Biotechnology and the Developing Countries

UNIT 15

European Initiative for Biotechnology Education

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The European Initiative for Biotechnology Education (EIBE) seeks to promote skills, enhance understanding and facilitate informed public debate through improved biotechnology education in schools and colleges throughout the European Union (EU).

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UNIT 15

European Initiative for Biotechnology Education

MATERIALS

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Acknowledgements

We thank, for the supply of materials, the International Rice Research Institute IRRI in Manila/Philippines especially Bob Huggan and Eugene Hettel.

We are grateful to Kluwer Academic Publishers in the Netherlands, in particular to Mrs. Berendina van Straalen for copyright permission.

Also many thanks to Elsevier Science in the UK for granting us permission to reproduce materials from the WWW.

We are thankful to Prof. Ingo Potrykus, ETH Zürich/Switzerland, not only for copyright but also for his advice.

Jan Frings, Gérard Coutouly (LEGTP Jean Rostand, Strasbourg/France) and Ognian Serafimov were co-organiser of a seminar in Überlingen/Germany in which materials in this unit were discussed. The partners were the Ministry of Education of the federal state Baden-Württemberg in Stuttgart, the District Office for Education in Tübingen and the College for biological-technical assistants at Jörg Zürn Technical High School in Überlingen. About 25 science and nonscience teachers from Baden-Württemberg under the guidance of Mrs. Brigitte Ferge took part and gave several helpful comments on the draft materials.

And last but not least we thank to Prof. María Sáez, University of Valladolid, Spain, for help.

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About this Unit

This unit comprises a collection of materials designed for teachers and students in order to give them some information and ideas concerning both on the impact of biotechnology on developing countries, and on the relationship between industrial and developing countries with regard to modern biotechnology.

At present products of genetic engineering do not have a significant influence on every day life in developing countries. Therefore this unit focuses on the present situation with a view to the future perspectives. Food based on rice, i.e. the basic food for one third of the world population - provides an appropriate example for considering the question: *Is the introduction of genetic modified rice in third world beneficial? If it is, beneficial to whom?*

Teaching guide

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Introduction

Sometimes textbooks tend to simplify information to give just one perspective of a subject such as transgenic plants. In reality when it comes to decision making it is found that the decisions are influenced by information from such different perspectives as history, economics, personal relations, feelings, advertising and a lot of irrelevant information.

Presenting complex topics such as the relationship between developing countries (countries of the so-called third world) and the industrial world; traditional breeding versus biotechnology; malnutrition versus supernutrition, can generate an awareness in the classroom of how much we all are influenced by different channels.

Why have we taken up this subject?
Why the problem solving approach?
What different aspects do we want to get out of it?

This unit is a problem oriented unit, which means that we have listed some of the conflict areas recognised. The students should be introduced to a variety of arguments, pros and cons; learn to evaluate the information given, and to realise that their decisions are formed by a combination of facts and feelings and that each of them evaluates the same information differently.

The information provided

The information for students is selected from several sources available when making this unit. The source materials are not given in full, the most important parts have been selected. Wrestling through the entire article might be difficult for many students and cause loss of interest.

The information presented is sometimes conflicting. This is done intentionally. In all important topics different points of view exist; this is not different for biotechnological subjects. Sooner or later student have to learn that simple truths, whether or not taught by an all-knowing teacher, are very seldom straightforward. The materials provided here could be supplemented with more and newer information; those who have access to a library or to the Internet might use the information provided as an introduction and starting point.

Suggestion for teaching

After outlining the problem (or rather the cluster of problems), preferably by involving the students (e.g. via some brainstorming session), it might be wise to stipulate that a good way of problem solving is to break the problem into sub-problems, and so on, if possible, until clear problems can be highlighted. Supposing, in the end, we find N solvable problems, the class may be split up in N groups (or 2N groups, making possible different approaches). For a given period, students then collect information that is relevant to them. After the given period the conclusions are then summarised. Possible methods of presentation are:

- an article for publication;
- a poster session;
- a discussion session;
- a booklet;
- a congress.

To the students it must be clear what is expected, what time they have and the demands of the final presentation.

Aims

Students should:

- realise that in multifarious problems with societal dimension there is no solely right or wrong answer but that the ‘truth’ lies in between;
- be able to identify conflicts (economic, ethical, social,...);
- be able to take a informed personal standpoint toward a situation and give balanced arguments to support their standpoint;
- be able to identify in the information the difference between facts, features

and opinions;

- become aware that opinions, standpoints and decisions are often directed by emotions and personal value systems;
- become aware that different interpretations of facts are possible because of different values, knowledge, skills and previous experiences;
- be able to express and defend their opinion/standpoint with a balance of arguments in a written or oral presentation.

Objectives

- To offer the opportunity of co-operation with teachers from other disciplines for integrated studies.
- To offer an opportunity to learn about genetechnology and rice.
- To offer an opportunity to see the connection between economy and biotechnology.
- To teach different ways of defining a problem, for example by making mind maps.
- To stimulate the search for information from different sources, and its critical evaluation.
- To be a starting point for teaching problem solving skills.

Student guide

The promise of biotechnology

Some arguments

Many arguments may be found in favour of developing and (later) growing transgenic rice. Here are two examples (there may be many more).

- Rice with resistance to pests: fungi, viruses or insects.

Much of a crop can be lost by pest damage; resistant varieties may result in higher yields, enabling more people to profit from the same agricultural area, but this might be temporary if pathogens develop resistance.

- Rice with Vitamin A.

This would be good because a lot of people eating rice lack this vitamin. It could improve health and life expectancy. Who would be against that? But is it a bit patronising? Who will pay for it in the end?

Reading critically

People promising benefits from biotechnology may be honest; they may have a hidden agenda. In the competition for research money people may be tempted to raise too high expectations. The border between factual information and the advertisements of a big company may be vague. On the other hand people can be against some developments for similar reasons. Just feeling that something is right or wrong is not very satisfactory.

Reading critically does not mean believing nothing, suspecting lies, but reading carefully.

Some hints:

- Look for too many emotional adjectives like good, fine, fantastic, bad, disastrous, unnatural.

- Consider the priorities of the writer - what are his or her interests in the short or long term in respect of: the money involved, jobs to be maintained, exerting power, fame.

Some possible arguments in favour (you may find more yourself):

- high yield;
- resistance to pathogens;
- drought resistance.

Some possible arguments against (you may find more yourself):

- it is the wrong issue, there is no food problem but a transportation problem;
- it is widening the gap between rich and poor;
- pathogens may become resistant.

When collecting data it is a good idea to distinguish:

- facts;
- possibilities, expectations;
- consequences.

INFORMATION

The promise of agricultural biotechnology

Back in the 1960s, in developing countries, a boost in food production was needed because of increasing demand. To avert threatening famine and malnutrition the so-called 'Green Revolution' started. The aim was to provide the farmers of the southern countries with seed of high-yielding varieties of wheat, rice and maize that were developed by plant breeding companies in Europe and the United States.

In practice, yields increased and so far food supply has largely kept in step with population growth. However, to attain their maximum yields, these high-yielding plants require regions with good climate and soil, sufficient water supply and plenty of fertilisers. Only a few regions in the developing countries were suitable, only rich farmers could afford the necessary watering systems, fertilisers and herbicides. Poor farmers who traditionally kept part of each crop as seed for the next vegetation period, had to buy new seed each crop because the hybrid varieties were not fertile enough to keep for seed.

Another disadvantage became apparent. It turned out that the high-yielding plants were not as resistant to pests as the old farm plants; so farmers also had to buy pesticides. People felt dependent on the plant breeding companies and on the industrial countries in general.

Rice terraces

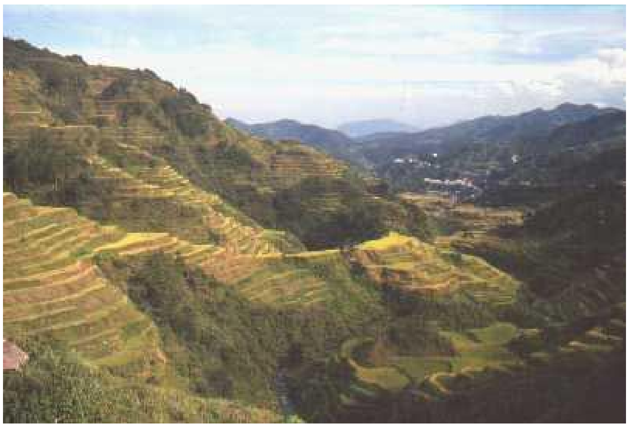

Photo: IRRI

Photo: IRRI

The rice harvest in India

An international centre for rice

- One of every three persons on earth depends on rice for more than half of his or her daily food.
- Ninety percent of the world's rice is grown and consumed in Asia, where more than half the world's people and about two-thirds of the world's poor live.
- Rice is also an important staple in Latin America and Africa.

The International Rice Research Institute (IRRI) was established 1960 in Manila. It was the prototype for a world network of 16 non-profit international agricultural, forestry and fishery research centres to help farmers in developing countries grow more rice on limited land with less water, less labour, and less chemical inputs, and to do so without harming the environment.

What impact has IRRI had on rice research and on society?

IRRI developed the first semidwarf breeding lines for rice in the mid-1960s. The high yields and rapid adoption of the new grain varieties triggered the Green Revolution. National agricultural programs worked in co-operation with IRRI to intensify rice production. The IRRI rices were soon followed by dozens, then hundreds, of semidwarfs developed by scientists in national programmes.


Photo: IRRI

Rice growing in the field

Average rice yields in South and Southeast Asia in 1991-93 were doubled to 1965-67. Total production rose by 120% while the land planted to rice increased by only 21%. The population of South and Southeast Asia, however, grew by 85% in the same period.

Seventy percent of the increased harvest was a result of higher yields and increased cropping intensity, but 30% resulted from new land brought under cultivation or shifted into rice from other crops. Much of the yield increase can be traced to the introduction of modern rice varieties and to the increased use of fertilisers, irrigation water, and other inputs.

Rice surpluses and low prices in recent years have given an impression that the world's food production problems are solved. But population pressure in the rice-growing countries is intense: about 80-100 million additional people must be fed each year. Prime rice lands are under pressure. Resource-poor farmers and the rural landless in Asia are being forced to till highly erodible and marginal lands, or to migrate to urban areas in search of livelihood, often leading to even more poverty.

The world's annual unmilled rice production, however, must increase by almost 70% from today's 520 million tons to keep up with population growth and income-induced demand for food over the next 30 years.

The Green Revolution

The socio-political ramification of such innovations also caused problems that were extremely complex. The Green Revolution seems to have passed by a substantial minority of the world's hungry who actually live in the world's agriculturally more productive areas, such as the plains of the Ganges and Brahmaputra in India, and the Kenyan highlands in Africa. The benefits of the increases in food production were felt mainly by the prosperous farmers - they by-passed the poor.

Learning from such mistakes, future food security policies must aim to enable food self-sufficiency and increase the income for the poor, so that city dwellers and agricultural labourers can buy food.

The challenge for the future

For biotechnology to have a useful role in income generation, it should aim to:

- improve existing cash crops and develop new ones that are better adapted to local climate and environmental conditions;
- lower crop losses caused by pests and diseases;
- improve harvesting and storage methods without raising costs for fertilisers, pesticides, etc.
- develop ecologically sustainable crops.

Modern biotechnology and genetic engineering appear to be the proper tools to affect improvement with the potential to improve:

- yield;
- quality on harvesting;
- resistance to pests (insects, fungi, viruses etc.);
- tolerance to stress (draught, salinity, frost etc.);
- nitrogen fixation;
- exploitation of natural resources.

Improvement of yield

The majority of hungry people - around two-thirds - live in marginal lands with poor soil and uncertain rainfall. These areas are never reached by the water-, pesticide- and fertiliser-demanding Green Revolution crops. Whereas the Green Revolution required alteration of the environment to suit the crop; such as demanding dams for irrigation and large applications of chemicals: biotechnology offers alteration of the crop to suit the environment. To achieve this involves the techniques of plant tissue culture and plant genetic engineering.

Two IRRI scientists investigating the development of test rice

Photo: IRRI

Plant tissue culture

Besides sexual reproduction, many plants can also reproduce themselves vegetatively. A complete new plant can often be grown from detached piece of root, shoot or leaf. Plants grow by cell division. So all cells that arise from one single cell are genetically identical 'clones' to the parent plant the cell came from. The advantage of using tissue culture are:

- cells can be multiplied on solid growth medium (a sterile soil substitute or a nutrient jelly) under optimised conditions to make identical copies of a plant, avoiding the genetic variability that arises in crossbreeding;
- crosses between distantly related species can be obtained by fusing cells of two species in tissue culture to produce a hybrid cell from which a new hybrid plant can be grown;
- international exchange of disease-free plant material is possible, together with ways of conserving and storing plant germplasm, avoiding infections;
- some plants take years to grow to maturity, flower and set seed., some elite plant species can now be propagated from tissue cultures and also induced to flower much earlier than usual.

Genetic engineering

Genetic engineering and its associated techniques is a much newer technology and can already offer:

- new biochemical methods for quickly detecting whether a certain gene is present in plant;
- techniques for extracting a gene from virtually any species and transferring it into plant cells in culture, from which a genetically novel plant might be grown;
- techniques for altering genes in the test-tube, before replacing them in their original cell or a new host cell.

Plant breeders can, in theory, take useful genes from any organism, insert them into plants and grow a transgenic crop with that new gene. In this way new plants could be designed to increase yields, while being adapted to the environment of arid regions with poor soil and being resistant to pests.

Improving harvest quality

The quality and value of a crop can be increased by introducing properties that make it easier to process.

Possible ways in which cereals, oilseed and other plants might be improved are:

- production of more of starch with various degrees of branching and chain length to improve texture and storage properties of starchy food;
- modification of fatty acids in oilseeds - removal of those linked to heart disease or particular tastes, improving its value to food manufacturers;
- changing the viscosity, volatility, temperature sensitivity or mixing properties of special oils for use in food manufacturing;
- production of proteins richer in essential amino acids.
- increasing the nutrition value of rice by shifting the ratio of insoluble glutelin and soluble prolamine (both rice proteins)
- extending the storage life of cassava by blocking an enzyme that causes decay.

Resistance to pests and diseases

One way to increase the productivity of high-yielding varieties of wheat and rice is to make them resistant to common pests and diseases. Pesticides cost money and have other environmental costs. Inbuilt long-lasting genetic resistance to disease is the long-term aim of the plant breeder. A high proportion of crop loss is due to the effects of pests and diseases. The number of pests is as numerous as the diseases. An example of a crop where science could have a revolutionary impact is cassava.

In Africa, cassava has the highest annual tonnage of all food crops (500 million tons). It is a hardy tropical shrub with tuberous root which stores much starch and a cyano-glucosid. It takes several hours to process cassava into gari, the regional cassava meal dish. If not thoroughly processed (cooked and leached) cyanide is produced. Cassava is very low in protein but is the ‘safety net’ crop for 300 million poor farmers. One target would be to reduce the effects of cassava mosaic virus, the effect of which causes million tons of crop loss in sub-Sahara countries. Can biotechnology help? Yes, of course.

Scientists in the United States have made tomato, tobacco and potato plants resistant to a broad range of viruses, using a trick that may be useful for developing country crops, such as cassava. The trick is to protect the plant by transferring the gene for the coat protein of tobacco mosaic virus into the target plant. Whereas normal plants suffered losses of 25-70% from the virus, the transgenic plants were unaffected.

Genetic engineering has already achieved insect resistance in tomatoes, tobacco and cotton by the transfer of genes from a common soil bacterium *Bacillus thuringiensis*. The genes directs the production of protein toxins (poisons), that kill certain insects.

Tomatoes with *Bacillus thuringiensis* gene were completely protected from an attack of caterpillars that stripped other unprotected plants in the same field down to their stalks. Also tobacco has been successfully protected from the tobacco hornworm with a *Bacillus thuringiensis* gene.

Many plants have natural insect-killing genes, producing toxins. A trypsin inhibitor gene has been detected in the genome of African cowpea, the protein it produces blocks the digestive enzyme trypsin in insects, effectively starving them, but is harmless to people. It is possible to clone this gene and introduce it into the genome of tomato, tobacco and maize plants.

‘Weed control’ is the current commercial terminology for the use of genetic engineering to make crop plants resistant to herbicides, allowing farmers to spray growing crops to kill weeds but not their crops.

An alternative method of ‘weed control’ would be, rather than introducing herbicide tolerant genes, to engineer crop plants to contain natural weed killers - for many plants have mechanism for defending themselves from encroaching neighbours.

Tolerance to stress

The most significant stress effects on crops in developing countries are drought, salinity, and harsh soil and climate conditions.

Many marginal lands are too dry for high-yielding varieties, although the soil can support older indigenous varieties. Natural soil conditions, irregular rain and bad irrigation practice over many years can all mean that soil is too salty, lacks essential minerals, or is too full of other harmful minerals to support many modern crop varieties. Resistance to salinity is related to resistance to drought - to the plant, the conditions are similar as both tend to dry the plant out. Research into one problem might benefit both. The plant breeder must first find genes that confer tolerance to harsh conditions such as salinity, drought and frost and then these genes must be transferred into useful modern varieties.

Genes for stress resistance are more likely be found in wild relatives of crop plants, or in the traditional farm varieties. Transferring genes from one species to another is difficult by conventional plant breeding but must be the goal for genetic engineering in future.

Researchers at the Rockefeller Foundation, working on a rice biotechnology programme, have been using protoplast fusion in an attempt to cross the highly salt-tolerant *Porteresia coarctata*, a wild relative of rice that grows in the seashore mangrove swamps of Bangladesh, into a rice species which is relatively easy to regenerate from protoplasts. *Porteresia* has special ‘salt hairs’ on its leaves, in which the salt is accumulated. The hairs burst, and the salt drops back into the surrounding water. *Porteresia* and food rice will not interbreed, so protoplast fusion is necessary. Researchers have finally succeeded in fusing the protoplasts and have ‘got the hybrid cells to start dividing’.

Frost damage can also be a problem in some developing country regions - such as Northern Asia, and the uplands of Africa and Latin America. Biotechnology offers a solution in the form of *Pseudomonas* bacteria. Up to a million bacteria are found per square centimetre of plant surface. In the Unites States, *Pseudomonas* has already been genetically engineered to reduce frost damage on strawberries. In this case, the trick was to remove a gene, which normally produces a protein which makes freezing water vapour crystallise to form frost. In experiments, these modified bacteria were sprayed onto strawberry plants to replace the indigenous bacteria with the result, that the plants were protected from mild frost.

Nitrogen fixation.

Plants require a supply of nitrogen to form amino acids, enzymes and proteins. Atmospheric nitrogen is not directly available to plants because they can only utilise nitrates or ammonia as nitrogen sources. The transformation of molecular atmospheric nitrogen into nitrogen-compounds is known as nitrogen fixation. This is achieved in two ways: by chemical reaction requiring a high energy input or biologically by bacteria.

There are some useful microbes in plant root systems: in particular the bacteria *Rhizobium* and *Bradyrhizobium* which colonise the roots of leguminous plants and trees, forming nitrogen-fixing ‘nodules’. Another nitrogen-fixing bacterium, *Frankia*, grows in the roots of alder trees. These species act as natural fertilisers by ‘fixing’ atmospheric nitrogen into a form easily assimilated by the plant. Some free-living microbes, such as *Klebsiella*, *Bacillus* and many blue-green algae (cyanobacteria), also fix nitrogen. All are possible targets for the biotechnologist. A conventional way of improving nitrogen fixation is by inoculation: soil and seedlings are inoculated with the bacteria. The inoculant cells must generally outnumber the indigenous ones by 1000 : 1 before they will take hold, so the process demands large doses of inoculant. This can be managed by using fermentation technology.

Greater success may come through the large-scale-screening of natural tropical varieties of nitrogen-fixing soil micro-organisms which is being organised through the UNESCO / UNEP Microbiological Research Centre Network (MIRCEN).

Bengali rice cultivators have long exploited nitrogen-fixing blue-green algae which occur naturally in the flooded paddy field. Rice yields can reach 4 tonnes per hectare without any application of chemical fertilisers or manure. The appropriate application of biotechnology here might be to enhance the effectiveness of such existing techniques, rather than introducing completely novel ones. In Vietnam rice yields were improved by experiments using the cyanobacteria *Anabaena*, a symbiont to *Azolla pinata* an indigenous aquatic fern.

Gene technologists aim to isolate the so-called nif genes (nitrogen-fixing genes) from bacterial DNA (17 in *Klebsiella*) and build them into plant DNA. This could reduce the requirements for fertilisers if crops could fix their own nitrogen. Neither direct nif gene transfer into plants, nor adjusting bacterial genes to enable the bacteria to colonise cereals or other plants, seem possible in the short term.

Exploitation of natural resources

In addition to these techniques to help improve yield and quality of crop there are many more areas where biotechnology and genetic engineering could help exploit natural resources. The applications of the new biotechnology are broad, the following list only shows a few examples.

Many of the chemical reactions of plant tissues are too complex to reproduce in the laboratory or in industry, why not use the plant itself as a chemical factory? Plants that cannot be grown in the temperate climates of the North, but with cells producing valuable products, could be grown in a laboratory anywhere in the world.

For example there are two alkaloid drugs called vinblastin and vincristine which are excellent cancer treatments, extracted from the Madagascar rosy periwinkle plant. They have revolutionised the outlook for children with leukaemia. Biotechnologists are now trying to culture rosy periwinkle cells. There is no doubt that successful tissue culture of valuable plants by the developed world could be a threat to livelihoods in developing countries . On the other hand, if the technology could be adopted in developing countries, it could be a valuable source of income.

The cultivation of the white daisy-like pyrethrum flowers grown in Kenya, Tanzania and Ecuador for the production of natural insecticides (pyrethrins) is also under threat, if pyrethrum cells could be grown by tissue culture in any laboratory.

Consider, for example, shikonin, a dye, ointment and cosmetic extracted from the root of a wild herb once collected in Japan, Korea and China and used to make the red dye of the Japanese flag. After much research, cell cultures were developed that contained 20% shikonin after eight months culture - whereas the plants collected wild, take four years to grow and produce only 1.4% shikonin.

Bacteria engineered to carry specific genes from humans, animals and viruses are now producing human insulin for diabetics, human interferon, human growth hormone, antibodies, virus proteins.

The use of bacteria for clearing of waste water and even the cleaning of poisonous industrial waste is already widespread, modified bacteria have even greater environmental potential.

Single cell protein (SCP) produced by micro-organisms in bioreactors is used for human (e.g. Quorn) and animal food. Many different products care be manufactured by similar techniques, e.g. citric acid, penicillin, detergent enzymes.

Bacteria have evolved to tolerate and exploit the most extreme conditions on earth, from boiling mud-pools around volcanoes to dark, sulphurous under-ocean vents and Antarctic snows. Some 10-20% of the world copper supply is currently extracted by the use of microbes on poor quality ores and slag heaps. *Thiobacillus ferroxidans* enjoys the acid conditions of the spoil heaps of worked-out mines.

This list, which could be continued, shows the potential of biotechnology to exploit natural resources. If developing countries are to benefit from the opportunities offered by biotechnology at least four fundamental elements appear to be necessary:

- an effective mechanism to asses real needs;
- skills in tissue culture, the essential basic plant biotechnology;
- an established infrastructure for plant breeding - presently lacking in many developing countries;
- regulation, to investigate and control risk.

As biochemical understanding of plant cells improves, more and more plant production of useful resources will certainly be developed. Meanwhile, there is much to explore in under-exploited and non-commercialised plants (and other organisms) from developing countries, particularly the species rich tropical forests. It is estimated, that only a few percentage of the up to 250.000 species of living higher plants have been systematically explored for useful products. Indigenous peoples, in forest areas in particular, have extremely valuable knowledge of the application of rare plants and trees. They need a market in which to sell their knowledge, to help protect their forests.

Health, medicine and gene modified rice

The scientific rationale

For more than two billion people in South-east Asia rice is the staple food. Two recent research projects have attempted the nutritional enhancement of rice using gene technology. One study concentrated on introducing genes containing provitamin A as beta-carotene, another tried to increase the intestinal absorption of iron. The stated rationale for doing this research, in both cases, lies in the claim that populations in developing countries are deficient in vitamin A and iron which results in various manifestations of disease.

Diseases resulting from a mild to severe vitamin A deficiency range from night blindness to an increased mortality from childhood diseases. In developing countries iron deficiency anaemia is thought to affect 50% or more of certain populations groups such as women of child bearing age, infants and children. Iron deficiency in pregnancy increases the risk of premature birth and raises perinatal morbidity and mortality rates. Lack of iron in childhood can limit intellectual growth causing permanent changes to mental and psychomotor development.

The researchers claim that traditional approaches to supplementation of the diet have not proved successful. Their tacit assumption is that, if the research proves successful, in future food may be nutritionally supplemented for medical reasons.

"Our goal is therefore, to introduce beta-carotene biosynthesis in rice endosperm to provide an easy and convenient way to fulfil the vitamin A requirements of these people predominantly relying on rice as a food source, without altering their dietary habits", says one of the leading world experts.

Which genes from where?

Beta-carotene

The rice transformation originally involved experiments using daffodil (*Narcissus pseudonarcissus*) DNA coding for one of the specific enzymes, phytoene synthase. This resulted in the introduced DNA being present through three generations of rice plants, seeds from these plants also produced phytoene in their endosperm. More recent work has aimed to transfer other genes necessary to enable rice to express beta-carotene in endosperm tissue. These genes originate from *Erwinia urodevora* and daffodil.

Iron

Two approaches to increasing human intestinal absorption of iron have been attempted. Firstly, scientists attempted to reduce the level of the main inhibitor of iron absorption, phytic acid. A phytase from *Aspergillus niger* was used. Secondly, they attempted to increase the absorption of iron with an absorption enhancing cystein rich protein, metallothionein. The genes were transferred by microprojectile bombardment *(see EIBE Unit 9)*.

Discussion points

- *Consider the changes in the symbolic meaning of food that genetically modified foods may precipitate*
  - *a) in terms of cultural identity and tradition;*
  - *b) in terms of the local environment.*
- *Compare and contrast the practice of using non genetic technologies with that of using genetic engineering techniques to nutritionally enhance processed food in industrial countries.*

The economics of gene modified crops

Economic implications

The term **developing countries** is used to refer to much of Africa, Asia and South America and in contrast with **industrialised countries** or **developed countries** where industry and agriculture are more advanced. Over half of the world's population depends on local subsistence farming. An increasing proportion of the population of developing countries lives in cities, sometimes 'mega-cities', and require quantities of agricultural products which cannot be produced by subsistence farming. Developing countries also need cash crops for export in order to earn money for necessary imports.

The most important and fundamental needs of those living in countries which rely on subsistence agriculture is adequate food and clean water. The application of appropriate technological expertise could benefit both resources.

Techniques for the selection of 'better' varieties of crops and farm animals have been used for thousands of years. There are no crop plants or animals in the world which have not been 'improved' over time by selective breeding. A major difference between traditional techniques and modern biotechnology is the speed at which modifications may be carried out.

It may be that many of the issues that arise from the genetic modification of agricultural crops are not significantly different from those that arise from traditional breeding methods. Industrialisation and intensification of farming has already happened in 'industrialised' countries without the use of modern biotechnology. In less-industrialised countries the impact on society of using new crops, developed either by traditional breeding methods or by genetic modification, may be profound.

Agrofood companies

The agrofood industry is one of the world's major industries. It is now dominated by a small number of large international companies which have been formed by company takeovers and mergers during the last two decades. This situation has come about because biotechnology on a commercial scale requires advanced techniques and equipment together with substantial financial investment (although the basic scientific techniques are relatively easy and cheap to perform).

There are therefore fears that the new technology will lead to:

- exploitation of those living in developing countries;
- monopoly control of agricultural chemicals and seeds;
- major changes in social structures affecting all types of agriculture and food distribution.

The plants and animals of developing countries, particularly in tropical areas, are not as well characterised as those of industrialised countries.

Patents and breeders rights

This is perhaps one of the most contentious issues between the developed and the developing countries. Currently farmers are able to keep seed from year to year so subsistence farmers do not need to regularly purchase new seed. Patents and new conditions under which seed is sold may prevent seed being retained, the additional cost of purchasing new seed may be too great for subsistence farmers.

Biodiversity, risk assessment and culture

Biodiversity

Biodiversity is a measure of the variety of living organisms in an ecosystem. Normally we understand the word to mean the number of different species or genetic varieties present in an area.

Microbes encompass the greatest variety of life and perform unique roles in ecological processes. One of the world's leading experts on microbiology estimated, from current knowledge, that: "*there are between 2 and 3 million species of bacteria and 1.5 million of fungi*". One gram of tropical soil, for example, can contain up to 90 million micro-organisms.

Looking at more visible organisms, of the known 10,000 to 50,000 species of edible plants, only 150 to 200 are used as human food. Nine crops (wheat, rice, maize, barley, sorghum / millet, potato, sweet potato / yam, sugar cane and soya been) account for more than 75 % of the dietary energy that people derive from plants, three of these (wheat, rice, maize) for more that 60 %.

In spite of the enormous untapped reserves of edible plants we are narrowing rather than broadening our plant food base. The Food and Agricultural Organisation (FAO) estimates that 75 % of the genetic diversity of agricultural crops has been lost since the beginning of the century.

If biodiversity is high there is a greater genetic potential, which gives optimum choice for crop breeding.

The extensive geographical range of rice is an indication of its tremendous genetic potential. Cultivated over a long period of time in south-east Asia, a great number of varieties of rice have been developed that are adapted to different physical habitats and different methods of cultivation. The IRRI has recorded nearly 1500 varieties, the perpetuation of which may be a result of traditional methods of harvesting involving ear-by-ear collection with tools which cut the rice plant singly. Varieties differ in form, habit and physical behaviour.

Examples of such differences are: the length of the maturation period, from short (90-100 days) to long ((200 days) growing periods; the soil / water requirements; and the photoperiodic sensitivity (from short-day to long-day). Also, rice plants differ in their tolerance of, or resistance to, adverse environmental conditions such as drought, flood, high wind force, soil salinity, and other soil toxicants (aluminium) or deficiencies (zinc).

There are only two species of cultivated rice: *Oryza sativa*, which is predominant, and *Oryza glaberrima*, which is only grown in very limited areas of West Africa. Within *O. sativa* three major groups of traditional varieties have long been distinguished on the basis of their geographical distribution: 1) *Indica;* 2) *Japonica;* 3) *Javanica*

Cutting across these traditional groups are the more recently developed hybrid varieties, the product of inter- or intra-group selection, breeding and now, transgenic manipulation. These have replaced the old varieties in certain parts of the Asian heartland and dominate the more recently established rice crops that are grown in the extra tropical periphery.

Along with the development of new varieties new problems arise. The early developed varieties were found to be both more pest- and disease-prone. This stimulated the development of more resistant varieties. While the search for evermore disease- and pest-resistant varieties goes on, new rice varieties, adapted to a wide range of environmental conditions, are continually being developed.

The gene pool of old rice varieties is important in the search for improvements, so that new varieties can be given an optimum combination of characteristics. Rice varieties are being collected and maintained, but there still are some gaps. For example, land species of rice from Madagascar, Mozambique, and Southern Asia are still under-represented in collections as are wild rice species from Eastern Central and Southern Africa, and from Latin America. Some 43 % of rice samples are stored in the six largest institutional collections (China, India, Japan, Philippines, Thailand and USA) all of which observe international storage standards. The largest collection of rice germplasm is held at IRRI. It also has developed an International Rice Genebank Collection Information System, which accommodates passport, characterisation and evaluation information.

Risk assessment

The most discussed risk associated with the production of transgenic plants is the risk of the transgene passing to wild relatives. For this reason there is great interest in assessing the likelihood of transgene hybrids forming between the transgenic crop and wild relatives.

The ecology of the transgenic and non-transgenic wild plants needs to be understood and answers found to questions such as:

- are fertile transgenic hybrids formed;
- if so, do the transgenic wild plants dominate the non-transgenic ones in the wild?

To answer such questions, research is necessary. The priority given to biosafety issues in some rice-growing countries seems to be behind that in other countries. In the USA six field tests of transgenic rice have already been accepted, following the regulatory procedures previously developed for other plants. Few field tests have been reported so far from other countries.

Field tests of transgenic rice plants may be forthcoming in developing countries, but there is still the problem of regulations or agreements on the release into environment of new genes that may cross international borders.

Solid risk assessment demands extensive information from several scientific disciplines, there is a need to collate all this information for reference, for example in databases.

Impact on local cultures

It is often stated that 30 crops “feed the world”. These are the crops which provide 95% of dietary energy and protein. Wheat, rice and maize alone provide more than half of the world-wide plant-derived energy intake. These three crops have received most investment in terms of conservation and improvement over thousands of years. They are the crops that, from the 1970s onwards, provided the ‘Green Revolution’ with the higher yielding strains . They are also the crops on which the major effort in genetic modification has been directed, although, of them, only genetically modified maize is currently being grown on farms.

A further six crops, sorghum/millet, potatoes, sweet potatoes, soyabean and sugar (cane and beet) bring the total to 75% of the energy intake. The remaining 25% is made up of crops which are important in local areas. Cassava, for example, supplies over half of the plant-derived energy in Central Africa although this is only 1.6% at the world-wide level. Beans and plantain are important staple foods in particular regions while others such as the potato, peanuts, pigeon pea, lentils, cowpea and yams are the dietary staples of millions of the world’s poorer people although they receive relatively little research and development attention.

Resource-poor farmers are over half of the world's farmers and produce 15-20% of the world's food. These farmers have not benefited from the high-yielding 'Green Revolution' crop varieties as much as those in the more developed countries. It is estimated that some 1,400 million people, approximately 1,000 million in Asia, 300 million in Africa and 100 million in South America are dependent, at the present time, on resource-poor farming systems in marginal environments.

The majority of the world's resource-poor farmers are women who produce more than 50% of the food grown world-wide. In many developing countries this proportion is much higher. For instance it is estimated that women produce 80% of the food grown in sub-Saharan Africa, 50-60% in Asia, 40% in the Caribbean, and 30% in North Africa, the Middle East and Latin America.

Culture and environment

Rice has been grown and developed for more than 7000 years by farmers. The knowledge and experience from the farmers is therefore an exceptionally valuable resource. Guided by a life-giving and life-sustaining worldview, indigenous people have devised and developed means to improve the genetic resources found in nature.

The practice of free sharing and exchanging seeds within communities has contributed to the continued domestication of wild plant varieties, to nurturing good varieties passed on through generations, and to continual development of new varieties.

Historically, woman have been considered as the chief curators of plant genetic resources in traditional agricultural societies. In the rainforest of central Liberia plant specialists found that woman farmers are more accurate in describing the characteristics of different rice varieties than men.

In present-day indigenous communities, plant and animal breeding continue to play a key role in human survival. Side by side with the activities of scientists and researchers, indigenous peoples continue their age-old tradition of conserving and further developing crop breeds which have been passed on to them by their ancestors.

Ironically, while modern biotechnology has virtually stolen the development role from indigenous communities, it has itself become heavily dependent on the genetic materials developed by indigenous farmers over thousands of years.

APPENDIX 1

Rice

Some data

All modern cultivated rice belongs to one of two species:

- *Oryza sativa*, from Asia and by most people thought of as ‘the’ rice,
- *Oryza glaberrima*, a red rice from West Africa.

There are now more than 140,000 varieties of rice flowering around the world.

Rice is a very important crop, especially in Asia, people depend on it for between 30 and 70 %of their daily calories. More than 91 % of the world’s unmilled, rough rice is grown and consumed by almost two-third of the world’s population.

Some history and geography

Rice (*Oryza sativa*) was originally a kind of grass, very well adapted to the monsoon climate in the Bengal Gulf. It was able to grow in the temporary flooded, wet areas and could also survive dry periods. The seeds of rice were found to be very nutritious.

Rice is now a major staple food. It is harvested on 148 million hectares, more than 10% of the earth’s arable land. In 1991 total rice production was about 520 million tons. About 55% is cultivated in ‘irrigated’ fields (81 million hectares); this contributes to 76% of global rice production.

The gene pool of rice is in S.E.Asia but rice is now grown all over the warmer parts of the world.

Rice is grown under many different conditions. The best known is using irrigated fields. The crop is heavily fertilised and yields can reach 5 t/ha in the wet season and more than 8 t/ha in the dry season. Irrigation systems are concentrated in semiarid and subhumid subtropics in Asia.

Other growing conditions for rice include:
Flood-prone. Rice fields are characterised by medium to deep flooding from tides and rivers. Flood-prone rice is grown in more than 10 million hectares, predominantly in S. And SE Asia.

Rain fed lowland. Rice is grown in puddled soil on level to slightly sloping, banded or diked fields with variable depth and duration of flooding, dependent on rainfall. World-wide the area is 37 million hectares; it is dominant in the humid and sub-humid tropics.

Upland. Rice is direct seeded in non-flooded, well-drained soil on level to steeply sloping fields. This is dominant in Africa and Latin America, but relatively less important in Asia. Upland rice is grown on about 19 million hectares world wide.

The origins of rice are in SE Asia, but rice has now found its way all over the world (*see Table 1*).

Table 1. World rice production, 1991

Area	**Production** (x 106 ton)	**Yield** (ton/ha)
Asia	*477*	*3.6*
Latin America	*17*	*2.7*
Africa	*13*	*2.0*
Australia	*0.7*	*8.2*
USA	*7*	*6.3*
Rest of the world	*5*	*4.4*
Total	**520**	**3.5**

(Deviation of total due to rounding the figures)
(Source IRRI = International Rice Research Institute)

Table 1 also shows that the yield of rice varies considerably. It has been estimated that the maximum yield is 10 t/ha (Biotechnology and Development Monitor no 22, March 1995). In practice the yields may decrease if the production capacity of the soil is lowered by intensive cultivation.

Much research has been done on rice genetics and the possibility of introducing genes which offer resistance again pests. Central in rice research is IRRI, the International Rice Research Institute:

IRRI
PO Box 933, 1099 Manila, Philippines,
Telephone (63-2)818-1926,
Internet: http://www.worldbank.org/html/cgiar/directory/IRRI.html

Rice has contributed to medical history. The Dutch physician Eykman found that chickens given ‘white’ rice suffered a disease very much like beriberi. After feeding the chickens ‘brown’ rice, most of them recovered. This was the beginning of the era of vitamin research. It was found that, in parts of the grain that were discarded when polishing the rice (i.e. making white rice out of brown rice), a substance was present that we now call vitamin B or thiamine. Eykman received the Nobel prize for this work in 1929.

Techniques

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Transgenic rice and rice genome research

This is an article by I. Havukkala, Rice Genome Research Program, STAFF Institute. 446-1. Ippaizuka. Kamiyokoha. Tsukuha. Iharaki 305, Japan. It was published in Field Crops Research 45 (1996) 27-35. Thanks to Elsevier Science, UK for permission to reproduce it here.

Abstract

The recent rapid progress in transferring foreign genes for expression in rice is evaluated. There is an apparent need for an international database and for information exchange about transgenic rice plants between molecular biologists, plant breeders, company researchers and government regulators. Progress in rice genome mapping will enhance further the development, evaluation and monitoring of transgenic rice plants. The special conditions of rice-growing nations transport of released genes over international borders need attention when developing and deploying new transgenic varieties in Asia and elsewhere.

Keywords: Database; Genome mapping; Oryza sativa; Review; Transgenic plants

Many *Bacillus thuringiensis* insect-toxicity genes have also been engineered into rice, as well as hydrolytic enzymes for fungal and bacterial resistance. Expression of plant chitinase genes is known to increase during fungal pathogen attack and to confer resistance, and various other chitinase genes could also be utilised in transgenic plants this way, hence the large number of transferred chitinase genes.

Many important crop traits are controlled by quantitative loci. In the future, pyramiding different genes for the desired effect by gene transfer may become feasible, as well as transfer of many genes involved in long pathways of secondary plant metabolism. Significant progress utilising secondary metabolism could be made also for rice, because some metabolic short-cuts may be possible, in a way similar to glucosinolate manipulation by myrosinase (Hallahan et al., 1992).

Conclusions

1. An internationally accessible database of genes transferred to rice and tested in the field could be very useful. The information in this paper (142 reports about 61 genes) will be available electronically at the WWW server (address http://www.staff.or.jp) and updating mechanisms are planned in order to develop a useful service to rice researchers worldwide. People interested in cooperating are asked to contact Ilkka Havukkala at ilkka@staff.or.jp

2. A detailed genome map of rice would facilitate development and risk assessment of transgenic rice, both for localising the inserted gene in the genome, and for assessing its stability. Such a map and associated screening technology would also enable effective further breeding and monitoring of the modified traits after release into the agricultural environment.

Two Institutions

★ ★

1. International Rice Research Institute (IRRI)

Thanks to IRRI for permission to use the following material.

To all the hungry, the malnourished, the undernourished whose staple food is
RICE

IRRI's Mission Statement

Our goal

To improve the well-being of present and future generations of rice farmers and consumers, particularly those with low incomes.

Our objectives

To generate and disseminate rice-related knowledge and technology of short- and long-term environmental, social, and economic benefit and to help enhance national rice research systems.

Our strategy

We pursue our goal and objectives through:

- interdisciplinary ecosystem-based programs in major rice environments
- scientific strength from discipline-based divisions
- anticipatory research initiatives exploring new scientific opportunities
- conservation and responsible use of natural resources
- sharing of germplasm, technologies, and knowledge
- participation of women in research and development
- partnership with farming communities, research institutions, and other organisations that share our goal

Our values

Our actions are guided by a commitment to:

- excellence
- scientific integrity and accountability
- innovation and creativity
- diversity of opinion and approach
- teamwork and partnership
- service to clients
- cultural diversity
- gender consciousness
- indigenous knowledge
- environmental protection

A criticism of IRRI:

This review is by Robin Pistorius, published in the Biotechnology and Development Monitor, No. 34, March 1998, 22. It is a review of:

> *Nicanor Perlas and Renée Vellvé (1997), Oryza Nirvana: An NGO Review of the International Rice Research Institute in Southeast Asia. SEARICE Publications [83 Madasalin Street, Sikatuna Village, Quezon City 1101, Philippines]. 181 p. ISBN 971-91917-0-8. Price: US $10.*

Thanks to Biotechnology and Development Monitor, The Netherlands for permission to use this article.

The conclusion of this book is simple and powerful: the International Rice Research Institute (IRRI) will continue to produce higher yielding but very unsustainable rice varieties because of its undemocratic organisation, conservative scientific assumptions and cultural distance from the main target group, the subsistence farmers. The title of the book “Oryza Nirvana” reveals this message in a subtle way. IRRI’ s first major contribution to the Green Revolution in 1963 were ‘ miracle varieties’ such as IR36 and IR8 containing a grassy stunt resistant gene derived from the Indian wild relative *Oryza nivara*. But freely translated from Sanskrit the word “Nirvana” means as much as “unattainable goal” or “dream”. This book is a sound source of critique on IRRI’ s research strategy and philosophy. It starts with a careful analysis of IRRI’ s political background. Here we find quoted evidence for the frequently heard claim that IRRI was just another pawn in the anti-communistic geopolitics of the USA. At this point, a flaw in the text could be detected. Apparently the authors did not manage to read the 1981 seminal work of Edmund Oasa: “The IRRI and the Green Revolution: A Case Study on the Politics of Agricultural Research”. This could have made the first chapter less dependent on secondary sources, and could have offered more insight to the scientific assumptions of IRRI’ s founding fathers. The historical overview nevertheless allows the reader to understand how narrow and technology driven IRRI’ s mandate has always been, and more importantly, how difficult it is to change it. Recently IRRI has proclaimed a more “demand driven” research approach. A comparison between this strategy and IRRI’ s real research results may be considered as the strongest part of this book. “Durable resistance”, “increased nutrient efficiency”, “limitation of external inputs”, are disclosed as flashy research goals enabling IRRI to carve out its existing mandate but not change it. IRRI’s real aim is to produce a 15-tonne yielding variety, which is three times the current yield per hectare. The authors not only consider the official double aim, “sustainable high yields”, to be a “nirvana”. The envisaged high yields, the authors argue, can never be created through the genetic improvement of a plant only, but always depend on extra external inputs.

IRRI’ s “double speak” reflects the dilemma of many institutes of the Consultative Group on International Agricultural Research (CGIAR). “Feeding the 8 billion in 2035” is increasingly used to consolidate funding from donors. Simultaneously, CGIAR institutes cannot neglect NGOs critiques regarding the social and environmental costs of the CGIAR technologies. This book repeats a simple but fundamental question: Does IRRI (representative for the other institutes of the CGIAR) really want to listen to and work with subsistence farmers? If so, the book concludes, no less than a paradigm shift in breeding strategies, organisation, funding, and political legitimisation is needed. The authors favour a reorientation of the IRRI’ s technical work on the basis of micro-economic, social and cultural criteria.

While this book presents a serious critique on IRRI, it is a pity that the authors refrain from outlining alternatives. Is IRRI changeable? Or should one abandon the entire institute, start from scratch with a very different scenario, on the basis of the criteria preferred by the authors? How then to tackle the mounting food short- ages due to population pressure? Readers who are concerned with IRRI’ s work would have been helped with an extra chapter on this matter.

2. Rockefeller Foundation

About the Rockefeller Foundation

In many developing countries where a single crop provides the lion’s share of nutritional sustenance for their people, agriculture often depends on small, resource-poor farms and traditional modes of cultivation. With the pressures to increase agricultural production growing stronger year by year, these smallholder farms have little chance of satisfying food needs.

In Asia rapidly growing populations have compelled farmers to utilise all available cultivable land in order to keep up with food demand, raising the question of how further to increase food production in the 21st century. In African countries rainfall limits the arable land and lack of fertiliser use depletes precious nutrients from cultivated soil. With current demand already outreaching the capabilities of African farmers, it is urgent to find ways of getting more from existing resources as soon as possible. Adding to the challenge of increasing yields in both Asia and Africa is the need to assure that productive lands will remain fertile in years to come.

Resolving these dilemmas is the motivation behind the Rockefeller Foundation’s work in Agricultural Sciences. The key to increasing the yield of staple crops in Asia is advances in genetic technology that allow farmers to reap bigger harvests from currently cultivated land, while preserving the land’s capacity to support continued agricultural activity. The key in Africa is to devise and implement improved management practices that increase nutrients to crops and sustain soil productivity.

In Asia the Foundation’s goal is to increase rice yields 20 percent by the year 2005 using biotechnology, without degrading the resource base or reducing farm incomes. An integral part of the process is to enhance research capacity in rice-dependent countries so that they will be able to sustain their work beyond the support of the Foundation.

Yield

Biotechnology and the future of rice production; study of yield potential and grain quality

This is an article by Dr J. Bennett, International Rice Research Institute, PO Box 933, 1099 Manila, Philippines. It was published in An International Journal of Physical, Biological, Social, and Economic Geography and Applications in Environmental Planning and Ecology , vol. 35 no. 3, 1995 March. ISSN 0343-2521. GeoJournal 35.3 333-335. Kluwer Academic Publishers

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Resistance to Biotic and Abiotic Stresses

Conventional breeding over the last 30 years has given IRRI's elite cultivars a wide range of genes for resistance to insects and diseases (Khush 1977,1989; Bonman et al. 1992). The same methodology will be equally important in the future. However, there are certain situations in which biotechnology will be utilised to enhance host plant resistance.

The first situation is where important resistance genes are to be transferred from wild rices to cultivated rice Unless the wild rices are closely related to cultivated rice (*Oryza sativa*) and share the same AA genome, the hybrids will be sterile as a result of embryo abortion. However, it is possible now to rescue hybrid embryos formed between *O. sativa* and distantly related species of the genus *Oryza* through plant tissue culture (Khush and Brar 1992).

The second situation is where there is no known source of resistance to a particular insect or pathogen in the rice germplasm. If the insect or pathogen is sufficiently important, it would be worthwhile to attempt to devise a resistance mechanism using purified genes from other sources. Yellow stemborer and sheath blight are targets for this approach. Transformation is being used to transfer synthetic genes encoding several types of (-endotoxins of *Bacillus thuringiensis*. A CryIA(b) gene of this type has been transferred to rice by Fujimoto et al. (1993), and the transformed plants are being tested at IRRI for resistance to yellow stemborer. Trypsin inhibitors are another class of potentially insecticidal proteins. The soybean trypsin inhibitor gene has been transferred to several rice varieties at IRRI. Chitinase genes and ribosome inactivating protein genes from barley are being transferred to rice in an effort to enhance sheath blight resistance. Protoplast-based and microprojectile-based transformation methods are in use at IRRI for both *japonica* and *indica* rices.

Study of Yield Potential and Grain Quality

Like blast resistance and drought tolerance, yield is quantitative trait governed by a number of genes Considerable progress is being made in mapping the most important quantitative loci governing yield components in plants. The application of this technology to rice has been initiated. Since yield is one of the most easily measured quantitative traits, it is unlikely that gene mapping will be used to select for yield through marker-aided selection

New Frontier Projects

IRRI has identified four research areas that combine the potential for enormous impact with great difficulty. The areas are (i) multiplication of hybrid seed through apomixis, (ii) nitrogen-fixation for improved nitrogen nutrition, (iii) allelopathy for control of weeds, and (iv) perennial rice for the uplands. Biotechnology will play a role in all four projects, but for the present we shall consider the involvement of biotechnology in apomixis 1' and nitrogen-fixation research.

Farmers enjoy a 15-20% yield advantage with hybrid rice compared with the best inbred lines. However, hybrid rice seed is costly because it must be purchased each season from specialised production companies. Farmers cannot reproduce hybrid seed themselves by inbreeding because the yield advantage of the hybrid declines significantly with each cycle of inbreeding. Apomixis is a method of reproducing seed directly from the ovule without fertilisation by pollen. Apomictic hybrid rice could be reproduced by farmers themselves at minimal cost and with minimal loss of hybrid advantage. Apomixis is unknown in rice but it is widely encountered in other grasses. Recent studies indicate that the switch from sexual reproduction to apomixis may be controlled by as few as 1-2 genes. Transfer of such genes from an apomictic species to rice would open up the possibility of introducing apomixis into rice. Biotechnology would be involved in both mapping and isolating the apomixis genes and in transferring them to rice. Some attention might also have to be given to ensuring that the foreign genes operate appropriately in rice.

Nitrogen nutrition is one of the major determinants of yield in rice cultivation. Nitrogen use efficiency in rice is low because of the losses that occur when fertilised fields are flooded. The losses are due in large part to microbial conversion of fertiliser into nitrogen oxides that pollute air and water. The continuous supply of nitrogen to rice plants through associative or symbiotic nitrogen fixation could make a significant contribution to nitrogen nutrition. For many years, IRRI has conducted important research on nitrogen supply by cyanobacteria, associative diazotrophs, and aquatic legumes such as Sesbania. The new frontier project on nitrogen fixation (Ladha and Reddy, this issue) focuses efforts on the genetic manipulation of the rice plant and associative bacteria to create either (i) a tighter interaction between free-living diazotrophs and rice, or (ii) nodule-like structures in rice to harbour nitrogen fixing symbionts. Biotechnology will play a key role in the modifications of both plant and diazotroph. The aim of such research is to replace nitrogen fertiliser (40-250 kg/ ha) by endogenous nitrogen fixation

Breaking the yield frontier of rice

This is an article by Gurdev S. Khush, International-Rice Research Institute, P. O. Box 933, Manila, Philippines. Thanks to IRRI for permission to reproduce it here.

Abstract

Major increases in rice production have occurred during last 25 years, due to large scale adoption of high-yielding semidwarf rice varieties. However, the rate of increase of rice production has slowed down and the rate of increase of population of rice consumers is now higher than the rate of increase of rice production. Severe food shortages are likely to occur in 20-30 years if the trend is not reversed. To meet these food needs, rice varieties with higher yield potential are needed. The yield potential of the modern high yielding varieties grown under the best tropical conditions is 10 tons per hectare. A research program is underway to develop varieties with a yield potential of 15 tons per hectare. One strategy aims at developing new rice plants with a harvest index of 0.6 (60% grain: 40% straw by weight) instead of 0.5, that of the modern high yielding varieties and with an increased ability for photosynthesis to increase total biological yield. Such varieties should have a yield potential of 12.5 to 13 tons per hectare. The new plant type varieties will be used for producing hybrid rices with a yield advantage of 25% over the best parent, Such hybrids would have a yield potential of 15 tons per hectare.

Pests

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Managing Rice Pests with Less Chemicals

This is an article by Heong, K L.; Teng, P.S.; Moody, K., An International Journal of Physical, Biological, Social, and EconomicGeography and Applications in Environmental Planning and Ecology, vol. 35 no. 3, 1995 March. ISSN 0343-252. GeoJournal 35.3 337-349. Kluwer Academic Publishers
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Abstract

Losses caused by pests remain an important constraint to achieving high rice yields. Potentials of protecting these losses have stimulated innovations in pesticide development. Today the rice pesticide market is valued at US $3.0 billion per year. With reducing land available for rice production and increasing demand for food production, attention is turning towards intensification through higher fertiliser inputs and cropping. Such intensifications may in turn increase pest intensities and demand for more pesticides.

A large proportion of insecticide sprays administered by rice farmers in Asia is influenced by misperceptions and overestimations of damages. Most farmers apply their first sprays in the first 40 days after crop establishment to control leaf feeding insects. However, these pests do not occur in sufficiently high densities to cause yield loss. Instead, such early season sprays may contribute towards development of secondary pests, such as the brown planthopper. Strategies to reduce insecticide use need to focus on enhancing naturally occurring biological control and understanding farmers' decision making behaviour.

Most fungicides used in rice are in the subtropical countries, like Japan, Korea, Taiwan and Vietnam. An important strategy towards reduction in fungicide use is through host plant resistance and gene deployment strategies. With biotechnology, tools may be used to characterise population structures in order to enhance these strategies. Cultural practices, such as rotations, cultivar mixtures, crop mosaics and planting times are being investigated.

As cost of labour increases, farmers are likely to resort to using herbicides. The best way to accomplish weed control is the simultaneous application of a variety of practices. These will include cultural, mechanical and chemical methods. The potentials of using naturally occurring enemies, such as plant pathogens, and the use of allelopathy are also being explored.

An important constraint to achieve higher rice yields is losses caused by pests. Pests are organisms that attack the rice crop or compete with it for nutrients, causing yield reductions. The common organisms that are pests of rice are insects, weeds, molluscs, mammals, birds, fungal and bacterial pathogens, and viruses. Many of these are herbivores that feed on the rice plant, others are parasitic disease organisms and weed species that compete with rice for nutrients, light and water.

Expressing a Gene from *Bacillus thuringiensis* Provides Effective Insect Pest Control

This extract is by Joachim Wunn, Andreas Klöti, Peter K. Burkhardt, Gadab C. Ghosh Biswas, Karen Launis, Victor A. Iglesias and Ingo Potrykus from: ETH Zürich. Institute of Plant Sciences. CH-8092 Zürich. Switzerland. Thanks to I. Potrykus, ETH Zurich for permission to reproduce it here.

Transgenic Indica Rice Breeding Line IR58 Expressing a Gene from *Bacillus thuringiensis* Provides Effective Insect Pest Control

...With the transfer of a Bt gene to the IRRI breeding line IR58 the Swiss researchers report about the stable transformation of an elite Indica rice breeding line with an agronomically important gene. The gene is efficiently expressed in leaves of transgenic rice plants and results in a highly effective control of two of the most destructive insect pests of rice in Asia, the yellow and the striped stem borer.

Rice Production in Asia

Pest Resistance

There are two major approaches to reducing plant damage by insects. *Bacillus thuringiensis* (Bt) produces a toxin that affects a variety of insect species. The toxin gene can be introduced into crop plants to protect them from selected insects. Plant genes that code for lectins, amylase inhibitors and protease inhibitors can also be used to slow the growth of insects.

Research is also being done on lectins as promising candidates for insect toxins. While the mechanism of action of lectins is not clearly understood, it is known that they bind to carbohydrate receptors on the surfaces of cells lining the insect gut wall. These lectin receptors are different from those for Bt toxin, making it unlikely that Bt resistance would affect lectin toxicity.

A number of transgenic plants have been created that are resistant to pests, diseases or water and salt stress. Japonica rice carrying multiple copies a protease inhibitor gene has shown resistance to insects. Strains carrying a modified ribosome-inactivating protein gene or a fungicidal peptide are being tested against fungal pathogens. To combat water or salt stress, a barley late embryogenesis abundant protein gene, a cold and salt stress resistance gene, a mannitol-dehydrogenase gene, and a gene that encodes a key proline biosynthesis gene have been incorporated.

Built-in Pest Resistance

Pest Resistance by a toxin

Some experts of the international Union of Concerned Scientists are concerned over the development of resistance of pests to the built-in *Bacillus thuringiensis* toxin Bt as a pesticide of transgenic crops. This worry is heightened by the recent mishap of the Bt cotton. Boligard. The US company Monsanto engineered transgenic cotton with the Bt gene to be resistant to the cotton bollworms. An year after it was approved for commercialisation, the Bt cotton plants turned out to be a major disappointment to US cotton farmers when it surrendered to the bollworms. Cotton bollworms survived in the Bt cotton fields so that farmers had to go back to the traditional method of spraying their fields.

The bollworms' triumph over the transgenic cotton renews concerns that the Bt cotton may encourage the natural adaptation of Bt resistance insects. The Union of Concerned Scientists is urging EPA to put a halt to the planting of Boligard until it has reviewed the pest management plan of Monsanto.

Stress

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Transgenic cotton cells aiding IRRI scientists in quest for flood tolerant rice plants

This is an extract from: IRRI REPORTER ,A quarterly summary of developments in rice research, published by the International Rice Research Institute, September 1992 (3/92). Thanks to IRRI for permission to reproduce it here.

Rice plants that can survive many days underwater would greatly benefit farmers who often lose their crop when heavy rains flood their fields. The first transgenic, or genetically modified, plant tissues brought into the Philippines may be the way to develop such rice plants.

In May, IRRI plant physiologists imported more than 100 transgenic cotton calli, or clumps of cotton cell tissue, with the permission of the Philippine Plant Quarantine Service. The cotton cells were genetically modified at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Canberra, Australia. They have naturally occurring flood tolerance genes from maize and cotton. *"These flood tolerance genes also naturally occur in rice,"* said Dr. Tim L. Setter, IRRI plant physiologist. *"However, IRRI is working to greatly increase the number of these genes in rice thereby increasing its flood tolerance."*

Like animals, plants drown underwater when they cannot get enough oxygen, Setter said. Gases diffuse 10,000 times more slowly in water than in air. Lack of oxygen slows and sometimes stops the metabolic processes that provide the plant with the energy needed to live and grow.

The flood tolerance genes allow the plant to obtain energy by other means. In this case, it is by converting available sugars to alcohol. This process, commonly used by yeast to produce energy and alcohol, requires no oxygen.

Setter and his team are probing the DNA of each of the cotton calli to determine if the flood tolerance genes have been incorporated. They will then subject the calli to decreased oxygen levels - in effect simulating drowning - and then measure survival and the amount of alcohol each callus produces.

"We will apply the screening procedures we develop to any transgenic rice plants with these genes," Setter said. *"This will allow us to test whether increasing this metabolic process in plants will improve flood tolerance."*

According to Setter, the development of transgenic flood tolerant rice plants is expected to take 1-2 years. With such plants, farmer could switch from transplanting to the less costly broadcast sowing of rice seeds. At present, broadcast sowing is not possible in many areas because seedlings are often flooded by heavy rains, resulting in severe crop loss in the early stages of rice growing.

APPENDIX 7

Vitamins

Genetic engineering of Indica rice in support of sustained production of affordable and high quality of food in developing countries

This is an article by I. Potrykus, P.K. Burkhardt, S.K. Datta, J. Futterer, G.C. Ghosh-Biswas, A. Klöti,G. Spangenberg , J. Wünn, Institute of Plant Sciences, Swiss Federal Institute of Technology (ETH), ETH-Centre, CH-8092 Zurich, Switzerland. It was published in Euphytica 85: 441-449, 1995. Thanks to Kluwer Academic Publishers, The Netherlands for permission to reproduce it here.

Key words: *Oryza sativa*, Indica-type rice, genetic engineering, vitamin A endosperm, insect resistance, virus resistance, fungus resistance, essential amino acids

Summary

Indica-type rice provides the staple food for two billion people in Third World countries. Several problems involved in the stable and sustained production of high quality food cannot be solved by traditional breeding. Methods have been established for gene transfer to Indica rice breeding lines to study possible contributions from genetic engineering. Experiments are in progress on the development of transgenic resistance towards Yellow Stem Borer resistance towards Rice Tungro Virus, accumulation of provitamin A in the endosperm, increase of essential amino acids in the endosperm such as lysine, cysteine and methionine and resistance towards fungal pests such as Rice Blast and Sheath Blight. Transgenic clones from Indica rice breeding lines have been recovered from several of the approaches mentioned some of which have been regenerated to plants

Approach towards provitamin A accumulation in: rice endosperm

According to UNICEF statistics world-wide, over 124 million children are estimated to be vitamin A-deficient. Improved vitamin A nutrition could prevent approximately 1-2 million deaths annually among children aged 1-4 years. An additional 0.25-0.5 million deaths may be avoided if improved vitamin A nutrition can be achieved during later childhood. Improved vitamin A nutrition alone, therefore, could prevent 1.3-2.5 million out of nearly 8 million late infancy and preschool-age child deaths that occur in each year in the highest-risk countries (West et al., 1989). Rice in its milled form, as it is consumed by most people in South East Asia, is characterised by the complete absence of provitamin A. The milled rice kernel consists exclusively of the endosperm. The embryo and the aleurone layer have been removed during processing of the rice grain. The aim of this project is to initiate carotenoid biosynthesis in the rice endosperm tissue to increase the daily vitamin A-uptake of people predominantly living on rice.

Approach towards improvement of nutritional quality

Milled rice not only lacks vitamins, it is also deficient in essential amino acids such as cysteine, methionine and lysine.

Concluding remarks

The goal of our scientific work is to contribute to future’ sustained production of affordable and high quality food in developing countries. In this applied project, the aim is to work on problems which are a heavy burden on a great number of poor people and to apply biotechnology in such a way that it complements traditional plant breeding. We can reach our goal only if the novel characters we introduce into Indica rice are used, in breeding programmes; this is guaranteed through our collaboration with IRRI. The novel characters will be successful in breeding only if they are stable and effective. This requires that we can provide breeders with a collection of many transgenic plants for each novel character to permit selection of the most appropriate individuals for the breeding programme. This in turn requires more efficient gene transfer protocols than those available to date.

Success or failure of our goal will, however, not only depends on success or failure of our experiments and subsequent breeding programmes. It will also depend on political and social circumstances in those countries in which the novel, genetically-engineered varieties are supposed to help to solve problems. Risk assessment will be an integral part of the projects. The judgement of scientists and national biosafety committees on the security of transgenic plants or of food produced from transgenic plants, however, will not necessarily lead to an acceptance of these plants or food by the local population. If we are, for example, able to recover a transgenic rice which accumulates sufficient provitamin A to prevent vitamin A deficiency, there is no guarantee that people would be willing to eat this rice. There is much educational and political work ahead of us in addition to what we are trying to achieve scientifically.

Further information

A very good starting point for further information on all aspects of rice is the IRRI website: www.cgiar.org/irri

For more general information on biotechnology (and for links to associated sites) see the National Centre for Biotechnology Education website: www.rdg.ac.uk/NCBE