and melons,
- fresher produce such as FlavrSavr tomatoes with prolonged shelf life,

- environmental benefits such as use of less pesticide while growing the transgenic resistant crops, therefore, less pesticide residues on foods, reduced leaching of pesticides into groundwater and minimum exposure of workers to such health hazardous chemicals, and
- finally benefits for developing countries as the improved transgenic crops such as golden rice with high beta-carotene be used to meet the vitamin diet in developing countries.

In nutshell, biotechnology touches almost every aspect of our lives and has contributed towards the evolution of all living organisms on earth. Although, biotechnology remains an integral and indispensable to our lives, there are concerns regarding its practices/applications.

Branches of Biotechnology

The study of biotechnology may be further divided into several branches. The important branches are classified as:

1. Red biotechnology

This is the branch of biotechnology which deals with improvements in medical and health care by using living organisms in designing novel therapeutics. A few well-known examples of red biotechnology include antibiotic production, vaccine development and genetic engineering.

Concerns/Risks associated with red biotechnology

The main concern with red biotechnology seems to be production of transgenic animals and subsequent unethical application of the gained knowledge (on such animals) on humans. Some of the other concerns include:

1. Potential harmful impact on the environment.

2. Health of animals.

3. Food safety and drug resistance associated with the foods derived from GM animals.

4. Unknown risks associated with the permits to research on animals without doing the thorough risk analysis.

5. Transfer of viruses and/or other infective agents from animals to humans; which generally do not infect human and are only confined to the specific animal.

2. Green biotechnology

This is the branch of biotechnology deals with agricultural processes. Under this branch, latest technological achievements/products/equipments are used to help preserve our environment. This technology has been successfully employed in developing more environment friendly farming solutions by using genetically altered plants as an alternative to traditional agricultural practices to address growing issues related to food quality, resistance to pests and diseases and also to the adverse environmental conditions. The following figure explains about the different steps involved in producing transgenic plants.

LINK FOR ANIMATION

http://passel.unl.edu/pages/animation.php?a=overview_genetic_engineering.swf&b=990818777

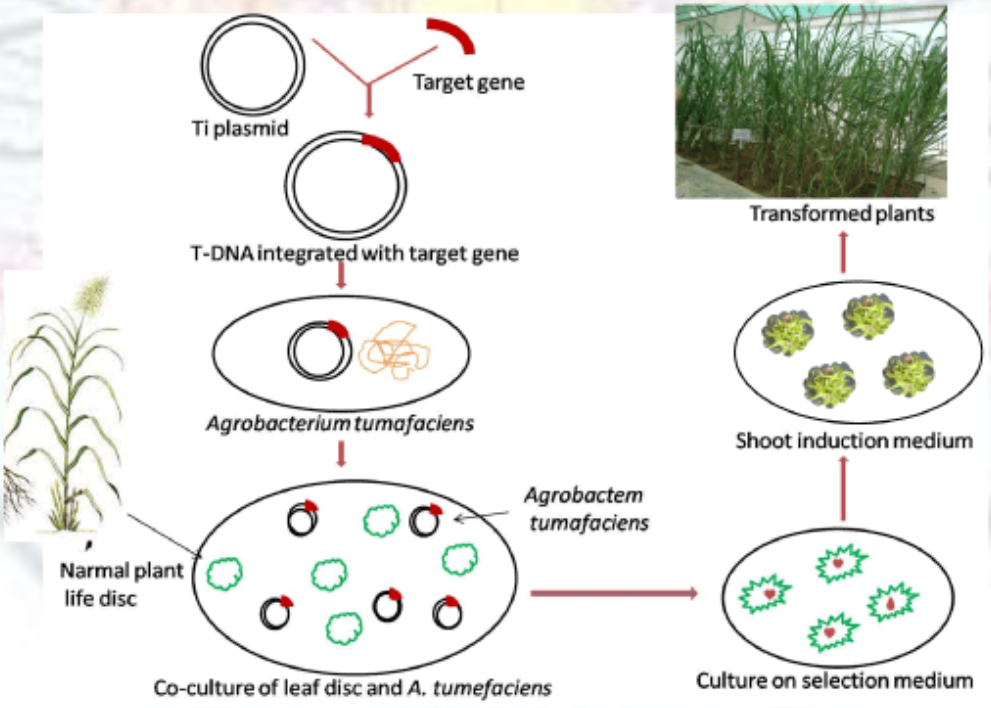

Figure: Different steps involved in generation of genetically modified plants. In this process, DNA containing gene for desired trait is first mobilized in *Agrobacterium tumefaciens* (see http://en.wikipedia.org/wiki/Agrobacterium_tumefaciens for further information). *Agrobacterium* containing gene of interest as a part of its Ti plasmid is then introduced to the plant cells. Thereafter, tissue culture methods are used to regenerate transgenic plants.

Source: http://omicsgroup.org/journals/current-status-of-sugarcane-transgenic-an-overview-2169-0111.1000112.php?aid=18824 (CC)

Concerns/Risks associated with green biotechnology

Whereas the political activity in environmental protection has continuously increased in the last decade, production of genetic modified (GM) crops also has gone up too. The cultivated area for GM crops now exceeds more than 175million hectares worldwide and recorded a 100 foldincrease in hectare between 1996 and 2013, thereby suggesting a positive mindset towards biotech crops. This fact shows that biotech crops are the fastest adopted crop technology in recent times. Now as per the International Service for the Acquisition of Agri-biotech Applications (ISAAA) 2013 year release on global status on GM crops, at least27 countries are growing GM crops in the world (http://www.isaaa.org/resources/publications/briefs/46/executivesummary/). In 2013, over 18 million farmers grew GM crops, including 7.3 million farmers from India. The global value of biotech seed alone was estimated to be over US$15.6 billion in 2013. The main concerns associated with green biotechnology are yet to be proved scientifically.

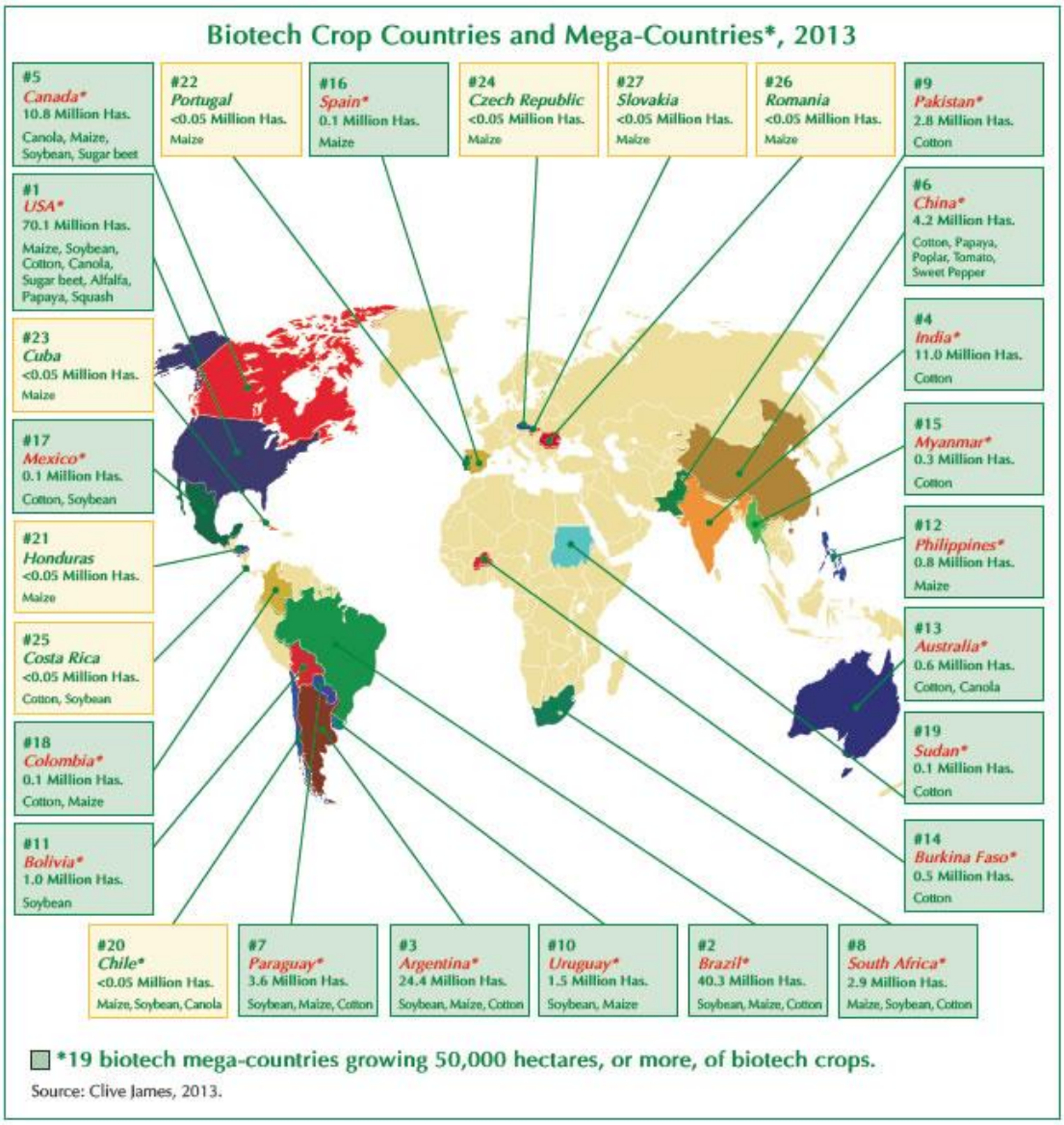

Figure: The image shows global map of biotech crop countries and mega countries in 2013. India is one of the mega countries that is involved in growing of biotech crops and only positioned after USA, China, Argentina and Brazil.

Source: http://www.isaaa.org/resources/publications/briefs/46/executivesummary/ (cc)

3. White biotechnology

This is the branch of biotechnology which deals with the use of modern biotechnological tools for the sustainable processing of chemicals and energy. White biotechnology is a European terminology used for industrial biotechnology. Basically, this branch promotes the use of enzyme and micro-organisms over pure chemical processes to make products in various industrial sectors including pharmaceuticals, paper, food and feed, energy, chemicals, and polymers.

The detailed document on this aspect can be found at webpage http://www.europabio.org/sites/default/files/report/industrial_or_white_biotechnology_research_for_europe.pdf for further reading.

Some of the products which are being produced using the micro-organisms and following the white biotechnology mandate are L-Glutamic acid, citric acid, vitamin C, starch, cellulose, ethanol (bioethanol), and antibiotics and secondary metabolites etc. See the web link for further information (http://www.bio-economy.net/reports/files/vision_docuement.pdf)

4. Blue biotechnology

This branch is concerned with the application of molecular biology tools to the marine and aquatic microorganisms for the sustainable processing of medicines, pharmaceuticals, and food and feed supplements and other natural marine products.

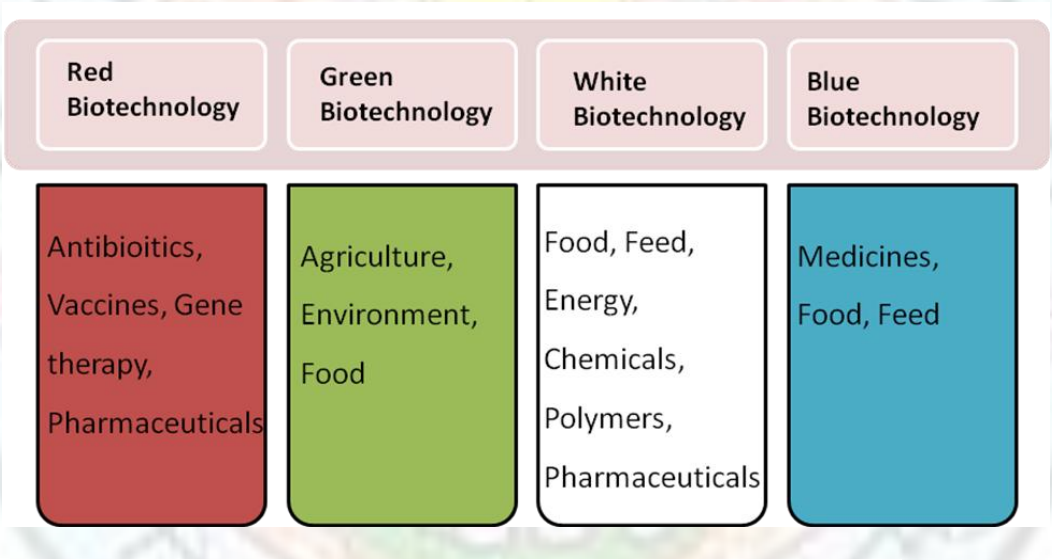

Figure: Different branches of biotechnology and their main applications.

Source: Namrata Dhaka, Department of Genetics, University of Delhi, South Campus

Concerns associated with biotechnology

1. Risks to human/animal health

The process of recombinant DNA technology involves use of microorganisms and techniques which may be a threat to the workers if used recklessly. Additionally, the end products i.e. GM-food/feed may be toxic or cause allergies. The selectable marker used

for development of GM crops may have some negative impacts on drug (antibiotic) resistance.

Concerns due to antibiotic resistance genes

Antibiotic resistance genes are used as selectable markers for plant transformation (Refer to the chapter – Methods of Gene Transfer in Plants). The use of these marker genes has led to the suspicion that these genes might be transferred to the environment and result in creation of antibiotic resistant human pathogens.

However, the mechanisms of transfer of the genes from GM crop to bacteria are itself questionable and it has not been experimentally shown. Apart from this, the antibiotics commonly used in development of transgenic crops are not the ones which are usually used in treatment of human diseases.

In spite of the doubtful status of any harm conferred by these marker genes, plant biotechnologists are now using techniques to generate 'marker-free plants'. It is also referred to as the 'clean gene technology'.

Method	Marker gene	Crop plants
Co-transformation	Neomycin phosphotransferase gene (npt)	Tobacco (*Nicotiana tabacum*)
Co-transformation	-	Tomato (*Lycopersicon esculentum*)
Cre/lox site-specific recombination	Hygromycin phosphotransferase (hpt)	Tobacco (*Nicotiana tabacum*)
Cre/lox site-specific recombination	Acetolactate synthase (ALS) and β-glucuronidase (GUS)	*Arabidopsis thaliana* and Tobacco (*Nicotiana tabacum*)
Ac-Ds transposon system	NPT-II, neomycin phosphotransferase II and β-glucuronidase (GUS)	Tomato (*Lycopersicon esculentum*)
Co-transformation	Hygromycin phosphotransferase (*hpt*), NPT-II, neomycin phosphotransferase II and β-glucuronidase (GUS)	Tobacco (*Nicotiana tabacum* L.) and rice (*Oryza sativa* L.)
MAT system (Multi-Auto-Transformation	Isopentenyl transferase (*ipt*) , Neomycin phosphotransferase gene (npt) and β-glucuronidase (GUS)	Hybrid aspen (*Populus sieboldii* 3 *Populus grandidentata*)
Co-transformation	Neomycin phosphotransferase gene (npt) and β-glucuronidase (GUS)	Rapeseed (*Brassica napus*) and tobacco (*Nicotiana tabacum*)
MAT system (Multi-Auto-Transformation	*npt, ipt and Gus*	Tobacco (*Nicotiana tabacum*)
TREGED (transposon-and recombinase-mediated genome deletion)	*tetR* gene and two visible markers, *GUS* and *Lc*	Petunia
Ac-Ds transposon system	Neomycin phosphotransferase gene (nptII)	Tobacco (*Nicotiana tabacum*)
Particle-bombardment	*aadA* and *bar* gene	Tobacco (*Nicotiana tabacum*)
Double T-DNA binary vector system	Gus and bar gene	Soybean
R/RS site-specific recombination and the Ac transposon	β-glucuronidase (GUS)	Rice (*Oryza sativa* L.)
MAT (Multi-Auto-Transformation)	ipt gene and the R gene	Tobacco, Aspen, Rice and Snapdragon.
Positive selection	pmi	Rice (*Oryza sativa* L.)
Co-transformation	Hpt, low-pI α-amylase, and α-glucosidase	Barley
Chloroplast transformation	BADH gene	Tobacco (*Nicotiana tabacum*)
GST-MAT vector system	*Ipt* gene combined with *iaaM/H* genes	Tobacco *Nicotiana tabacum*
GST-MAT vector	*ipt gene*	Hybrid aspen (*Populus Sieboldii* X *Populus grandidentata*)
Co-transformation	Gus, hph and npt II	Tobacco (*Nicotiana tabacum*)
Ac-Ds transposon system	synthetic *cryI B* gene, gfp and hph gene	Rice (*Oryza sativa* L.)
Co-transformation	hygromycin phosphotransferase (*hpt*)	Rice (*Oryza sativa* L.)
Cre/lox Site-Specific Recombination	hygromycin phosphotransferase (*hpt*) and neomycin phosphotransferase (npt)	Tobacco (*Nicotiana tabacum*)
Co-transformation	*hpt* gene and *pmi* gene	Rice (*Oryza sativa* L.)
Marker-free binary vector	-	Potato (*Solanum tuberosum* L.)
Co-transformation	*hpt* gene and *uidA* gene	Wheat (*Triticum aestivum* L.)
Inducible site-specific recombination system	R recombinase gene, HPT, hygromycin resistance gene; hybrid gene for positive (*npt*II) and negative (*cod*A) selection; GUS, β-glucuronidase reporter gene	Strawberry

Figure: A list of different methods used for development of marker-free plants.
Source: http://www.ias.ac.in/jbiosci/mar2012/167.pdf

Food safety

By 2013, there were 27 countries all over the world which grow GM foods. Some of them are listed in the table ahead. Although there are no scientific reports till date that prove that GM food may be toxic or unhealthy, there is public concern about the safety of GM foods. The issues have mainly been raised by the anti – GM lobby which comprises mainly of environmentalists and media persons and therefore, the debates regarding the safety of GM foods often do not reflect the true scientific concerns of GM crops. There are proper rules and regulations laid down by authorities worldwide, which, take care of

safety trials of GM foods before their release in to the markets. So the problem of GM food safety seems to be blown out of proportion by biased opinions of anti-GM groups.

Table: Transgenic crops grown in different countries and the total area under their cultivation.

Country	GM planted area (million hectares)	Transgenic crops
USA	70.1	Maize, Soybean, Cotton, Canola, Sugarbeet, Alfalfa, Papaya, Squash
Brazil	40.3	Soybean, Maize, Cotton
Argentina	24.4	Soybean, Maize, Cotton
India	11.0	Cotton
Canada	10.8	Canola, Maize, Soybean, Sugarbeet
Total	175.2	----

Source: http://en.wikipedia.org/wiki/Genetically_modified_crops(cc)

Pusztai affair

The Pusztai affair is a controversy that began in 1998 after protein scientist Árpád Pusztai went public with research he was conducting at the Rowett Institute with genetically modified (GM) potatoes. The potatoes had been transformed with the Galanthus nivalis agglutinin (GNA) gene from the Galanthus (snowdrop) plant, allowing the GNA lectin protein to be synthesised. This lectin had been shown to be toxic to some insects. Rats were fed on raw and cooked genetically modified potatoes, using unmodified potatoes as controls. Twelve feeding experiments were conducted, ten short-term (10 days) and two long-term (110 days). Rats fed raw or cooked potato modified with the GNA gene showed statistically significant thickening of the stomach mucosa compared to rats fed the unmodified potato. As these effects were not observed in rats fed control potatoes injected with GNA protein, Pusztai concluded that the differences were a result of the transformation procedure. In a short interview on Granada Television's current affairs programme World in Action Pusztai said that rats fed the potatoes had stunted growth and a repressed immune system. This resulted in Pusztai and the Rowett Institute receiving numerous phone calls from government, industrial, NGO and media organisations. Following the media frenzy, Pusztai was suspended and misconduct procedures were used to seize his data and ban him from speaking publicly. The Rowett Institute and the Royal Society reviewed Pusztai's work, concluding that the data did not support his conclusions. The data was published in the *The Lancet* in October 1999, and reported significant differences in the thickness of the gut epithelium of rats fed genetically modified potatoes (compared to those fed the control diet), but no differences in growth or immune system function were suggested. After publishing, it was criticised on the grounds that the unmodified potatoes were not a fair control diet, and that any rats fed only on potatoes will suffer from a protein deficiency.

Source: http://en.wikipedia.org/wiki/Pusztai_affair (cc)

2. Risks to environment

The risks include genetic contamination of other crops, transfer of toxin/allergen from one life form to another and evolution of altogether new toxins/allergens and impact on soil fertility. Also, improper release of dangerous chemicals or pathogens used in the experiments, into the environment may be a threat.

Horizontal gene transfer (HGT)

Horizontal gene transfer is the transfer of genetic material from one organism to another organism which is not its offspring. It remains the biggest concern associated with GM-crops. In 2001, in a study evidence was provided that GM genes from GM maize have transferred to the non-GM maize by cross-pollination, thus contaminating the wild type maize. Validity of the experiments and results were disputed at the time of publication, and were later rejected as no evidence of such adulteration was detected in wild growing maize.

In another example, GM herbicide-resistant creeping bentgrass was found to be grown beyond the designated cultivated area (almost by 4 km) in Oregon, USA. It was postulated that the spread occurred by the pollen mediated sexual crossing between wild and GM crops and subsequent seed dispersal. However, these studies are regularly taken up by the critics of this technology in their defence.

It is also feared that such an event which involves micro-organisms can lead to development of super bugs (bugs with enhanced ecological fitness due to acquisition of a new trait especially resistance to some antibiotic conferred by the selectable marker transgene after HGT) or highly evolved viruses (as many gene constructs contain sequences of virus-origin such as cauliflower mosaic virus promoter) thereby enhancing the levels of antibiotic resistance in environment. However, many soil organisms have such genes naturally as a part of their defence against other organisms and generate antibiotics, therefore it is highly unlikely that genes acquired occasionally from transgenic plants would cause a change in the existing level of antibiotic resistance in the environment.

Super weeds due to herbicide resistance genes

Any HGT between plants is feared to be able to lead to generation of super weeds. Generally weeds cause significant yield loss to a crop when they become invasive, infest the agricultural lands and compete for the common resources. One of the main concerns associated with cultivation of transgenic crops in open lands is that either selection markers such as antibiotic or herbicide resistant genes or the genes which make transgenic plant resistant to abiotic and biotic stresses can escape to the closely growing weeds. In that scenario, weeds can acquire improved fitness and become more resistance which might accentuate the characteristics of weediness, leading to greater invasiveness and persistence of the already existing weeds. Super weed is a term which is generally used for such weeds. Thus, there is always a risk concern of increased resistance/tolerance of target organism which in turn may create some serious pest/weed management problems, as currently observed in case of normal weeds as

well. The other concern is about the altered nutritional value of such transgenic products which might lead to increased attractiveness of such crops to the pest causing a more severe infestation of the crops by their pests and leading to yield loss. Similarly to weeds, transfer of transgenes to their pests can create the insecticide-resistant pests, which might pose a serious threat on the survival and yield of both GM and non-GM crops. Another concern about GM crops is that they can become more effective and aggressive weeds. In this case, spreading and invasion of resistant GM crops (with transgenes that confer resistance against biotic and abiotic stresses) into other natural ecosystems would outcompete the naturally inhabiting plants and therefore can lead to monoculture and loss of genetic diversity. Altogether, these concerns make the non GM crops vulnerable and have ability to change in the cost of agriculture by forcing changes in agricultural practices. Though scientifically possible, these concerns are yet to be supported by conclusive scientific evidences; which are still missing till date.

Applications and concerns of herbicide- resistant transgenic crops

Applications

Herbicide-resistant transgenic varieties of four crops – cotton, maize, rapeseed, and soybean were readily adopted by farmers after their introduction in 1996. Within a decade, their use increased to millions of hectares, all over the world. Therefore, the success of transgenic herbicide resistant crops indicates that it has benefitted the farmers. According to a report, US farmers benefited largely due to reduced application of herbicides and obtained higher yields per hectare. The seed companies earned huge profits from selling seeds and herbicide to farmers.

The benefit of herbicide resistant crops is that the farmers do not need to plough the field for eliminating the weeds. Instead, herbicide spray can be used for removal of weeds. Reduced ploughing can help to improve soil texture and to increase the biodiversity of rhizosphere and also decrease the likelihood of soil erosion.

Concerns

There is concern that in some crops which have closely related weed species, herbicide-resistance trait may be incorporated into the weeds by cross-pollination. This may cause the formation of so-called 'super-weed', because they would be resistant to herbicides. But research has shown that such transfer of herbicide resistance trait into weedy crop relatives is very unlikely to result in emergence of more virulent weedy hybrids.

The problem of herbicide tolerance is a perennial one that has grown with the increasing

use of herbicides. A report states that by 2009, more than 300 weed species had acquired resistance to at least one commercial herbicide. The most frequent forms of resistance were to PS I and PS II inhibitors, AHAS inhibitors, ACCase inhibitors, synthetic auxins and glyphosate. However, the development of resistance of one weed to one herbicide may not necessarily effect overall yield due to the availability of many types of herbicides.

A risk in focusing on the use of just two herbicides for most crops, for example use of glyphosate and glufosinate, is that farmers increasingly become dependent on these herbicides. In transgenic crops glyphosate the most frequently used herbicide. From an evoulutionary point of view, this may lead to an increased selection for glyphosate resistance in weedy species. The most plausible mechanism for resistance to glyphosate is through mutations in EPSP synthase gene which enables the plants to produce an enzyme which makes them glyphosate-resistance.

Impact on soil fertility

In case of negative effects of GM crops on soil fertility, the main concern is about the leakage of different compounds (as many plants leak chemical compounds in the soil through their roots) than the normal crops; as an unintended consequence of their altered DNA. It is assumed that in that scenario, these harmful chemicals can disturb the growth of micro-organisms communities living near the transgenic plants.

Impacts on biodiversity

Since the interactions between plants and micro-organisms are very complex and these organisms also contribute to the ecological fitness of plants as well as soil fertility, there are apprehensions that any transgene integration can negatively affect the fine balance between plants and micro-organisms which in turn can lead to the reduced soil fertility. For example, Bt corn roots are reported to leak Bt toxin in the soil, where it binds to some soil components and become resistant to degradation and more stable (potentially for even 200 days) without losing its ability to kill insect larvae (Saxena et al. 1999). Although this situation is good in context of controlling the insect, however, if the toxin is stable and plants are continuously leaking the Bt toxin into the soil, it will result in a long-term build up of this toxin which might affect the non-target organisms living in the same environment. It is plausible to think that high concentrations of such toxin in soil for long time would adversely affect the soil micro-flora and fauna; which might lead to

decreased genetic diversity in that environment. Therefore, much more research must be done to understand the intricate interrelationships between plants and micro-organisms.

Applications and concerns of Bt technology

Applications

Transgenic Bt crop varieties can help in controlling target insect species which can help in increasing average crop yields. They also decrease the requirement of pesticide sprays which have toxic effects on the environment. Also, decreased use of pesticides has economical and health benefits. In India, Bt cotton has been widely adopted by millions farmers, leading to yield increases by up to 65%.

Concerns

The potential danger is the production of pest resistant crop due to depending upon a single type of toxin, like Bt toxin, because in such a case, there would be an intense selection pressure favoring the survival of any insects which would be able to somehow sequester the toxin. By 1995, at least two insect species had been shown to become resistant to Bt toxins in the field and at least another ten species were shown to have the potential for resistance in laboratory studies. One way to prevent or at least delay the acquisition of resistance by insects is 'gene stacking' - that is, several unrelated toxin genes can be included in a transgenic crop. The strategy of gene stacking is expensive to develop but is an effective long-term solution that could greatly reduce the chances of producing pest resistant crops.

Another solution to deter the development of resistance to Bt toxins is to sow 'refugia', (which are portions of land adjacent to the main transgenic crop), with crops on which non-tolerant insect populations thrive so that there are chances that they outcompete conspecifics that might develop Bt tolerance. This method depends upon the cooperation of farmers and can fail if it is not implemented on all fields.

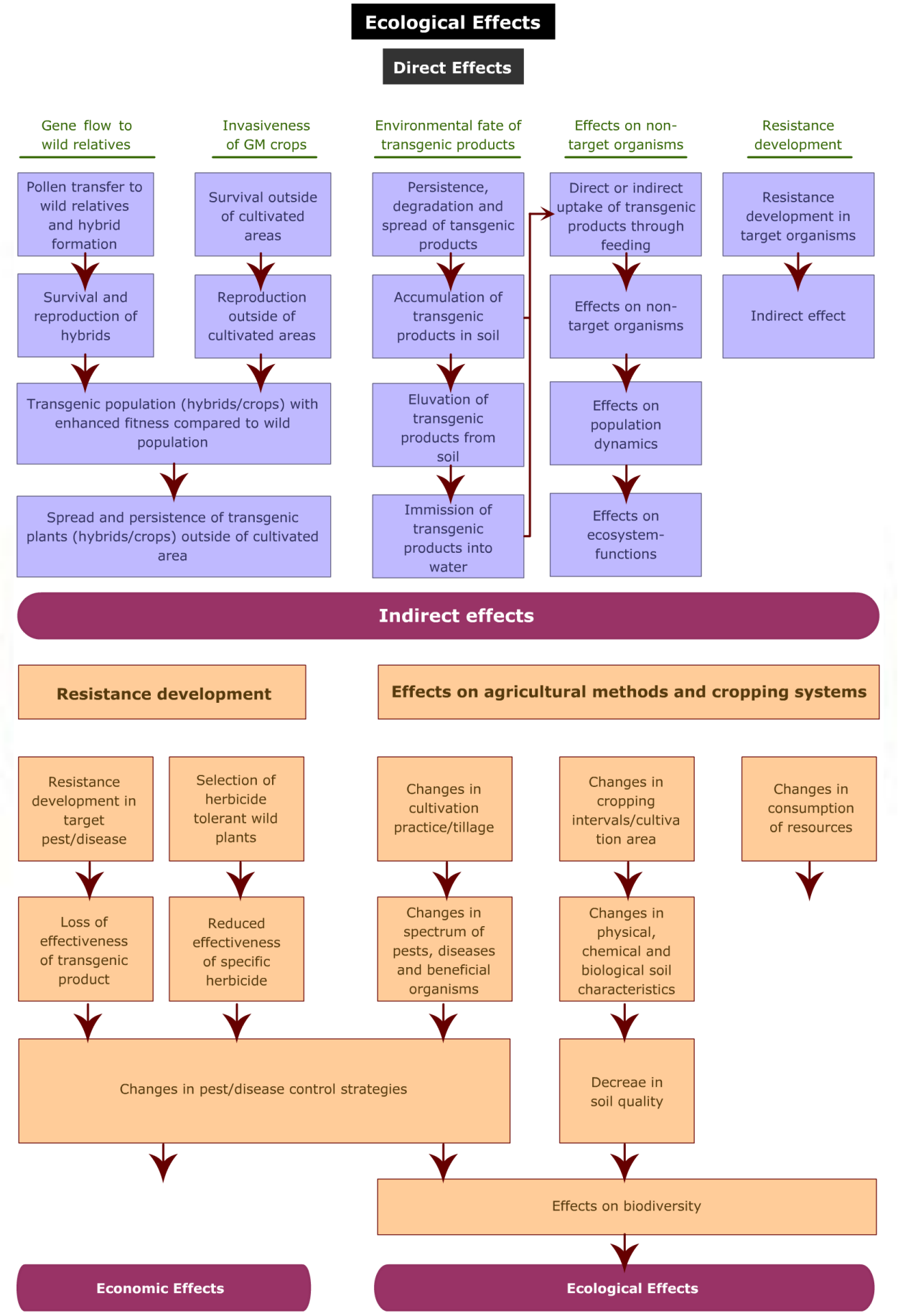
Ecological Effects
Direct Effects
Gene flow to wild relatives
Invasiveness of GM crops
Environmental fate of transgenic products
Effects on non-target organisms
Resistance development
Pollen transfer to wild relatives and hybrid formation
Survival outside of cultivated areas
Persistence, degradation and spread of tansgenic products
Direct or indirect uptake of transgenic products through feeding
Resistance development in target organisms
Survival and reproduction of hybrids
Reproduction outside of cultivated areas
Accumulation of transgenic products in soil
Effects on non-target organisms
Indirect effect
Transgenic population (hybrids/crops) with enhanced fitness compared to wild population
Eluvation of transgenic products from soil
Effects on population dynamics
Spread and persistence of transgenic plants (hybrids/crops) outside of cultivated area
Immission of transgenic products into water
Effects on ecosystem-functions
Indirect effects
Resistance development
Effects on agricultural methods and cropping systems
Resistance development in target pest/disease
Selection of herbicide tolerant wild plants
Changes in cultivation practice/tillage
Changes in cropping intervals/cultivation area
Changes in consumption of resources
Loss of effectiveness of transgenic product
Reduced effectiveness of specific herbicide
Changes in spectrum of pests, diseases and beneficial organisms
Changes in physical, chemical and biological soil characteristics
Changes in pest/disease control strategies
Decreae in soil quality
Effects on biodiversity
Economic Effects
Ecological Effects

Figure: Possible adverse effects of GM crops

Source: ILL inhouse

3. General concerns

Besides the specific risks as mentioned above, there are some general concerns associated with use/practice of GM crops cultivation. Some of these are detection and analytical methods, ethical issues (for example labelling of GM products), perception and public attitude, legislation, IPR (Intellectual Property Rights), socio-economic conditions (the big difference between situation of poor farmers from developing viz-a-viz rich and well-off counterparts from developed countries), GM traceability / commodity segregation. Socio-economic issues such as patent of genes and organisms by companies; due to the commercial values of biotechnology products originating from them. This is a real threat since a large section of human population is still poor and such patents make these genes and organisms unavailable to these people. Production of new biological warfare agents/weapons is also a concern. Ethical issues associated with development of GMOs; which is considered as 'anti-nature' by some people.

Figure: A cartoon depicting debate over GM labelling

Source: http://freegankolektiva.wordpress.com/2012/01/05/gm-food-controversies-what-people-want-and-what-european-commission-does/gm-food-labelling/(cc)

One of the most appealing arguments given by GM producing companies in favour of transgenic crops is the reduced applications of environment degrading pesticides and

herbicides while growing them. However, besides Bt cotton where claims of reduced pesticides applications/spraying are clear, same does not hold true in case of Bt corn, herbicides resistant corn and soybean (for more information, kindly explore the following web link: http://cls.casa.colostate.edu/transgeniccrops/spray.html). Therefore, more comprehensive data in context of transgenic crops and reduced use of chemicals are required as although transgenic technology may result in the reduction of chemical spraying in some cases, it cannot be generalized for all cases.

Definition of biosafety

Why do we need to know about the biosafety regulation/principles in first place? Initially, biosafety principles were applied to only pharmaceutical and microbiological research laboratories with regard to maintain occupational health and safety of environment. However, with the advent of biotechnological tools such as recombinant technology (r-DNA technology) and generation of Genetically Modified Organisms (GMOs) and/or Living Modified Organsims (LMOs), the principles of biosafety have also extended to the handling and transportation of such organisms.

Since the phenotypic expression of any living cell depends on its genetic constitution and r-DNA technology provides a method to change this constitution at will, some apprehensions started arising about the use of r-DNA technology and its products in the early 1970s. These concerns initiated a wide discussion on biotechnological products then which finally culminated in the so called "recombinant debate" among scientists. In 1975, in a meeting in Asilomar, CA, USA, it was suggested that certain type of experiments should not be performed until their potential risks are analyzed.

One year later, National Institute of Health (NIH) issued primary guidelines on r-DNA technology based products. One of the main recommendations of these guidelines was the initial contained handling of any recombinant organism for a few years so that the risk factor associated with the recombinant-DNA organisms can be assessed properly. Later these guidelines became the inspiration for the first world-wide publication in 1986 of the OECD (Organization and Economic Cooperation and Development) on "Recombinant DNA safety considerations". The publication laid out the first international safety guidelines for the use of recombinant organisms in agriculture, industry and environment. Later these biosafety regulations were implemented by several countries and have been updated/ modified since then. In summary, based on its wide range, biosafety can be described as:

'Application of safety principles to laboratory practices in which potentially hazardous biological material or organisms are manipulated or handled.'

or

'Regulations to handle the perceived risks of GMOs released into the environment, including their possible adverse impact on human health or biological diversity'.

Principles of biosafety

Although biotechnology has emerged as a field with an immense number of applications, its use has aroused public concern regarding the health of humans and animals and environmental issues. This is especially true for GM crops which are a topic of constant debates between scientists and environmentalists due to the so – called risks associated with them. Therefore, it is important to understand what are these 'risks' and what are the measures of 'biosafety' to tackle them.

Biosafety refers to the following;

- Efforts to protect the environment including human and animal health from the possible adverse effects of the Genetically Modified Organisms (GMOs) and products thereof derived from the use of modern biotechnology.
- The use of safe laboratory practices and procedures
- proper use of containment equipment and facilities
- Risk assessment and risk management
- Evaluation of GMOs etc.

In essence, the rules and regulations of biosafety have been put in place to facilitate and regulate use of modern biotechnology work at different stages to achieve the objectives of biosafety.

Guidelines for biosafety

The guidelines for biosafety are developed based on the perceived negative impacts to human health and environment and the impact can be either known or potential risks. The guidelines for biosafety are laid down by competent authorities on a national or international level and are mandatory to follow by all research institutions performing experiments pertaining to biotechnology. This is done to assess the risk associated with such organisms and also to reduce exposure of laboratory personnel, other persons, and the outside environment to such agents. Implementation of biosafety principles includes creation of certain guidelines for the safe handling of potentially hazardous biological material. These guidelines mostly cover the basic precautions which should be taken at

the time of working with potentially harmful biological materials including infectious microorganisms, insects, animals or plants. Additionally, biosafety guidelines for handling rDNA molecules and transgenic organisms and their products have also been developed. These guidelines primarily focus on safe commercialization of genetically modified products, their release into environment and their trade between the countries.

Basically, the guidelines are laid down to identify risks and classify them into four risk groups and follow the measures of biosafety accordingly.

Risk analysis

Since levels of biosafety measures depend on the levels of risk, analysis of risks associated with handling of hazardous biological materials is very important. The risk analysis reveals the nature and magnitude of risk involved which in turn helps to decide the levels of biosafety procedures/practices. Risk analysis comprises of three components:

1. Risk assessment

It includes identification and characterization of hazard and calculates the risk of exposure. Generally, it includes the study of

(i) The attributes of the organism (or a new trait) involved.

(ii) Its intended use (if rDNA organism is to be made, then its initial trials have to be carried out under contained conditions).

(iii) The characteristics of the area where this work was done.

These three things help in assessing the risk associated with an rDNA organism. Also, final utility of such products greatly depends on through risk assessment as it is performed to protect the environment and human health. Risk assessment becomes easier if some history is available for the organism involved in the study. In case this kind of study is performed on a totally unfamiliar organism, then risk managers have to cope with the uncertainties. The risk levels have been divided into four categories. These categories are the basis for classification of four biosafety levels explained ahead. The following table describes various risk groups.

Group	WHO[4]	NIH[5]	EU[6]	China[7]
1	A microorganism that is unlikely to cause human or animal disease.	Agents that are not associated with disease in healthy adult humans.	One that is unlikely to cause human disease.	Under normal circumstances, does not cause human or animal disease.
2	A pathogen that can cause human or animal disease but is unlikely to be a serious hazard to laboratory workers, the community, livestock or the environment. Laboratory exposure may cause serious infection, but effective treatment and preventive measures are available and the risk of spread of infection is limited.	Agents that are associated with human disease which is rarely serious and for which preventive or therapeutic interventions are often available.	One that can cause human disease and might be a hazard to workers; it is unlikely to spread to the community; there is usually effective prophylaxis or treatment available.	Can cause human or animal disease but under normal circumstances, it does not pose a serious hazard to people, animals or the environment, the risk of transmission is limited, Laboratory infection rarely causes serious illness with effective treatment and prevention.
3	A pathogen that usually causes serious human or animal disease but does not ordinarily spread from one infected individual to another. Effective treatment and preventive measures are available.	Agents that are associated with serious or lethal human disease for which preventive or therapeutic interventions may be available (high individual risk but low community risk).	One that can cause severe human disease and present a serious hazard to workers; it may present a risk of spreading to the community, but there is usually effective prophylaxis or treatment available.	Can cause serious human or animal disease. It is relatively easy to spread between people, animals and people, among animals, directly or indirectly.
4	A pathogen that usually causes serious human or animal disease and that can be readily transmitted from one individual to another, directly or indirectly. Effective treatment and preventive measures are not usually available.	Agents that are likely to cause serious or lethal human disease for which preventive or therapeutic interventions are not usually available (high individual risk and high community risk).	One that causes severe human disease and is a serious hazard to workers; it may present a high risk of spreading to the community; there is usually no effective prophylaxis or treatment available.	Can cause very serious disease in human and animal, including biological agents has not been found in China

Note: For ease of comparison, the category order of China is reversed.
doi:10.1371/journal.pone.0101163.t001

Table 1: The table enlists the four risk groups (RG) and how these risk groups are classified by different organizations.

Source: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0101163#pone-0101163-t001(cc)

In case of GMOs/rDNA organisms, there have been several controversial debates about their risk potentials, however, now it is accepted that the risk assessment of such materials should be done on the basis of full set of their characteristics rather than in the manner they are obtained.

In case of GMOs, the risk assessment study has to include the following parameters:

(i) Creation of novel organism- this study further includes the nature of host organism, the donor organism, the vector, the gene/trait in question and empirical data on the newly created novel organism.

(ii) Its intended use and scale of its release.

(iii) The environment where the novel organism would be released.

2. Risk management

It includes formulation of effective biosafety guidelines, in consent with all the all interested parties, after risk assessment and considering other factors relevant for maintaining human health and environment. This is done to minimize the risks associated with the novel product/organism to human health and the environment.

3. Risk Communication

It includes exchange of relevant information on risks, risk-related factors and perceptions to all the interested parties. This is done to make all the concerned parties aware about the new product and the risk associated with it.

Further, the interactive relations among the three factors have been summarized in the following figure.

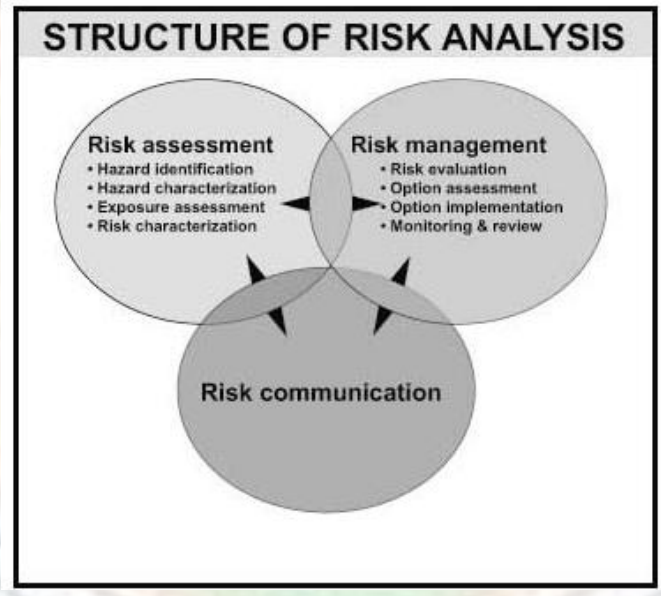

Figure: Image shows the interactive correlation among the risk assessment, risk management and risk communication. These parameters are generally included to minimize the risk associated with a newly created GMO to human health and the environment.

Source: http://www.fao.org/docrep/009/a0238e/A0238E01.jpg (cc)

Containment

The principle of containment remains one of the most important biosafety principles. The term "containment" refers to the implementation of safe methods, facilities and equipment for managing and maintaining the recombinant DNA organisms/products in the laboratory environment.

1. Physical containment

It is done to prevent the spread of hazardous microorganisms by

- Following good laboratory practices.
- Using safety equipments.
- Safe laboratory designs and facilities.

2. Biological containment

It involves the use of containments like glasshouses to prevent the escape of pathogenic vectors like plant viruses.

3. Gene containment

It involves the use of measures to prevent the transfer of foreign genes from transgenic crops to other crops or wild plants, which may occur due to open pollination. The techniques used for gene containment are listed in the table ahead.

Technique	Advantages	Disadvantages	Status
Maternal inheritance	Prevents gene flow through outcrossing and volunteer seeds. Relatively well developed. Field tests indicate low incidence of sympatry and mixed stands extinct in three years. High levels of transgene expression and no evidence for gene silencing or position effects.	Techniques to export proteins are not yet available. Foreign proteins have not been targeted to ER for glycosylation.	Demonstrated in tobacco, potato, and tomato. Further development required to extend to other food crops.
Male sterility	Prevents outcrossing. Shelf-life of flowers may also be extended. Several tapetum-specific promoters available.	Crop needs to be propagated by cross-pollination from non-GM crop or by artificial seeds. Potential for volunteer seed dispersal.	Demonstrated in tobacco and commercialized in glufosinate-tolerant rapeseed.
Seed sterility	Controls both outcrossing and volunteer seed dispersal.	If transgene is silenced, introgression will occur. All linked genes should segregate together.	Terminator technology has not been demonstrated in the field. RBF demonstrated in tobacco.
Cleistogamy	Pollination occurs before flower opens, theoretically preventing outcrossing.	Genes to modify floral design not readily available. In practice, introgression occurs despite self-pollination.	Not yet demonstrated in transgenic crops.
Apomixis	Seed is of vegetative origin and not from sexual cross. Controls both outcrossing and volunteer seed dispersal. Hybrid traits can be fixed.	Only known in a few crops. Genes not yet available.	Not yet demonstrated in transgenic crops.
Incompatible genomes	Prevents recombination after pollination.	May not be applicable to crops that exhibit homologous recombination. Crops will not produce seed unless propagated with compatible plants.	Not yet demonstrated in transgenic crops.
Temporal and tissue-specific control via inducible promoters	Gene either activated only when product is necessary or excised before flowering.	May not be applicable to traits required throughout the plant's life. If chemical treatment fails to penetrate plant tissues, residual levels of transgene may be present in pollen or seed that could be outcrossed.	Not yet demonstrated in transgenic crops.
Transgenic mitigation	Neutral for crops, but harmful for weeds.	Does not address gene flow between crops and may force wild relatives to extinction.	Not yet demonstrated in transgenic crops.

[a]Abbreviations: ER, endoplasmic reticulum; RBF, recoverable block of function.

Figure: Techniques of gene containment

Source: http://www.nature.com/nbt/journal/v20/n6/pdf/nbt0602-581.pdf

link for permission

https://s100.copyright.com/AppDispatchServlet?publisherName=NPG&publication=Nature%20Biotechnology&title=Molecular%20strategies%20for%20gene%20containment%20in%20transgenic%20crops&author=Henry%20Daniell&contentID=10.1038/nbt0602-581&publicationDate=06/01/2002&volumeNum=20&issueNum=6&numPages=6&pageNumbers=pp581-586

Biosafety Levels (BSLs)

In the laboratories, biosafety levels (BSLs) are decided depending on the level of risks perceived to be associated with biologically harmful material. Since generation of any GMO includes both use of microorganisms such as bacteria during cloning of the gene of interest and harmful chemical during propagation and subsequent testing of its phenotype for various characteristics, all laboratories involved in this kind of work must perform all the steps under safe environmental conditions. To maintain the required safe work conditions in the laboratories, some basic standard of precautions required for safeguarding human health and environment have been formulated and divided mainly into four levels of biosafety. With the increase in number of BSL, the level of risk to human health also increases.

Biosafety level 1

The first level is suitable for work on the well-characterized agents with history of not causing diseases in healthy adult humans. It includes several kinds of non-pathogenic bacteria such as *E.coli*. Also the precautions against biohazardous materials are kept at minimum levels as some sort of facial protection and use of a lab coat and gloves are sufficient during work. The experimental place is not necessarily separated from the general space and work is generally performed on open benches.

Biosafety level 2

Like the first biosafety level, the level 2 is also suitable for working on the agents with moderate potential hazard. Such agents include viruses and bacteria that cause mild diseases to humans. In this kind of work, there is limited access to the laboratories and trained personnel can only enter in the experimental area.

Figure: Work area in containment level II cabinet. Class II cabinets are used in clinical and research laboratories.

Source: http://en.wikipedia.org/wiki/File:Laminar_flow_hood_2.jpg (cc)

Biosafety level 3

The biosafety level 3 deals with the high-risk level agents that pose serious threat to human health after exposure/inhalation. To carry out work with such agents, first laboratory personnel are trained in handling such potentially lethal agents. All work on potentially infectious material is done in biological cabinets/hoods. To maintain the sterile environment, laboratory is equipped with special engineering such as double-door access zones and the filtered exhaust air room in the laboratory and the access to the laboratory is restricted while the work is going on.

Figure: A researcher observing a specimen through the built-in microscope in a Class III biosafety cabinet.

Source: http://en.wikipedia.org/wiki/Biosafety_cabinet#mediaviewer/File:BSC_with_microscope.jpg

(cc)

Biosafety level 4

BSL4 facility deals with the most hazardous biological materials, including high-risk aerosol-transmitted laboratory infections or agents causing fatal disease in humans for which vaccines or other treatments are not available. Therefore norms of containment are the strictest at this level. Some of the practices needed at this level includes the use of highly specialized and totally encapsulating positive pressure personnel suits, a segregated air supply to the laboratory, multiple shower units at the entrance and exit of the facility, a vacuum room, an ultraviolet room and a facility to destroy all traces of the biohazardous agents. Additionally, all the incoming and outgoing air and water services have to undergo decontamination procedure to eliminate the accidental release and spread of such agents. Staff working in BSL4 environment is highly trained and well informed about the primary and secondary risks associated to the work and all experiments are supervised by scientists. Access to such facility is totally restricted for unauthorized persons and is strictly controlled by the director of the facility. Further, such building where BSL4 is operational is generally well separated from other buildings in the neighborhood.

Figure: A BSL-4 laboratorian working in an ILC Dover Chemturion "Blue Suit". Biosafety level 4 hazmat suit: researcher is working with the Ebola virus.

http://en.wikipedia.org/wiki/Positive_pressure_personnel_suit#mediaviewer/File:Biosafety_level_4_hazmat_suit.jpg

(cc)

Table: The four biosafety levels and their respective laboratory practices.

Risk level	Biosafety level	Laboratory practices	Safety equipment
1	BL1	Basic laboratory	Open bench
2	BL2	BL1 + Protective clothing, Biohazard Sign	Open bench + BSC[a]
3	BL3	BL2 + Special clothing, Controlled access, Directional airflow	BSC + and/or other primary devices for all actives
4	BL4	BL3 + Air lock, Shower exit, Special Waste disposal	Class III BSC, positive pressure suits, double-ended autoclave, filtered air

Source:
http://synapse.koreamed.org/DOIx.php?id=10.4167/jbv.2013.43.3.217&vmode=PUBREADER

(cc)

Table: Summary of the biosafety levels, practices adopted and equipments used.

BL	Agents[a]	Practices[a]	Equipment[a]	Facilities[a]
1	Not known to consistently cause diseases in healthy adults	Standard microbiological practices	- No primary barriers required. - PPE: laboratory coats and gloves; eye, face protection, as needed	Laboratory bench and sink required
2	- Agents associated with human disease - Routes of transmission include percutaneous injury, ingestion, mucous membrane exposure	BL-1 practice plus: - Limited access - Biohazard warning signs - Sharps precautions Biosafety manual defining any needed waste decontamination or medical surveillance policies	Primary barriers: - BSCs or other physical containment devices used for all manipulations of agents that cause splashes or aerosols of infectious materials - PPE: Laboratory coats, gloves, face and eye protection, as needed	BL-1 plus: Autoclave available
3	- Indigenous or exotic agents that may cause serious or potentially lethal disease through the inhalation route of exposure	BL-2 practice plus: - Controlled access - Decontamination of all waste - Decontamination of laboratory clothing before laundering	Primary barriers: - BSCs or other physical containment devices used for all open manipulations of agents - PPE: Protective laboratory clothing, gloves, face, eye and respiratory protection, as needed	BL-2 plus: - Physical separation from access corridors - Self-closing, double-door access - Exhausted air not recirculated - Negative airflow into laboratory - Entry through airlock or anteroom
4	- Dangerous/exotic agents which post high individual risk of aerosol-transmitted laboratory infections that are frequently fatal, for which there are no vaccines or treatments - Related agents with unknown risk of transmission	BL-3 practices plus: - Clothing change before entering - Shower on exit - All material decontaminated on exit from facility	Primary barriers: - All procedures conducted in Class III BSCs or Class I or II BSCs in combination with full-body, air-supplied, positive pressure suit	BL-3 plus: - Separate building or isolated zone - Dedicated supply and exhaust, vacuum, and decontamination systems

Source: http://synapse.koreamed.org/ArticleImage/0079JBV/jbv-43-18-i003-l.jpg (cc)

Table: List of BSL-4 facilities in India

Name	Location	Year when established	Description
High Security Animal Disease Laboratory (HSADL)	Bhopal	1998	This facility deals especially to zoonotic organisms and emerging infectious disease threats.
Centre for Cellular and Molecular Biology	Hyderabad	2009	National Bio-Safety Level-4 Containment Facility for Human Infectious Diseases & Clinical Research Facility in Regenerative Medicine
All India Institute of Medical Sciences	New Delhi	1993	Conducts studies on major pathogenic organisms. Has contributed in discovering new strains & vaccines.
Microbial Containment Complex	Pune	2012	Bio-Safety Level-IV Laboratory established by ICMR with support from Department of Science & Technology

Source: http://en.wikipedia.org/wiki/Biosafety_level(cc)

Regulations for biosafety

There is a requirement for regulations which ensures that both, the process and end product of biotechnology does not pose any kind of threat to humans, animals or the environment. For this purpose, there are many national and international regulatory bodies which frame the rules to be followed by biotechnologists right from the start of the process of development of a GM crop to its release into the market or export to other countries.

International regulations

Since biotechnology is a powerful tool which can genetically modify living organisms, several safety, ethical, and legal issues/risks are associated with it. Genetic engineering, for example, enables unconstrained transfer of genes and their properties from one organism to another; which is generally constrained by natural reproductive barriers. This raises concerns about the uninhibited horizontal gene transfer among organisms. The inherent risks of such gene transfer must be critically evaluated. Cloning of mammals from the somatic cells of adult animals remains another sensitive area. Therefore, if society has to accept such products, all such concerns should be addressed before their release in the environment.

Image 9: Biological safety/hazard (Biosafety) symbol

Source:
http://en.wikipedia.org/wiki/Biological_hazard#mediaviewer/File:Biohazard_symbol.svg

(cc)

Biosafety protocols areadopted to minimize and eliminate the potential risks-associated with biotechnological applications. With the aim to promote sustainable and safe development,Convention on BiologicalDiversity (CBD)was formulated under the umbrella of United Nations and adopted in 1992. Its major objectives included "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" (http://www.cbd.int/). Integration of biotechnological tools led to development of new safety procedures which majorly focuses on the safe transfer, handling and use of any LMO ("living modified organism)/GMO, especially those created by biotechnological tools. These safety measures were developed to minimize any adverse effect of such organisms on the conservation and sustainable use of biological diversity. These procedures led to formal adoption of 'Cartagena Protocol on Biosafety'(CPB) in 2003. The detailed document can be accessed at their webpage at http://bch.cbd.int/protocol/

Since, all the countries are still not signatories of CPB, a uniform regulatory network does not exist. This situation has created confusion among GM-crop growing countries for harmonising environment and trade agreements and regulations between them.

Biosafety regulations in India

India has constituted a biosafety programme which emphasizes to facilitate and implement biosafety procedures and guidelines for ensuring safety of the use of GMOs and products thereof in research and application to the users as well as to the environment. Moreover, India is a party to Cartagena Protocol on Biosafety and follows the practices suggested by it.

Under the rules, every institution and industry involved in recombinant DNA work has to obtain a prior approval from

- Institutional Biosafety Committees (IBSCs),
- Monitoring-cum-Evaluation Committee (MEC) and
- Review Committee on Genetic Manipulation (RCGM) and
- Other institutional structures.

The Review Committee on Genetic Manipulation (RCGM; http://dbtbiosafety.nic.in/committee/rcgm.htm) is constituted by the Department of Biotechnology (DBT), Govt. of India. Its main function is to monitor the safety related aspects of the ongoing recombinant-DNA projects. Further, it also supervises the controlled field experiments of transgenic crops by following the Rule-1989 of

Environment (Protection) Act, 1986 (EPA-1986). The other roles of RCGM include its participation in several policy decisions, including standardization of protocols for multi-location field trials of transgenic crops, formulation of data collection parameters, nomenclature of transgenic crop/gene etc. In the area of recombinant pharma sector, it plays an important regulatory role which starts from formulation of protocols for different kind of r-DNA pharma products to import, marketing and release of purified materials from GMOs as products for commercialization. Additionally, the Department reviews the progress of ongoing projects and merit of submitted projects and provides inputs on rationalization of biosafety regulatory procedures related to transgenic crops and recombinant DNA therapeutics to several committees set up by the Government of India. Finally, it also organizes workshops on 'National Consultation on Biosafety aspects' related to GMOs to update the IBSCs members on biosafety Rules, Regulations and Procedures. However, the major concerns associated with biotechnology are discussed in the following section.

Current status of risk assessment of transgenic crops

Although as per the information released by WHO on GM crops, all the GM products in international arena have passed the risk assessments and show no risks to human health. However, Domingo (2007) when reviewed the international literature on human and animal toxicological/health risks studies on GM foods, he could find only a few such studies on this aspects and raised the concern whether scientific evidence showing that GM plants/food are toxicologically safe? On the other hand, transfer of a gene from bean to pea to confer resistance against weevils in transgenic pea was found to make these GM peas harmful as they caused lung allergy in mice (Prescott et al. 2005). Further, transgenic soya bean expressing a Brazil nut protein was shown to be allergenic in tests (Nordlee et al. 1996). Most often, people concerned with GM products cite these examples and also there is lack of comprehensive data on risk assessment studies in public domain, however due to proper risk assessment studies, the two above mentioned projects were withdrawn and no GM product was released in the markets. Further, these concerns can be addressed by generating marker-free GM plants and very intensive trials of such products on human/animal health before introducing them to the markets.

Although r-DNA technology has immensely benefitted us at least in the areas of medicine, diagnosis and production of therapeutic products, there is still a need to address the above mentioned safety concerns. Equally important is the involvement of public, through informed debates, on the development and application of modern biotechnology tools to make them recognize the benefits associated with it.

For further reading, the reader should go to the link:

http://dbtbiosafety.nic.in/

Summary

Although very little data is available in public domain where negative effects of GM crops on human health and environment have been highlighted, it is clear that there are many concerns associated with the use of biotechnology. On one hand, use of transgenic crops seems to be a potent tool which can quickly help us in our fight against hunger to alleviate it completely from world and simultaneously protect our environment, on the other hand questions are being asked and concerns are being raised about the mostly unstudied aspects of negative influence of GM crops on human health and environment. At present, it seems plausible that cultivation of GM crops should be continued, however simultaneously answers for the raised concerns must be found and comprehensive data on the studied aspects must be made public.

However, if we address the biosafety concerns properly, practice bioethics principles, use biotechnological tools judiciously, carry out thorough analysis of risks, and adopt risk management guidelines then we can improve the health of our environment and humans through the use of biotechnology, without affecting them adversely.

Exercise/ Practice

Short answer questions

1. Define Biosafety.

2. List important branches of biotechnology.

3. What are the biosafety concerns on green biotechnology?

4. Define Horizontal gene transfer.

5. What do you understand by recombinant DNA technology? Briefly explain the various steps involved in it.

6. Briefly mention some of the notable examples where biotechnology has contributed in the improvement of agronomic traits in crops.

7. What do you understand by 'containment' in biosafety? What are the different methods for gene containment?

8. What are the different facilities and laboratory practices for the Biosafety levels 1, 2, 3 and 4?

9. Name the important regulatory bodies responsible for framing and implementing Biosafety regulations in India.

10. What is 'Cartagena Protocol'?

11. What are the possible adverse affects of use of biotechnology on the environment?

12. Explain the guidelines for biosafety.

Expand the abbreviations

1. HGT

2. CBD

3. CPB

4. IPR

5. RCGM

6. LMO

7. IBSC

Multiple Choice Questions

1. Which company/companies is/are involved in production of GM crops?

A. Monsanto
B. Bayer CropSciences
C. Syngenta
D. All of the above

2. Which enzyme (s) is/are involved in r-DNA technology

A. T4 DNA Ligase
B. Restriction Endonucleases
C. T4 DNA Polymerase
D. All of the Above
E. None of the above

3. In which year was the 'Cartagena Protocol on Biosafety formally adopted?
   A. 2000
   B. 2001
   C. 2003
   D. 2004

4. Golden rice is enriched in which one of these vitamins?
   A. Vitamin A
   B. Vitamin B
   C. Vitamin C
   D. Vitamin E

Glossary

Biotechnology: Any technological application that uses biological system or living organisms to make or modify the process or products for specific use.

Biosafety: Application of safety principles to laboratory practices in which potentially hazardous biological material or organisms are manipulated or handled.

Genetic engineering: It is the direct manipulation of an organism's genome using biotechnological tools.

Horizontal gene transfer: It the transfer of genetic material from one organism to another organism that is not its offspring.

Molecular cloning: It is the laboratory process used to create recombinant DNA

Recombinant DNA: It is a DNA, which is made by combining DNA from two or more sources or organisms.

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Further Reading

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http://www.who.int/csr/resources/publications/biosafety/en/Biosafety7.pdf

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