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ENVIRONMENTAL AND AGRICULTURAL RISKS OF GENE TRANSFER BETWEEN SPECIES

by

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Environmental and Agricultural Risks of Gene Transfer between Species

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Genetic engineering, mainly by gene transfer from totally different species, is increasingly being used to produce "better" plants and animals for use in agriculture. So far this process has been of only minor importance, but in the future its potential is enormous, and could revolutionize modern agriculture. The benefits would be obvious, but the dangers are serious. First, the new organisms (i.e., modified cultivars of crop plants) themselves may be harmful, possibly by being "aggressive" and replacing existing species, or by damaging the environment by their numbers. Secondly, genes may escape into other cultivated or wild species, with results which, at present, cannot be foretold. Regulations are being enforced in various countries to try to minimize these dangers, but it is probably impossible to eliminate them entirely. For this reason there are those who would wish to make gene transfer totally illegal. However, the majority of scientists consider the risks small and worth taking.

Without genetic engineering, man has, for thousands of years, by selective breeding and the use of spontaneous mutations, improved and greatly altered crop plants and domesticated animals. Some of the most striking changes were made by "primitive" farmers long before anything we would now recognize as civilization had been achieved, and long before writing had been invented. One interesting case is maize, which appeared in a recognizable form some 10,000 years ago. The ancestral grasses produce seed in a tassel at the top of the

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plant (as does sorghum today). By a process of simple selection for propagation and the intercrossing of odd-looking plants, maize with its seeds on bulky ears growing out of the stalk was produced. Maize soon became a widely-grown crop in the new world, where its propagation was entirely dependent on man. It could not be dispersed naturally, as the seed remained firmly attached to the ears. Maize has been cited as an example of the lack of danger from a man-modified crop plant.

Most crop plants produced by selective breeding are unable to survive unless man cherishes them--I know of none which has become a serious weed. Some domestic animals, including pigs, cattle, horses and goats, have escaped and become, in some localities, serious pests. However, these pest individuals have generally resembled the wild ancestors of the species, and highly modified domestic races seem unable to survive in the wild.

Where wild species of plants and animals, particularly insects, have been introduced into new countries, they have often become pests. Most of the agricultural weeds of North America are descendants of plants introduced with the crop species from Europe. These have behaved much as they did in the "old country"; they have not been more serious pests in their new location. In Australia introduced ***Opuntia*** and ***Lantana*** were serious pests of range country, until they were controlled by the introduction of pest insects from their original habitat. Many insects have been the cause of serious damage when transported overseas, as for instance the Colorado potato beetle and the cottony cushion scale, and mammals such as the rabbit devastated much of Australia.

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It is generally believed that plants and animals produced by genetic engineering are unlikely to be as successful as those species which are the products of natural evolution. Their genes are all those which occur in unmodified individuals of normal virility. The products of genetic engineering may have properties of particular value to man, but in the majority of cases the presence of "foreign" genes is likely to produce individuals of reduced virility, unlikely to compete successfully when removed from man's protection. This lower virility has been demonstrated in most organisms so far developed, but it is also realized that occasionally more aggressive types may be produced, and care must be taken to recognize and contain these if they do appear.

Plant breeders have for many years sought for individuals which are resistant to diseases such as mildew and rust in cereals. They have, by the ordinary hit-and-miss processes of selection, often been successful. Unfortunately, few resistant plants have been valuable for long periods, as mutations in the disease organisms have, in a few years, restored the susceptibility of the crop plant to the disease. It should be possible to produce resistant plants much more rapidly by gene transfer from a wide range of sources, but there is no reason why the results should be able to survive any longer than those produced by selection. However, it is likely that work in this field will continue, and that some at least of the results will be of importance in protecting many agricultural crops. There would seem to be little danger from this work. The genes may be transferred to non-crop or even weed plants, but these are unlikely to present any serious environmental problems to the farmer.

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Many attempts are being made to reduce the amounts of chemical insecticides in agriculture. Plants are being sought which are lethal to insect pests, or which are unattractive to them. The bacterium ***Bacillus thuringiensis*** produces a very potent protein toxin which is active against the larvae of certain lepidoptera. As an insecticide it has the advantage that most beneficial insects are unharmed. Dried preparations of the bacterium are widely used, especially in forestry plantations, against moth caterpillars. However the bacterial preparation is simply an insecticide, and as such is disliked by some people. The ***B. thuringiensis*** gene which encodes the toxin can be introduced into plants and the toxin then appears in their leaves. These are toxic to the limited range of insects the original bacterium controlled. There seems little potential harm in this process. Even if the ***B. thuringiensis*** gene is transferred to weeds or other plant species, unless these are normally controlled by the caterpillars which feed on the crop there will be little effect.

Many plants contain substances, not normally regarded as toxins, which render them unpalatable to some insects. Legumes generally contain the seed protein lectin. Potatoes with a pea lectin gene expressed in the leaves have some degree of immunity to aphid attack. It is likely that many crop plants will be made unattractive to pests in this way. It is difficult to see how this could be harmful.

Agriculture in developed countries depends heavily on the chemical control of weeds. Farmers would hope to have crop varieties which were unharmed when herbicides were used to control weeds growing with them. Some progress in this field has been made. Not everyone is happy with this work. If the genes are accidently transferred from the crop to

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the weed species, then these will become impossible to control.

Plant breeders have always been concerned with improving crop plants by increasing the amount and the quality of the substances stored in their edible seeds, particularly grains and legumes. Proteins would seem a good target for such work, as they are the products of a relatively few genes present in multiple copies and active specifically in the endosperm (in cereals) or in the fleshy seedling, leaf or cotyledon (in the legumes). These would seem suitable targets for the introduction of exotic genes, with the object of improving the nutritional value of the crop. Such developments are unlikely to have harmful environmental effects.

In the early discussions of the possible value of genetic engineering to agriculture, most importance was given to the suggestion that we should create new crop plants which could obtain their nitrogen from the atmosphere rather than from chemical fertilizers. Only some legumes (beans, peas, soybeans, clover and lucerne) have this nitrogen-fixing ability, which they owe to the presence in root nodules of bacteria of the genus ***Rhizobium***. Many attempts have been made with such crops as wheat. The problem is a complex one. The host plant must produce suitable nodules in which the nitrogen-fixing bacteria can flourish. The general opinion today seems to be that the creation of new nitrogen-fixing plants does not have a high priority. It is thought that the improvement of existing nitrogen-fixing plants is a more realistic goal, and that the bacteria involved are also a suitable subject for study.

Many crop plants as grown at present have bad as well as good properties -- it has always been the intention of plant breeders to eliminate bad as well as to enhance good properties. Attempts are being made to achieve the knock-out of unwanted genes by the use of antisense RNA. So far only one successful case has been reported where this technique has been successful. This is in producing a tomato with an extended shelf life. No doubt many other improved plants will be produced; it is difficult to see how these could have any harmful effects.

Genetic engineering has been most successful in endowing animals with the capacity to synthesize pharmaceutically valuable products. Little work has been done with plants to this end. However, the simplicity and cheapness of the culture of most plants, as compared with industrial microorganisms or farm animals, suggests that more work on this subject is likely in the future.

Hybridization of plant varieties has contributed to the production of many cultivars used in agriculture. It may now be possible to extend the range of plant hybridization. New species have arisen in nature when there is a fortuitous doubling of chromosome numbers in an initially sterile species hybrid. Such doubled hybrids are called "amphidiploids" because they have two diploid chromosome sets, one from each of the parent species. They tend to be fertile, however dissimilar the parent chromosome sets are from each other, because each chromosome has a like partner with which it can pair. Plant breeders have made many sterile crosses in the hope that a few new amphidiploids will appear--one successful case is triticale, a wheat-rye compound with some potential as a new crop if

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world climate is subject to change. The grass of salt marshes ***Spartina townsendii*** which appeared in 1878 in Southampton Water (England) is an amphidiploid, originating from ***S. maritima*** and ***S. stricta***. It is a very vigorous plant, a serious pest in some waterways--and a warning that products of this technique should be treated with care.

An alternative method of producing new amphidiploids is by cell fusion. Protoplasts obtained from cells of different species can be induced to fuse, and fusion of the cell nuclei may follow. This is done in cell culture. If whole plants can be regenerated from the cell culture, a new amphidiploid hybrid may be produced. One successful experiment on these lines was the production of a potato-tomato hybrid. Unfortunately, it has neither edible fruits nor useful tubers.

As will have been seen, I do not think that many of the new types of agricultural plant produced by genetic engineering are likely to prove a serious environmental danger. Nevertheless, it is wise to control the release of new plants rigorously. One plant which has been released in Britain is the potato containing the pea gene for lectin, giving resistance to aphids. This has been grown on a field scale, but all flowers have been removed to prevent fertilization of plants outside the experiment. It was decided that the experimental plants would not, themselves, pose any environmental hazard. There were no wild species to which the engineered potatoes might transmit the pea gene. Finally, the question whether it would really matter if, through some rare and so far unobserved train of events, the pea lectin gene were to be transferred to other plant species, was considered. The answer was: "not so far as one can see."

Genetic engineering has, so far, had little effect on animal husbandry. There is obviously potential to improve the yield of animal products and to improve disease resistance. As mentioned above, farm animals can be used as pharmaceutical "factories." There seems to be little risk from these practices.

On the other hand, there is considerable opposition to genetic engineering from animal-rights activists. They feel that the inherent natures of animals ought to be respected and not tampered with. They fear that what is done to animals today may be done to man tomorrow. Regulations in most countries are such as to prevent such abuses.

Most large-scale releases of genetically manipulated microorganisms, within which category we may include fungi, bacteria and viruses, are likely to be for agricultural purposes. The use of microbes for the improvement of agricultural processes is already big business. Genetic engineering is bound to contribute considerably to this field.

Bacteria contribute to animal nutrition and to the production of silage. There is already a substantial trade in root-colonizing ***Rhizobium*** to improve nitrogen fixation in leguminous plants. Other species of soil bacteria are also cultivated. These are all cases where genetic engineering is likely to play an increasing part. It is not easy to assess the potential dangers, but most workers consider them to be slight.

One interesting example which has received some publicity is that of bacteria used to control frost damage in fruit. Many species, including strawberries, can survive temperatures several degrees below freezing point if there are no suitable nuclei on their leaves around which ice crystals can form. A strain of "ice-minus" ***Pseudomonas syringae*** has been produced by the deletion of a part of the bacteria's genome. No genetic material was added. This sort of deletion must commonly occur in nature -- the products have not been found to persist. Experiments showed that the ice-minus ***Pseudomonas*** does not persist in the environment in competition with the natural bacterial flora. It is perhaps ironical that this ice-minus bacterial experiment was vandalized by opponents of genetic engineering.

Nevertheless there are many who are not convinced that genetic engineering involving bacteria is really so very safe. Most scientists agree that continued vigilance is necessary. The lateral transfer of introduced exotic genes is always possible, and the results are hard to foretell. How likely is this with introduced genes? The following is the cautious verdict of a group of American ecologists:

> The available scientific evidence indicates that lateral transfer among micro-organisms in nature is neither so rare that we can ignore its occurrence, nor so common that we can assume that barriers crossed by modern biotechnology are comparable to those constantly crossed in nature.

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Reference

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