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GENETICALLY ENGINEERED CROPS FOR THE CARIBBEAN?

Susan B. Persad-Chinnery and Louis E. Chinnery

Department of Biology, The University of the West Indies,
P.O. Box 64, Bridgetown, Barbados.

ABSTRACT

The first genetically engineered crops have been approved and released for commercial production in North America. Before their introduction into the Caribbean, a number of questions will need to be answered. Amongst these are: (i) What do we know about gene flow between crop and weed species in the Caribbean?; (ii) Given the climatic conditions of the region, will plants engineered for resistance be effective?; (iii) Will genetically engineered plants accelerate the erosion of indigenous varieties?; (iv) Do we have the appropriate intellectual property rights?, and (v) Can our major crops be engineered to produce alternative industrial products? Each of these questions will be discussed.

INTRODUCTION

Genetic engineering is an all inclusive term used to cover all biotechniques used to alter the genetic makeup of organisms so that they can subsequently synthesize increased yields of compounds, form entirely new compounds, adapt to drastically changed environments such as drought and salinity, produce food with improved quality or exhibit resistance to pest and diseases. The biotechniques of genetic engineering promise to solve problems that have not yet been solved by conventional breeding. Often these biotechniques involve manipulating genes in ways that bypass normal sexual or asexual transmission. Thus, genes can be transferred across taxonomic boundaries and this has created public concern.

As a result of these concerns guidelines have been set up to regulate the introduction of transgenic plants into the field and into large-scale cultivation. A major task of the molecular biologist is to assure the regulatory agency that the transgenic plant will not become a plant pest or have other negative environmental impacts. This assurance can only be given after several years of highly controlled and contained field testing. Accordingly, although several agronomically important crops have been genetically engineered for selective traits, very few have been approved for release into the field for large-scale cultivation (Table 1).

The first genetically altered food plant to be released in the USA for commercial production and consumption is the Flavr-Savr tomato that was developed by Calgene, California (Pennisi, 1994). The new tomato softens less readily than regular tomato because the polygalacturonase gene has been altered in the tomato genome causing less of a softening enzyme involved in fruit ripening to be produced. These transgenic tomatoes can remain on the plant for a longer period to vine-ripen without softening. Previously, tomatoes were harvested green and firm, and ripened using ethylene gas. The flavour of vine-ripened tomatoes is thought to be far superior than that of ethylene-ripened tomatoes.

Another transgenic plant released for consumption in the USA is the Freedom II yellow crook-neck squash developed by Asgrow Seed Company, Michigan. Freedom II squash plants carry an inserted gene for a protein found in the water-melon mosaic virus 2 (WMV2) and the zucchini yellow mosaic virus (ZYMV) which make the transgenic squash resistant to these viruses (Anon, 1995b).

Table 1 Some genetically engineered varirties of tropical crops

Crop species	Genetic modification*	Reference
Coffee (*Coffee* sp.)	Herbicide tolerance and insect resistance	Anon. (1994)
Corn (*Zea mays*)	Herbicide tolerence, insect resistance, virus resistance, wheat germ agglutinin	Kareiva (1993)
Cucumber (*Cucumis sativa*)	Virus resistance	Kareiva (1993)
Cotton (*Gossypium hirsutium*)	Insect resistance, herbicide resistance, novel biopolymers (plants produce cotton that has wrinkle resistance, reduced shrinkage and reduced absorbency).	Anon. (1994) Anon. (1995a) Langermann (1995)
Jojoba (*Simmondsia chinensis*)	Liquid wax production	Anon. (1995b)
Papaya (*Carica papaya*)	Virus resistance	Pers. comm.
Potato (*Solanum tuberosum*)	Exhibits no phenolic browning; virus resistance	Zabeau (1995) Kawchuk et. al. (1991)
Rice (*Oryza sativa*)	Herbicide resistance (the bar gene from Streptomyces hygroscopicus encodes phosphinothricin acetyltransferase which confers resistance to the herbicide bilanofas and glufosinate has been cloned into rice).	Uchimiya (1993)
Squash** (*Cucurbita pepo*)	Virus resistance	Anon. (1995b)
Tomato** (*Lycopersicon esculentum*)	Delayed fruit softening, delayed fruit ripening	Pennisi (1994) Martin (1995)

* Resistance expressed by transgenic plants is generally toward a specific insect, herbicide or virus. Patents have been obtained for all trangenic plant varieties listed in the table

** Crop plants that have been approved for release in North America

More recently, Martin (1995) reported the release of the Endless Summer transgenic tomato, developed by DNAP, California, for commercial growth and consumption in the USA. The gene responsible for the enzyme ACC synthase that is involved in ethylene production has been suppressed so these tomatoes exhibit delayed fruit ripening.

It is likely that several more genetically engineered crop plants will be released for commerce in the near future as approval has been given for a selected few to date. Thus, very soon farmers in the Caribbean may have the choice to grow genetically altered crops. For prudent decisions to be made about the introduction of transgenic crops in the Caribbean it is important to examine the implications of releasing these crops in the region.

GENETIC RESOURCES AND GENEFLOW

Despite the advances in molecular biology, genes cannot be created but originate from an existing organism. Consequently, to engineer new plant varieties researchers need to obtain the desired gene that may exist in an old variety or in an insignificant weed (Shiva, 1989). The discovery and isolation of useful genes (for example, genes for disease resistance and drought resistance) resident in wild type varieties of plants require their preservation if researchers are to use them to develop 'superior' plants. It should be noted that genes considered useful today may no longer be so as environmental conditions change. As biodiversity and genetic engineering are interdependent a balance has to be sought to protect biodiversity while still facilitating the development of better agricultural crops. Also, the opportunities provided by genetic engineering such as the transfer of genes between species further increase the potential of genetic diversity for enhancing agricultural productivity.

It is possible that wild type relatives could be lost through genetic erosion by the introduction of genetically engineered varieties. Therefore strategies have to be developed to minimize the effects of genetic erosion. Already the extensive use of genetically uniform crops is thought to promote genetic erosion and ultimately reduce genetic diversity. During the last 10 years the use of high-yielding varieties of plants and genetically improved varieties have replaced several traditional varieties of the third world where most of the world's genetic resources lie. In Barbados the indigenous finger squash (Cucurbita sp.) is less widely cultivated and imported genetically uniform varieties of cucurbits have become the choice of many farmers. There is no germplasm collection for finger squash and at the moment the faithful traditional farmers are the unofficial custodians of this genetic resource. Similar situations exist for other crops in the Caribbean.

No scientific studies have been conducted in the Caribbean to adequately answer the questions as to whether genetically engineered plants will accelerate the erosion of indigenous varieties when compared to growing genetically uniform plants, whether the potential for genetic erosion is similar for engineered and non-engineered crops or whether engineered plants will have less of an impact on genetic erosion. However, high yielding varieties developed by conventional breeding have been known to have detrimental effects on native varieties elsewhere and one can only guess that similar effects may be incurred by introducing genetically engineered crops into the Caribbean region. Besides considering the actual physical replacement of native plants by genetically engineered ones in natural habitats, one has to consider the implications of geneflow between genetically modified plants and the native, wild type relatives.

Geneflow is the exchange of genes between different populations, usually of the same species and results in changes in gene frequencies. The primary gene pool of a biological species generally includes domesticated forms, weedy forms and wild type progenitors (Sano, 1993). All three forms tend to be compatible with each other. Nothing is known about geneflow between crop and weed species in the Caribbean. Escape can occur if the crop persists after harvest and becomes a weed of cultivation or becomes established outside of, but adjacent to, agricultural land. Alternatively, the introduced gene may be transferred via pollen to another crop or a wild species by sexual hybridization and the hybrid may become a weed.

Research from outside the Caribbean has shown that some non-engineered agricultural varieties of plants can readily hybridize with wild relatives. This is particularly true for *Brassica, Daucas, Raphanus, Helianthus* and *Sorghum* (Colwell et. al., 1985). Non-transgenic commercial sorghum (*Sorghum bicolor*) is sometimes contaminated with seed whose pollen parent is Johnson grass (*Sorghum halepense*) that produces an aggressive perennial hybrid weed in sorghum fields (Colwell et. al., 1985). Also, Gressel (1992) reported that wild oats (*Avena fatua* L.) cross readily with cultivated oats and there is evidence to suggest that wild oats are acquiring resistance to some herbicides from genetically modified oats. Franetovich (1995) reported that herbicide resistant weeds particularly those resistant to triazine are becoming a major agricultural problem in many parts of the world. These studies have looked at closely related plant species but some commercially grown crops are intergeneric and as such their hybridization potential is likely to be higher. One such plant grown in the Caribbean is sugar cane (*Saccharum* sp.), where commercial varieties have been developed from intergeneric crosses (Maretzki, 1987). Therefore, if sugar cane is targeted for genetic modification it would be imperative to incorporate precautions to reduce the potential of transmitting the introduced gene(s) to other grasses. The precautions taken to reduce the incidence of hybridization include: (i) planting a buffer zone of distantly related plants around the genetically engineered crop; (ii) engineering the transgenic plants for pollen sterility if the plant is not required to fruit; and (iii) unsynchronizing the time of flowering between the wild relative and the transgenic plant (Sawahel, 1994).

The question remains as to the extent of hybridization that will occur between transgenic plants and relatives. What would be the implications of such a hybrid acquiring an agriculturally desirable trait? No long-term studies have been conducted to satisfactory answer this question. A study by Ellstrand (1988) showed hybridization between cultivated transgenic plants and wild relatives could occur in instances where the two plant types were separated by several kilometers.

Another concern about the use of transgenic plants is the possible invasiveness of these plants into natural areas where they are not wanted (Kareiva, 1993). One of the first studies done to evaluate the invasiveness of transgenic oilseed rape (canola) found that transgenic plants did not exhibit a different rate of population growth when compared to unmodified canola (Crawley et. al., 1993). Although the transgenic canola was not more invasive than the non-transgenic canola it is unresolved as to whether this observation is true for other crop species.

PEST AND DISEASE RESISTANCE

Formulations of *Bacillus thuringiensis* (Bt) have been used as biological insecticides to control agricultural pests. One such formulation is Dipel (Abbot Laboratories). Strains of the bacterium B. *thuringiensis* are unique in that they produce insecticidal compounds during sporulation that are specific and toxic to different insects. For example, the compounds from B. *thuringiensis* subsp. *kurstaki* are toxic to lepidoptera while *B. thuringiensis* subsp. *tenebrionis* is toxic against coleoptera. The compound when ingested and dissolved in the midgut of insect larvae, breaks down to produce endotoxins that alter the osmotic status of the gut epithelium cells causing them to burst (Hofte, 1989). When this happens, the larvae stop feeding and eventually die. *B. thuringensis* insecticides have been useful in that they are highly active and are harmless the environment as they do not persist in the field.

However, for a longer lasting effect plant transformation techniques have been used to introduce specific Bt genes into the genome of agricultural crops such as cotton and potato. When these insect-resistant trangenic plants are grown extensively they will inadvertently support several generations of the target insect. Although these populations will be small, they would be exposed continuously to the toxin, conditions conducive to the development of resistance. A laboratory experiment conducted by McGaughey (1985) found that after two generations of the Indian meal moth (P*lodia interpunctella*), a 30 times increase in resistance to Dipel was recorded. After 15 generations, resistance was 100 times higher than that of the control.

The Caribbean region is tropical and as such is characterized by a continuous growing season. Thus, trangenic plants with Bt genes introduced, are unlikely to function effectively for any length of time, as continuous generations of the target insect would promote resistance development. Thus, a modified Bt gene would have to be introduced periodically to prolong insect control. Resistance is less unlikely to arise in temperate regions as rapidly as in the tropics since winter disrupts plant growth which naturally reduces or eliminates pest populations. It is possible that transgenic plants containing Bt gene may only offer short-term relief in pest management in the Caribbean unless a programme is initiated to engineer altered versions of the gene.

Similar problems would be expected with plants engineered for resistance to pathogens.

INTELLECTUAL PROPERTY RIGHTS

As genetic engineering is profitable, there is the desire to establish ownership of genetically improved plant material. Breeders rights, intellectual property rights, farmers rights and patents are types of protection that have been ascribed to genetically modified plants. There is no formalized legislation to govern the use of genetically engineered crops in the Caribbean. Without this the potential for this region to become a testing ground for biotechnology companies is a realistic concern. Also, the lack of regulation in the region may cause seed companies to withhold genetically engineered varieties from growers as they would not have any legal rights on the use of their products Accordingly, the appropriate legislation should be developed soon to reflect the advances in scientific developments.

Without the proper legislation the cost of food production may increase in the Caribbean with the introduction of genetically engineered plants. For example, without farmers' rights legislation, farmers would be unable to use trangenic seed that had been collected on their holdings. If the seeds are hybrid then a new batch would have to be purchased repeatedly for planting. Additionally, some biotechnology companies are licensing biotechniques or obtaining broad patents which could increase the cost of agriculture as now royalties will have to be paid in order to grow certain crops. Examples of companies seeking broad patents include Agrecetus that has applied for a patent that would cover all genetically engineered soybeans and Calgene that has applied for a patent that would cover all genetically engineered vegetables in the brassica family.

The development of techniques to genetically engineer crops can be of additional concern depending on who makes the decision on how a particular crop is engineered. This is exemplified by the following examples. ESCAgenetic has received a US patent on the genetic modification of coffee cells and the method of producing coffee plants and seeds from the cells (transformation system) (Anon., 1994). Coffee represents a large proportion of the total exports of many third world countries and techniques to produce a 'superior' variety are obviously advantageous. As such engineering for herbicide tolerance and pest resistance (for example, coffee leaf rust, Hemilei*a vastatrix*, and coffee berry disease, *Glomerella cingulata*) would be more beneficial to the countries whose major export crop is coffee. However, engineering for frost resistance that would transfer the coffee production to a more temperate climate or engineering for uniform flowering or other traits that facilitate mechanical harvesting would have a serious implications on employment in places like Colombia, El Salvador, Burundi, Ethiopia, Rwanda, Uganda, and Jamaica.

Cotton and oil palm are also widely grown in the third world for which North American patents were sought. The world's supply of laurate originates from coconut and palm kernels grown in tropical third world countries. Oilseed rape (canola) normally grown in temperate climates has been engineered to produce high levels of laurate that now enables temperate regions to produce a product that previously could only be obtained from the tropics (Anon, 1995c; McDonnell, 1994). This could have negative economic impacts for several countries in Asia. In such situations genetic engineering would not have helped agricultural advancement in the developing world.

OTHER CONSIDERATIONS

When a gene is introduced into a plant it is usually accompanied by a selectable marker gene that allows distinction between transgenic and non-transgenic plants. Commonly used selectable markers are antibiotic resistance genes and herbicide resistance genes. Limited research has been done to examine the possibility of: (i) transfer of antibiotic resistance genes from plants to pathogenic micro-organisms, and (ii) antibiotic resistance spreading to human pathogens rendering antibiotic therapy less effective or ineffective (Harding, 1995).

Another concern also arises about food that contains live genetically modified organisms, for example yoghurt, if the genetically modified organism is carrying an antibiotic resistance marker gene. It is known that feeding antibiotics to farm animals encourages antibiotic resistance in humans (Slayer, 1995). Certainly more research is needed in this area to determine the risk associated with using antibiotic or herbicide resistance genes as selectable marker genes in transgenic plants. One option to consider is the replacement of these genes after the research and development phase with another gene of lesser consequence. Moffat (1991) discussed a new procedure that could be used to excise marker genes after the plants have acquired the gene of interest. Markers are difficult to remove as they are linked to the gene of interest and therefore cannot be bred out by standard procedures without losing the gene of interest. The new procedure uses the enzyme 'Cre' (control of recombination) isolated from a bacterial virus which functions like scissors by cutting out any DNA located between a pair of identical 34 base pair sequences.

A further concern is the 'limited' knowledge that presently exists about the functions of DNA. There is no guarantee that the function of a known gene introduced into another species will be expressed in exactly the same way it was expressed in the organism from which the gene was isolated and characterized. How do we know that the gene introduced into a crop will not affect the expression of other genes in the plant with consequences to human health? Knowledge about DNA is rapidly changing and there are still many questions about the functioning of DNA that are not known. The knowledge of non-coding DNA exemplifies this point. Coding regions of DNA are separated by non-coding sequences referred to as 'junk' DNA. It is widely thought that junk DNA is functionless and represents ancestral DNA sequences for which there is no present need. However, recent studies suggest that junk DNA may be functionally important in cells and may be involved in gene regulation and in DNA repair (Stanley, 1995).

Another concern is that genetic engineering has resulted in the alliance of university research programmes and private sector biotechnology companies as commercialization of products from the application of the biotechniques is essential for continuance. The implication of this phenomenon is that important areas of agricultural research without a commercial potential are likely to be neglected for more profit oriented research.

USES OF MOLECULAR BIOLOGY IN THE CARIBBEAN

Genetic engineering should not only be viewed as biotechniques to improve food production. The biotechniques can be used to produce novel industrial products. This point could be expounded by considering the decline in the banana industry in the eastern Caribbean that has created an impetus for agricultural diversification. It is possible that genetic engineering could be employed to develop transgenic banana plants that produce a novel product with commercial value like biodegradable plastics. Polyhydroxybutyrate (PHB), a biodegradable thermoplastic, is commercially produced by fermentation using the bacterium Alicagenes eutrophus (Hemming, 1995). This process of plastic production is expensive. An alternative would be to introduce the gene for PHB into banana. These transgenic plants would produce high levels of PHB that could be extracted and exported or processed regionally. A tissue culture regeneration system already exists for banana and the PHB gene has already been isolated and cloned, hence some major steps to achieve such an objective already exist. However, the fruits from such transgenic plants will no longer be edible! Promising progress has been made in using plants to produce biodegradable plastics. Sommerville (1995) reported high levels of PHB in transgenic Arabid*opsis* and is presently working on transferring the PHB gene into *Solanum* potato.

Genetic engineering can be used to assist in the protection of endangered species by developing novel ways of producing a desired commodity previously obtained from these endangered species. An example of this is the introduction of a reductase gene from rapeseed into jojoba to enhance long chain liquid wax production (Anon., 1995b). These waxes are used in the manufacture of cosmetics and lubricants and previously were obtained from sperm whales.

CONCLUSION

Genetic engineering promises food with a higher nutrient content, longer shelf-life, drought-resistant plants, plants with disease resistance, plants with high yields. Although many scientists believe that through genetic engineering, the world's food production can be secured for the future, there is resistance by sceptics to embrace the technology. This resistance to genetic engineered crops is realistic and justifiable since only a few decades ago researchers promised food security in abundance with the use of high-yielding varieties thereby starting the Green Revolution. Yet famine almost became widespread in parts of Asia as a result of occurrences that had not been taken into account. Many people believe that it is not the amount of food that is produced but rather the distribution of the food. Some argue, for example that the introduction of nitrogen-fixing genes in maize is not relevant and a natural method of intercropping maize with legumes is a better and less risky option than genetically engineering plants with Rhizo*bium* genes.

There are several considerations that must be addressed before genetically engineered crops are introduced into the Caribbean. Such considerations are: (i) the effect transgenic plants will have on the natural flora; (ii) the safety of products of these plants to consumers; and (iii) the financial impact these crops will have on agriculture. This presentation does not advocate outright rejection of transgenic plants but rather cautions that appropriate studies must be done to evaluate the introduction of these plants into the region before a decision is made. In this evaluation, consideration should also be given to the positive ways in which the biotechniques of genetic engineering can be applied to produce novel products from traditional agricultural crops.

Finally for consideration is the question to which no satisfactory answer has been given by the scientific community: what is the sustainability of genetically modified varieties when the improved attribute is usually based on one gene?

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