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All you ever wanted to know about GM foods but were afraid to ask

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Are genetically-modified crops and other foods 'safe'? Is the manipulation of genetic material to provide medical treatments related to the production of GM food? Can science insert animal genes into plants and if so is this a huge new threat to nature?

What is a gene?

A gene is a part of a living plant or animal that carries information and passes it down from parent to offspring. Look at it this way: plants and animals are made up of many tiny cells. Bacteria and yeasts have only one cell, larger plants and animals, including human beings, have millions of cells in their bodies. During life they are all working away to keep the organism alive. Think of them as little factories, taking in raw materials and using them to make the thousands of products needed for life. Different types of cells do different things; nerve cells transmit electrical messages around the body, cells in the digestive system produce enzymes to break down the food so producing raw materials for other cell factories to use.

Each cell is far more complicated than any factory human beings ever built. It may be producing hundreds of different products at the same time. Not surprisingly controlling the activities of a cell is a very complicated business. A man-made factory would be controlled by a computer and living cells also have a control system that in many ways is quite like a very powerful computer. The computer running a factory needs instructions so that it can tell the machines what to do and when to do it. In the same way each living cell needs instructions – and that is where the genes come in. They carry the instructions to make the cell factory work. Not surprisingly it takes many genes to handle the information needed by living cells. A human cell for example contains tens of thousands of them.

As an animal or plant grows, its cells divide, increase in number and take on their specialised roles. Each cell has a complete set of genes and every time a cell divides they are copied so that each new cell has a set identical to that of the parent cell.

Does that mean that every time I eat part of a plant or animal I am taking in millions of genes?

Yes! But they don't affect you in any way because they are either broken down as the food is digested or, if they are contained in resistant structures such as seeds, they pass unchanged through the body and are excreted. We have been consuming genes ever since we first evolved and there is no evidence that they can enter human cells from the food we eat. The same applies, of course, to any modified genes that may be present in food. People have expressed concern about genes in meat from animals fed on genetically modified maize and in honey from bees feeding on genetically modified crops, but there is no evidence that they can get into human cells.

What is a GM Food?

We are really talking about several different things: Firstly there are products that are eaten more or less unprocessed – a lettuce that contains a gene making it resistant to insect attack, or a tomato in which a gene helping it to ripen has been inactivated to increase its shelf life for example. These products will contain – intact – modified genes when they are consumed.

Then there are processed foods, such as tomato purée or soya flour, in which the genes have been denatured and inactivated by the processing. Also there are products extracted from plants such as sugars, oils or lecithin (an emulsifying agent). These may come from GM plants but contain no genes and are identical to the same products extracted from unmodified plants.

Finally there are foods whose production involves the use of enzymes derived from GM sources. A familiar example would be 'vegetarian' cheese made with an enzyme from a genetically-modified micro-organism instead of with calf rennet. Here the modified genes never come into contact with the food.

What is 'modification'? How do genes get altered?

A huge amount of information is needed to instruct a growing cell, and it is not surprising that things can go wrong occasionally. Just as the instructions fed into a computer can become corrupted so the information in genes can be damaged. This can happen naturally as cells grow and divide. The information can be changed in various ways. Some chemicals – like those in tobacco smoke for instance – can do it. Such changes are called *mutations*. The agents causing them are *mutagens*.

Some mutations are lethal and the cell dies but more usually the information is only slightly changed and the cell – and all its descendants, because they inherit copies of the new gene – show a minor change in its behaviour. The plant or animal is genetically altered and it may, or may not, show obvious changes as a result – depending on the kind of mutation that has taken place.

Spontaneous mutation of this kind is a completely random event; we have no way of predicting what kinds of mutations will arise or when or where. Within the last 25 years we have learned to make such alterations in a deliberate and controlled way so providing biologists with a set of powerful research tools and vastly expanding the ability of the pharmaceutical industry to produce new drugs for the treatment of disease.

Are all mutations harmful?

By no means. There are countless examples of small, naturally occurring, changes in plants or animals that help them to cope better with their environment. A plant for example may develop a mutation that enables it to grow better under cold conditions or an animal may develop a protective colour. This process, whereby advantageous mutations are favoured by the environmental conditions under which an organism is growing, is known as *natural selection*. It is the driving force behind evolution and is the main reason why we have such a wonderful diversity of living things around us today.

Ever since human beings first grew food crops and raised animals for food they have made use of this process to improve the plants and animals on which agriculture depends. In effect they have taken the 'natural' out of natural selection by purposely selecting plants and animals for qualities that will increase their value. Wheat has been bred to half the height it was three hundred years ago. This both reduces storm damage and decreases the proportion of the plant's energy which is put into the stalk. Both effects lead to increased yield. Different varieties of wheat are used depending on whether the end use is bread-making or animal feed. Some varieties of cattle have been selected for beef production and some for milk. All our domesticated animals and crop plants have been improved in this way.

The yeasts used in beer-making have been selected for qualities such as production of flavour chemicals and the ability to settle quickly, while those used to make bread rise have been selected for high levels of carbon dioxide production.

Traditional plant and animal breeding is a very slow process. The small genetic changes on which it is based are completely random events and desirable genes are transferred along with many others which may have undesirable effects. This means that the selection of desirable new varieties is both time-consuming and expensive. The slowness and imprecision of traditional plant and animal breeding make the new technology of genetic modification, which is rapid and precise, highly attractive as a means of improving the plants and animals on which agriculture depends.

What has now happened to bring this whole subject of genetically-modified food to the fore?

This takes us back to a brilliant piece of research carried out in the 1950s. We had known quite a lot about genetics, inheritance of desirable and undesirable characteristics, and breeding, for a long time but we knew very little about how genes worked. Then came a major breakthrough. Scientists deciphered the genetic code – the way in which the gene stores information. Perhaps not surprisingly, it turned out to be very like a computer code. Genes are arranged in sequence along molecules of DNA and the cell is able to read the information they contain progressively from one end of a gene. It is rather like a computer 'reading' instructions by accessing the different bands on a CD rom and, like a computer, there are controlling elements built into the DNA telling the cells which genes to read and when.

The discovery of the genetic code was the key to understanding the control of growth processes. Even more important was the discovery that the code was identical for all kinds of living things. This meant that we might be able take a gene from one plant or animal and introduce it into a different one. If we could get the conditions right the plant or animal receiving the new gene might be able to read its instructions and begin to do something it had never been able to do before. The way was suddenly opened for us to modify directly the genetic composition of living things. Instead of relying on the uncontrolled process of natural mutation followed by time-consuming selection all we had to do was take a gene for a desirable characteristic from one organism and introduce it into a different one. Transferring genes in this way, or inactivating genes already present, results in a plant or animal being *genetically modified*. Such GM plants or animals are often referred to as *transgenic*.

Put that way it sounds simple but it must be really difficult. If this understanding was around 50 years ago why is it only now that it is beginning to have an impact on our lives?

Yes, it is difficult. Many years of research were needed before we were able to extract the precise gene we wanted – and no others – and then introduce it into a new cell in such a way that it would go on working. Not only was it necessary to isolate the particular gene we wanted but we also had to get all the control mechanisms working properly before the message could be read. This is an important point when we think about genes 'escaping' into the environment. It is not simply a question of introducing a 'foreign' gene into a cell of a new plant or animal – which is difficult enough – it is also necessary for the cell to have all the control mechanisms in place if the gene is to work in its new home.

First successes were with simple bacteria. When we had learned how to transfer genes between these simple life forms we were able to apply the knowledge gained to transfer genes between bacteria and plants and finally between larger species. At first it was difficult to get the conditions right and there were many failures but in the last two decades we have become much more proficient. Today we have a good chance of succeeding when we set out to make a particular gene transfer. When Zeneca produced a genetically-modified tomato for use in making purée for example, they were able to make 210 successful gene transfers to provide the basis for further selection, breeding and development.

What kind of things have been achieved?

The earliest successes all involved medical applications.

The first has been helping many people with diabetes for many years. A diabetic patient may need regular injections of insulin. Until a few years ago the insulin was extracted from dead pigs. Unfortunately pig insulin is not exactly the same as human insulin. When it is injected into a human the body's defence mechanisms may identify it as a "foreign" chemical and begin to produce antibodies which can interfere with the insulin and stop it doing its job. However, scientists learned to take the human gene for insulin production and introduce it a micro-organism that could be grown in bulk by the pharmaceutical industry. As it grew in the fermentation tank, it produced insulin – human insulin. When this is injected into human patients their bodies do not recognize it as foreign; antibodies are not formed and the insulin treatment can be continued successfully for years if necessary. Most insulin used in the UK today is produced using GM technology.

The blood clotting factors needed by boys who have inherited the genes for haemophilia were readily available from blood donations. Unfortunately some of this blood also contained HIV, and many recipients, before screening became routine, contracted AIDS through their blood transfusions.

The few patients who need injections of growth hormone to compensate for a natural deficiency faced a different problem. In this case an animal source was not possible because the hormones are species-specific. Here the molecules were extracted from the pituitary glands of cadavers. This precipitated two serious issues. Firstly, there was an insufficient supply, and secondly it exposed the recipients to the risk of contracting Creutzfeldt Jakob disease (CJD)

These three examples show that it is safe to inject such products into a vein, and strongly suggests that oral ingestion is unlikely to give rise to any negative health consequences. Indeed the GM product is actually safer than the alternative.

Now let us look at examples in the food chain.

Fruit is at its best for eating when it is 'ripe', and food technologists have put much effort into altering both the rate of ripening, and the rate of decay which succeeds it. Both the use of refrigeration (including in the home), and the use of gases, such as ethylene have been used for years.

A university scientist in Nottingham, interested in how fruit ripens, discovered one of the genes involved in tomatoes. He then worked out how to switch it off. This had the effect of slowing the rate of deterioration in tomatoes in storage. It also improved the suitability of such tomatoes for processing into tomato sauce, and this product swept away the opposition when it was introduced in the last millennium.

Another interesting case is that of a bacterium, *Bacillus thuringiensis*, which produces a protein toxin that kills the caterpillars of many types of insect crop pests. Cultures of this bacterium have been used as an insecticide since before the Second World War. They are used by organic farmers who find them acceptable as a natural method of pest control. The protein has no toxic effects whatsoever on humans, animals or plants or even on useful insects such as bees. Insecticides based on *Bacillus thuringiensis* are among the very few approved for use right up to harvest on crops that will be consumed in the uncooked state.

In recent years it has proved possible to extract the gene that makes the toxin from the bacterium and introduce it into crop plants. The leaves become resistant to caterpillar attack but remain perfectly safe as human food. Used in this way *Bacillus thuringiensis* toxin is a cheaper and more effective method of controlling insect pests.

Crop yields are often depressed by competition from weeds growing among the plants. It is possible in some cases to introduce resistance genes into crop plants making them resistant to particular weed-killers. This simplifies the control of the weeds, improves crop yields and reduces the overall amount of weed-killer needed. A case in point is the herbicide, Round-Up, which acts by interfering with the production of tryptophan – an amino acid required for healthy growth – in growing plants. Since humans and animals do not make their own tryptophan they are not sensitive to Round-Up. The problem with Round-Up is that it will kill virtually all plants and must be used with great care. Some twenty years ago, scientists at Monsanto discovered how to produce plants which are resistant to Round-Up by increasing their ability to manufacture tryptophan. This means that weeds can now be killed by the herbicide without damage to the resistant crop plants.

Do we really need GM foods?

Until recently, food had never been cheaper in developed countries such as those in Western Europe. Since the end of rationing in the early 1950s, the percentage of disposable income spent on food by the average family has shrunk from around 30% to just over 10%. Indeed this over-abundance of food has generated problems of obesity rather than starvation.

Eating has been described as the only sensual pleasure indulged by consenting adults in public three times daily!

Matters are however changing rapidly. Nations which have traditionally had a low intake of meat in their diet are increasingly developing a taste for meat, which demands large quantities of grain to feed them. For example imports of soya from Brazil into China have increased ten-fold in the last ten years. This is having a huge effect on world prices of all primary agricultural products.

It is obviously beneficial, for us and the environment, to develop crops that require less energy intake and land, as well as fewer chemical insecticides, fungicides and weed-killers. Today something like a quarter of all the food produced world-wide fails to reach the plate because of spoilage. In Britain the loss is much less but in many parts of the world more than half of the food produced is lost by damage in the field or by spoilage. GM crops can, and already in some parts of the world do, make a significant contribution to lowering the costs of food production, protecting the environment by reducing chemical usage and increasing the resistance of food to spoilage.

Crops attacked by moulds or bacteria can have their natural defence mechanisms boosted by genetic modification. By making their leaves toxic to insect pests they can be protected from destruction without the use of chemical insecticides. By making a plant resistant to a particular weed-killer it becomes easier to control the weeds invading the crop.

There is another way of looking at this question. In spite of the efforts of governments around the world the population continues to rise at an alarming rate. By this time tomorrow there will be some 260 000 more mouths to feed. The majority of these people will be in developing countries and about half are destined to die, prematurely, from the effects of malnutrition.

Genetically-modified crop plants alone cannot solve this problem; but they can make a major contribution. They can greatly increase the yields of crops without a proportionate increase in the land used for agriculture. GM technology offers the prospect of crops growing on land previously unsuitable through salinity or shortage of water.

There are other applications under development. Blindness due to Vitamin A deficiency affects 700 million people – mainly in developing countries. Genetically-modified rape plants yielding an oil with a much increased vitamin A content are already undergoing testing in laboratories. They offer us an opportunity to prevent much of the world's diet-related blindness.

To grow crops effectively soils need adequate supplies of nitrogen which plants use to make protein. Nitrogen is usually supplied as expensive fertiliser containing ammonium salts which is out of reach economically for much of the developing world. Some plants have nitrogen-fixing bacteria associated with their roots and are able to grow without added fertiliser by using nitrogen gas from the air. A great deal of research is aimed at trying to isolate nitrogen-fixing genes from these and other bacteria and inserting them into crop plants. When this proves successful it will have a dramatic impact on much of world agriculture with important benefits for developing countries.

Ever since the 1950s, when environmentalists like Rachel Carson drew attention to the threat posed to our environment by massive use of agricultural chemicals, scientists have been searching for more natural strategies for pest and weed control – so far with only limited success. Genetic modification is beginning to offer us real opportunities to make progress.

Why do people worry about GM foods?

There are many issues here, most of them not the unique responsibility of the scientist. The Prince of Wales, among others, has expressed concern about scientists playing God. Such concerns have always been expressed whenever new technology concerned with human breeding has been introduced. This goes back to contraception, and more recently the creation of donor siblings. These are legitimate worries for the many who have particular ethical beliefs, and each of us will have to square such advances with our individual consciences.

In the early days, the safety of eating the products of such a new and untried technology was an issue. This seems less of a concern now that 270 millions citizens of the US, together with 10 million British visitors to the US, have been consuming the products daily for nearly ten years without a single case of an unpleasant side-effect. The knowledge that several million diabetics have been injecting such materials with increased safety may also have played a part.

This should also be set in the context of the numerous cases of poisoning due to accidental exposure to agricultural chemicals that occur each year. However, we should not be complacent. The UK government takes an active interest in any possible health risks associated with new foods, GM or otherwise. It looks for advice on food-related issues to a series of independent committees made up of academic and industrial scientists as well as representatives of consumer associations and other interested organizations. The Advisory Committee on Novel Foods specifically monitors new foods, including GM foods, for any possible risks.

We also need to remember that the safety of all technologies is challenged when they are new and untried. Thus vaccination, the railway, electricity, pasteurised milk, frozen peas and mobile phones have all been questioned in their day.

Growth of GM plants is presently restricted to experimental trials aimed at providing answers to the key questions. The Advisory Committee for Release to the Environment is charged with keeping the situation under constant review. Its agreement is an essential requirement for permission to be granted for commercial planting in the United Kingdom.

Conditions in a small, densely-populated, island like Britain are very different from the United States where vast areas of land are used primarily for the production of a single crop. In Britain much of our land is used both for recreation and for mixed farming. Environmental conditions and the implications of introducing new types of crops must be carefully studied before UK farmers will consider growing GM crops commercially.

As plants have evolved they have developed elaborate and highly effective mechanisms to prevent cross-pollination other than between closely related strains. We know that pollen can travel considerable distances and we need to assess the extent to which pollen from GM crops can introduce modified genes into similar non-GM crops or into wild, but closely-related, species.

Crop plants can be spread by seed dispersal – stray rape plants are a common feature of the countryside today. We need to assess the extent of such spread with GM crops and to determine whether or not this poses any hazard to the environment.

Although strategies are available to prevent spread of crop plants, it has not proved necessary to employ them - the spread of conventional crop plants or their genes into the environment seems not to pose any threats. There are no grounds for thinking that the situation will be any different where GM plants are concerned – but this must be demonstrated by carefully controlled experiments both in the laboratory and under field conditions. In the 1970s scientists imposed their own moratorium on research of this kind and have been carefully judging the position on the accumulated evidence since then. It is clear that GM crops have been accepted and grown commercially in other countries. We need the information that can only come from field trials in our own country if our farmers and food manufacturers are to make use of the opportunities undoubtedly offered by these new technologies and to retain their competitive positions.

A point which was tackled head on in the early days is that of information. The cheese produced from GM rennin, and the tomato paste from GM tomatoes were both clearly, indeed boastfully, labelled. However it soon became clear that since most processed foods contain derivatives from soya and maize, it would be necessary to label ALL foods as containing GM-derived material. Thus the information content would effectively be reduced. This would also have the effect of removing the element of choice, from those who in spite of the apparent advantages described above, would still prefer to desist from consuming such food.

At the moment the arguments seem very confusing. Why, for instance, should organic farmers object to GM crops when they seem to reduce the need for agricultural chemicals? How can we make sense of the situation?

It is difficult. When new technologies are introduced to society it is never easy for people, or indeed governments, to see the potential or to recognize the risks. Railways, electricity, motor cars all generated fierce arguments when they were first introduced. Few people recognized the potential of the transistor when it first became available as an alternative to the thermionic valve. Genetic modification is no different. It has the potential to make far-reaching changes to our lives and it does not fit easily into our traditional ways of thinking. It is quite right for the people who will be affected to question and challenge scientists, industrialists and politicians in an attempt to understand what is possible and what is desirable – which are not necessarily the same thing. The GM food debate seems set to continue for some time yet.

Many people, including enthusiasts for 'organic' farming, recognize the possible benefits of GM technology but, understandably, are concerned about the long time-scales that may be involved before problems appear. Experience with BSE has also not encouraged people to accept the argument that the absence of evidence is not the same as evidence of absence.

Let us emphasise three things:

It is important to separate the purely scientific questions from the more philosophical issues. Whilst it cannot, at the moment, produce all the answers, science is capable of providing a background of facts against which the wider issues can be discussed sensibly. Much of the confusion in the present debate has its origin in failure to distinguish what is fact, what is hypothesis, what is opinion, what is speculation and what is simply fear of the unknown.

Secondly, continued experimentation is vital for a proper understanding of these new and potentially valuable technologies. Only through carefully planned and strictly controlled experiments with *our* foods and *our* crops in *our* environment will we learn to avoid the problems and take advantage of the opportunities presented by genetic modification.

Finally, from the global perspective, we can do little better than to quote Florence Wambugu, Director of the International Service for the Acquisition of Agro-Biotech Applications, who concluded a penetrating and perceptive article in the journal Nature recently – 'The criticism of agrobiotech products in Europe is based on socio-economic issues and not food safety issues, and no evidence so far justifies the opinion of some in Europe that Africa should be excluded from transgenic crops. Africans can speak for themselves.'

Future prospects

With the exception of Europe (including the UK) several countries and crops have taken to GM technology in a big way. About 80% of soya from South America and the US is GM. Most High Fructose Corn Syrup (HFCS), used for sweetening soft drinks, is GM. Virtually all processed food currently on sale in the UK contains GM produced ingredients. Most animal feed imported into the UK contains significant amounts of GM maize and soya-based material.

Most cotton produced in China, India and the US is GM. Although this is not ingested, it does suggest that the environmental consequences are not great, and not negative. Vitamin A-enhanced rice is already being grown. Some of the early (and wild) promises of salt and drought-resistant plants have not yet been achieved. However both these traits are well advanced in the laboratory.

Compare the 40 year gap between Faraday and Edison's light bulb. There were predictions that pregnant women who travelled at more than 20 mph in the new railways would miscarry – after all, no one in the history of mankind had ever travelled so fast. Contemplate the 60 year gap between the Wright brothers and the Jumbo jet; 200 years elapsed between Jenner, and the final eradication of smallpox, 25 years between the Walkman and the iPod seems trivial. The mobile phone of 20 years ago led to the iPhone of today, and so far no brains have actually been turned into scrambled egg. GM technology fits in well among these. The hysteria and the time scale for fulfilment both seem familiar. Our grandchildren will definitely wonder what all the fuss was about.