The production of genetically-modified foods remains a mystery to many. Over the past year Murray Ballard, a photographer, and Elliot Hammer, a graphic designer, have visited the John Innes Centre – Europe’s largest independent research facility for the study of plant science and microbiology – with the aim of gaining a deeper understanding of genetic modification technology and its application in the development of crop plants.
About the Project

Genetic modification (GM) refers to the direct human manipulation of an organism’s genome using modern DNA technology.

This newspaper/exhibition is about understanding the science behind GM and its application in the development of crop plants.

This project has been researched by two ‘non-scientists’ – Murray Ballard, a photographer, and Elliot Hammer, a graphic designer – who have followed three scientists working at The John Innes Centre - Europe’s largest independent research facility for the study of plant science and microbiology.

This newspaper/exhibition is divided into three sections, each dealing with a different experiment. The first looks at the development of drought resistant barley and the initial stages of the genetic modification process. The second section goes on to look at the development of tomatoes with increased levels of nutrition. This section delves into more detail and explains how a particular piece of DNA is selected and transferred. It also looks at the testing processes and the comparison between genetically and non-genetically modified tomatoes. The final section follows the field trials of blight resistant potatoes. This part of the experiment takes place after the genetic modification has been carried out and is designed to test the effectiveness of the new potato crop.

We sincerely hope this project helps you to gain a better understanding of the science and inspires you to further your knowledge of the subject.

We are keen to make this project a dialogue rather than just a presentation of what we have found. We would like to hear your responses to this newspaper/exhibition and have included comments cards, which can be filled out and posted to us.

To make the project as accessible and as engaging as possible it can be read as a newspaper or two copies can be dismantled and displayed as an exhibition. More information and online version of project can be found at: www.howtogeneticallymodifyato.mato.info

Publicly Funded, Independently Researched

Throughout this project we have strived to provide a neutral and transparent representation of what we found. We have received funding from the following sources for the project:

British Science Assoication Agriculture and Food Section
John Innes Centre
The Sainsbury Labaratory

1 The genome is the entirety of an organism’s hereditary information.

2 DNA is a nucleic acid that contains the genetic instructions used in the development and functioning of all known living organisms (with the exception of RNA viruses). The DNA segments that carry this genetic information are called genes, but other DNA sequences have structural purposes, or are involved in regulating the use of this genetic information. Along with RNA and proteins, DNA is one of the three major macromolecules that are essential for all known forms of life.
Dr Wendy Harwood

Wendy Harwood leads a research group working on genetically modified (GM) crops. She has over 20 years experience working in this area and her group works to improve the technology for genetic modification, to increase understanding of the genetic modification event, and to provide data for use in the safety assessment of GM foods. Wendy is active in science communication and she is an Honorary Lecturer at the University of East Anglia.

Dr Cathie Martin

Cathie Martin is a project leader at the John Innes Centre, the leading plant research institute in Europe and Professor at the University of East Anglia. Her interests span from fundamental to applied plant science. She is particularly interested in cellular specialisation in flowers (colour and cell shape) and how these traits are used by different plants for pollinator attraction.

Recently she has been co-ordinating research into the relationship between diet and health and how crops can be fortified to improve diets and in developing genetic screens to identify crops which lack toxins that cause nutritional diseases, such as konzo. She is Editor-in-Chief of The Plant Cell, through which she has been piloting new features in scientific publishing, including ‘Teaching Tools in Plant Biology’ and she is a co-author of the undergraduate-level textbook: Plant Biology published by Garland Science (2009).

Murray Ballard

Murray Ballard is a photographer born and based in Brighton, UK. He graduated from the University of Brighton in 2007 with a BA (Hons) in Photography, and was selected for Fresh Faced and Wild Eyed ’08, the annual showcase of work by the most promising recent graduates at The Photographers’ Gallery, London. In 2011 the British Journal of Photography recognised him as one of the ‘Emerging Photographers of Note’ following his debut solo show, The Prospect of Immortality, at Impressions Gallery, Bradford. His work has been published in many international magazines and newspapers including: The Guardian, The Independent, GEO, Wired, Intelligence in Lifestyle, and the photography journals: 8 and YVI. As well as working on his own projects he continues to assist renowned Magnum photographer Mark Power.

Elliot Hammer

Elliot Hammer graduated from Typo/Graphic Design course at the London College of Communication and is the Creative Director of Birch, an interdisciplinary design studio based in London.

He is a tutor at the Colchester School of Art and Design as well as one of the founding members of Black Box Press, a not for profit platform for designers, writers and artists to publish their work and further collaborative projects.

He has a keen interest in science but is particularly interested in engaging individuals and communities through communicating complex ideas simply to promote discussion and action.

Thank You

Firstly, thank you for taking the time to be part of the project. We would also like to thank (in no particular order) ...

Simon Foster, Cathie Martin, Wendy Harwood, Eugenio Butelli, Steve Mackay, Yang Zhang, Matthew Smoker, Dee Rawsthorne, Dawn Barrett, Paul Pople, Sân Astley, Catherine Reynolds, Zoe Dunford, Andrew Chapple, Jonathan Jones, Walter Verweij, Kamil Witk, Sara Perkins, Laurence Tomlinson, Stephen Johnson, Kevin Crane, Max Gosling, Barry Robertson, James Allen, Varvara Zaytseva, Hae Ni Kim, Gabriella Rizzello, Rob Hornstra, Mark Power, Oliver Perrott, Kathryn Hall, Rob Savage, James Rosington, Anne McNeill, Sarah Deane, Pippa Oldfield, Indya Mealing, Jennifer Sobol, Angela Sheard and everyone else that has helped us throughout the project.

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All photography by Murray Ballard except photographs of potato blight which were kindly provided by Walter Verweij.
Wendy Harwood works on the genetic modification of cereal crops including barley. Her group concentrates on developing improved technologies for genetic modification and are also interested in understanding the genes that allow plants to cope with drought conditions.
Barley is the fourth most important cereal crop in the world and is the most widely grown in semi-arid areas of countries such as Jordan, where lack of water is the most important factor limiting yield.

A large amount of research has been carried out to understand which genes allow plants to cope better with drought. Certain genes act as ‘master switches’ which control a large number of other genes that need to be switched on to help the plant cope in drought conditions. Some of these genes are now being tested in barley, using genetic modification, to see if the crop can be improved to grow better under drought conditions.

Barley is easy to genetically modify using a naturally occurring soil bacterium, Agrobacterium, to introduce the new gene. This bacterium is able to transfer a piece of its own DNA into plant cells. In nature the bacterium uses this process to cause Crown Gall disease which results in the growth of familiar galls on many plants. Scientists use Agrobacterium that no longer causes the disease symptoms, but still has the ability to move DNA into plant cells, for genetic modification. Agrobacterium has been referred to as ‘Nature’s own genetic engineer’.

As well as a method to introduce the new gene, successful genetic modification needs a suitable plant target tissue to accept the new gene. In barley the best targets are immature embryos that are isolated from immature seed. When immature embryos are provided with the correct nutrients and plant hormones they divide rapidly to form a ‘callus’ which is a disorganised mass of cells. Many individual cells within the callus are capable of forming a whole new barley plant.

Agrobacterium is used to introduce the new gene into cells within immature embryos. As well as the new gene of interest, a second gene is introduced that makes the cells resistant to an antibiotic. When the immature embryos are grown in the presence of the antibiotic, only the genetically modified cells containing the antibiotic resistance gene will grow. This allows genetically modified cells to be selected, however, the antibiotic resistance gene can later be removed so genetically modified plants contain only the new gene of interest.

The genetically modified cells within the immature embryo divide and form a genetically modified callus. After about 12 weeks of culture it is possible to regenerate genetically modified plants from the callus.

This method is being used to introduce some of the ‘master switch’ genes into barley and is enabling us to understand the genes involved in making plants more tolerant to drought. This is the first step to producing new barley varieties that will give higher yields under drought conditions.
In nature Agrobacterium causes Crown Gall disease. The familiar galls seen on many plant species are the result of Agrobacterium infecting wounded plant tissue. When the bacterium infects plants it transfers genes responsible for the growth of the gall as well as genes that direct the plant cells to make compounds used by the bacterium as a food source. For use in genetic modification, the bacterial genes needed for the disease symptoms have been removed from Agrobacterium, but the genes needed for DNA transfer retained.
Agrobacterium is a naturally occurring bacterium which introduces a portion of its own DNA into plant cells.
Selection of a barley spike with immature embryos of the correct size. Individual spikes are collected from the barley plants in the controlled environment room and checked to make sure that the immature embryos are at the correct stage.

To find the correct stage, a single immature seed is taken from the middle of the spike so that the size of the immature embryo can be checked.
A barley embryo on Wendy’s finger. Each cell within the embryo contains all the genetic information required to grow a barley plant. Immature embryos of 1.5-2mm in diameter are the correct size to use as target tissue for genetic modification. When the correct size of immature embryo is found, the spike that it came from is collected to take back to the laboratory to use for genetic modification experiments.
The plants that provide the immature embryos for genetic modification experiments, and the young GM barley plants produced, are grown in a controlled environment room with GM plants later moved to a containment glasshouse.

Controlled growth conditions are very important to give high quality immature embryos for genetic modification experiments. Once the GM plants are mature and dry, the seed is harvested and used to produce the next generation for analysis.
To obtain the best possible genetic transformation results, the plants from which the immature embryos are collected must be grown under controlled conditions. This ensures that good quality starting material is available all year round.
After a further 2 weeks, the plant hormones are removed altogether and small GM plants develop on the plates. When the plants are large enough they are transferred to glass tubes for rooting.

At this stage the plant hormones in the nutrient medium are changed to promote regeneration of plants rather than callus growth.

The callus from each immature embryo is cultured for 6 weeks, with fresh nutrient medium every 2 weeks, before being placed in low light.

When roots are well established they are transferred to soil. At this stage molecular techniques are used to check that the gene of interest is present in the plants.
The day after isolation of the immature embryos they are ready to be genetically modified. A bacterial method is used to introduce the gene of interest. Agrobacterium is a bacterium found in the soil and normally responsible for crown gall disease in plants. It is often referred to as nature’s own genetic engineer as it causes the disease by transferring some of its own DNA to the plant cells. Scientists have enabled Agrobacterium to transfer genes of interest into plant cells but without causing the disease symptoms. Agrobacterium is simply pipetted onto the immature embryos and the embryos are then transferred to a clean plate and incubated with the bacteria for 3 days.
Isolation of immature embryos. The immature embryos are only 1.5-2mm in diameter so they are isolated under a microscope. All work is carried out in a laminar flow hood under sterile conditions. The embryos are isolated using very fine forceps and the embryonic axis is removed from each embryo to prevent them from germinating. They are then placed onto nutrient medium in a petri dish.
Cathie Martin works on cell specialisation in plants. Her group is currently focused on optimising genetic and regulatory processes within cells for nutritional enhancement of tomato and orange.
The colour or pigment in the flowers and fruits of most plants are created by compounds called anthocyanins which are naturally occurring health-promoting chemicals found in high levels in berries such as blackberry and cranberry. As part of the human diet, anthocyanins and related chemicals called flavonoids, protect us against a broad range of diseases such as cancers, heart disease and age-related degenerative diseases. There is also evidence that they have anti-inflammatory properties, improve vision and help prevent obesity and diabetes.

If commonly eaten fruits and vegetables such as tomatoes could be produced with higher levels of these naturally occurring compounds this would help people have healthier diets.

It was found that two genes in snapdragon induce the production of anthocyanins in snapdragon flowers and these have been identified and also found to be present in tomatoes. However, in fruit they are inactive or switched off. The genes were turned on in tomato using genetic modification which resulted in fruit with much higher anthocyanin levels, higher than anything previously reported in both the tomato peel and flesh. The fruit are an intense purple colour due to the increased levels of anthocyanin pigment.

Cancer-susceptible mice fed a diet supplemented with the high anthocyanin tomatoes showed a significant increase in life span compared to animals fed a diet supplemented with regular tomatoes. The next step will be to do human studies with volunteers.

This is one of the first examples of genetic modification that offers the potential to promote health through diet by reducing the impact of chronic disease and the first example that really offers benefit for all consumers.

If this is successful, it may be possible to increase the levels of other naturally occurring plant nutrients with health-promoting properties in tomatoes.
The anthocyanin pigments produced in the purple tomatoes are the same as pigments produced in leaves of regular tomatoes, particularly when they are stressed. These purple pigments are easy to see in old, dry leaves of red tomato plants.
the fruit purple and are the same pigments as found in blackcurrants and blackberries.

Tomato plants genetically modified to produce high levels of anthocyanin pigments in their fruit. The anthocyanin pigments make
Extracts of juice from control red tomatoes (left) and purple tomatoes (right) demonstrating the high levels of anthocyanin pigment in the purple fruit.
Freeze-dried powder of purple tomatoes (right) and control, red tomatoes (left) ready for incorporation into mouse food to test for health properties of anthocyanin pigments.

This is not a GM tomato but a ‘natural’ variety (called Sunblack) which has anthocyanin in the skin of the fruit. However because anthocyanins are not produced in the flesh, their levels are much lower than in the GM purple tomatoes shown.

The anthocyanin in the GM purple tomatoes is produced at high levels in both the skin and the flesh.
The transformation experiment in process; Cotyledons\(^1\) are excised from 10 day old tomato seedlings, wounded and immersed in to a suspension of Agrobacterium carrying our gene of interest. Cotyledons are blotted briefly and placed abaxial side uppermost (upside down) on to co-cultivation plates for 2 days.

\(^1\) an embryonic leaf in seed-bearing plants, one or more of which are the first leaves to appear from a germinating seed.
Digestion of the DNA used to transform tomato to confirm that the genes are in the correct order. The DNA has been cut with different enzymes such as EcoRI and KpnI (map of genes used to produce tomatoes) and then the DNA has been separated using gel electrophoresis. The same DNA in the different tracks has been digested with different enzymes. The DNA fragments move through the gel at different speeds, according to their size (smallest move fastest). The DNA has been stained with ethidium bromide so that it fluoresces under UV light. The first track on the left has been loaded with DNA size markers (a 1 kb ladder) to allow the sizes of the digested DNA fragments to be measured.
Anthocyanins are pigments produced by most flowering plants in their flowers and in some fruits.
Transformation of tomato. Shoots are regenerated from callus which forms on tissue explants that have been inoculated with Agrobacterium and cultured on medium containing plant hormones.

Shoots regenerated from explants inoculated with Agrobacterium are cultured on selective medium to identify which plants make roots (resistant to the antibiotic selection) and are therefore transformed.

Successful selection of a transformed line. Root growth on selective medium is a reliable sign that the new plant carries the genetic information for antibiotic resistance and, alongside, the new genetic trait.
Mature GM tomato plant. The genes inducing anthocyanin production are expressed only in ripe fruit, so the plants look just like regular tomatoes until the fruit start to ripen and the purple colour starts to form.
Samples prepared for separation. These containers store a collection of all of the DNA required to make the changes to the tomato plant (shown on the map of genes used to produce tomatoes). The DNA can be placed onto a rectangular gel and separated using gel electrophoresis. This enables the scientists to identify particular sections of DNA by their size.
Enzymes used to cut DNA into pieces and to determine whether the new DNA is inserted in the host genome appropriately.
Gene conferring kanamycin resistance in transformed plants

Left Border
Marks the start of the genetic information which is to be transferred to the tomato

MAP OF GENES USED TO PRODUCE TOMATOES

E8 Promoter
Specific to the fruit of the tomato. This ‘switches on’ the gene.

Gene conferring kanamycin resistance in transformed plants
CMV
This DNA signals the end of the gene

Delila and Rosea1 genes
(Antirrhinum majus) From Snapdragon
Delila and Rosea1 proteins interact and activate anthocyanin biosynthesis in snapdragon flowers

Right Border
Marks the end of the genetic information transferred to the tomato

Tetracycline Resistance
A gene which makes the agrobacterium resistant to tetracycline. This is used to select bacteria carrying the new genetic material.

The enzymes which were used to build the genes for transformation of tomato. These enzymes provide a map of the DNA which can be used to verify its structure

Xhol::SalI
HI
EcoRI
KpnI
BamHI
SstI
Xhol
EcoRI
EcoRI
EcoRI

E8 p
ROS
CMV.
RB
TET'r
Simon Foster is in charge of running the potato field trials. These GM potato plants in the glasshouse are being grown in pots to produce tubers ready for planting in the 3rd year of the field trial in 2012. The hairnet is to prevent transfer of insect pests from the outside onto the glasshouse-grown crop.
Potato is the fourth most important food crop in the world and is widely grown in Europe, USA, South America, Canada, China, India and Africa.

Many diseases caused by viruses, bacteria and fungi reduce potato production. The most serious disease affecting potato is late blight, caused by a fungal-like mould called Phytophthora infestans. Late blight was the cause of the Irish Potato Famine in the mid 19th Century when millions of people in Ireland either starved or emigrated as a direct result of this devastating disease.

Since then, a lot of effort has gone into introducing resistance to potato late blight in cultivated potato varieties that we find in our supermarkets today. Despite this effort late blight is still the main problem facing modern potato growers because late blight is very adaptable and it has evolved and overcome much of the resistance bred into modern potato varieties. Modern pesticides have made it possible to prevent late blight epidemics from causing the hardship that we have seen in the past, but farmers need to spray their crops heavily to prevent disease. Late blight can decimate a potato crop within 10-14 days if untreated and so growers will spray their crops weekly as an insurance against late blight – a crop can receive as many as 15 sprays in a season.

Potato and late blight originated in South America and have co-evolved over many centuries but wild South American potatoes have effective resistance genes against late blight. These genes have been identified and put into popular UK potato varieties using genetic modification. Field trials are currently taking place to see how effective these genes are in protecting the potatoes against late blight with the aim of reducing the reliance on chemical fungicides to protect crops.

Potato is very easy to genetically modify using strains of nature’s genetic engineer the bacterium Agrobacterium tumefaciens, which transfers only specific genes (the ones we wish to transfer) into cells of potato. Unlike barley where immature embryos are used, stem pieces are used for making genetically modified potato plants. Cells which have received the gene from the bacterium form a mass of undifferentiated cells, or callus, on the cut ends of the potato stem pieces. These changed or ‘transformed’ cells are encouraged to form new shoots and roots and after a few weeks become a genetically modified potato; exactly the same as the original potato, except that it now contains the additional introduced gene, in this case resistance to potato blight.

As potatoes reproduce by the production of tubers we can quickly produce many potato plants that are identical to the original genetically modified potato. These potatoes have been planted in a field trial in Norwich and are proving to be very resistant against potato late blight, without requiring any pesticide sprays.
A sample of the genetically modified crop before planting. Non-genetically modified potatoes on the left and genetically modified potatoes on the right. Due to the weather the planting day was delayed and the potatoes over developed, growing stalks. The field trial continued as normal.
Some wild potato species in South America possess effective resistance genes against late blight. These genes have been transferred into potato cultivars that are popular amongst consumers.
Photographs from the first trial in 2010. Late August and blight has entered the trial crop. The non-GM plants have been killed by the disease. The remaining green plants are the GM plants which contain an additional blight resistance gene and the Maris Piper guard plants. After a further week, the Maris Piper plants were also destroyed by blight.
This is what the potato plants look like 2-3 days after infection, the leaves become brown and shrivelled. These diseased leaves also carry millions of infective spores that will spread late blight to neighbouring plants and crops.
On the 5th of May 2011 a total of 192 GM potatoes were planted in the field trial and will be positioned according to a planting plan. To ensure no mistakes are made, holes are systematically dug before any tubers are planted.
All potatoes are cultivated in the same way as any other potato variety.
Potato berries: Potatoes are propagated by planting tubers, which are clones of the parent plants. These berries are produced by pollination of potato flowers. Potatoes predominantly self-pollinate, as they are generally not visited by pollinating insects (potato flowers contain no nectar reward for insects). The berries are of no use in this stage of the experiment and are therefore collected in order to reduce the amount of seed that could germinate and produce volunteer plants in the following season.
Due to the planting of the potatoes being later than planned they are carefully placed so that the shoots are pointing upwards. Once grown they will form the stem of the plant.

The potatoes will be tended to for the next five to six months throughout the experiment. Next year’s potato trial will be placed in a new area of the field, as is normal for potato cultivation.
All of the potatoes are carefully labelled as they have a specific place in the field trial. The position of the GM plants in relation to the non-GM ‘control’ plants was randomised throughout the field trial area. This is done to prevent positional effects from affecting the results of the experiment. For example, if the GM plants were always planted toward the centre of the trial area, they may be more protected from exposure to late blight than the non-GM plants. For similar reasons, the GM and non-GM plants (all Desiree variety) are surrounded by a ‘guard’ crop of the variety Maris Piper to prevent any difference in the exposure of the experimental plants to wind, rain and other external environmental factors.
Genetically modified potato plant (Desiree)
Non genetically modified potato plant (Desiree)
Guard Crop (Maris Piper)
Coloured tags indicate where the GM and non-GM potatoes are planted. The plant on the right (with the red tag) is the genetically modified variety and contains an extra resistance gene against potato late blight. The plant on the left (with the yellow tag) is a non-GM Desiree plant.
This is the second in a three year trial. Each year the potatoes are grown on a new section within the caged area to make sure that the plants are not damaged.

This photograph was taken on the 1st of July 2011 before any signs of late blight, but it’s important to keep checking the crop for signs of pests and diseases. As this crop is not being sprayed with fungicide there is always the possibility that other fungal diseases could infect the crop.