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Review Article

ROLE OF GENETIC ENGINEERING IN AGRICULTURE

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Abstract

Among the millions of species that inhabit the planet, only twenty species provide ninety per cent of the human food supply. Since the introduction of genetic engineering, however, livestock and crops have a more productive future. Transfer of engineered genes from organism to organism occurs through hybridization, conjugation and transformation in microorganisms. By the substitution of genes into agricultural species, biodiversity can flourish to improve social and economic development. Although methods of gene and DNA implantation quickly develop advanced products, even precise genetic alterations do not ensure that the environment will remain balanced or that changes in the genome will not occur. With careful design and a good understanding of transgenic organisms, minimal ecological and social risks will occur with the development of genetically engineered organisms. To improve methods of plant breeding, farmers turn to the hybridization of genes. New genes from wild species are transferred into cultivated varieties of similar crops to attain desired traits. Specific properties such as disease resistance, stress tolerance and nutritional qualities are advantageous to the farmer because more time is spent on cultivation rather than outside interferences. However, crossbreeding results in mass amounts of genes transferring to the plant recipient, only a few of which are desired. Thus, only sexually compatible species of the crop can be used to breed. Farmers using crossbreeding and hybridizing methods are able to attain improved products, but could cause great damage to the genome in the transfer of unknown, undesired genes.

Key words : Genetic engineering, protoplast transformation, transgenic organisms, crossbreeding and hybridizing methods.

Introduction

In more recent biotechnology, breeders are turning to genetic transformation as a more precise method of genetic engineering. Instead of transferring large blocks of genes from donor plant to recipient, small isolated blocks of genes are put into the plant chromosome through biolistics, vectors or protoplast transformation (Horsch, 1993). Biolistics is a technique that shoots the gene block into the potential host cell. In order for the process to succeed, the microscopic particles and DNA must enter the cell nuclei and combine with the plant chromosome. Biolistics is commonly used but has a slight failure risk since the breeder has little control over the destination of the gene block (Mooney and Bernardi, 1990). Bacteria or viruses can also carry the gene blocks into a new cell. Common vectors in gene transfer between plants are *Agrobacterium tumefaciens* and *Agrobacterium rhizogenes*. In the soil, the bacteria will infect the plants with their own plasmid, transferring the desired gene that was placed in the bacteria's DNA. Vector gene transfer is a preferred method of transformation since this modification already occurs naturally in the environment (Rudolph and McIntire, 1996). Last is protoplast transformation, which uses enzymes to dissolve the cellulose in the plant wall that leaves a protoplast. Once a specific gene block is added to the protoplast, the cell wall will re-grow into a transgenic plant.

Direct manipulation of DNA focuses on selective breeding, altering organisms to achieve higher quality products and more of them. These improved crop modifications centre either on agronomic traits or quality traits (Nielsen, 1999). Reductions of herbicides, insecticides and water usage are some effects of replacing plants with desired properties. Farmers choose these agronomic traits to reduce their costs of poisons and water, therefore increasing profitability. Quality traits focus more on the consumer of the product. By improving product characteristics such as phenotype, nutritional value and preservation, consumers will benefit. In return, agricultural industries will be able to sell products at a higher price and increase their profit in the near future.

Beneficial crop modification through agronomical trait selection

Transgenic organisms can be designed to minimize the chance of environmental risks. The agronomic traits that farmers select for crops improve the control of pest insects, plant pathogens, weeds and water. The main toxin used for insect pest control is a gene from the bacterium *Bacillus thuringiensis* (Bt). By inserting the Bt virus, crops have an internal resistance to insects and pests, which allows the farmer to decrease insecticide sprays. Agrochemicals serve as a good protection against insects, but are not as ecologically sound as gene transformation since outside plants and trees can be accidentally sprayed (Horsch, 1993). Although, seed price will increase, the total cost of seeds and agrochemicals will decrease, helping the farmer gain profit. Today, several crop plants and trees have been inserted with the bacterium strain and show effective resistance against pests such as caterpillars and beetles. In addition, engineered Bt has been approved for use as a conventional insecticide (Nottingham, 1996).

Plant pathogen control can also help reduce costs for the farmer. In 1998, K1026 from *Agrobacterium radioloacter* was introduced as a genetically engineered bacterial strain to help control crown gall disease in pitted fruit trees (Paoletti and Pimentel, 1996). The disease control proved highly effective, leaving farmers with a more abundant crop of fruit and a higher financial intake. Modifications of fungi are also beginning to arise as an excellent plant pathogen control. Metarhyzium anisopliae is used to protect plants against the benomyl fungicide. Pathogenic fungi are another promising goal because high yields of fungicides will not reduce the effectiveness of the entomophagus fungus. Today, 75% to 100% of agricultural crops contain some degree of host plant resistance (Paoletti and Pimentel, 1996).

The herbicide resistance gene is derived from glyphosate, an herbicide that produces a surplus of target enzymes (EPSPS). In transgenic petunias that contained the EPSPS enzyme, glyphosate could be used heavily since the plant was tolerant to normally lethal concentrations (Horsch, 1993). After much research, EPSPS genes that have a greater tolerance to glyphosate were found, cloned and expressed in many transgenic plant crops. Farmers with herbicide-resistant crops will not have problems with weed control. The amount of failed crop seasons will also be reduced and the market price will decrease since more products are grown. However, more money will by spent on herbicides since the EPSPS gene allows heavier usage of them. In the end, farmers with herbicide-resistant crops should gain more profit from the increased crop production, which brings in more money than what is spent on herbicides.

The last consideration of agronomical trait selection is soil and water usage. In order to control weeds, crop soils need to be tilled to up-root weeds. However, with the mass reduction in weeds due to herbicide-resistant crops, the soil can remain un-tilled and decrease the amount of machine work done by the farmer. With little use of farming machines, pollution is decreased and crops are not infected with exhaust from the gasoline (Altiere, 1998). Crops can also be engineered to tolerate drought. During dry seasons, farmers with drought-resistant crops do not have to use much irrigation water, saving expenditure for the farmer.

Beneficial crop modification through quality trait selection

Aside from the farmer, consumers and food companies also benefit from transgenic genes. Modifying organisms with quality traits positively affects consumer health, the actual product, the environment and food business. Genetically modified food can help develop new sources of human therapeutics and provide more nutritional value than normal food crops. According to the Ministry of Agriculture and Forestry in New Zealand, US researchers developed a banana with an antigen from the hepatitis B virus in 1996. If research continues, a vaccine could be produced that would cost only a fraction of the current hepatitis B vaccine. Other raw fruits contain helpful antigens that could be engineered to prevent disease at low costs. Nutritional value of food, such as vitamin, mineral, carbohydrate, protein and fat content, can also be increased or decreased with genetic engineering (Pollan, 1998).

Better products create better consumer sales and higher industry profit. Quality traits that alter the phenotype of a crop are produced to attract consumers to the food. For example, red delicious apples can be transformed to be brighter red and not oxidize as quickly when being preserved. Onions could also be genetically engineered to reduce the amount of fumes released when cutting them, preventing consumers from tearing (Nottingham, 1996). If more consumers buy products due to improved characteristics and higher attraction, food industries can make more sales. Food companies with increased profits are then able to continue the production and sale of genetically modified food.

When consumers buy food products, many people want them to be naturally produced or environmentally safe. With herbicide and insect-resistant crops, fewer chemicals are used on the plants and help reduce the amount of pollution in the atmosphere. Although, the crops are not "naturally" produced, man-made substances are used less and the genes transferred to the modified plants are from other wild vegetation (Nielsen, 1999).

The benefits that arise from introducing quality traits into crops happen because of the profits gained in the food industry. Although genetically modified food is more expensive, consumers are more willing to pay for vaccine research in bananas and chemical free products. According to the Ministry of Agriculture and Forestry in New Zealand, global market values for genetically modified crops are expected to be up to six billion dollars in the year 2005. Using genetic technology, the development process of organisms is quicker, reducing breeding cycles of fifteen years to only two or three years (Paoletti and Pimentel, 1996). With more crops being produced rapidly, businesses are able to run a company of increasing profitability and decreasing management costs (Nielsen, 1999).

Risks associated with genetically modified organisms

Genetic engineering in agriculture provides many benefits to social, economic, and environmental welfare. However, ecological risks are unavoidable, even under careful monitoring (Altieri, 1998). According to Rissler and Mellon (1996), the most serious risks of transgenic crop use include: simplifying crop systems and promoting genetic erosion, the potential transfer of genes from pesticide-resistant crops to wild vegetation, the generation of new virulent strains of viruses, insect resistance to Bt toxin and the destruction of natural relationships in the ecosystem. Although all of these cases have not yet been proven, signs of ecological imbalance and environmental hazards have already appeared through the application of genetic engineering (Regal, 1996).

Total weed removal by herbicides may lead to undesirable ecological impacts (Altieri, 1998). Weed diversity in and around crop fields is important to the balance of the ecosystem because weeds provide insect pest control, reduce erosion by covering soil and help prevent insecticides from spraying into forests. The complexity of the agro-ecosystem will also be reduced. Low plant diversity caused by the elimination of weeds will enhance free-range weed growth, insects and disease since other organisms will not fill the empty ecological niches (Rissler and Mellon, 1996). As herbicides continue to become more and more effective, species that have adapted to the herbicides will become the favoring competitor, further reducing plant diversity and replacing the natural species with transgenic organisms.

Another major ecological risk comes from the release of transgenic crops into the wild. Gene-altered crops may transfer their cross a gene to other plants, creating new weed species in the wild (Levin & Strauss, 1991 and Altieri, 1998) refers to these new species as "super weeds." The main concern of "super weed" growth is the hybridization between distinct plant species, which cannot be controlled in the wild. Many crops are grown near plants with some degree of cross compatibility, such as *Raphanus raphanistrum* and *Sativus*, a cross of wild radishes with genetically engineered radishes (Wright, 1996). If release of transgenic crops continues, "super weeds" will eventually control the main population of wild and domestic plants, reducing biodiversity. Disease-resistant crops could also impact the ecological system. New pathogens might occur by the recombination between RNA virus and a viral RNA inside the transgenic crop, leading to even more severe disease problems (Rissler and Mellon, 1996). Researchers such as Geweke *et al.* (1999) have shown that under specific conditions of recombination, new viral strains with altered host range have occurred in transgenic plants. This possibility that virus-resistant plants may widen the host range of some viruses or produce new virus strains in transgenic plants requires thorough experimental investigation under strict regulatory control (Paoletti and Pimentel, 1996).

The main focus of many scientists concerned with insect-resistant plants is the Bt toxin. Bt genes replace the synthetic insecticides so that fewer chemicals are used in controlling insect pests. Bt toxin mainly targets Lepidoptera species, the family classification for butterflies and moths in all metamorphic stages. According to the Ministry of Agriculture and Forestry in New Zealand, Bt is very effective on species such as *Plodia interpunctella* (Indian meal moth) and *Pieris rapae* (cabbage caterpillar), but not all insect pest varieties. Therefore, insecticides are still needed to control pests that are not affected by the endotoxin expressed by the crop (Ginzburg, 1991). Although, Lepidoptera species are affected by Bt toxin, field and laboratory tests suggest that many resistance problems are likely to develop in Bt crops. This resistance combined with the extended use of Bt toxin could create a strong selection pressure against the Bt toxin (Ginzburg, 1991). Eventhough different strains of Bt toxins can be developed, insects will continue to develop resistance against the insecticide, creating a never-ending struggle between insect and plant.

Bt crops also impact the ecological balance of nature. By keeping pest population at low levels, parasites and natural enemies will starve because prey is needed to survive in the agro-ecosystem (Altieri, 1998). The Bt toxin may affect non-target organisms as well. A study in Scotland posed that aphids were capable of gathering the Bt toxin from crops and transferring the toxin to its predators. The transfer of Bt toxin from the aphid affected the predator beetle's reproduction and longevity (Altieri, 1998). According to Reaka-Kudla *et al.* (1997), it is not uncommon to find plant alleles that affect a parasite's performance in nature, but the potential of Bt toxins moving through food chains may cause serious changes to agro-ecosystems. Neighboring farms could also be at a disadvantage, if Bt toxin reaches their crops. Insect pests might then acquire a resistance to Bt toxin and make it impossible for farmers to control the pests. Resistant insect population produced from Bt toxin overuse may end up colonizing other farming fields, leaving farmers defenceless (Pollan, 1998). Since insect resistance is not directly controlled by anyone, no one can be accountable for such losses.

Biodiversity helps maintain stability of the planet and is vital to enabling living things to cope with future change. The use of genetic modification technologies might lead to a decrease in biodiversity due to competition of original and transgenic plants. Although inserting a new gene into an existing genome can be regarded as increasing biodiversity, older plants might not be superior to newly introduced genetically modified organisms. If natural selection chooses transgenic plants, natural flora and fauna may be irretrievably lost (Regal, 1996). Since, biodiversity is such a critical issue among scientists, much effort is aimed at the preservation of original plant species. According to the Ministry of Agriculture and Forestry in New Zealand, India and China developed new varieties of wheat and rice in the 1950's and 1960's. The new staple crops were so much better than the original crops that farmers stopped growing traditional varieties, decreasing biodiversity. However, the International Plant Genetic Resource Institute conserved the obsolete cultivars and maintained the potential biodiversity of the planet.

Author's reasoning for support of transgenic organisms

The many benefits and risks of genetic engineering in agriculture are hard to weigh. Technology is always trying to push forward, yet social, ethical, economic, and ecological concerns need to be taken into consideration. If researchers and scientists plan to continue the biotechnology of gene alteration, they should direct their attention to promoting effectiveness while monitoring potential problems (Ginzburg, 1991). After much research over transgenic plants and gene transformation, I support the timely development of environmentally sound products through the use of advanced biotechnology. However, experimentation and use of genetic engineering must be done under careful regulations and only under scientific policies that encourage improvement without compromising agro-ecological relationships.

Genetic engineering in agriculture is a stepping-stone in technology

Biotechnology is a key target for solving food production problems in developing countries. The Rockefeller Foundation has funded many programs to build institutional capacity for biotechnologies around the world. Resource-poor farmers are able to use biotechnology in genetic engineering to produce products of low cost and high efficiency against insects, weeds, and disease. As products derived from transferred genes appear in the market place of undeveloped and developing countries, world hunger will come closer to ending because crops will be less expensive and more abundant. Although many believe that world hunger will never be completely eliminated, genetically engineered crops might help reduce the amount of food needed in third world countries and cut back on the need for foreign country dependence.

Another social issue that is greatly debated is the public acceptance of genetically modified organisms. As with any new technology, people are naturally cautious about change. To examine the scientific issues and data needed to assure safety of food products by genetic modification, the food industry formed the International Food Biotechnology Council. Even though transgenic plants have not yet made booming achievements in the market place, safety assessment is still being conducted. In order to appease people's concerns over food production, consumers must be able to choose whether or not to purchase the genetically modified product. This requires complete and reliable information as to whether food products consist of modified organisms or have been produced using genetic engineering techniques. Labelling requirements should be regulated and the USDA must approve products being put on the market.

As for ethical issues, views ranging from extreme to rational sweep the minds of people. On the extreme side, some people are concerned with the issue of cannibalism when using human gene copies. Does eating a cow with transferred human genes make me a cannibal? From any direction one looks at this question, the answer is no. If a consumer eats a tomato with a corn gene in the chromosome, she is still eating a tomato that looks and tastes like a tomato. However, so many genes can be used for genetic transfer that using human genes is not really necessary. Another question on consumer minds is are we playing God? Some can argue yes because natural selection and evolution should occur without the interference of humans. However, genetic engineering in agriculture can also be considered another form of natural selection, just speeded up. Technological advances in history have allowed humans to produce complex machines and life saving vaccines. Most people have accepted the wide use of computers and rely on vaccines for disease resistance. Eventually, people will be able to understand that biotechnology is not a matter of playing God, but improving human and environmental life through the careful application of new scientific knowledge. Vegetarians have also voiced opinions on altering plant genes. When animal DNA is used in developing genetically modified crops, products can be considered not purely vegetarian. With appropriate labeling, vegetarians can make their own personal choice of whether or not to consume genetically modified crops.

Economic concerns are few to none in the consideration of genetic engineering in agriculture. Since herbicide-resistant crops reduce the amount of herbicides used, farmers will be spending less money on them. With insect-resistant crops, less money spent on pesticides and chemicals create a greater profit for the farmer. Food production will also be greatly increased since genetically modified food can be produced much faster than normal developing rates of natural harvests. This means that food industries can put higher quality food of higher quantity on the market.

Most engineered organisms will probably pose minimal ecological risk. Many genetically engineered organisms will be modified, domesticated species living under controlled agricultural conditions. Although, domesticated animals sometimes establish untamed population, most crop plants cannot easily be converted into organisms that can survive and reproduce without human support. However, in cases where an organism may persist without human intervention or when a genetic exchange is made between a transformed organism and an unaltered organism, an assessment of environmental risk is required. This ecological oversight should be directed at promoting effectiveness while guarding against potential problems. Different organisms, traits and environments present different adverse effects, making it difficult to establish regulation of transgenic organisms. Ecological knowledge, however, should be useful in developing regulatory policy and recognizing the degree of risk associated with different attributes of engineered traits, organisms and environments. With small controlled field testing, categorization of genetically produced organisms, strictly enforced regulatory policies and consistency of regulation, ecological risks should be easy to control and keep at a minimal level. Transgenic organisms themselves can also be designed to reduce the chance of environmental perturbations. The choice of the trait and parent organism used, the form of the genetic alteration and the control of spread is focused on to prevent the likelihood of undesirable effects. In addition, the conditions of the organism's introduction can be planned to minimize potential problems.

Genetic engineering technology holds exceptional promise for improving agricultural production and keeping it environmentally sound. Potential benefits include higher productivity of crops and livestock, increased pest control and reduced pesticide use, reduced fertilizer use and improved conservation of soil and water resources. Along with the potential benefits for agriculture come some risks. The release and regulation of genetically engineered organisms into the environment could cause devastating results. The loss of naturally wild flora and fauna, insect resistance to genetic pesticides, "super weed" growth, development of new plant pathogens and potential slowing of biodiversity. Therefore, time and effort must be devoted to laboratory and field-testing before the release of genetically engineered organisms. Without caution and suitable regulation, environmental problems are likely to arise and the expected benefits of genetic engineering are likely to be jeopardized. But with careful design and a good understanding of transgenic organisms, genetic engineering in agriculture will push our society closer to a balanced agro-ecological system, allowing biodiversity to flourish and improving social and economic development.

References

Altieri, M. (1998). *The environmental risk of Transgenic Crops: an agroecological assessment* (research paper). California: Department of Environmental Science, Policy and Management, University of California at Berkeley.

Brooks, R. A. and P. Maes (Eds.) (1996). *Artificial Life IV*. Cambridge, Massachusetts : MIT Press.

Geweke, J. F. *et al.* (Eds.) (1999). *Sowing seeds of Change*. Washington, D.C.: National Academy Press.

Ginzburg, L. R. (Ed.) (1991). *Assessing ecological risks of Biotechnology*. Boston, Massachusetts: Butterworth-Heinmann.

Horsch, R. B. (1993, November 29). The production and uses of Genetically Transformed Plants. *Philosophical Transactions: Biological Sciences*, **342** : 287-291. Great Britain: The Royal Society.

Levin, M. A. and H. S. Strauss (Eds.) (1991). *Risk assessment in Genetic Engineering*. New York: McGraw-Hill.

Ministry of Agriculture and Forestry Network (n.d.) (2000). About the New Zealand Ministry of Agriculture and Forestry : Issues and ethics surrounding Genetic Engineering of foods. (2000, November 27).

Mooney, H. A. and G. Bernardi (Eds.) (1990). *Introduction of Genetically Modified Organisms into the environment*. Wiley, New York: International Council of Scientific Unions.

Nielsen, C. P. (1999). *Economic effects of applying Genetic Engineering in agriculture* (Report No. 110). Copenhagen : Danish Institute of Agriculture and Fisheries Economics.

Nottingham, S. (1996). *Eat your Genes*. London, New York : Zed Books.

Paoletti, M. G. and D. Pimentel (1996). Genetic Engineering in agriculture and the environment : assessing Risks and Benefits (2000, November 27).

Pollan, M. (1998, October 25). *Playing God in the Garden*. New York Times, Sunday.