Genetically Modified Crops: Threat or Promise?

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1 Introduction

Genetic modification (GM) is an important new technology that has already seen widespread impact and controversy in a variety of applications. Here the possibilities and pitfalls of the use of GM in agriculture will be considered.

2 GM technology

GM is the modification of genetic material in living organisms. The easiest and most common modification is gene insertion. First the target gene must be identified and isolated, then incorporated into the organism.

2.1 Plasmids

Plasmids are small circular sections of DNA found in prokaryotes. They contain genes and an origin of replication and are reproduced and expressed along with the main chromosome.

2.2 Restriction enzymes

Restriction enzymes cleave the DNA strand at specific combinations of bases. Many such enzymes are known, each recognising a unique nucleotide sequence typically between 4 and 8 bases long and cleaving it either symmetrically ("blunt ends") or asymetrically ("split ends"). Split-ended DNA fragments have the useful property of spontaneously hydrogen bonding with another, complementary split-ended fragment to form a single stretch of double-stranded DNA. DNA ligase can then be used to reform the phosphodiester bonds necessary for backbone stability.

It is thus possible to join two sets of DNA fragments from differing sources into a single length of DNA, called recombinant DNA. Typically this is used to insert genetic material into a plasmid, which can then be introduced easily to a prokaryotic cell (e.g. a bacterium) and replicated several million times.

2.3 Gene isolation

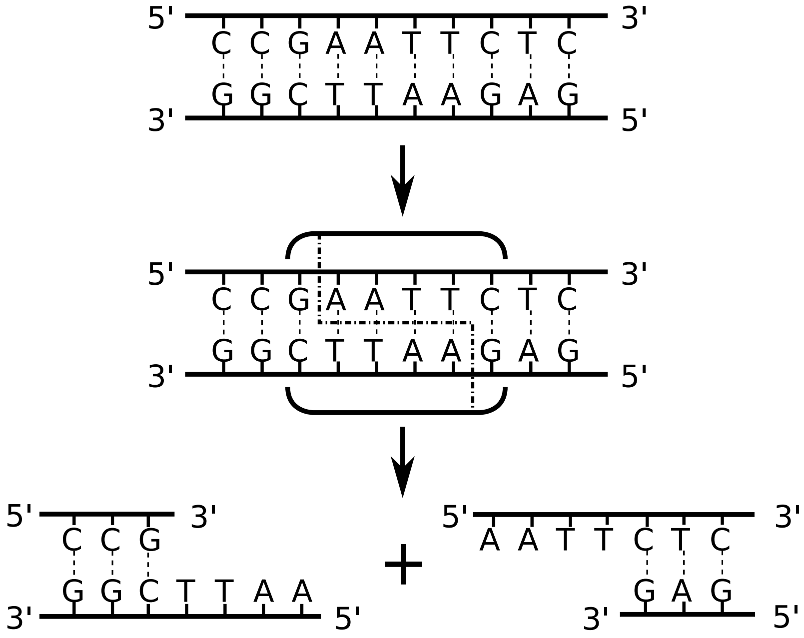
Restriction enzymes can also be used to locate specific genes by fragmenting DNA and testing which fragments result in the expression of the gene. This is a tedious procedure, as the number of possible fragments is extremely large.

Alternatively, cells can be induced to express the gene, and the transcribed mRNA collected and isolated. Conversion of mRNA back to double-stranded DNA is achieved by reverse transcriptase and other enzymes.

2.4 Gene incorporation: direct methods

While inducing DNA uptake into prokaryotes is relatively straightforward, eukaryotic cells such as plant cells present a much more challenging proposition. The technique of microinjection – simply injecting DNA into cells with a small syringe – has a low success rate due to the relative volumes of a eukaryotic cell and its DNA-containing nucleus. Another primitive technique, biolistics, involves firing DNA-coated metal particles at cells from a "gene gun". This also has a very low success rate, mitigated by the fact that an entire cell culture is targeted rather than an individual cell.

Figure 1: Outline of the operation of the restriction enzyme *Eco*RI, which recognises the nucleotide sequence GAATTC and cleaves it asymmetrically



2.5 Gene incorporation: indirect methods

The bacterium *Agrobacterium tumefaciens* attacks many species of plants to form galls. The tumour-inducing (Ti) plasmid responsible causes a DNA fragment to be incorporated into the host's genome. This can exploited by genetically modifying the plasmid to alter the incorporated DNA fragment, inserting the plasmid into bacterial cells and exposing plants to the modified bacteria.

Species that *A. tumefaciens* does not attack can still be modified by a similar method that introduces the Ti plasmid directly into the host cell.

3 Applications

Use of GM in agriculture can bring benefits to crop yield and quality.

3.1 Cold tolerance

The first GM organism released into the environment was "ice-minus", a strain of the ice-nucleating bacterium *Pseudomonas syringae* modified to lack the gene responsible for ice formation. When sprayed onto crops it competed with the wild *P. syringae* to reduce the amount of ice formed and thus reduce the temperature at which crops could survive before succumbing to frost damage.

3.2 Herbicide tolerance

Glyphosate (Roundup) is a widely-used weedkiller that inhibits the EPSPS enzyme required for synthesis of aromatic amino acids. *E. coli* and other bacteria have a mutant enzyme that is not susceptible to glyphosate's inhibitory effect. The gene responsible was inserted into soybeans and other crops, allowing them to survive being sprayed while weeds died. Such crops are now in widespread use.

3.3 Pest resistance

Bacillus thuringiensis (Bt) is a bacterium that produces a protein toxic to several species of insect, including some responsible for widespread crop damage. The gene producing this protein has been inserted into a variety of crops, conferring pest resistance, and large-scale planting of Bt corn and Bt cotton commenced in 1996.

3.4 Increased shelf life

The "FlavrSavr" tomato was genetically engineered to fail to produce a protein that hastens rotting. This was accomplished by inserting a new gene that was the complement of the protein gene, which when expressed as mRNA would bind to the mRNA coding for the protein and prevent its translation. It was not a commercial success.

4 Risks

Tinkering with self-replicating organisms has inherent hazardous potential, and human understanding of the machinery of life is still very incomplete. Caution has thus been the dominant approach to the use of GM organisms outside the laboratory.

For example, a risk of crops toxic to pests is that pests may acquire resistance to the toxin, rendering the exercise counterproductive as it would also reduce the effectiveness of the toxin itself as a pesticide. Another possibility is that such crops may prove toxic to humans also.

Biodiversity is a problem. A single strain of crops being used over a wide area – a monoculture – has the potential for being a single point of failure. Such a failure was a contributing factor to the Irish Potato Famine of 1845-49.

Horizontal gene transfer – the transfer of genetic material to organisms that are not offspring – is a still a relatively poorly-understood phenomenon, and has raised concerns of engineered genes "escaping" into the ecosystem with potentially disastrous effects.

There are groups who feel that GM is ethically wrong. There are groups who, regardless of the merits of GM, disapprove of the business practices of the biotechnology companies responsible. Some governments have banned the use of GM foods entirely.

5 Conclusion

GM is a technology still in its infancy, but has already shown great promise in agriculture, despite the risks.