

A close-up photograph of several green wheat grain heads, showing the individual spikelets and their developing grains. The grains are bright green and have a slightly fuzzy texture. The background is dark and out of focus.

GM plants

Questions and answers

GM plants: Questions and answers

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Front cover image

Wheat. © John Innes Centre.

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Foreword



For a rational debate about whether or not society should make use of new technologies or scientific methods, it is necessary to have access to reliable information so that all interested parties can make judgements about whether the procedures work, whether they are safe and what advantages or disadvantages they offer. Genetic modification of crops is one such technology.

In the United Kingdom half of the population do not feel well informed about genetically modified crops (GM crops) and a further 6% have never heard of them.

As the UK's national academy of science, the Royal Society has drawn on scientific experts to answer a number of questions about scientific and technological issues relating to GM crops.

The answers draw on a wide range of evidence and give some specific examples. In general it is important to recognise that when the GM method is used the crops produced should be assessed on a case by case basis. GM is a method, not a product in itself. Different GM crops have different characteristics and it is impossible, from a scientific point of view, to make a blanket statement that all GM is good or bad.

GM is a contentious subject and not all public discussion has been informed by independent scientific evidence. This discussion has taken place against a backdrop of the debate about how we ensure that we have sufficient food, grown in as sustainable a way as possible, to feed

the world's growing population. Our goal with this project is to present the scientific evidence in an accessible way. We commissioned Ipsos Mori to help us identify the issues people want to find out about and what questions they have.

A lot is known about GM, but scientists do not have answers to every question and it is important to be clear about what is known and what is not known. In our answers we explain the science of GM. We do not address all the non-scientific issues in relation to GM crops, which include broader socio-economic issues such as the availability and pricing of food, including politics and transport, and issues of trust in businesses and politicians.

We recognise that our answers will not end the controversy, but we hope that they will inform people about the science and allow those who might previously have felt excluded from the discussion to form a view.

A handwritten signature in black ink that reads "V. Ramakrishnan". The signature is written in a cursive, flowing style.

Venki Ramakrishnan
President of the Royal Society



Image
Kale cabbage. © LOVE_LIFE.

Introduction

There have been long running debates about the use of new technologies for agriculture, and these have been especially prominent around genetically modified crops. There are parallels with climate change, and following the success of the *Climate Change: Evidence and Causes* document, the Society decided to produce a similar document on genetically modified (GM) crops, identifying questions from the public and then answering them as accurately and as dispassionately as possible.

To identify the questions Ipsos MORI were commissioned to carry out a series of focus groups to explore participants' questions about GM. These discussions were held in London, Downham Market, Swindon and York. There were eight groups in total and 66 members of the public took part. Participants were recruited for a range of views based on those for and against GM or who were undecided, in order to reflect the findings of a nationally representative survey on the subject. They were also recruited to reflect the wider population in terms of gender and socioeconomic background. The following set of 18 questions was the outcome of the responses from the focus groups.

The answers to the questions were written by a group of experts who have endeavoured to ensure the answers are factual, as much as possible, and not associated with any value judgement. The aim was not to present comprehensive reviews with scientific details, but instead to provide succinct accounts that will be accessible to non-scientists.

The Society's report *Reaping the benefits*, published in 2009, sets out its views that a range of technologies will be required to address the challenges of sustainable and sufficient food and agriculture, and GM is only one of the technologies that could be used. It will not be sufficient on its own but it may be useful for addressing some of the challenges facing agriculture. Our earlier report provides a broader discussion of the challenges to food crop production, how sustainable intensification might be achieved and the consequences and complications of innovation in this area.

The questions and answers given here are intended to provide a resource to those who are interested in what GM is, how it is used and potential future uses. They will hopefully inform a larger debate on what the system that produces food globally should look like.

QUESTION 1

What is genetic modification (GM) of crops and how is it done?

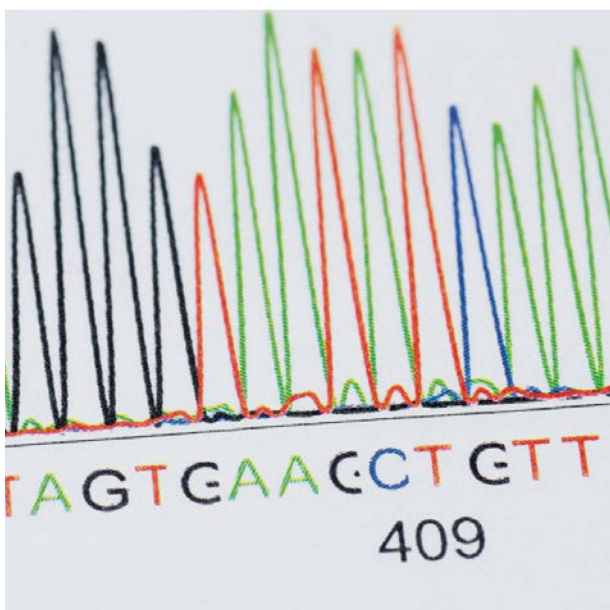
GM is a technology that involves inserting DNA into the genome of an organism. To produce a GM plant, new DNA is transferred into plant cells. Usually, the cells are then grown in tissue culture where they develop into plants. The seeds produced by these plants will inherit the new DNA.

The characteristics of all living organisms are determined by their genetic makeup and its interaction with the environment. The genetic makeup of an organism is its genome, which in all plants and animals is made of DNA. The genome contains genes, regions of DNA that usually carry the instructions for making proteins. It is these proteins that give the plant its characteristics. For example, the colour of flowers is determined by genes that carry the instructions for making proteins involved in producing the pigments that colour petals.

Genetic modification of plants involves adding a specific stretch of DNA into the plant's genome, giving it new or different characteristics. This could include changing the way the plant grows, or making it resistant to a particular disease. The new DNA becomes part of the GM plant's genome which the seeds produced by these plants will contain.

The first stage in making a GM plant requires transfer of DNA into a plant cell. One of the methods used to transfer DNA is to coat the surface of small metal particles with the relevant DNA fragment, and bombard the particles into the plant cells. Another method is to use a bacterium or virus. There are many viruses and bacteria that transfer their DNA into a host cell as a normal part of their life cycle. For GM plants, the bacterium most frequently used is called *Agrobacterium tumefaciens*. The gene of interest is transferred into the bacterium and the bacterial cells then transfer the new DNA to the genome of the plant cells. The plant cells that have successfully taken up the DNA are then grown to create a new plant. This is possible because individual plant cells have an impressive capacity to generate entire plants. On rare occasions, the process of DNA transfer can happen without deliberate human intervention. For example the sweet potato contains DNA sequences that were transferred thousands of years ago, from *Agrobacterium* bacteria into the sweet potato genome.

There are other ways to change the genomes of crops, some of which are long established, such as mutational breeding, and others of which are new, such as genome editing, but in this Q&A we are focusing on GM as it is currently usually defined for regulatory purposes in Europe.

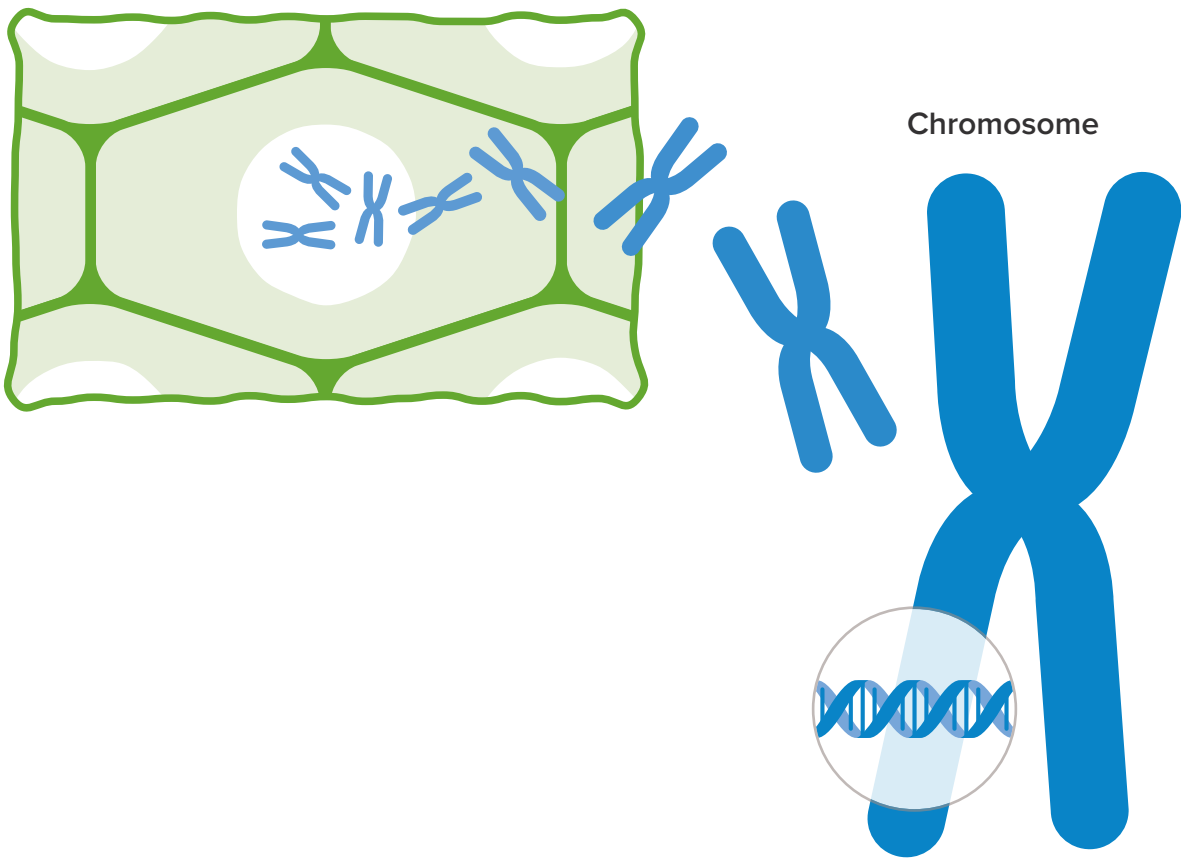


Left
DNA sequencing results. © Zmeel Photography.

FIGURE 1 The relationship between DNA, genes, chromosomes, genomes and cells

Cell

Cell nucleus containing genome packaged in chromosomes.



DNA

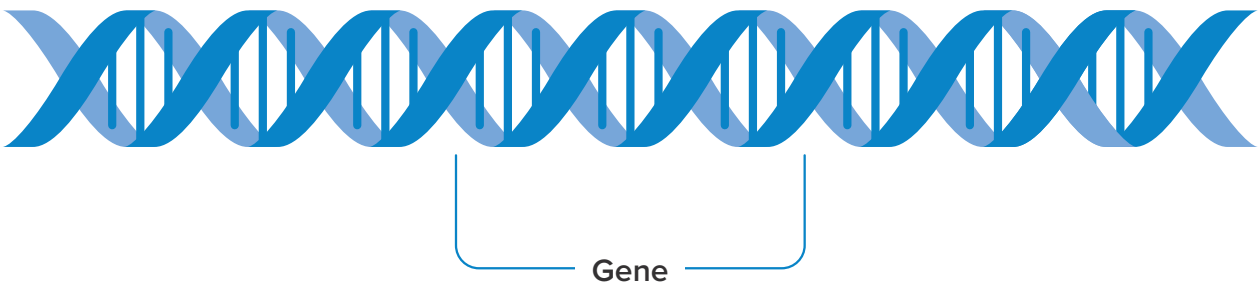
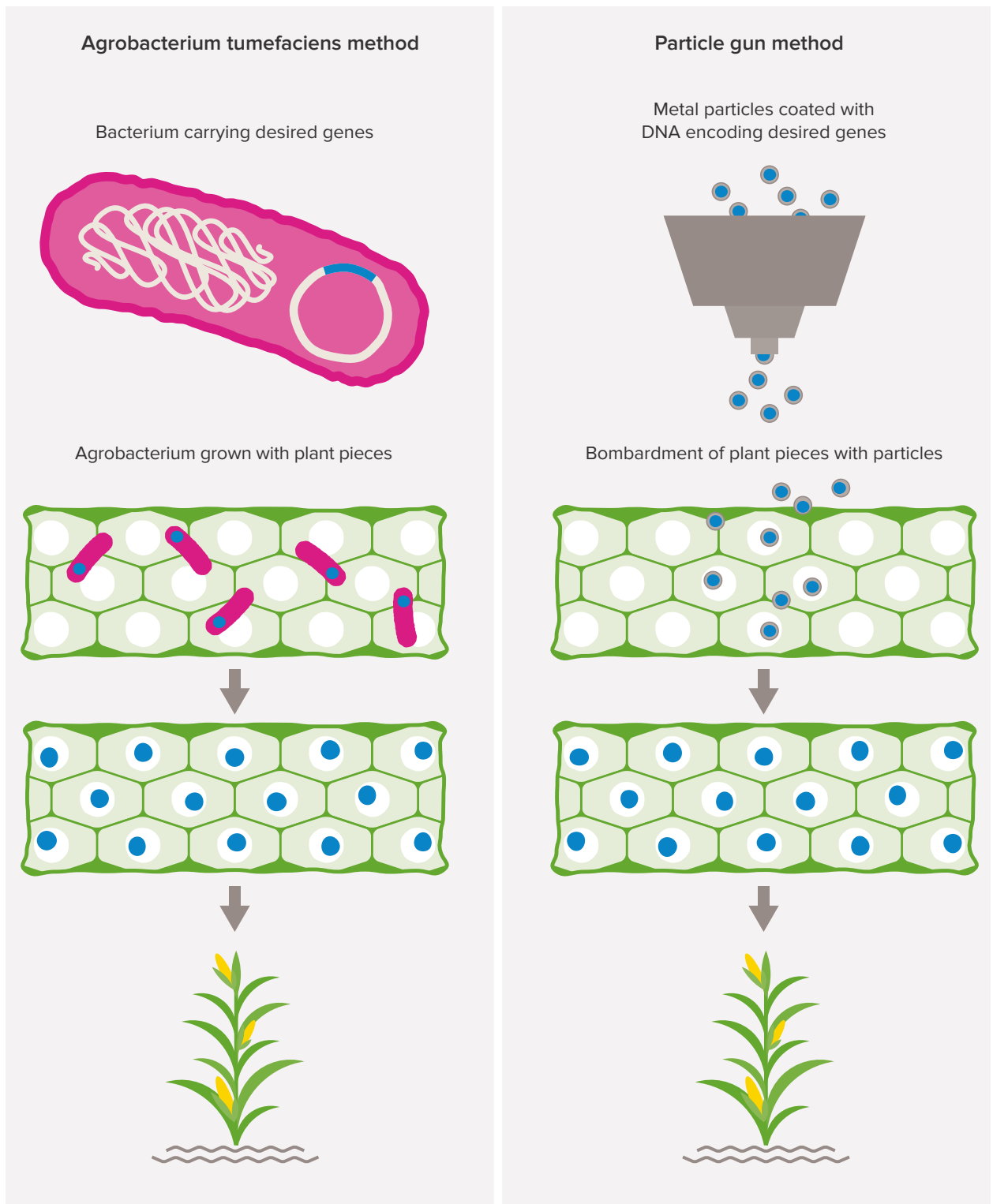


FIGURE 2 DNA transfer procedures



QUESTION 2

How common are genes in food?

All food, whether from plants or animals, contains genes. In cooked or processed foods, most of the DNA has been destroyed or degraded and the genes are fragmented. Whether fresh or cooked, when we eat food, we digest it into its constituent parts from which we make our own genes and proteins.

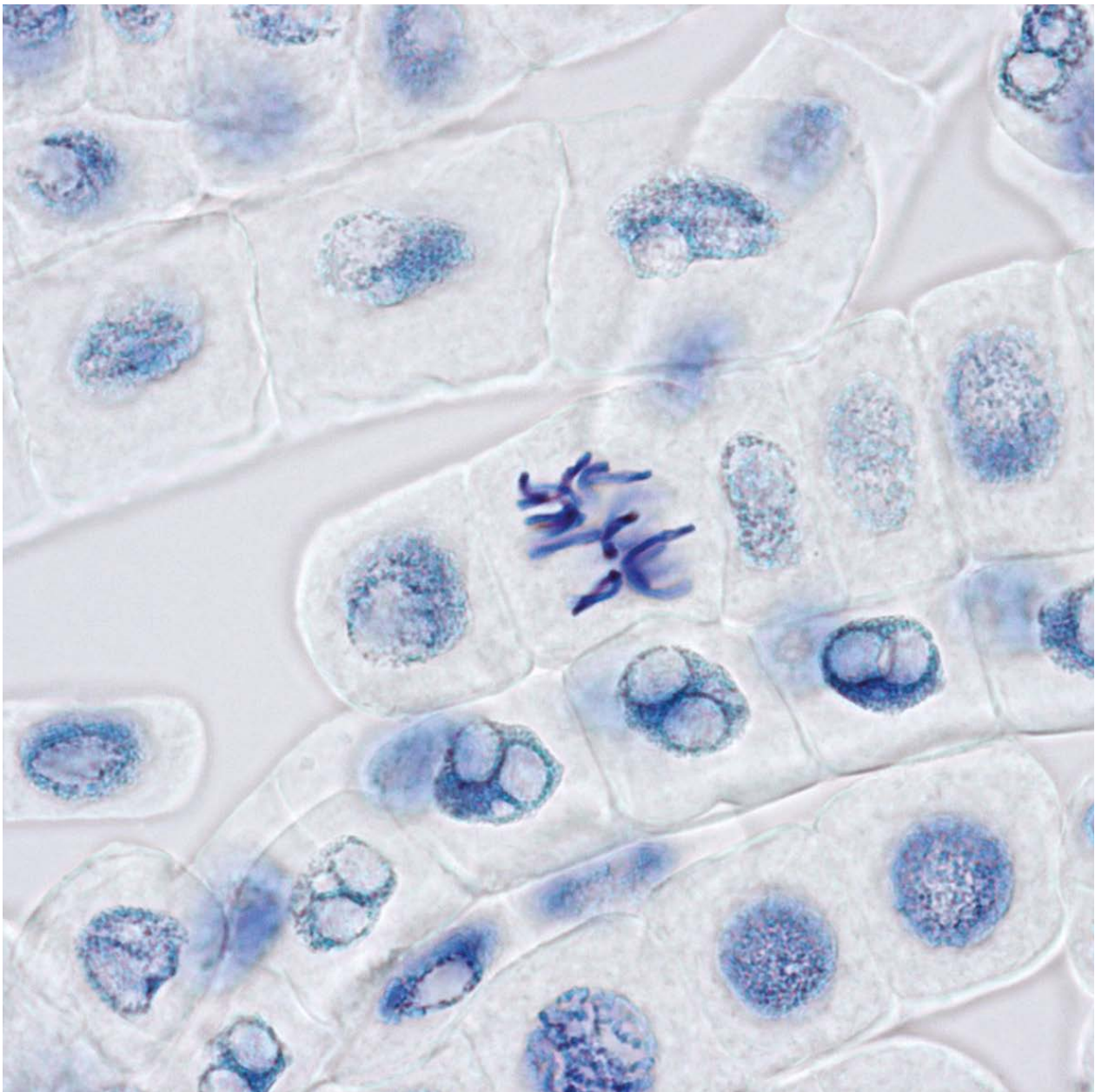
Each cell in a plant contains about 30,000 genes.

GM usually involves adding an extra 1 – 10 genes.

It is estimated that we each eat many billions of genes every day, which come mainly from fresh food.

Below

Onion root tip cells showing chromosomes and nuclei of dividing cells. © Alan John Lander Phillips.



QUESTION 3

How does GM differ from conventional plant breeding?

The goal of both GM and conventional plant breeding is to produce crops with improved characteristics by changing their genetic makeup. GM achieves this by adding a new gene or genes to the genome of a crop plant. Conventional breeding achieves it by crossing together plants with relevant characteristics, and selecting the offspring with the desired combination of characteristics, as a result of particular combinations of genes inherited from the two parents.

Both conventional plant breeding and GM deliver genetic crop improvement. Genetic improvement has been a central pillar of improved agricultural productivity for thousands of years. This is because wild plants make very poor crops. Natural selection tends to favour plants that can compete with neighbouring plants for light, water and nutrients, defend themselves from being eaten and digested by animals, and disperse their seed over long distances. These characteristics are in direct conflict with the goals of agriculture, which require plants to invest as many of their resources as possible into making nutritious, easy to harvest products for human consumption. Because of the stark contrast between what natural selection has produced and what makes a good crop, for thousands of years we have used conventional breeding approaches to convert plants that compete well in the wild, to plants that perform well in agriculture. The result is our modern crop varieties, which are much higher yielding and more nutritious than their wild ancestors, but which compete poorly in the wild.

Many genes are now known that could contribute to improving sustainable food production. In some cases conventional breeding will be the best way to transfer them and in others GM might be easier or indeed the only way they can be transferred.

New characteristics can be introduced into crops using either conventional or GM approaches. This raises the question of when a plant breeder might choose a GM approach vs a conventional approach. GM can only be used to introduce a new characteristic into a crop if two requirements are met.

Firstly, it is necessary that the characteristic can be introduced by adding only a small number of genes, and secondly, it is necessary to know what gene or genes those are. At the time GM technology was invented we knew much less about which plant genes do what, which greatly restricted the number of useful applications for GM in crops.

With improvements in our knowledge about which plant genes do what, we now know many genes that could contribute to improving sustainable food production. In some cases conventional breeding will be the best way to deploy these genes – that is by cross-breeding with the plant that contains the genes providing these characteristics.

In other cases GM, where scientists take a gene and insert it directly into a plant, might be easier, or indeed the only way they can be deployed.

There are two main reasons why GM might be preferable. Firstly, the gene of interest might not exist in a species that can be successfully crossed with the crop. The gene might come from an entirely different kingdom, such as a bacterium, or it might come from a different plant species.

Dwarf wheat and the Green Revolution

In nature, many plant species respond to shading by increasing their height, allowing them to compete for light. The ability to adjust their height depends on a particular protein that prevents stem elongation and the plant can fine-tune its growth by changing the amount of this protein in the stem.

During the 1960s, the development of dwarf varieties of wheat dramatically increased yields as part of the so-called Green Revolution. The dwarf wheat varieties take advantage of a change in the gene carrying the instructions for the height-adjusting protein, increasing the amount of the protein in the stem so that stem growth is always inhibited. This results in wheat varieties that invest less resource in their stems and more in their seeds. They are therefore higher yielding and also less prone to being flattened in the wind, a major cause of yield loss known as lodging.

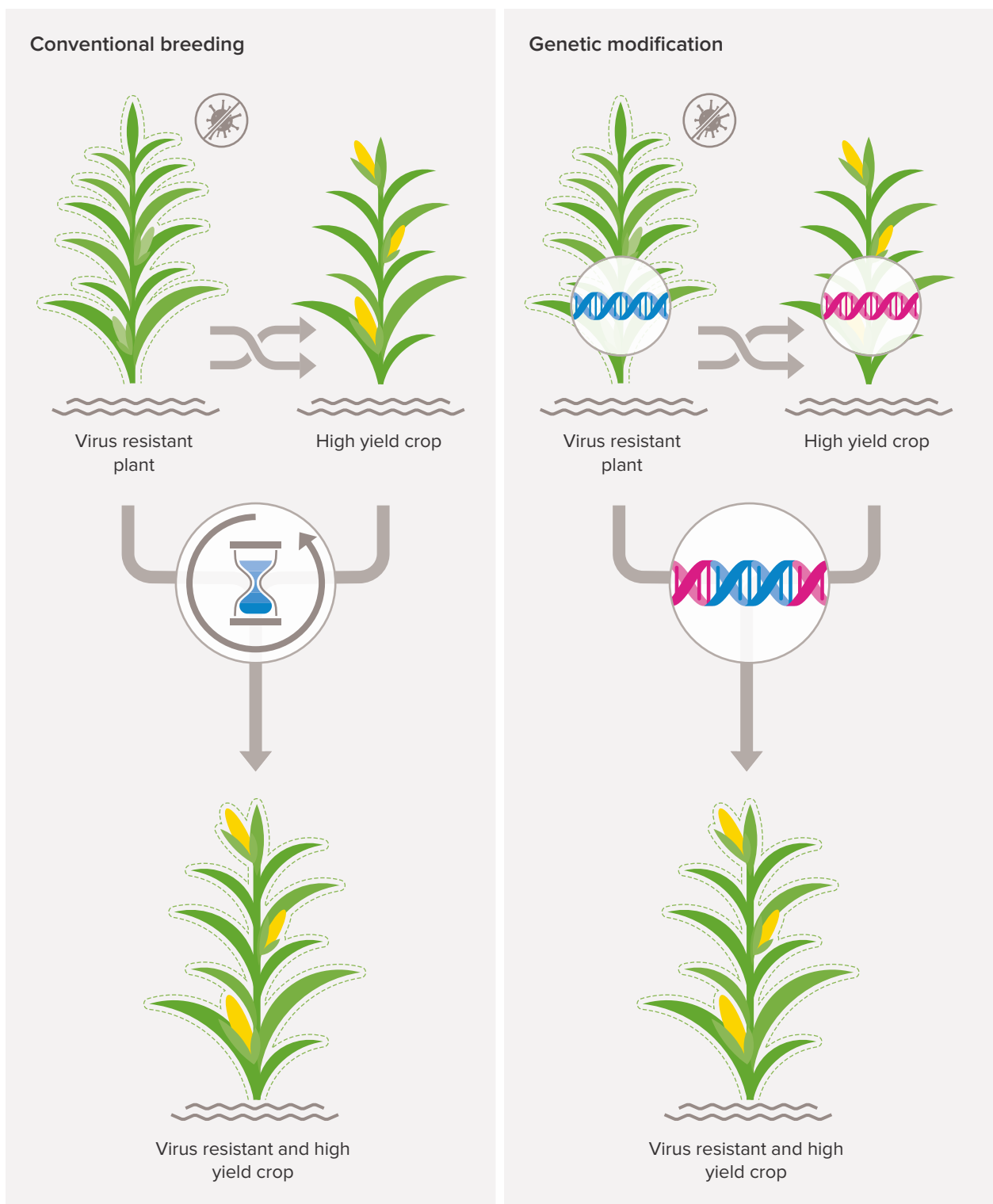
Because we know so much about how this height gene works, it can be used to make dwarf varieties of almost any crop. There are no GM crops modified in this way currently being grown commercially, but there have been proof of principle studies in rice.

Our understanding of dwarfing genes illustrates an important point. It is possible to introduce exactly the same characteristic into a crop by conventional breeding or by GM methods. Each method has advantages and disadvantages, and the choice of which is better to use will depend on the specific case.

Secondly, today's high yield crop lines have carefully honed combinations of genes. If a useful gene or gene variant is discovered in a wild relative, crossing the high yield line with the wild relative will result in mixing together the genomes of the two parents, destroying the carefully selected combination of genes in the high yield line. Using modern molecular breeding techniques, such as 'marker assisted breeding', it is possible to reassemble those gene combinations over a relatively small number generations.

Nonetheless, it does take multiple generations, and therefore several years. Furthermore, even then it is almost always the case that additional genes that are very close to the gene of interest are also transferred. These problems can be avoided if it is possible to introduce the gene directly into the high yield crop by genetic modification.

FIGURE 3 Differences between conventional breeding and GM



QUESTION 4

What about unforeseen consequences of GM?

There is no evidence that producing a new crop variety using GM techniques is more likely to have unforeseen effects than producing one using conventional cross breeding.

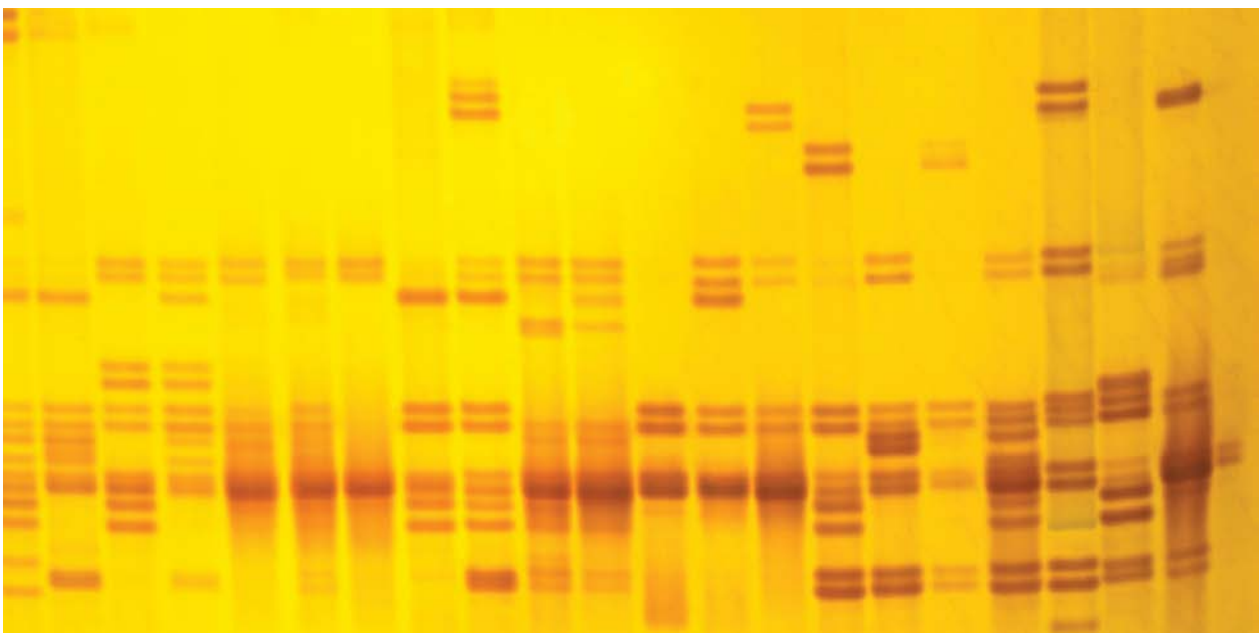
Concerns have been expressed that simply inserting new DNA into a plant genome by GM, might have unpredictable consequences. However, as our knowledge of genomes has increased it has become clear that similar insertion events occur frequently in all plants. For example, some bacteria and viruses insert new genes into the genomes of plants that they infect. We have also discovered that plant genomes contain many so-called 'jumping genes' that move around the genome, re-inserting themselves in different places. We also know, from studying the genomes of different members of the same species, that gain and loss of genes within species is very common too.

We have also discovered that plant genomes contain many so-called 'jumping genes' that move around the genome, re-inserting themselves in different places.

Because of these processes, all new crop varieties, however they are produced can include genes inserted in new unknown places in the genome and new genes that may not have previously been in the food chain or come from non-plant species. This means that there may occasionally be unforeseen consequences from both GM and non-GM crop varieties.

Below

Plant DNA fingerprint. © PanuRuangan.





Above
Cabbages infested with
caterpillars. © Sophonibal.

QUESTION 5

Which genes have been introduced into GM crops so far and why?

The most prominent examples include genes that make the crops resistant to herbicides, insects, or viruses.

Herbicide tolerance

The first GM characteristic to be widely adopted was resistance to a herbicide called *Roundup* (or glyphosate) in soybeans. There are also varieties of herbicide tolerant crops produced by non-GM methods. Resistance to these types of broad herbicide – which would usually kill both weeds and crops – means that efficient weed control is possible because the herbicide can be applied while the crop is growing, without damaging the crop. Without herbicide tolerant crops, a range of different types of herbicides might be needed to clear out all the weeds before planting the crop. Another benefit of herbicide tolerant crops is that they can be planted into a weedy field, because the weeds can be controlled with herbicide. This reduces the need for ploughing, which means less soil erosion. Disadvantages are that the farmer must buy the proprietary herbicide to match the herbicide tolerant crop, and this type of control runs counter to attempts to reduce the dependency of agriculture on chemical inputs.

Insect resistance

The bacterium *Bacillus thuringiensis* (Bt) produces a group of proteins known as the Bt toxin, which are toxic for certain insects, but do not harm beneficial insects or other animals. *Bacillus thuringiensis* is used as an insecticide spray in organic farming. Genes for several Bt toxins have been introduced into many crops by GM. For example over 90% of the cotton planted in the USA, India, China, Australia and South Africa are GM varieties containing Bt toxin genes¹. Over the last 20 years, it is estimated that the application of 450,000 tons of insecticide has been avoided due to the use of Bt toxin genes in crops.

Bacillus thuringiensis is used as an insecticide spray in organic farming. Genes for several Bt toxins have been introduced into many crops by GM

Virus resistance

GM has been used to resurrect the papaya industry of Hawaii as papaya ringspot virus almost destroyed its plantations in the 1990s. There are no known papaya varieties with natural resistance to this virus but by adding a gene to the papaya from the virus itself, resistant papaya strains were created. Today 77% of Hawaiian papaya farmers grow GM papaya².

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1. James Clive. 2015. Global Status of Commercialized Biotech/GM Crops: 2015. *ISAAA Brief* No. 51. ISAAA: Ithaca, NY
 2. <http://hawaii.tribune-herald.com/sections/news/local-news/papaya-gmo-success-story.html> (Retrieved 16 May 2016)

QUESTION 6

What GM crops are currently being grown and where?

In 2015, GM crops were grown in 28 countries and on 179.7 million hectares – that is over 10% of the world’s arable land and equivalent to seven times the land area of the UK. The USA, Brazil and Argentina are the leading producers. There are currently no GM crops being grown commercially in the UK although scientists are carrying out controlled trials.

The GM crops grown commercially included: potato (USA), squash/pumpkin (USA) alfalfa (USA), aubergine (Bangladesh), sugar beet (USA, Canada), papaya (USA and China), oilseed rape (4 countries)³, maize (corn) (17 countries)⁴, soya beans (11 countries)⁵ and cotton (15 countries)^{6,7}.

GM crops were first introduced in the USA in 1994 with the Flavr Savr tomato, which had been genetically modified to slow its ripening process, delaying softening and rotting.

The farming of GM crops has massively increased since the mid 1990s. In 1996, just 1.7 million hectares (MHa) were planted with GM crops globally⁸ but by 2015, 179.7 million hectares of GM crops were grown, accounting for over 10% of the world’s arable land⁹.

The top GM crop grown in 2015 was soybean (92.1 MHa), followed by maize (53.6 Mha), then cotton (24 Mha) and oilseed rape (canola) (8.5 Mha) (Figure 4). This represents 83% of the world production of soybean, and 75% of production of cotton¹⁰. GM crops made up 29% of the world’s maize produce, and almost a quarter of the world’s oilseed rape that year¹¹.

Among the countries growing GM crops, the USA (70.9 Mha), Brazil (44.2 Mha), Argentina (24.5 Mha) India (11.6 Mha) and Canada (11 Mha) are the largest users¹². Within Europe, five EU countries grow GM maize – Spain, Portugal, Czech Republic, Romania and Slovakia¹³. Spain is the leading country (0.1 Mha). In Africa, GM crops are grown in South Africa (2.3 MHa), Burkino Faso (0.4 Mha) and Sudan (0.1Mha), with the main crop being GM cotton¹⁴.

3. USA, Canada, Australia, Chile

4. USA, Brazil, Argentina, Canada, Paraguay, South Africa, Uruguay, Philippines, Spain, Columbia, Honduras, Chile, Portugal, Vietnam, Czech Republic, Slovakia, Romania

5. USA, Brazil, Argentina, Canada, Paraguay, South Africa, Uruguay, Bolivia, Mexico, Chile, Costa Rica

6. USA, Brazil, Argentina, India, China, Paraguay, South Africa, Pakistan, Australia, Burkina Faso, Myanmar, Mexico, Colombia, Sudan, Costa Rica

7. James Clive. 2015. Global Status of Commercialized Biotech/GM Crops: 2015. *ISAAA Brief* No. 51. ISAAA: Ithaca, NY

8. James Clive. 2015. Global Status of Commercialized Biotech/GM Crops: 2015. *ISAAA Brief* No. 51. ISAAA: Ithaca, NY

9. Total arable land 1407134 MHa, World Bank 2013 <http://data.worldbank.org/indicator/AG.LND.ARBL.ZS> (Retrieved 16 May 2016)

10. James Clive. 2015. Global Status of Commercialized Biotech/GM Crops: 2015. *ISAAA Brief* No. 51. ISAAA: Ithaca, NY

11. James Clive. 2015. Global Status of Commercialized Biotech/GM Crops: 2015. *ISAAA Brief* No. 51. ISAAA: Ithaca, NY

12. James Clive. 2015. Global Status of Commercialized Biotech/GM Crops: 2015. *ISAAA Brief* No. 51. ISAAA: Ithaca, NY

13. James Clive. 2015. Global Status of Commercialized Biotech/GM Crops: 2015. *ISAAA Brief* No. 51. ISAAA: Ithaca, NY

14. James Clive. 2015. Global Status of Commercialized Biotech/GM Crops: 2015. *ISAAA Brief* No. 51. ISAAA: Ithaca, NY

FIGURE 4 GM plant production around the world



Country	Arable land used to farm GM plants (Mha)	Available arable land (Mha)	% GM
USA	70.9	153.7	46
Brazil	44.2	71.9	61
Argentina	24.5	38.0	64
India	11.6	157.0	7
Canada	11.0	42.7	26
China	3.7	105.4	4
Paraguay	3.6	4.3	84
Pakistan	2.9	21.3	14
South Africa	2.3	12.0	19
Uruguay	1.4	1.8	79
Bolivia	1.1	3.9	28
Philippines	0.7	5.4	13
Australia	0.7	47.6	1
Burkina Faso	0.4	5.7	7

Country	Arable land used to farm GM plants (Mha)	Available arable land (Mha)	% GM
Myanmar	0.3	10.8	3
Mexico	0.1	22.9	1
Spain	0.1	12.4	1
Colombia	0.1	1.5	6
Sudan	0.1	29.2	0.5
Honduras	<0.1	1.0	3
Chile	<0.1	1.3	1
Portugal	<0.1	1.1	1
Vietnam	<0.1	6.4	>0.1
Czech Republic	<0.1	3.2	>0.1
Slovakia	<0.1	1.4	>0.1
Costa Rica	<0.1	0.3	>0.1
Bangladesh	<0.1	7.7	>0.1
Romania	<0.1	9.0	>0.1

Note: Core data values are rounded to one decimal place.
 Data compiled from James Clive. 2015. Global Status of Commercialized Biotech/GM Crops: 2015. *ISAAA Brief* No. 51. ISAAA: Ithaca, NY

QUESTION 7

Where are GM crops being eaten?

The main GM crops, maize (corn) and soybean, are used mostly for feeding animals. Meat, milk and eggs from animals fed with GM crops are eaten by people in many countries including the UK. GM crops are also used in many processed foodstuffs eaten around the world including cooking oils and other ingredients. The main GM foods eaten in a fresh state are alfalfa, squash and papaya in the USA, tomato, papaya and sweet pepper in China, and aubergine in Bangladesh. There are no fresh GM fruit or vegetables approved for consumption by humans in the EU.

The consumption of GM crops varies between countries. Tens of millions of tonnes of GM maize and soybean are exported from North and South America to other parts of the world where there is a shortage of inexpensive plant protein for animal feed. For example, about two thirds of all protein-based animal feed in the EU comes from soy¹⁵, of which about 70% is imported, and over 90% of that is produced from GM soybeans¹⁶. Meat, milk and eggs from animals fed with GM crops is eaten in many countries including the UK. In the UK, meat, milk or eggs labelled as organic will be from animals that have been fed non-GM feed¹⁷. Of the UK supermarkets, only Waitrose commits to ensuring non-GM feed is used to produce its eggs, chicken, turkey, farmed fish and New Zealand lamb¹⁸.

GM crops are also used in processed foodstuffs including cooking oils, specialist starch (often added to foods like coatings and batters) and other food ingredients. For example, cooking oil, sauces, biscuits and other confectionary made from or containing GM crops – which must be labelled as such – are available in UK supermarkets.

A GM virus-resistant variety of papaya is widely grown in the USA and China and is exported to other countries including Japan.

15. http://www.foe.co.uk/sites/default/files/downloads/livestock_impacts.pdf (Retrieved 16 May 2016)

16. http://www.gmo-compass.org/eng/news/572.eu_imports_gm_soy_sustainable.html (Retrieved 16 May 2016)

17. <http://www.usda.gov/wps/portal/usda/usdahome?contentidonly=true&contentid=organic-agriculture.html> (Retrieved 16 May 2016)

18. http://www.waitrose.com/home/inspiration/about_waitrose/the_waitrose_way/gm.html (Retrieved 16 May 2016)



Image
Hereford calves eating corn
from feed bunk. © emholk

QUESTION 8

Is it safe to eat GM crops?

Yes. There is no evidence that a crop is dangerous to eat just because it is GM. There could be risks associated with the specific new gene introduced, which is why each crop with a new characteristic introduced by GM is subject to close scrutiny. Since the first widespread commercialisation of GM produce 18 years ago there has been no evidence of ill effects linked to the consumption of any approved GM crop.

Before any food produced using GM technology is permitted onto the market, a variety of tests have to be completed. The results from these tests, including results from animal feeding trials, are considered by the authorities responsible for determining the safety of each new GM product. This makes new GM crop varieties at least as safe to eat as new non-GM varieties, which are not tested in this way.

There have been a few studies claiming damage to human or animal health from specific foods that have been developed using GM. The claims were not about the GM method itself, but about the specific gene introduced into the crop, or about agricultural practices associated with the crop, such as herbicide treatments. The statistical analysis and methodology of these studies have been challenged¹⁹. All reliable evidence produced to date shows that currently available GM food is at least as safe to eat as non-GM food.

An animal feeding trial of GM tomatoes modified to produce high levels of antioxidants showed the GM tomatoes reduced the levels of cancer²⁰. This is not because the tomatoes are GM, but rather because they produce antioxidants, which are known to reduce cancer.



Above
Tomatoes © ZoiaKostina.

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19. Elsevier, 2013. Elsevier announces article retraction from *Journal Food and Chemical Toxicology* November 28, 2013. Available at: <http://www.elsevier.com/about/press-releases/research-and-journals/elsevier-announces-article-retraction-from-journal-food-and-chemical-toxicology> (Retrieved 16 May 2016)
20. Butelli E, Titta L, Giorgio M, Mock H, Matros A, Peterek S, Schijlen E, Hall R, Bovy A, Luo J and Martin C, 2008. Enrichment of tomato fruit with health-promoting anthocyanins by expression of select transcription factors. *Nature Biotechnology*, 26, 1301 – 1308

QUESTION 9

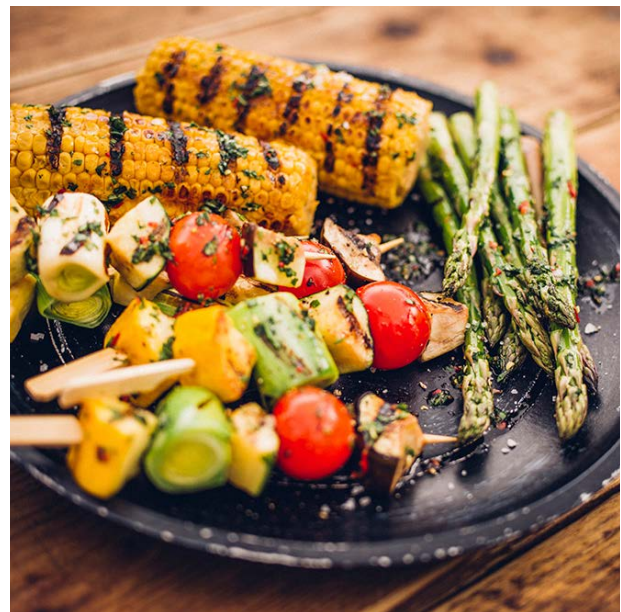
Could eating GM food have an effect on my genes?

No. Eating GM food will not affect a person's genes. Most of the food we eat contains genes, although in cooked or processed foods, most of the DNA has been destroyed or degraded and the genes are fragmented. Our digestive system breaks them down without any effect on our genetic make-up. Our own genes are made by our bodies from the building blocks that we obtain from digesting any food. This is true of food from GM and non-GM sources²¹.

Most plants or animal cells contain about 30,000 genes, and most GM crops contain an additional 1 – 10 genes in their cells.

Humans have always eaten DNA from plants and animals. Most plants or animal cells contain about 30,000 genes, and most GM crops contain an additional 1 – 10 genes in their cells. We all eat DNA in our diets, mainly from fresh food and the composition of DNA in GM food is the same as that in non-GM food.

Processing food by cooking leads to the partial or complete breakdown of the DNA molecules, whatever their origin. Likewise, most DNA that is eaten is broken down by our digestive systems but small quantities of fragmented DNA can pass into the bloodstream and organs without having any known effect.



Above
Grilled vegetable kebabs with corn and asparagus
© wundervisuals.

21. Rizzi A, Raddadi N, Sorlini C, Nordgård L, Nielsen KM and Daffonchio D, 2012. The stability and degradation of dietary DNA in the gastrointestinal tract of mammals—implications for horizontal gene transfer and the biosafety of GMOs. *Critical Reviews in Food Science and Nutrition*, 52, 142-161.



Image
Three stages of the cotton
plant: flower, pod, ripe boll.
© David Sucsy.

QUESTION 10

Have GM crops caused damage to the environment?

Crops do not damage the environment simply because they are GM. Some farming practices, such as the overuse of herbicides resulting in the excessive eradication of wild plants from farmland have been shown to harm the environment. These problems are similar for non-GM and GM crops.

In a large farm scale evaluation of herbicide tolerant GM crops conducted in the UK between 1999 and 2006 it was shown that when weed control is particularly effective insect biodiversity is reduced. It did not matter whether or not the crop was GM, the important factor was how many weeds remained in the crop. Damage to wildlife can be reduced if a small amount of agricultural land is set aside for biodiversity²².

A related issue is the growing problem of weeds becoming resistant to herbicides, due to the overuse of those herbicides. Herbicide tolerant crops, whether GM or non-GM, can cause this problem because repeated growth of the same herbicide tolerant crop involves repeated use of the same herbicide. One solution is the rotation of crops resistant to different herbicides, or rotation of herbicide use with use of other weed control strategies.

The use of GM crops resistant to insects through introduction of the gene for Bt toxin has environmental benefits. For example, GM insect resistant cotton has substantially reduced the application of more environmentally damaging insecticides, with consequent environmental benefits and health benefits for cotton farmers.

Damage to wildlife can be reduced if a small amount of agricultural land is set aside for biodiversity.

However, just like herbicide resistant weeds, insect pests can develop resistance to insecticides whether they are produced in the crop itself by GM, or sprayed onto the crop. This problem is less frequent if a rotation of different insect control procedures is used.

22. <http://webarchive.nationalarchives.gov.uk/20080306073937/http://www.defra.gov.uk/environment/gm/fse/> (Retrieved 16 May 2016)

QUESTION 11

If we grow GM crops will they cross-breed with other plants?

Yes. GM crops may cross-breed with closely related plants. This includes non-GM varieties of the same crop and wild relatives of the crop. For GM crops approved by regulators the consequences of cross-breeding have been assessed and judged not to be a risk to health or the environment.

Both non-GM crops and GM crops can cross-breed with closely related plants. Cross-breeding between crops and their wild relatives could cause problems if this results in the wild relative acquiring characteristics that might make it more weedy and invasive. For example, herbicide resistant weeds could be produced if a herbicide tolerant crop,

GM or non-GM, were to breed with weedy relatives. Their offspring might be resistant to the herbicide if they inherit the tolerance gene from the crop. Other herbicides would then have to be used to control these weeds.

Image

Germinated wheat. © tuchkovo.



QUESTION 12

What can be done to prevent cross breeding of GM crops?

Research has been conducted aimed at making GM plants that cannot reproduce. There are various ways to do this, but the most high profile has been Genetic Use Restriction Technologies (GURTs) or ‘terminator seed’ technology. The seeds from these GM plants would be prevented from germinating, so if they breed with wild relatives there would be no viable offspring. However this technology would also prevent farmers from being able to save seeds to plant in future years. There has been an international moratorium on the use of terminator seeds since 2000.

Genetic use restriction technology (GURT) is based on the prevention of seed germination and was patented in the 1990s by the US government and licensed by commercial companies, including Monsanto. The technology was never shown to work reliably in practice. The concept became known as ‘terminator seed’ technology since the plants would not be able to produce fertile seeds. In 2000, the United Nations Convention on Biological Diversity introduced an international moratorium on the use of GURTs because of concern about the potential economic effect on farmers, who would not be able to save seed for future planting.

Saving seeds is not legal for either GM or non-GM crops where licence restrictions are in place. In addition farmers and gardeners alike will be familiar with F1 hybrid varieties, made by crossing together diverse parents, from which seed cannot be usefully saved because they don’t breed true.

Saving seeds is not legal for either GM or non-GM crops where licence restrictions are in place.



Above
Wheat field trials. © John Innes Centre.

QUESTION 13

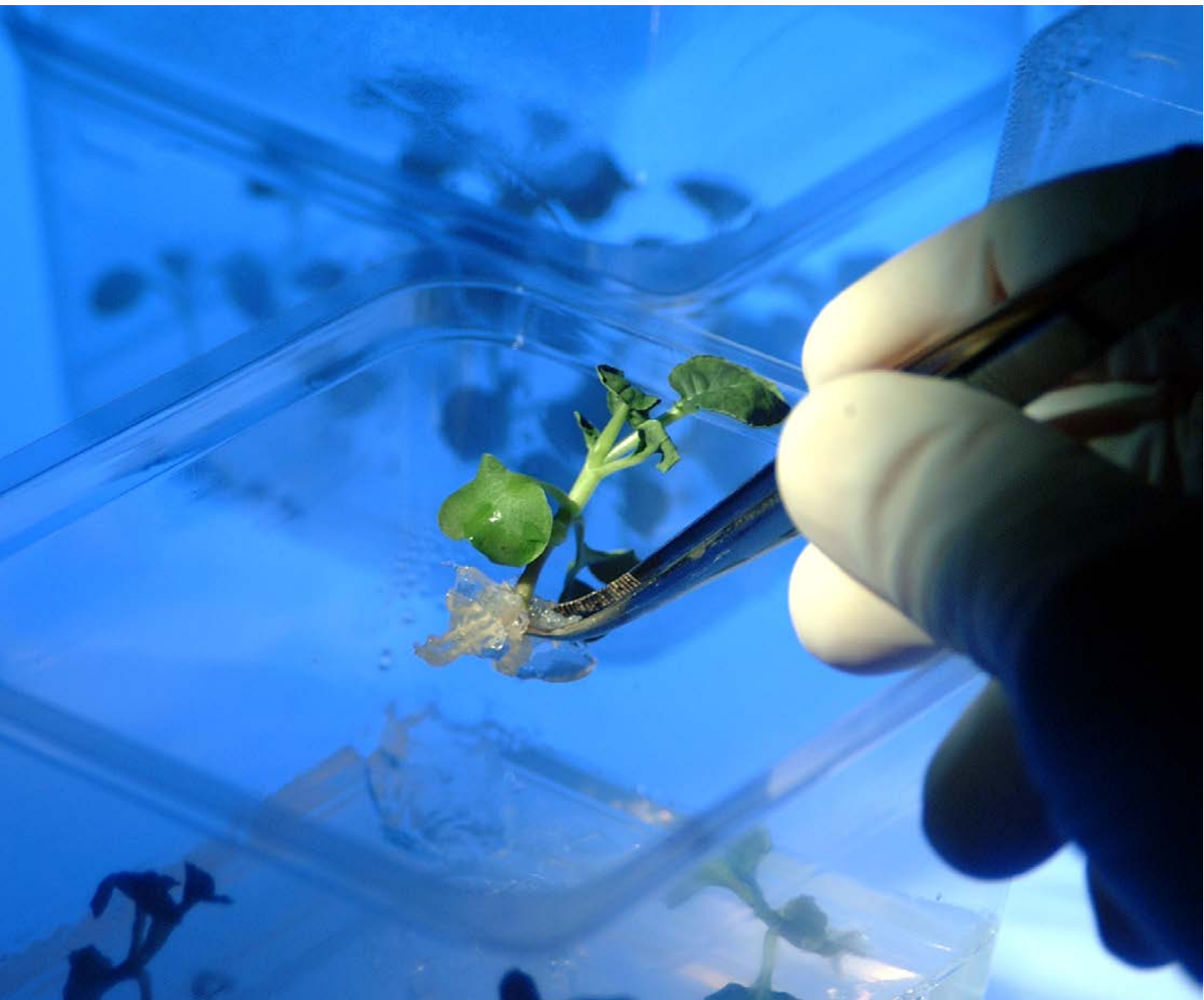
GM crops have only been around for 20 years, might there still be unexpected and untoward side effects?

Yes, there could be unexpected side effects from any new crop variety, GM or non-GM, as well as with any new agricultural practices. Risk assessment and appropriate testing of all new crops, along with ongoing monitoring should mitigate the risks.

GM crops are more extensively tested than non-GM varieties before release (see Q14) both for their environmental effects and as foods. They also tend to have fewer genetic differences from their predecessor than new non-GM varieties.

Image

GM Brassica. © John Innes Centre.



QUESTION 14

How are GM crops regulated?

GM crops cannot be grown, either for experiments or commercial farming, without approval by the appropriate regulatory agency, in the UK by DEFRA^{23,24}. The movement of GM crops or food between countries is also regulated. Details of this process vary from country to country but the same objectives underlie all regulation; that the novel GM crop is safe for human or animal health and the environment.

All applications to develop a GM crop within the EU are assessed using the same regulatory system. This involves the European Food Safety Authority (EFSA)^{25,26}, the regulatory authorities of independent member states and, finally, approval by the central European authorities in Brussels. A recent change has given final responsibility for local implementation back to member states, who can now decide whether to opt out from cultivation of a GM crop that was authorized at the EU level. The assessment covers details supplied by the applicant, including the particular GM method used, information about the inserted DNA and characteristics of the plant, and results from animal feeding trials, where appropriate.

Applications also include an environmental assessment, which examines the possible interactions between the GM crop and factors like soil and other organisms in the ecosystem.

Since 1992, the EU has approved 2404 experimental GM field trials for research. In comparison, over the same time there have been 18,381 GM trials for research in the USA²⁷. In crops for commercial use, there is only one GM crop, an insect resistant maize variety, that is grown commercially in the EU and no GM crops have yet been approved for human consumption as fresh fruit or vegetable. In comparison there have been 117 commercial releases in the USA since 1992²⁸ and in other countries outside Europe. For example, since 1995 there have been 3 permits for commercial releases in China, 41 in Brazil and 93 in Canada²⁹.

Regulatory systems differ around the world. While EU regulations focus on the technique used to modify the crop, other systems, like the Canadian system³⁰, focus on the characteristics of the crop produced. In other regions, including many countries in Africa, biosafety regulation is still being developed.

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23. Nicolia A, Manzo A, Veronesi F, Rosellini D. 2014. An overview of the last 10 years of genetically engineered crop safety research. *Crit Rev Biotechnol.* 34(1):77-88.
 24. Smyth, S. & Phillips, P.W. B. (2014) Risk, regulation, and biotechnology: The case of GM crops. *GM Crops and Food* 5(3):170-177
 25. Devos Y, Aguilera J, Diveki Z, Gomes A, Liu Y, Paoletti C, du Jardin P, Herman L, Perry JN, Waigmann E. 2014. EFSA's scientific activities and achievements on the risk assessment of genetically modified organisms (GMOs) during its first decade of existence: looking back and ahead. *Transgenic Res.* 23(1):1-25.
 26. Raybould, A. & Poppy, G.M., 2012. Commercializing genetically modified crops under EU regulations: objectives and barriers. *GM Crops and Food: Biotechnology in Agriculture and the Food Chain*, 3(1), 9–20.
 27. <http://www.isb.vt.edu/search-release-data.aspx> (acknowledged notifications and issued release permits) (Retrieved 16 May 2016)
 28. <http://www.isb.vt.edu/search-petition-data.aspx> (approved petitions for deregulation) (Retrieved 16 May 2016)
 29. <http://www.cera-gmc.org/GMCropDatabase> (Retrieved 16 May 2016)
 30. Smyth, S.J. (2014) The state of genetically modified crop regulation in Canada. *GM Crops and Food.* 5(3): 195-203

QUESTION 15

Who is paying for GM crop development and who owns the technology?

The discoveries that enabled GM technology were largely made by public sector scientists. They went on to develop the technology further, as did scientists in the commercial sector. The public and private sectors, along with charities, own GM methods and plants and continue to invest in GM research and crop development. They take out patents on discoveries and techniques. Most current GM methods and GM crop varieties are owned by companies.

Owners of intellectual property, such as patents and registered varieties, can insist on payment of a license or royalty fee by other users of their proprietary technology. These patents also ensure that the science and technology behind an invention are available for anybody to read. This framework also applies to drug development, and to other discovery- or invention-dependent products, including increasingly to non-GM crops. Conventional non-GM crops may also have licence agreements and restrictions on saving seed.

Patents give rights to the companies that develop new crops. Farmers who buy seed protected by some types of patent must sign an agreement not to sell or save seed from these crops – so they are obliged to buy fresh seeds every year.

GM crop research is also funded by national research agencies and by charities, such as the Bill and Melinda Gates Foundation, where patents are held for the public good. Public, private and charity sectors can work closely together.

Farmers who buy seed protected by some types of patent must sign an agreement not to sell or save seed from these crops – so they are obliged to buy fresh seeds every year.

Patent holders may choose to release their GM varieties without charge for public benefit. Golden rice – the GM rice being developed as a source of vitamin A – will be available free of charge in regions of the developing world where people are suffering from vitamin A deficiency.

Some of the early GM patents have expired or will soon expire. This may mean farmers will be able to save some GM seed for re-planting, or that other companies can make cheaper versions of the crops. The outcome is uncertain because of standard varietal protection on some of the seed and the potential need for new regulatory approvals if a GM trait is used in a conventional breeding programme.



Image
Cambodian woman harvesting
rice in field. © phiesen.



Image
Soybeans ready for harvest.
© ghornephoto.

QUESTION 16

Are there examples where GM has not delivered the promised improvements in crops?

Yes, there are cases where a GM crop has not delivered the intended improvements such as increased crop yields or virus resistance. The same problems arise with conventional breeding approaches.

Some of the first GM herbicide-resistant soybean varieties had lower yields than non-GM varieties, in spite of the promise of better yields with better weed control. The new DNA for herbicide resistance was transferred into low yielding varieties that were available when the GM project was started. Some farmers still adopted these GM varieties because they were able to control weeds with less labour and energy than with the conventional variety.

Another crop that has been slow to deliver its promise is GM rice produced for the *Golden Rice* project. This initiative aims to address vitamin A deficiency in some parts of the world by adding genes to the rice to improve its nutritional content. But the first varieties did not work well enough

and would not have adequately bolstered vitamin A in the diets of populations needing it. Improved varieties are now undergoing field trials.

A frequent criticism of GM is that it has failed to deliver more than herbicide tolerance, insect resistance and a few examples of disease resistance. This is because these uses are based on genes available 20 years ago. With increasing knowledge of gene function, new GM crops with other characteristics are being developed and some of these are close to becoming available to farmers³¹ (see question 17). Of course among these new applications, there are likely to be failures as well as successes.

BOX 2^{32,33}

'Whiffy wheat'

Recent work to produce a GM wheat that repelled aphids did not work as anticipated. The GM wheat, nicknamed 'whiffy wheat', was expected to ward off aphids by releasing an alarm signal scent. In the wild, when released by aphids the scent causes aphids to flee. It also attracts aphid predator species, which have learned that this is a signal for finding aphids.

After success in the lab, the genetically modified wheat turned out to be ineffective at repelling aphids in the outdoor trial. Although the wheat failed to repel aphids, this has generated further hypotheses that the scientists will go on to test.

Anti-GM groups criticised the research, saying that it was a waste of public funds on a technology that had yet to yield the promised breakthroughs.

31. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/292174/cst-14-634a-gm-science-update.pdf (Retrieved 16 May 2016)

32. <http://www.independent.co.uk/news/science/field-trial-of-genetically-modified-wheat-failed-to-show-it-can-repel-aphid-pests-scientists-say-10345202.html> (Retrieved 16 May 2016)

33. <http://www.telegraph.co.uk/news/earth/agriculture/geneticmodification/11698763/Pointless-3m-GM-wheat-trial-fails.html> (Retrieved 16 May 2016)

QUESTION 17

What new GM crops are being developed?

GM crops are being developed to be more disease-resistant, to have enhanced nutritional value, increased drought tolerance and improved uptake of nutrients, such as nitrogen. They are being tested in the laboratory or in contained field trials – in which plants are grown in an area to prevent spread into the environment.

Crop disease is a big problem for farmers and GM can be used to produce disease resistant plants. Disease resistance genes from wild relatives can be transferred into commercial crops using GM. For example, there have recently been very promising field trials of a GM blight-resistant potato. A gene from a wild relative in South America has been introduced which triggers the potatoes' immune system to recognise blight³⁴. The potatoes have not been commercialised yet and would be labelled GM if they were in supermarkets.

GM can also be used to enhance the nutritional value of crops in the human or animal diet. The Golden Rice project, to make rice a source of Vitamin A, is one such example. The World Health Organization estimates that up to half a million children become blind every year due to Vitamin A deficiency³⁵ and Vitamin A deficiency can also reduce resilience to infection. Golden Rice is in field trials in the Philippines and Bangladesh and is completing the regulatory requirements in these two countries.

GM crops are also being developed to help decrease pollution of rivers and seas. One such crop aims to reduce the environmental impact of manure. Cereal and grain based animal feed often contains seeds with high levels of a compound called phytic acid, which passes into manure undigested. This can contaminate soil and waterways like rivers with phosphate, which harms fish and aquatic life.

GM has been used to produce seeds low in phytic acid content so that this pollution risk could be reduced³⁶.

There are other long term GM projects that aim to produce nitrogen fixing cereals (plants that will harness nitrogen from the air as a nutrient), improve the efficiency of photosynthesis and produce perennial crops that would not need planting each year. Examples of both medium and long term projects are described in more detail in a recent report by the Council for Science and Technology³⁷.



Image

Golden rice (GM) compared with non-GM rice. © FotografiaBasica.

34. <http://www.tsl.ac.uk/news/gm-spuds-beat-blight/> (Retrieved 16 May 2016)

35. <http://www.who.int/nutrition/topics/vad/en/> (Retrieved 16 May 2016)

36. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/292174/cst-14-634a-gm-science-update.pdf (Retrieved 16 May 2016)

37. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/292174/cst-14-634a-gm-science-update.pdf (Retrieved 16 May 2016)

BOX 3

Making farmed fish more nutritious

An example of the use of GM to enhance the nutritional value of food involves the “good fats” we normally obtain from eating oily fish like salmon. These long chain omega-3 fatty acids are healthy for the heart and brain.

Fish need these Omega-3 fatty acids to stay healthy but do not produce them naturally themselves. They get them from marine algae that are eaten by small fish and passed up the food chain. Farmed fish consume large quantities of fish oils mainly through fish meal and it is possible that conventional sources of fish oil may not be able to meet future demand.

Scientists have used GM to transfer the algal genes that make these fatty acids into oilseed crops. These could be fed to farmed fish and in the longer term, the fortified crops could be used to supplement other foods with omega-3 fatty acids for human consumption.

Image

Sea fish farm. © Takis_Milonas.





Image
Aerial view of circular irrigation.
© Kris Hanke.

QUESTION 18

What methods other than genetic improvement can improve crop performance?

Crop genetic improvement, by GM or conventional approaches, is only one of many methods that can be used to improve crop performance. Others involve improvements in farm practices, irrigation, drainage, and herbicide, pesticide and fertiliser use. Better food storage and transportation to reduce waste can also play their part in securing a reliable supply of foodstuffs.

Remote sensing combined with computer technology is leading to better prediction and prevention of disease epidemics.

Genetic methods to improve sustainable increases in yield are very attractive because seed can easily be distributed to producers. It is also an attractive commercial target, because seed is a definable product that can be traded.

Other developments include the use of GPS (global positioning systems) in what is called precision agriculture, so that fertilizers and pesticides are applied only where they are needed and in the right amounts. Remote sensing combined with computer technology is leading to better prediction and prevention of disease epidemics. And robots are being developed that could selectively kill the weeds growing among crop plants.

New understanding of the interactions between crops and other plants or with microbes in the soil will also inform a farmer's choice of crop management.

None of these innovations, including GM, are exclusive of each other and although some may be more expensive to implement than others, all could play a part in delivering sustainable agriculture that meets global needs.

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