Nuffield Farming Scholarships
The Frank Arden Memorial Award

The
Appliance of New Science
and
Frontier Technologies
to
Transform UK Agriculture
And
UK Agri-Food

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Forward

The last 8 months have been a journey for me. My brief was to produce a report that would enthuse UK farmers about New Science and Technology. When I started I expected to study new science relating to conventional husbandry but I found it to be of an incremental nature rather than transformational. My understanding is that a Nuffield Scholarship never quite works out as you first expect.

I have pursued five broad areas of new science and technology that I believe have the potential to transform UK agriculture over the coming years. They are all offering opportunities to UK farmers right now and will offer much more as they continue to develop.

My intention was to produce a report that outlined the basic science behind the technology and then demonstrate the potential of that technology with a number of very diverse case studies. The report should be 'an interesting read for the thinking farmer'. I hope it meets its purpose and inspires the reader to take a greater interest in new technology in the future. I look forward to hearing that some readers have followed up the case studies and are incorporating them into their businesses.

There are inevitably many excellent Institutions and projects around the World that I was unable to visit that could have formed part of this report. Time limited the number of places I could visit and I am sorry if the reader feels there are significant omissions.

I would like to thank The Frank Arden Memorial Trust, John Stones and the Nuffield selection board for giving me the opportunity to participate in this study.

I also owe thanks to all the scientists who spent time with me to enthuse about their work. I enjoyed meeting them all.

Finally I must thank the Managing Director of the Co-operative Farms, Christine Tacon, for encouraging me to put myself forward for this scholarship and for picking up my key duties while I was away and my wife, Sioux, for whom this study has also been a test of endurance.

Executive Summary

Introduction – the Frank Arden Memorial Fund was established to support studies that address key topics of importance to the UK agricultural industry. Study themes are set bi-annually and in 2009 the Nuffield Board chose 'The appliance of New Science and Frontier Technologies to transform the UK agriculture and food sectors'.

Over the last 60 years new science and technology has resulted in dramatic improvements in the productivity of UK farms. During this 'Green Revolution' performance increased dramatically as a result of developments in mechanisation, plant and animal breeding, crop nutrition, plant protection, animal nutrition, animal health and irrigation. It was a period of significant Government investment in research and development with numerous Experimental Husbandry Farms and a world class extension service. However since the 1980s Government investment in R & D has declined and the extension service has diminished.

The Nuffield Board believe that there are growing concerns and evidence that the UK is falling behind other developed countries and becoming less competitive, partly due to a knowledge and innovation vacuum. The Board have taken the view that there is a need to look again at the latest scientific research across the Globe and how we can effectively connect that research with farmers and the food industry. The Board believe that UK farmers have quite simply lost interest in new science.

The aim of this study is to identify the new technologies and recent innovations from the UK and around the world which are of most value to the UK industry. The Nuffield Board hope that this study may play a role in re-enthusing UK farmers about science and technology. That they will go forward with a new awareness that new science that is relevant to their businesses is emerging and that they will take a fresh approach in seeking out that science and will then take the opportunities that exist to profitably exploit it in their own businesses.

The study concluded that research associated with conventional husbandry techniques was incremental in its nature rather than transformational. A number of distinct areas emerged as study subjects and these were –

- Gene technology including -
  - Animal Genetics
  - Plant Genetics
- Functional Foods
- Non-food uses of agricultural produce but excluding energy
- Robotics and Smart Engineering

Gene technology – is a relatively new discipline that includes the discovery of genes, understanding gene functions and interactions, the use of genetic markers, controlling gene activity, modifying genes and transferring genes. It is clear that genetics are far more complex than was originally thought and to date gene technology has failed to deliver what was expected in the past but the science is developing to the point where it can offer real benefits to the agricultural industry.

Genetic material is made up of DNA which consists of a double chain of paired nucleotides. This contains the information that plants and animals need to grow and function. There are only four different types of nucleotides but the number of them is staggering. Cattle have 3 billion pairs which encode about 30,000 genes. The cattle and chicken genome have been fully sequenced with the pig and sheep genome to follow. Wheat is a hexaploid and its genome is huge. It has not been sequenced.

Scientists have identified a vast number of individual genes along with their functions. They have also developed an understanding of how genes are transcribed and translated to produce proteins, a process known as gene expression. Genes have promoters that switch them on and off. It has become increasingly clear that genes and gene expression are very complex, far more complex than was envisaged when gene technology first started to develop. Gene expression in vertebrates is thought to be much more complex than in plants and there is much still to discover.

The differences in the genome within each species is of particular interest to scientists because these small differences are responsible for the productive traits in our crops and livestock that are so important to us; the sweetness of an apple or the tenderness of a piece of beef. These differences occur as Single Nucleotide Polymorphisms or SNPs where a single pair of nucleotides differ from individual to individual. Many of the traits that are important to us are influenced by not one SNP but a large number, some of which are more important than others. Scientists use genetic markers to identify parts of the genome that are of importance to us. If the marker is there then it is assumed the gene is there and the characteristic and performance of the plant or animal can be predicted. Identifying these markers involves comparing the genome with the phenotype of large numbers of individual plants or animals. However there are problems with the reliability of some markers that are used.

Plant geneticists have a tremendous amount of genetic variation in the gene pools of the crops they work with. This creates huge opportunity to incorporate useful genes from ‘wild types’ into our domesticated crops. Scientists have discovered a vast number of genes that influence characteristics as diverse as disease resistance to produce quality. Plant geneticists work with two model species, Arabidopsis and Brachypodium, to test their ideas in relation to plant genetics. Once a concept is proven on the model species it is tried on commercial crops.

Plant geneticists have also made significant progress in understanding the principles of genetic modification. This involves modifying and transferring genes from one plant to another. Two methods are currently used to transfer genes. One involves firing genes into cells with a miniature gun and the other using bacteria to transfer genes.

Interesting case studies associated with plant genetics include an apple that doesn’t turn brown when cut, a vaccine for plant viruses and the genetic modification of Oil Seed Rape so that it produces long chain Omega 3 oils that we normally associate with oily fish.

Animal geneticists have identified a number of individual genes associated with genetic defects and also identified many genes associated with desirable traits in our livestock. However their focus has been predominantly on using

the genome to replace progeny testing in traditional breeding programmes. SNP markers are used to identify those parts of the genome that will result in a desirable trait in an individual animal. This has proved much more difficult than was envisaged. The process relies on accurate phenotypic data from a large number of animals to relate the genetic markers back to the desired trait. In the early days of marker assisted breeding scientists thought that 200 markers used along with 500 phenotyped animals would deliver results. They now think that in excess of 200000 markers are required along with 30000 phenotyped animals. Scientists are in the process of moving from using 50000 markers to 500000 markers. In due course using the genome to replace traditional progeny testing should improve accuracy, increase the rate of genetic gain and allow selection for traits that are currently difficult to measure. At present using the genome to predict progeny performance is less reliable than using a conventional progeny test.
Interesting case studies associated with animal genetics include the DNA proven sires programme offered by LIC in New Zealand and the Myostatin gene in sheep.
Our understanding of the genomes of our cultivated plants and our animals has now developed to the point where farmers can look forward to the technology delivering improved performance, new traits and improved disease resistance.

Functional Foods - are an important part of a healthy diet. Foods are not medicines but a healthy diet can promote well being and reduce the risk of developing certain non-communicable diseases. A diet can only be healthy if the combinations of individual foods is good and is not just about limiting foods that contain components of concern such as fatty acids but is also about including elements that can provide extra benefits. Aspects of lifestyle, diet and physical activity all play a role in the incidence of many diseases and it has become clear that diet can play a role in reducing their incidence and improving long term health.

A functional food is a food that has beneficial health effects beyond basic nutrition and is consumed as a food and not as a pill, capsule or supplement.

Functional foods can have an influence on the following aspects of well being and health –

Early development and growth
Regulation of energy balance and body weight
Cardiovascular function
Defence against oxidative stress
Intestinal function
Mental state and performance
Physical performance and fitness

They can also be used to target specific dietary requirements such as gluten and lactose intolerance.

A functional food can be a natural unmodified food buts scientists are involved in modifying foods in a number of ways to improve their functionality. These modifications include –

- Enhancing components through special growing conditions, breeding or biotechnical means
- Adding a component to provide benefits
- Removing a component by technological or biotechnological means so that the food provides benefits not otherwise available
- Replacing a component with an alternative component with favourable properties
- Modifying a component by enzymatic, chemical or technological means to provide a benefit

Anti-oxidants are an important feature of many functional foods. They have been demonstrated in some large human studies to have an impact on the incidence of cancer and cardio-vascular disease. However scientists are still developing their knowledge of exactly how they work. Many are not absorbed by the body in significant quantities and may work by stimulating the bodies own defences against oxidative stress.

New science is also developing the prospect of personalised diets. Genetic markers have been identified that can be used to tailor diets to an individual's specific risk factors. There are genetic links to many diseases including Cardiovascular disease, many cancers, arthritis and Crohn's disease. The reliability of some of these markers is questionable but will improve as science develops. However Direct-to-Consumer genetic tests are now available and as time progresses more and more people will become aware of their own risk factors.

This will lead to a segmentation of the market place. Groups of individuals seeking diets to address their own specific concerns, problems or risk factors. This will create opportunities for farmers and the food industry. As these segments develop some businesses will successfully capture the fledgling market and develop into significant businesses.

Case studies to demonstrate how recent scientific developments can be applied include low saturated fat milk, barley that has high levels of fibre and resistant starch, hyperimmune milk to treat thrush, brassicas rich in antioxidants and an apple with red flesh.

The non-food use of agricultural produce – excluding energy - Agricultural produce can be used for a whole variety of purposes beyond food. Indeed as fossil fuels decline agriculture will become an increasingly importance source of renewable materials and chemicals. Mankind has spent over 100 years manipulating crude oil to produce a wide variety of raw materials but we have only recently started to study in depth the various chemicals and fibres that agriculture can offer. A vast amount of scientific research is taking place around the world to discover and develop new and novel uses for our agricultural produce. Indeed the basic raw materials that agriculture produces offer a bewildering range of possibilities in terms of their potential uses.

Agricultural produce falls into a number of broad areas for alternative uses. These are –

Oils
Carbohydrates
Fibres
Specialist uses including pharmaceuticals and cosmetics

There are significant market opportunities for oils, fibres and carbohydrates but the markets for some specialist crops are limited and could easily be over-worked.

The principle uses for oil crops are lubricants, surfactants, surface coatings, polymers along with functional additives and reactive agents for industrial manufacture.

The principle uses for fibres are composite boards, paper, packaging materials, textiles, filters, absorbents, fibre composites, cellulose-based ion-exchange and novels uses for items such as car panels.

Carbohydrates produced in the UK are primarily in the form of starch and sugar. Uses for starch include paper, board, detergents, pharmaceuticals, cosmetics, adhesives, surfactants, paints, agrochemicals, plastics, polymers and specialist fibres. Uses for sugar include a wide range of chemicals that are used in pharmaceuticals, health care products, polymers, agrochemicals and printing inks. Sugar is also used in the manufacture of plasterboard, concrete and glazes and tiles.

Specialist crops and animal products are used for the production of pharmaceuticals, health care products and cosmetics.

Many of the products above are produced by large scale industrial processes that extract and modify plant products before turning them into useful products and raw materials. Technology is improving these industrial processes to widen the range of agricultural produce that can be utilised and to develop more novel uses for the end product. Many of these processes involve the production of ‘platform chemicals’. These are simple functionalised molecules that can serve as building blocks for further chemistry. The facilities to produce these chemicals cost hundreds of millions of pounds and are way beyond the scope of farmers. As a result this area of technology represents only a limited opportunity for farmers who will invariably become just commodity suppliers of raw biomass.

However opportunities do exist from time to time to grow novel crops on the farm and engage in on farm processing. Specialist crops have an emphasis on aromatic and essential oils. These are often grown by smaller companies and offer the potential for on farm processing.

The research effort associated with alternative uses for agricultural produce centres on –

Novel crops and novel products
The breeding and husbandry of novel crops
The properties, modification and processing of raw materials

The performance and properties of products

Plant biotechnology including the genetic modification of plants to synthesise chemicals directly or improve the quality of the raw materials they produce which has the potential to widen the scope of this area significantly.

Some of the potential associated with non-food uses of agricultural produce will only be realised through the development of genetically modified organisms.

Case studies associated with the non-food use of agricultural produce include the on-farm manufacturing of Ultrathin Lightweight Packaging from straw, the development of an anti-coagulant from animal by-products and the use of starch aquagels to produce lightweight concrete.

These case studies demonstrate the extraordinary diversity associated with the non-food uses of agricultural produce. New technology will only extend that diversity still further.

Robotics and Smart Engineering - developments in engineering and computer based technologies offer huge opportunities for agriculture. Many tasks in farming are dull and routine and involve huge gangs of labour performing repetitive tasks. These mundane tasks can potentially be replaced by robots. Farmers also require information about their operations in order to manage them effectively and developments in new sensing technologies offer opportunities to produce more timely data and information that has to date been uneconomic to collect.

The development and use of robots in agriculture is still in its infancy. The good robotic engineer has to be capable of thinking outside the box to solve problems. The starting point in developing suitable robotic technology is understanding the problem. What is it that has to be done? And are there opportunities to adapt what is done to make the robotic solution easier? For example growing strawberries on table tops presents fruit to a robot in a much more acceptable way than growing strawberries on the ground. Robots have to be economic and cost is an important factor in developing them. Once solutions have been found the cost of components tends to come down rapidly making new applications financially viable.

Robots consist of a number of key components –

Sensing systems – to see, locate and feel

Control systems including a CPU (Central Processing Unit)

Power units – to provide the power

The mechanical machine that actually does the work

Robots make use of a number of different sensing systems including machine vision. Machine vision is used to help robots locate where they are working and also for a wide variety of other applications including locating produce for harvesting, plants for spraying and animals for condition scoring. Machine vision makes use of a variety of different sensors from colour cameras through to ultra sound. Algorithms then process the images to create a picture of the surrounding environment.

Other sensors are also used to allow robots to locate where they are. These include GPS, wheel encoders and inertial measurement units. All of these systems have advantages and disadvantages associated with them.

Control systems on robots consist of a CPU. High level control systems make decisions whereas low level control systems operate the steering and control the implement. These two systems need to communicate effectively.

Power unit options include batteries, engines, electricity through a power cable and hybrid systems all of which have advantages and disadvantages.

A wide variety of solutions are used on the mechanical machine to solve the problems associated with dong the task. These include pneumatics, hydraulics, wheels, tracks, hub motors and many others. Flexibility of design as well as performance influences choices as the robot is developed.

Safeguarding is an important feature of any robot. The robot must be able to detect dangers and should fail safe, that is, stop when there is nothing there.

Machine learning is used in the development of robots. The machine rewrites its own software based upon its own experiences.

Most robotic engineers currently envisage a future based on groups of small robots under the control of a single operator. The driverless machine is a technical reality and its uptake appears to be limited by legal issues rather than technical ones - who will be responsible when the machine drives through someone's living room? Smaller machines will limit the potential damage that might occur and could also be more easily retained by a series of 'tank trap' ditches around the working area.

Developments in sensor technology are creating a revolution in the information that is available to farmers. Systems are being developed that can be used for applications as diverse as identifying crop disease to measuring livestock activity.

Case studies associated with the application of robotics and smart engineering include a robotic asparagus harvester, robotic weeders, spot spraying, livestock activity meters, livestock condition scoring and fruit harvesting including a prototype strawberry harvester. Fruit harvesting represents a particular challenge to the robotics engineer. Ripe fruit has to be identified and then picked without bruising it. This latter point usually involves imitating touch which is far from easy.

Conclusion – new technologies being developed around the world have the potential transform UK agriculture. However only some of these technologies will have an impact across the industry. Clearly advances in plant and animal breeding that improve performance will be widely applied as will some new engineering technology but many of the applications associated with the technologies identified by this report will only be adopted by entrepreneurial businesses. Some specific attributes that the plant breeders will develop in their crops will relate to niche markets and the functional food market is one that will create a segmented market that will appeal to the entrepreneurial spirit. The opportunities for the entrepreneurs in the industry are fantastic. New markets will emerge as a result of some of these technologies and some farmers will capture these markets at the right time and develop big businesses as the market grows.

The connection between scientists and farmers remains a problem. Over the last 25 years the Government funded extension service in the UK has been eroded and the loss of Government funded extension is a compliant amongst scientists across the Globe. There are some scientists in the UK who believe that we have lost the basic skills that interpret science on behalf of farmers. Possible solutions include requiring scientists to spend a proportion of their time on extension activities, judging scientists on their impact to the industry, scientists working with industry groups and bodies and also introducing awards for extension activities to raise its status in the scientific community. Connecting UK farmers with new technologies overseas is a particular problem and a number of organisations can play a significant role in facilitation including the AHDB.

Farmers also have to take some responsibility for seeking out new technology and applying it on their farms. The web has opened up new avenues for farmers to delve into what is going on else where in the world. Perhaps this study will inspire UK farmers to browse the web occasionally on a wet afternoon or a winter evening in search of the technological breakthrough that will transform their business.

Introduction – the Frank Arden Memorial Fund was established to support studies that address key topics of importance to the UK agricultural industry. Study themes are set bi-annually and in 2009 the Nuffield Board chose 'The appliance of New Science and Frontier Technologies to transform the UK agriculture and food sectors'.

Over the last 60 years new science and technology has resulted in dramatic improvements in the productivity of UK farms. Yields of wheat have trebled and the improvement that took place after the Second World War is referred to as 'the Green Revolution'. During this period rapid developments took place in mechanisation, plant and animal breeding, crop nutrition, plant protection, animal nutrition, animal health and irrigation. This was a period of significant Government investment in research and development with numerous Experimental Husbandry Farms and a world class extension service, first as NAAS and subsequently as ADAS. Science had something new to offer UK farmers on a regular basis which they adopted and reaped the benefits. However since the 1980s Government investment in R & D has declined and the extension service has diminished.

The Nuffield Board believe that there are growing concerns and evidence that the UK is falling behind other developed countries and becoming less competitive, partly due to a knowledge and innovation vacuum. Our falling competitiveness has certainly coincided with a reduction in R&D funding and Government resources over the last two decades. The Board have taken the view that there is a need to look again at the latest scientific research across the Globe and how we can effectively connect that research with farmers and the food industry. The Board believe that UK farmers have quite simply lost interest in new science.

The aim of this study is to identify the new technologies and recent innovations from the UK and around the world which are of most value to the UK industry. These technologies should be able to differentiate and significantly improve the competitiveness of the sector. How farmers might access this technology is also considered. Ultimately the Nuffield Board hope that this study may play a role in re-enthusing UK farmers about science and technology. That they will go forward with a new awareness that new science that is relevant to their businesses is emerging and that they will take a fresh approach in seeking out that science and will then take the opportunities that exist to profitably exploit it in their own businesses.

Methodology – this study was conducted over an eight month period from July 2009 to February 2010. The study was approached with a completely open mind in terms of its subject matters. A methodology was presented to the Nuffield selection committee although at the time the author did anticipate studying new science within each of the agricultural sectors; in dairying, potatoes, fruit, etc.

The eight month study period was divided into four reasonably distinct periods of about two months.

The first two months were spent conducting a desk study and visiting leading UK institutions. The desk study involved researching New Science from a number of countries across the Globe. These included – the USA, Canada, Chile, Brazil, Argentina, New Zealand, Australia, China and India. They were selected on the basis that they represented a good cross section of developed world and developing world economies and they have some significant agricultural sectors that are common to the UK. Websites of leading Agricultural Research Centres were visited and Journals were reviewed. Europe was excluded because it was anticipated that contacts in UK institutions would lead to key research projects across our own continent.

The following UK institutions, businesses and individuals were visited –

Rothamsted
Reading University
York University
David Pennell
The Arable Group
SAC in Edinburgh
Kingshay Farming Trust
Crop Management Information
Melvyn Askew
Campden BRI
NNFCC

Lindsay Hargeaves who has also conducted this study visited a number of other UK institutions including The John Innes Institute and NIAB.
The purpose of these visits was to explore their current research activities and to discus major Institutes and projects elsewhere in Europe and the World.

The outcome of this initial period of study was a conviction that the best new science is being conducted in the developed world. There are centres of excellence in the developing world but they appear to be small in comparison with the best that the developed world has to offer. As a result Japan, as the world's second biggest economy, became the subject of a desk based study.

It also became clear that the projects that had the most to offer in terms of transforming UK agriculture were not sector based but fell into a number of distinct areas. Research projects focused on the development of conventional husbandry were incremental in their nature rather than transformational. In many cases their applicability to the UK was also questionable. The distinct areas that appeared to have most to offer were chosen as study subjects and were –

Animal Genetics
Plant Genetics
Functional Foods
Non-food uses of agricultural produce but excluding energy
Robotics and Smart Engineering

Energy was excluded because the previous Frank Arden Memorial Award had studied the Carbon Footprint of British Agriculture and Julian Morgan's paper reported on many of the new technologies associated with energy production on farm. Environmental research was also excluded because it was considered that this area of research tends to lead to greater regulation for farmers rather than a competitive advantage.

This period of study concluded with decisions on which overseas Institutions and businesses to visit.

September and October 2009 were spend organising visits to the chosen Institutions and businesses and on further desk research into the five chosen areas of study to develop a basic knowledge of the underlying science.

The six weeks prior to Christmas were spent visiting the following Institutions and businesses –

Cornell University – Geneva Campus
Cornell University - Ithaca Campus
National Institute of Robotic Engineering at Carnegie Mellon University
The Meat and Animal Research Centre in Nebraska
Washington State University – Pullman Campus
Centre for Precision Agricultural Systems WSU at Prosser
Western Regional Research Centre in San Francisco
Geiger Lund Engineering in Stockton California
AgResearch Ruakura Research Centre at Hamilton
LIC – Livestock Improvement Company
Plant and Food Research – In Auckland and Palmerston North
Centre for Reproduction and Genomics at the Invermay Agricultural Research Centre
AbacusBio Ltd at Dunedin
The Australian Plant Phenomics Centre, Adelaide
CSIRO, Queensland Bioscience Precinct
National Centre for Engineering in Agriculture, University of Southern Queensland
Future Grains, CSIRO, Black Mountain Laboratories, Canberra
NARO, Japan
BRAIN, Japan

January and February 2010 were spent writing up this report and visits were made to Tillett and Hague at Silsoe and Ice Robotics in Edinburgh to research specific case studies for completion of the report. In writing up the report the intention was to produce 'an interesting read for the thinking farmer'. The structure chosen for the report was an introduction to each subject area followed by a number of very diverse case studies to demonstrate how the technology can be applied including case studies that are market ready and others that are futuristic. It is hoped that this approach will stimulate readers to take a new interest in new science and start seeking out new technologies applicable to their businesses for themselves.

Gene Technology

Gene technology - is a relatively new scientific discipline that started in the late 1970s and since then scientists have revolutionised our understanding of genetics. It includes the discovery of genes, understanding gene functions and interactions, the use of genetic markers, controlling gene activity, modifying genes and transferring genes.

The discovery of genes is called genomics. Understanding gene functions and how genes interact with each other and other parts of cells is called functional genomics.

To date gene technology has failed to deliver what was expected in the past but the science is developing to the point where it can offer real benefits to the agricultural industry. A variety of genetic products are now commercially available and there are reasons to believe that the science is on the threshold of transforming animal and plant breeding.

It is clear that genetics are far more complex than was originally thought and as knowledge has developed our appreciation of what we don't know has grown significantly.

DNA - Plants and Animals are made up cells which have a nucleus that contains DNA – deoxyribonucleic acid. The DNA stores genetic material and is like an instruction manual. It contains the information that plants and animals need to grow and function. Only about 10% of DNA is genes. Genes are linear sequences of nucleotides in DNA molecules. Each DNA molecule consists of a double chain of nucleotides. There are four kinds of nucleotides in DNA: G (guanine), C (cytosine), T (thymine) and A (adenine). A pair of nucleotide chains in a DNA molecule twist around one another in the form of a double helix. (Stanford Encyclopaedia of Philosophy:2007) The nucleotides along side each other are referred to as base pairs. Each cell has over a meter of DNA tightly twisted to form chromosomes. The average gene has over 1000 base pairs. The number of genes varies considerably between different plants and animals. Barley has about 30000 genes whereas wheat has about 100000 genes. Humans have about 30000 genes. (Molecular Plant Breeding CRC and Australian Centre for Functional Genomics)

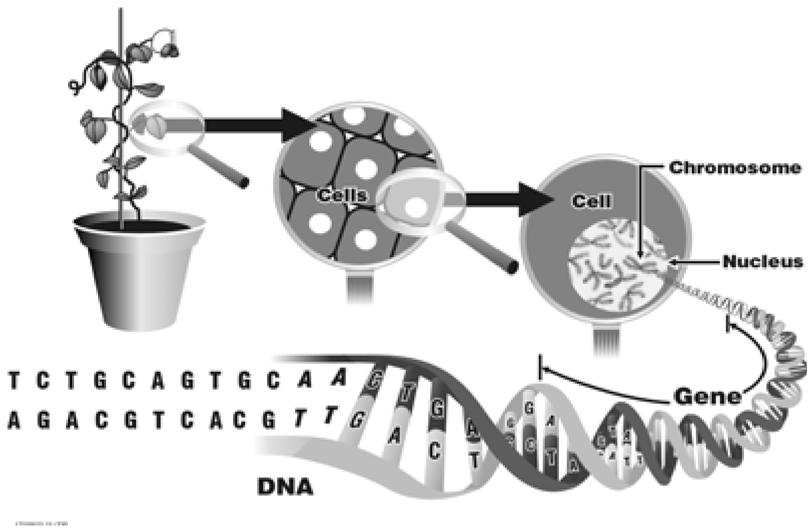


Image courtesy of CSIRO

Over recent years scientists have put a huge amount of effort into sequencing the genomes associated with the major crops we grow and the livestock species we farm. Sequencing the bovine genome was a huge international effort and involved 300 researchers from 25 countries and took six years to complete. The bovine genome was published in 2004 and contains 3 billion base pairs encoding about 30,000 genes. A Hereford cow was sequenced in detail and individual animals from six other breeds — Angus, Brahman, Charolais, Holstein, Limousin, Jersey and Norwegian Red — were also sequenced at a much lower coverage to discover genetic polymorphisms, or small differences in the DNA sequence, that help to define each breed as well as individual variation within a breed. (Farming Ahead: 2009). The chicken genome has been sequenced and the swine genome is expected to be completed during 2009 with the sheep genome to follow. (Green: 2009).

The rice genome has 390 million base pairs and was published in 2000. The apple has been sequenced but not yet published. Wheat is a hexaploid, it has three sets of chromosomes and its genome is huge. An international consortium has been established to fully sequence it.

Sequencing the genome means listing the nucleotides (the As, Cs Gs and Ts) in the order in which they appear along all the chromosomes. It doesn't mean that scientists know what they all do. There is much that is still unknown – the function of only a fraction of the 30000 genes in the bovine genome is really understood. Unravelling what all the genes do and how they all work is an immense challenge.

A gene is a coded set of instructions to produce proteins. There are 20 different building blocks - amino acids - used in a bewildering array of combinations to produce our proteins. The different combinations make proteins as different as keratin in hair and haemoglobin in blood. (Welcome Trust: 2010)

Different proteins have different functions, some form the structural parts of the organism like the bricks and mortar of a house whereas others make other types of molecules such as starch, oil, fibre and fat that are used within the organism. An organism is mainly made up of proteins and the things proteins produce. They give rise to different characteristics such as height, flavour and colour and are involved in the development and functioning of organisms. They regulate all the important cellular functions and have an impact on issues such as the resistance to disease and the ability to handle various stresses.

Identifying the individual genes along with their function is of major importance to scientists. The gene pool of both plants and animals offers huge genetic variation and provides the basis for agronomic and nutritional quality improvement. Genomics research has produced a wealth of information on DNA sequences that can offer a range of benefits. Once discovered a genes function can be defined. Targeted strategies are used to clone and characterise gene function in desirable traits. (Food and Crop Research: 2009).

There are three basic parts of a gene:

- The gene promoter that switches the gene on and determines when the gene manufactures protein and how much is produced.
- The protein coding region which specifies the make up of the protein produced by the gene.
- The downstream stop switch which stops the gene producing protein.

When a gene is switched on transcription and translation takes place.

Transcription, Translation and Gene Expression - When a gene is activated transcription takes place. The Gene is copied many times from the DNA. These copies are called messenger ribonucleic acid or mRNA. They are similar to DNA but move from the cell nucleus into the cytoplasm. Translation then occurs to create proteins. The mRNA undergoes various modifications, some sections of the mRNA that are not required to produce proteins are removed and the ends of the mRNA are protected. Polypeptide chains are produced that are then modified to produce fully functioning proteins. Scientists refer to the process of a gene working as 'gene expression'.

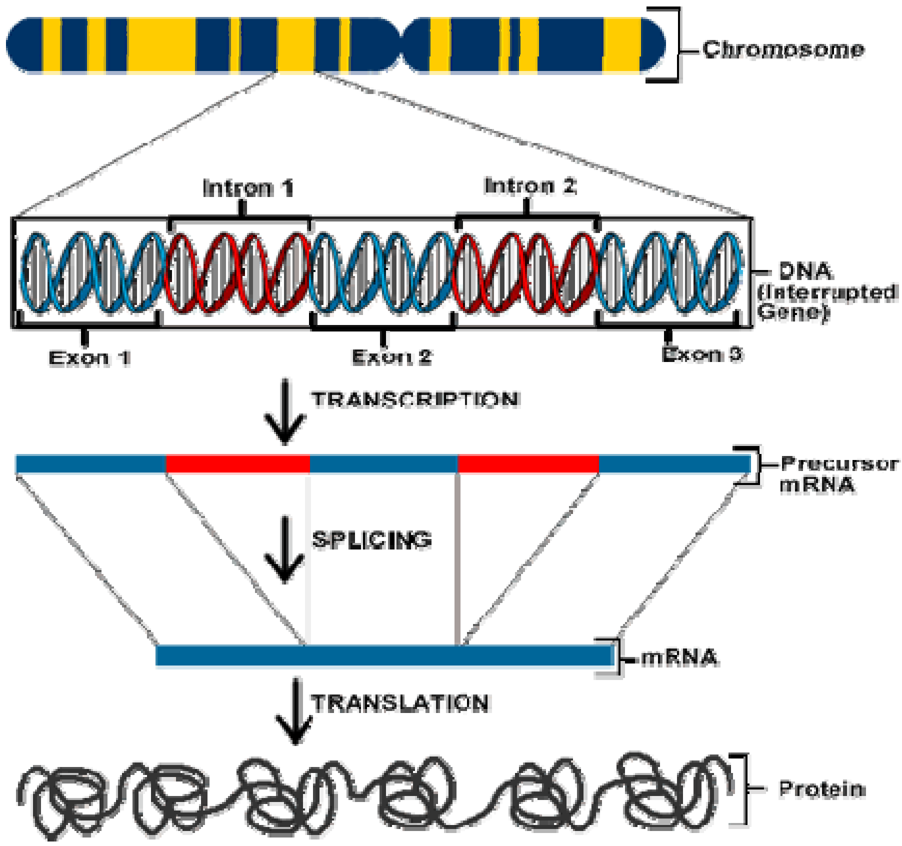


Image courtesy of US National Library of Medicine

Scientists can tell which genes are working by analysing the mRNA in growing tissue. The extent to which genes are expressed can be influenced by how much mRNA is produced and for how long it is produced. This process isn't always straight forward and if the gene is wrapped tightly inside the nucleus the expression of the gene can be physically limited by its ability to transcribe in a confined space.

Scientists can generate stains in plant tissue that show where a promoter is turned on and the gene is being expressed. Sometimes a gene will be expressed throughout the plant or animal and sometimes it will only be expressed in specific organs. The pictures below demonstrate this point. In the plant on the left a gene is being expressed in both the roots and the leaves whereas in the plant on the right a gene is being expressed in just the leaves.

Images courtesy of Dr Roger Thilmony, USDA-ARS

Just how many genes are expressed at one time can be illustrated by taking a close look at the physiology and development of a wheat grain. A wheat grain is made up of wide variety of different tissues all of which will have genes controlling their growth.

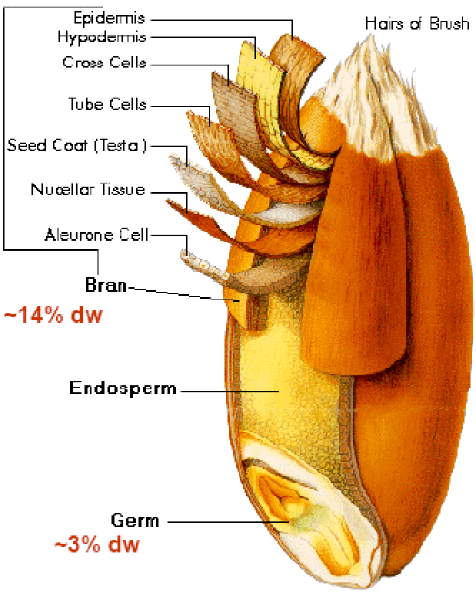


Image - www.goldengrainmills.biz

The chart below demonstrates that as the grain develops a variety of different genes are switched on and off cumulating with those genes associated with desiccation.

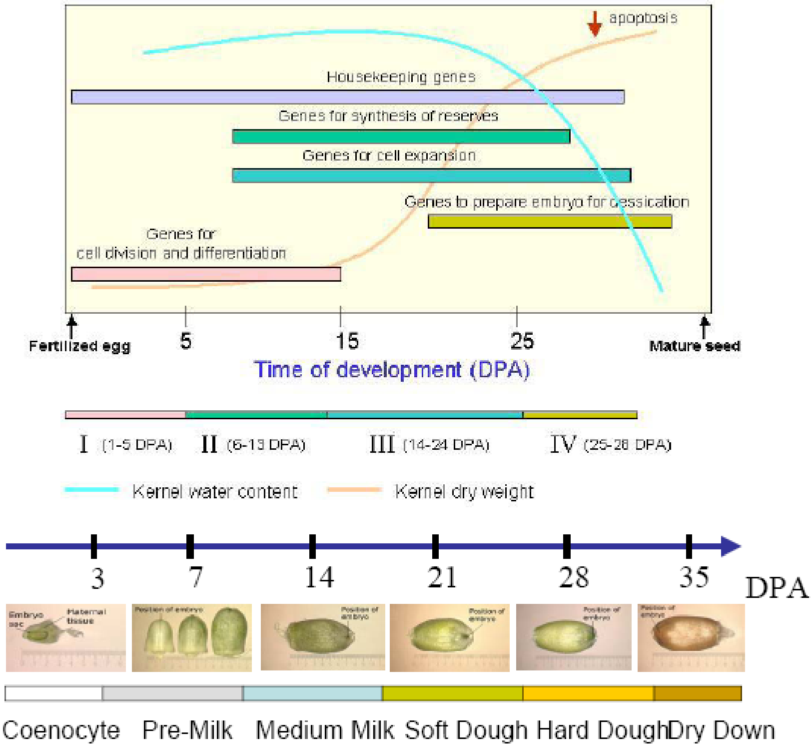
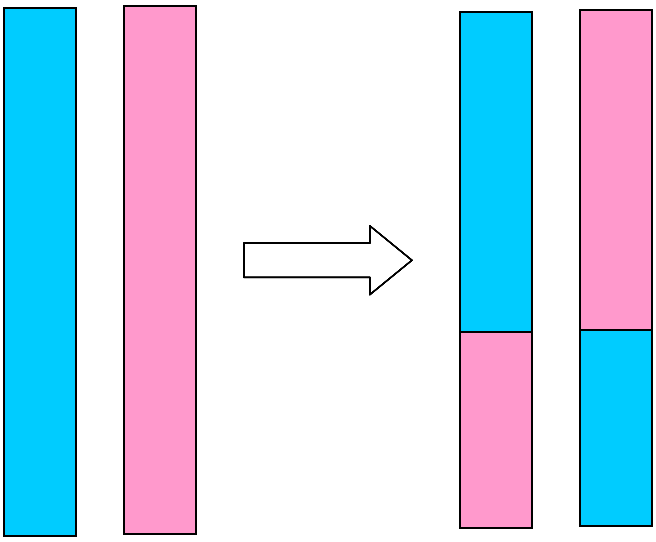


Image courtesy of Dr Debbie Laudencia-Chingcuanco, WRRC

As our knowledge of genetics has increased it has become clear that gene expression is very, very complex. Scientists believe that gene expression in vertebrates is significantly more complex than in other organisms and that differences occur in the phenotype that cannot be fully explained by just the DNA sequence. A complex process of gene expression is thought to be responsible for these differences. Unravelling and understanding these processes is proving challenging.

Scientists are also starting to believe that there are other molecular processes involved in inheritance beyond the DNA sequence. A secondary process called epigenetics is thought to exist that accounts for some inherited traits. (Science Daily: 2009). Indeed researchers at the National Food Research Institute in Japan have discovered that different foods have an influence on the way in which genes are expressed with some foods resulting in genes being expressed more strongly. This research is in its early days and needs more investigation but it may become an issue that could drive the feeds we will provide for our livestock and the foods that consumers demand from us.

Recombination – is an important feature in the science of genetics. It occurs in germ cells – the cells that make up egg and sperm. Individual organisms have one set of paternal chromosomes and one set of maternal chromosomes. Most of the time these chromosomes are passed down to the next generation as they came from the parents. However as the egg and sperm are formed the chromosomes can pair up and exchange parts. This process is called recombination and after recombination the new chromosome will contain paternal and maternal parts. Sometimes the chromosome will split and reform at slightly different places so that one of the resulting chromosomes contains more genetic material than the original chromosomes and the other resulting chromosome will contain less. Recombination occurs very frequently and it is thought that it usually occurs in at least one pair of chromosomes each time division occurs to produce eggs and sperm in ourselves and farm livestock. Very rarely a chromosome will recombine with part of a chromosome that wasn't part of the original pair.



During Recombination the paternal chromosome (in blue) and the maternal chromosome (in pink) exchange parts and recombine. The offspring will inherit a chromosome that includes material from both of the original chromosomes. Chromosomes can split and recombine at any point along their length.

Recombination is important because –

- It is responsible for creating genetic variation. It probably creates more variation than new mutations.
- It creates the possibility that where a useful gene is found in a chromosome with some antagonistic or undesirable genes they may get split apart during a recombination event leaving a new chromosome with just the beneficial gene.
- It makes the genetic markers that scientists use to identify genes unreliable.

SNPs and 'the causative mutation' – within a species the genetic variation between individuals is very small. In humans our DNA differs only by 0.2% between individuals. The differences within each species of farm livestock will be very similar. The differences are made up of SNPs or Single Nucleotide Polymorphisms. They are referred to as 'snips'. SNPs are where a difference occurs in a single base pair that makes up the genetic code. Where that difference creates a difference in the protein that is produced variability between individuals will occur.
An example of a SNP is the Melanocortin Receptor 1 Gene in cattle that determines coat colour.
The code – GTGCTGAATGTCATGGACG**C**GGGCG – creates a black coat
The code – GTGCTGAATGTCATGGACG**T**GGGCG – creates a red coat

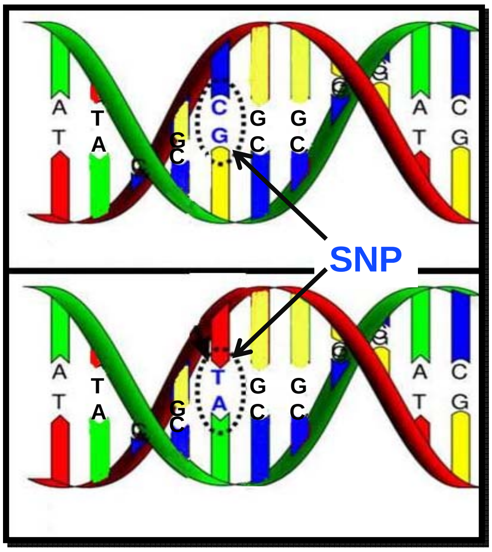


Diagram and Picture courtesy of Dianne Hyndman, AgResearch, Invermay

This difference in the genetic code is 'the causative mutation' in relation to coat colour. (A mutation is a change in the DNA of a gene that alters the genetic message carried by the gene)

In cattle a SNP occurs about every 500 to 600 base pairs. There will be about 6 million SNPs across the whole bovine genome.
SNPs are of huge interest to animal and plant breeders because they explain the differences between individuals within the species. As the example above demonstrates they account for difference in coat colour but they also account for all the productive traits that are of interest to us including milk yield, meat tenderness, grain protein content and so on.

Genes seldom act alone. In some cases a single gene is responsible for a particular trait especially in relation to defective traits – BLAD in cattle is a good example of this and the gene can be bred out of the commercial population. However the typical bell shaped distribution curve that is associated with most desirable traits in animals and plants indicates that many genes are associated with most functional traits. If scientists can identify the genes associated with a particular trait they can use markers to follow

those genes through either a breeding programme. (Australian Centre for Functional Genomics)
The extent to which a whole host of genes can be associated with a particular trait is demonstrated by research conducted by Scientists at the US Meat Animal Research Centre who have identified 308 significant markers for birth weight of beef calves, 79 for milk production in beef cows but just 11 for the marbling of the meat. Most functional traits are associated with a small number of major genes that have a large influence on the trait and also a large number of minor genes that each has a small influence on the trait but collectively are important. Identifying all these genes is a major challenge to scientists and involves genetic markers.

Genetic Markers – also known as DNA markers are DNA sequences that naturally exist in an organism and sit near a specific gene of interest, and can be easily identified. DNA markers are tools that help locate a gene of interest. They are used for both conventional breeding and genetic engineering.
Studying phenotypes is an important factor associated with using markers. The phenotype is any observable characteristic or trait of an organism including its morphology, development, biochemistry or physiological properties, or behaviour. Phenotypes result from the expression of an organisms genes as well as the influence of environmental factors and possible interactions between the two. (Plant Accelerator: 2009).
Scientists match the genotype to phenotype — identifying genetic markers and linking them to a particular characteristic or trait.
Plant breeders and animal breeders do appear to put a slightly different emphasis on their use of genetic markers.
Plant breeders appear to be most interested in identifying individual genes or small groups of genes with a specific function and place a significant emphasis on the use of ESTs or Expressed Sequence Tags. These are short pieces of DNA sequence (usually 200 to 500 nucleotides long) that are generated by sequencing either one or both ends of an expressed gene. They are used to identify new genes and as genome landmarks – if the EST is there the gene must be there. They can be used to track genes across a breeding programme.
Animal breeders appear to be most interested in large groups of genes that influence a desirable trait and place a significant emphasis on the use of large numbers of SNPs as markers.
In theory plant and animal characteristics and performance can be predicted by the presence of known markers. Positive and negative attributes can be pin pointed. Using markers can accelerate the breeding process by reducing cycling times and make the whole process more efficient.
However the use of markers has created some significant frustrations in both plant and animal breeding which are explored in more depth below.
Studying phenotypes is an important factor in using genetic markers. Phenotyping both plants and animal involves physically measuring those characteristics that are of interest to us. It is expensive and the availability of large quantities of good quality data is essential to develop useful accurate markers. Plant and animal breeders are addressing the availability of this data.
This process produces vast quantities of data that has given rise to the scientific discipline of Bio-informatics – crunching the data through vast computers. Our ability to analyse all the data that is created could become a limiting factor in the development of genome based breeding programmes.

Plant Genetics

Plant geneticists are pursuing a number of different goals in terms of improving crop performance. These include improving plant efficiency, improving the functional quality of the produce and improving the way in which plants respond to disease and various stresses. There is a tremendous amount of natural variation in the plants we grow and this variation represents a huge gene pool from which scientists can draw genes with potential uses.

The diversity in the apple offers scientists a huge gene pool from which to draw genes with potential uses
Image courtesy of Professor Susan Brown, Cornell University

Scientists have discovered a vast array of different genes associated with the plants we grow including for example –

- The genes that confer resistance to apple scab
- The genes that create dwarfing in a variety of plants
- The genes that build protein in wheat

Sometimes just a single gene is involved whereas on other occasions a number of genes contribute to the trait.

Markers associated with these genes have been identified but it has sometimes proved a challenge to find markers that are robust over different seasons and in different geographical areas. Invariably a marker will appear reliable in one location but when that plant is moved elsewhere the marker lacks reliability.

Model Species - plant scientists use 'model species' to test their ideas in relation to plant genetics. Model species are simple plants that are easy to work on but have genomes that are aligned with the genomes of the crops we grow. Once a concept has been proven to work on the model species it is tried on commercial crops. Model species include -

Arabidopsis is a small member of the mustard family that is used as a model dicotyledon. It has a small genome of just 150 million base pairs and 5 chromosomes. It takes just 6 weeks from germination to mature seed. It was the first plant to be fully sequenced in the year 2000. Although it is not economically important in its own right it is a useful model plant because it is easy and quick to grow with limited space requirements. Its genome can be manipulated through genetic engineering more easily and rapidly than any other plant genome. (Arabidopsis Thaliana Functional Genome Project : 2002)
Tobacco (nicotiana benthamiana) is also sometimes used as a model dicotyledon

Brachypodium is monocotyledon that is used as a model plant for studies on temperate grasses and cereals. It also has a small genome of just 300 million base pairs and 5 chromosomes. It is also quick and easy to grow with a short life cycle.

Arabidopsis – Wikipedia 2010

Brachypodium – Wikipedia 2010

Phenomics - is used by plant breeders to understand the information coded in the genome. It involves the study of the phenotype of a plant. Borrowing imaging techniques from medicine, phenomics offers plant scientists new windows into the inner workings of living plants: infrared cameras to scan temperature profiles, spectroscopes to measure photosynthetic rates, lidar to gauge growth rates, and MRI to reveal root physiology. Phenomics will give plant scientists the tools to unlock the information coded in genomes.(Finkel: 2009)

Plants are compared under normal growth conditions and under stress and the scientists seek to identify how the plants gene expression has changed in response to that stress. Genes that have responded to the stress are identified, their function defined and that knowledge is then used in both conventional and transgenic breeding programmes. (Australian Centre for Functional Genomics). This is already resulting in some success stories. Selecting plants for salt tolerance has historically resulted in salt tolerant plants that are slow growing and of little use. CSIRO scientists in Australia have recently discovered that salt tolerance is associated with a plant's ability to resume growth after osmotic shock. Using a three dimensional camera to record minute changes in growth responses after wheat plants transplanted into salty soil went into osmotic shock the gene that helps plants resist osmotic shock has been identified. (Finkel, E: 2009)

A number of novel facilities exist around the world to automatically produce data on phenotypes. The largest publically owned facility of this type is being opened in Adelaide in December 2009.

The **Plant Accelerator** is a facility that has been recently built on the Waite Campus at the University of Adelaide. It is a robotic facility that will study plant phenotypes in vast numbers.

The facility consists of numerous temperature controlled greenhouses. It includes 2 'Smarthouses' that can hold up to 2400 plants at any one time. Over a kilometre of conveyors can deliver these plants to a variety of imaging booths for the non-destructive testing of plants. Cameras are located above and to the side of the plants and the plants can be rotated. The imaging techniques include the measurement of –

- Shoot mass, leaf number, shape, angle, and other morhometric data, and leaf colour and senescence using visible spectrum images
- Leaf water and carbohydrate content using near infrared images
- Leaf temperature using far infrared images
- Removal of water from the soil in the pots using near-infrared wavelengths
- Plant health by monitoring the state of the chlorophyll using fluorescence imaging
- Fluorescent proteins

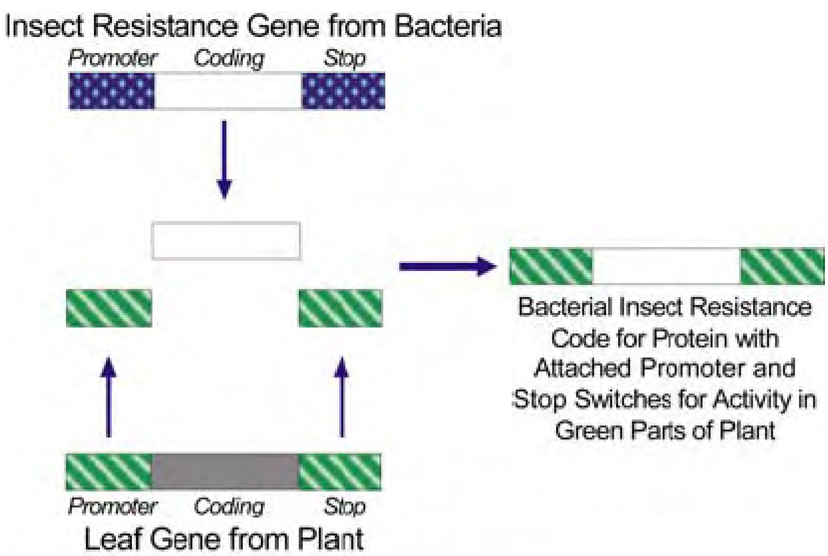
Plants can be imaged on a daily basis over a period of time to build up dynamic data.

The facility will be used to screen populations of plants including mutant and wild populations for features of plant growth and function. It will allow the thorough characterisation through time of plants of particular interest. It will also be used to develop plants with increased tolerance to drought, salinity, mineral deficiencies and disease.

The accelerator is twinned with the High Resolution Plant Phenomics Centre at Canberra that will focus on the 'deep phenotyping' of plants (delving into the metabolism and physiological processes within the plant) and reverse phenomics (dissecting traits to discover their mechanistic basis).

The information produced by these facilities will then be related back to the genotype. Between them the two facilities will build up a wealth of data very quickly and will quite literately accelerate the process of plant breeding

Genetic modification - There has been significant investment and activity in the genetic modification of plants in recent years. Genetic engineering involves modifying and transferring genes and includes controlling gene activity, or expression, by switching genes on, off, or modulating them up or down. These techniques are used to introduce, enhance or delete characteristics, depending on whether they are considered desirable, like better starches, or undesirable, like unhealthy fats.
To work a gene must have a promoter, a coding region and a stop switch as referred to on page 19 but they don't have to come from the same source. They can be 'recombined' from different sources. The promoter often comes from the receiving plant because it knows how to work in that plant but the protein coding part of the gene can come from a donor – so when the plant switches the gene on it builds the proteins that the donor organism would have built. The three parts of a gene are 'recombined' to make a functional gene with instructions to produce proteins of interest. This is called a gene construct and will become a transgene when it is transferred to a new host. (CSIRO:2007)



Reconstructing a gene

Image courtesy of CSIRO

There are three types of Genetic Modification

- Transgenic – moving a gene or part of a gene from a different species
- Intragenic – moving part of a gene from same species
- Cisgenic – moving a whole gene from same species –including the promoter and stop switch

Genetic Modification has the potential to offer enormous benefits across a wide range of different attributes. The commercial growing of GM crops is not currently permitted in the UK although attitudes towards GM do appear to be softening.
The potential benefit is probably best demonstrated by the C3/ C4 crops issue. Maize is a C4 crop and it has a fundamentally more efficient photosynthetic pathway than rice and wheat that are C3 crops. For the same input of water and nitrogen maize produces twice the carbohydrate content of rice. Phenomics will help scientists understand how this works but creating a C4 rice will almost certainly involve transgenics. (Finkel, E: 2009). The C4 pathway involves over a dozen genes but it has evolved independently in a number of different plants which perhaps implies that there are just one or two promoters associated with its expression.

Genetic engineering techniques are also used by conventional plant breeders to 'prove the concept'. Genes can be easily transferred within the species to discover if a particular gene will have a predicted effect in a commercial variety of a crop. If the gene works the breeder can then confidently go back and back cross the desired gene through the generations into that commercial variety.

Transgenics: How is a gene transferred into a plant?
Genes must be transferred into single plant cells. Inside the cell, the introduced gene is pasted into one of the cell's chromosomes where it becomes a permanent part of the cell's genome. The cell is then referred to as a transformed cell. When that cell divides, the new gene will be passed on to all of its offspring along with the plant's other thousands of genes.

Two methods are commonly used to transfer genes into plants: biolistics and agrobacterium.

Biolistics involves coating the gene construct onto tiny gold or tungsten particles, which are then shot into the cell using a miniature gun.

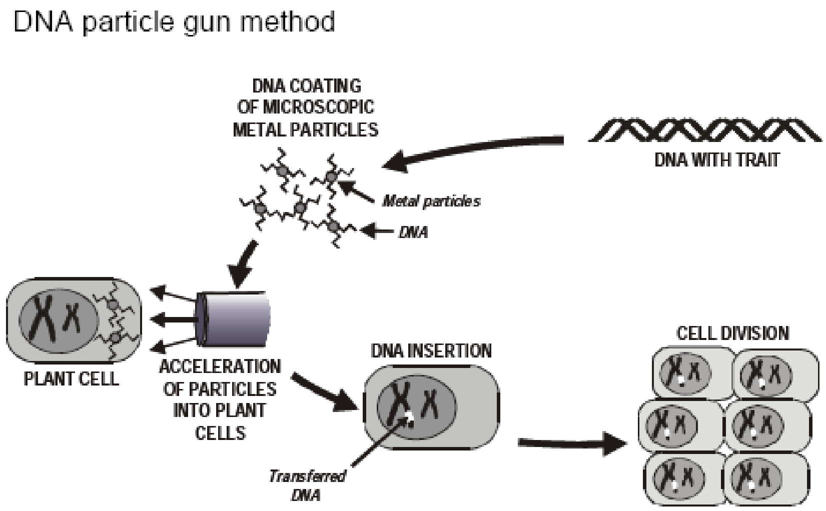


Image courtesy of CSIRO

Agrobacterium is a soil microbe that infects a wide range of broad-leaved plants and normally transfers a number of its own genes into a host plant's genome. Because of its natural ability to transfer genes to plant cells scientists replace the bacterial genes in agrobacterium with their gene construct. The gene is then transported directly into the DNA of the plant cell using the same mechanism that would otherwise carry the microbe's genes into a plant. The agrobacterium method is the most common method used to transfer genes.

Agrobacterium method

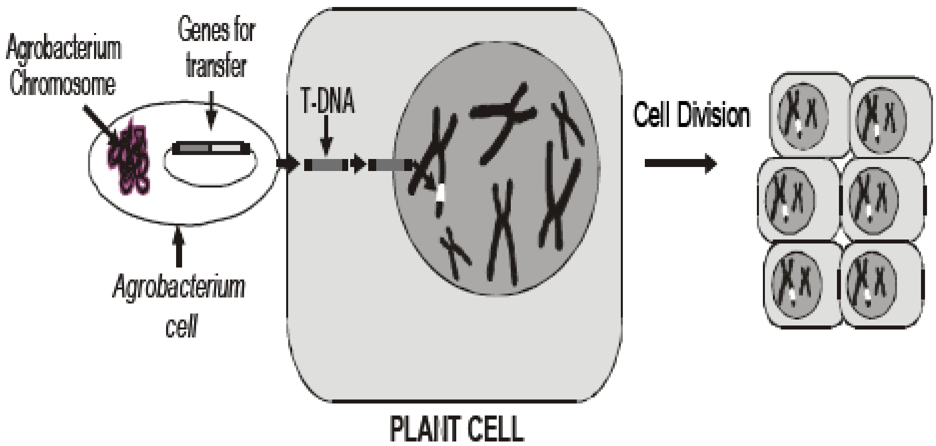


Image courtesy of CSIRO

These techniques are very 'hit and miss' and the frequency of transferring a gene into plant cells is relatively low, so scientists expose many cells to the agrobacterium and then use a selective agent to find those that have successfully taken up the new gene.

Plant genetic modification is made possible because plants can re-grow from a single cell using specific tissue culture procedures. Transformed cells are caused to divide, grow and develop into a small shoot or embryo and finally form a whole plant. This is called regeneration. Growing transformed cells requires precise and careful procedures, which means that new techniques have to be developed for each type of plant transformation. Plant transformation is a slow process. It takes between two and 12 months to select cells that have taken up the new gene and regenerate plants from these cells, depending on the plant species. (CSIRO:2007)

Genetic engineers are also working with novel enzymes from microbial organisms that can take DNA and manipulate it. The use of agro-bacterium and ballistics is random in terms of where the gene finishes up. However these microbial enzymes can be used to target where the new gene goes. They can also be used to remove parts of genes.

Historically antibiotic markers were used along with the gene so that a check could be made that the gene had been successfully transferred. This involved a theoretical risk of the antibiotic getting into the consumers gut bacteria.

These markers have now been replaced by a new testing procedure which is much more acceptable to the public.

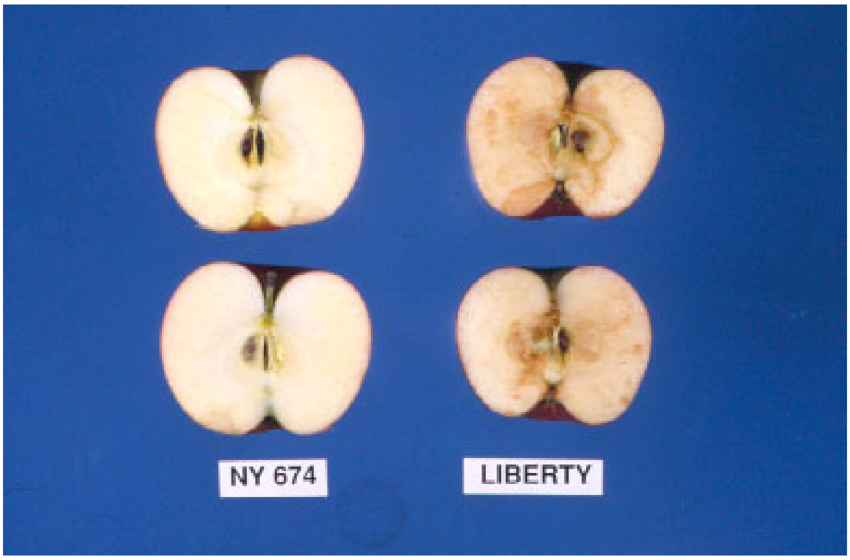
Gene Silencing is an important part of genetic engineering and represents a particular challenge for scientists. Switching off genes helps scientists to understand what they do and an effective technology to switch off genes could be used to treat some diseases. Genes can be switched off using RNA interference (RNAi). (CISRO: 2009) This is a molecular process that interferes with transcription. Genes often control more than one function so switching a gene off can have unexpected consequences.

Researchers at the National Food Research Institute in Japan have discovered that many ‘silent’ genes exist in micro-organisms which could be useful to genetic engineers. What do those genes do? Could they be used to develop new functions in plants (and animals!)? Are there similar ‘silent’ genes in other organisms? What promoters are required to switch them on and off? This clearly represents an area for future research.

Case Studies – to demonstrate the diverse way in which genetics can be used to advance crop husbandry

Autumn Crisp Apples

A new variety of apples has been developed by scientists at Cornell University in the USA that has flesh that doesn’t brown when cut. Apples are currently sold cut but they are treated with ascorbic acid (Vitamin C). This involves cost and ’added preservatives’ which have a negative impact in the minds of the public.



The white appearance of Autumn Crisp (NY 674) in comparison with a control variety
Image courtesy of Professor Susan Brown, Cornell University

Autumn Crisp was developed using conventional breeding techniques and is available to growers now. However scientists have identified the factors that are associated with non-browning. These are low levels of polyphenol oxidase which is the enzyme that causes browning and low levels of phenolics. The team have already identified the genes involved in creating this unique characteristic and will be able to breed this characteristic into other varieties by tracking the relevant genes through a breeding programme.

The characteristic offers new marketing opportunities for farmers. Pre-cut apples are thought to represent a significant market and a completely natural product will be very attractive to many consumers.

Apple slices free of preservatives offer a new market for farmers

Image courtesy of Professor Susan Brown, Cornell University

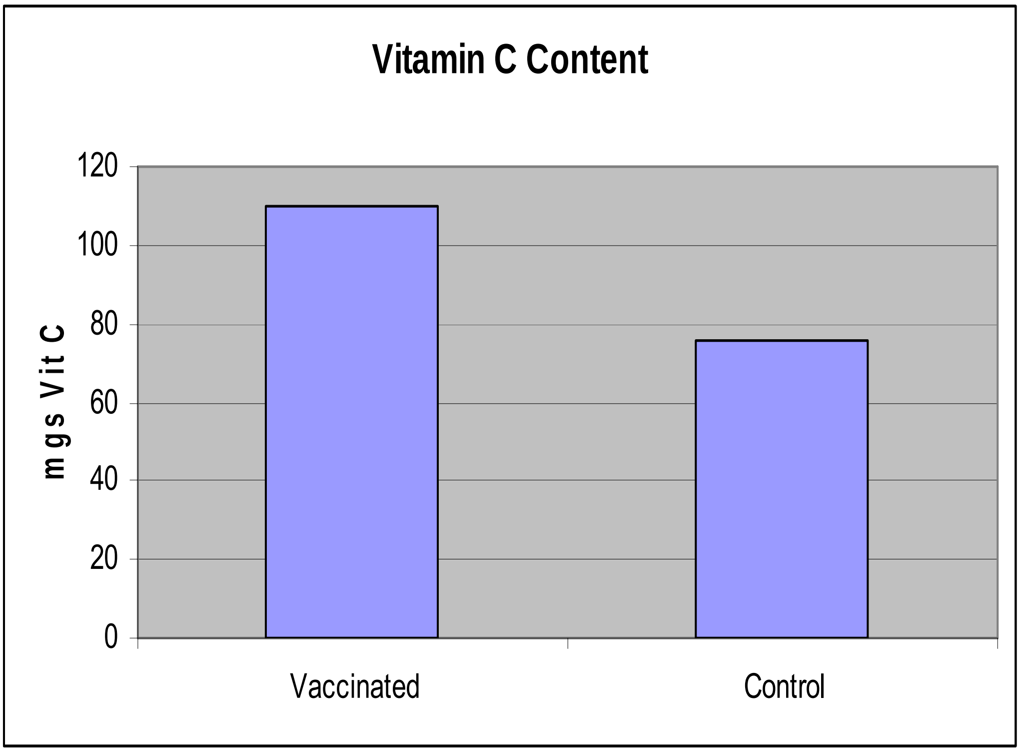
Using genomics to develop a vaccine for plant viruses

Scientists at the Department of Plant Pathology at NARC in Japan have used genome sequencing to develop a vaccine for Pepper Mild Mottled Disease. The virus results in mild chlorosis and stunting, especially if plants are infected when young. Fruits are small, malformed, mottled and some have necrotic depressions. (ICTVdB Management:2006). It is a problem worldwide in field grown peppers and has appeared in Glass House Grown Peppers in Canada and Spain. It is a potential problem for UK growers with production facilities in Spain.

Infected Peppers – Wikipedia: 2010

The traditional method of controlling the virus was to sterilise the soil with Methyl Bromide but this is being phased out around the developed world for environmental reasons. The research team discovered that the virus mutates when the peppers are grown at temperatures in excess of 25˚C. Some of these mutations render the virus unviable but if they are applied to a young plant they act as a vaccine. These mutations are taken and multiplied up. They are then sequenced. The scientists then look for the mutations that have taken place. They know in which regions of the genome the mutations need to be to successfully make the virus unviable and they are ideally looking for several mutations because that makes the vaccine more stable. When suitable mutations are found the host plants are crushed and the sap recovered. This is then applied to the cotyledons of young pepper plants that are then vaccinated against the disease.

In tests the vaccinated plants have produced yields in line with disease free control plants but have had the added benefit that the level of vitamin C in the vaccinated peppers is almost 50% higher than the control.

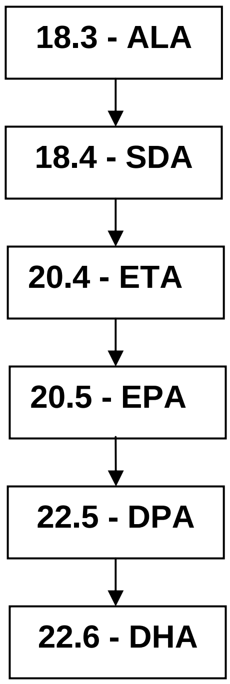


The team are in the process of applying for IP on the technology and will then make the vaccine available to the industry through commercial partners.

Developing Oilseed Rape with Omega 3

Scientists at the CSIRO Future Grains project have developed a transgenic Oilseed Rape that is rich in Long Chain Poly-unsaturated Fatty Acids – high quality Omega 3. (See Appendix 1 on Fatty Acids for an explanation of Omega-3s)

High Quality Omega 3 is developed in several stages as unsaturated fat molecules get longer and less saturated as demonstrated below –

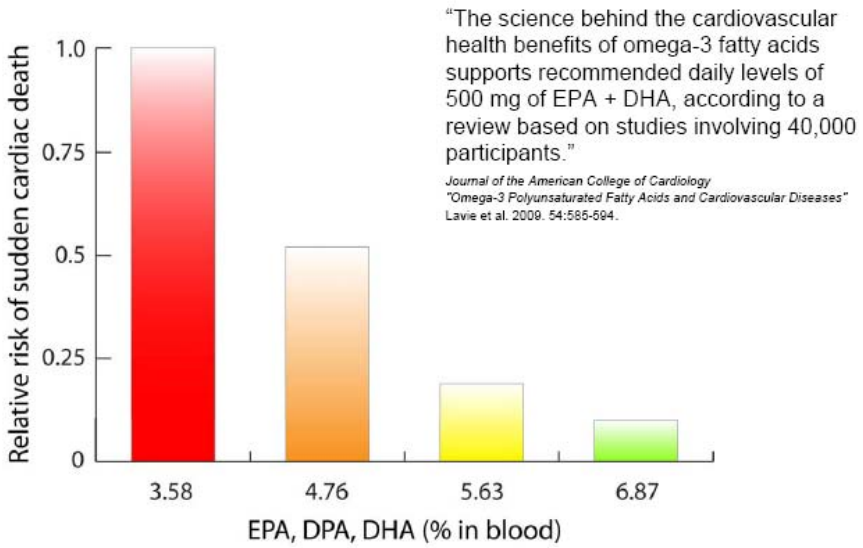


The short chain Omega 3's ALA and SDA are found in plants including oilseed rape, olives and flax. They will convert to EPA but not DHA and it is DHA that is really valuable for human health.

There is conclusive evidence that long chain Omega 3's prevent a number of diseases including

- Cardiovascular disease
- Stroke
- Hypertension
- Inflammatory diseases
- Rheumatoid arthritis

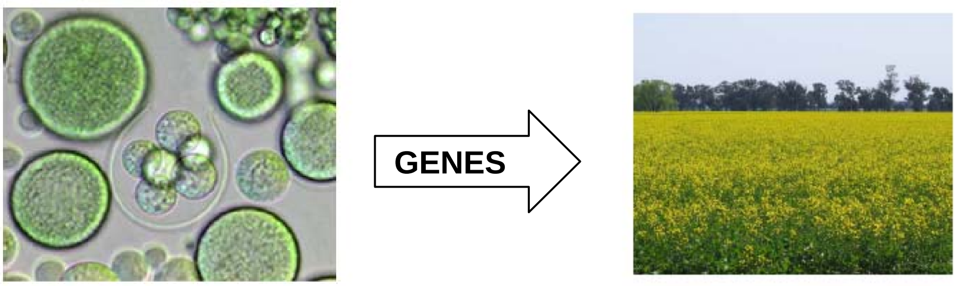
There is also some limited evidence that it had an impact on mood, asthma and cognition.



Albert, C.M. et al., 2002. *The New England Journal of Medicine*, 346(15)1113-1118

However there are only very limited quantities of high quality Omega 3 oils available. Very few fish synthesise their own DHA. Most acquire it in their diets from marine microalgae. Farmed fish acquire it from fish meal that is fed to them. Quite simply there is only enough DHA Omega 3 available from fish to provide the recommended daily intake for a small part of the population. An alternative source is required.

The team set about identifying genes that could build the Omega 3 at each part of the chain.



marine microalgae
(current primary producers of DHA)

transgenic oilseed crop
(new primary producers of DHA)

Images courtesy Dr James Petrie, CSIRO

By 2005 using genes from Zebra fish and microalgae they had successfully proven the concept and had synthesised DHA in the model plant Arabidopsis. However at two points in the chain the process was very inefficient – only 36% of the ALA was converted to SDA and only 21% of the EPA was converted to DPA. Indeed less than 1% of the original ALA was finally converted to DHA.

The team set about improving the efficiency of the process. They identified a range of potential genes that could be put into each point of the chain and tested them for efficacy. The conversion of EPA to DPA was improved from 21% to 95%.
The team also developed a new rapid assay to test gene function and then successfully extended that assay to cover the whole chain.
The significant hurdles associated with this project have been overcome. The conversion of ALA to DHA across the chain is now close to 100% and the prospect of cheap high quality Omega 3 oil being available in large quantities is now a reality.
This new GM crop is now progressing towards commercialisation in Australia although the regulatory process will take several years to complete. Of course at present Genetically Modified crops are not available to UK farmers but this is a crop with very tangible consumer benefits. Is this the crop to break consumer resistance to GM?

Animal Genetics

Scientists are using genomics to identify individual genes of interest in our farmed livestock and to develop breed improvement programmes. Genomics can also be used to confirm parentage.

Individual genes have been identified for genetic defects. Of these the BLAD gene is probably best known in the UK but others include arthrogryposis multiplex, neuropathic hydrocephalus and mannosidosis in cattle and microphthalmia in sheep.

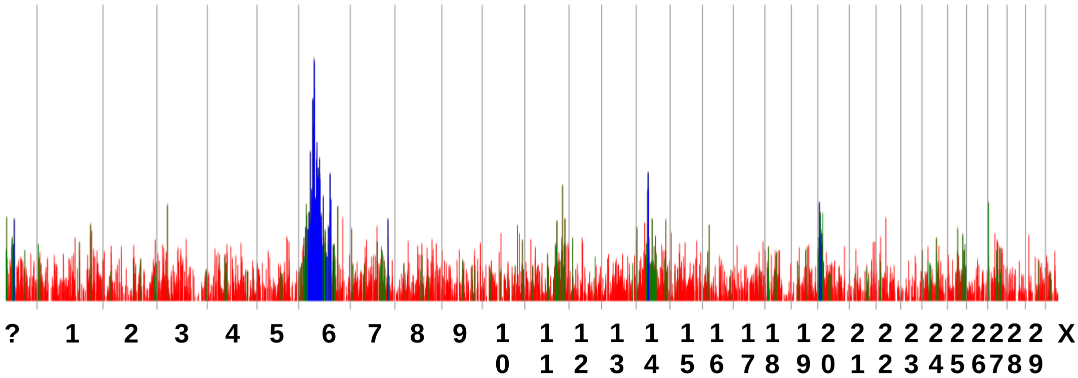
Individual genes have also been identified that influence tenderness, muscling and fat colour. Of these the myostatin gene in Belgian Blue Cattle and Texel Sheep is probably best known. The myostatin gene inhibits muscle growth in most animals. Mutations to this gene can result in this inhibition being lifted. In Belgian Blue cattle the mutation is 11 missing base pairs in the genome sequence.

However it is the concept of using the genome to replace progeny testing in traditional breeding programmes that has involved most scientific effort. Traditional breeding programmes using phenotypes and pedigrees have been successful in creating genetic improvement.
Modern breeding programs attempt to maximize progress by targeting the four determinants of genetic response: genetic variation, generation interval, intensity of selection and accuracy of selection. This is well illustrated by the breeding strategies developed for dairy cattle:

- Artificial insemination has had a major impact because of its effect on selection intensity
- Progeny testing is implemented to increase the accuracy of selection

- Nucleus schemes exploiting embryo transfer to select bulls based on the performances of their sister aimed at reducing the generation interval

The production traits that animal breeders are interested in such as milk production, fertility and muscling are clearly under the influence of multiple genes but scientists remain unsure whether individual traits are influenced by a vast number of genes with a small influence or if a subset of those genes have a significant influence on the trait and then the rest have a very small influence. It is identifying all the genes that have an impact on a trait that has been a major challenge for scientists.



The distribution of genetic effects for calf birth weight throughout the genome – some genes have a big effect but there are many more genes with progressively smaller effects.
Image courtesy of Larry Kuehn, USMARC

Marker assisted breeding uses SNP markers to identify areas of the genome that have known effects to predict the genetic breeding value of an animal without progeny testing it. Indeed it is believed that the prospect of success can be doubled using genome information. It is estimated that it is possible to achieve accuracies of predicted breeding values from markers alone of 0.85. The implication is that the accuracy of a GEBV (Genetic Estimated Breeding Value) can be as high as the accuracy of an EBV (Estimated Breeding Value) after a progeny test. The GEBV can be estimated from the embryo and the bull can start breeding from 2 years of age rather than 5 resulting in a doubling of genetic gain. Larger numbers of embryos can be screened resulting in increased selection intensity. The costs savings for breeding companies are potentially significant. (Hayes et al: 2009). However to date this possibility has not become a reality.

Finding and identifying all the genes that have an impact on a trait isn't easy. Scientists use SNPs as genetic markers that are evenly spread across the whole genome. Scientists used to use 5000 of these markers across the genome to try to identify important areas of interest, more recently they have used 50000 markers and they are just starting to use 500000 markers. 50000 markers represent just one in every 120 SNPs across the bovine genome. These markers could be 'the causative mutation' but probability would suggest that they aren't. They are used on the assumption that if the marker is there then the causative mutation that is near it is probably also there.

The process relies on accurate phenotypic data from a large number of animals to relate the genetic markers back to the desired trait. The amount of available phenotypic data varies across the different breeds and species. The Dairy Industry has an advantage here in that it has vast quantities of such data from past progeny tests that can be compared to the original genetic material of the animals sires. The heritability of a trait is also important in terms of how many phenotyped records are required. The higher the heritability the fewer the number of records are required. However for low heritability traits a vast number of phenotyped records will be required to achieve a high accuracy of GEBV in an unphenotyped animal. (Hayes: 2009)
In the early days of marker assisted breeding scientists thought that 200 markers used along with 500 phenotyped animals would deliver results. They now think that in excess of 200000 markers are required along with 30000 phenotyped animals. Until recently it wasn't realised that this many would be required. Scientists are now starting to use 500000 markers and some people in the industry are starting to look towards the day when sequencing the whole genome of individual animals will be affordable.

There are a number of problems with these markers –

- Recombination can result in a marker being split away from the causative SNP. The drive towards using ever larger number of markers is partly driven by getting them closer to the mutation where they will be less likely to be split by recombination.
- Antagonistic genes exist that can negate the effect of a desirable gene.
- A proportion of markers are mis-identified.
- Markers are less reliable across different breeds than within a breed. So a reliable set of markers across the Hereford breed might have limited use within the Angus breed. This means that each breed needs its own body of phenotypic data which often doesn't exist. A specific example of this point is the markers used for resistance to facial eczema in parts of New Zealand, Australia and Spain. 2 markers have been identified for resistance to facial eczema in Friesians but just one in Jerseys. The one in Jerseys is different to the two identified in Friesians and is a more reliable test for resistance.
- Genes can have their promoters on a different chromosome. If the promoter is missing the gene won't be expressed.

However as the total number of animals with phenotypes and marker genotypes increases the accuracy of estimating marker genotype effects should approach 1.0. (Georges: 2006)
At present critics will point to the reliability associated with Marker assisted breeding. They will point out that markers don't yet explain enough of the genetic variability. Scientists at the US Meat and Animal Research Centre in Nebraska have correlated predictions of genetic merit based on markers to results of a conventional progeny test and found they were generally in the range of 0.1 to 0.4. This was poorer than was hoped for and they believe that denser markers and more phenotypes are needed to significantly improve the prediction.
Despite this Angus breeders are incorporating genome material into their EPDs (Estimated Progeny Differences) by combining the conventional

progeny test with genomic data. It increases reliability and is particularly useful for carcase traits including marbling, rib eye area and back fat. Other breeds are not in such a good position as they don't have the data. With cross-breeds there is still a lot to learn!
Pfiser have commercialised a number of tests for the beef and sheep industry. For beef farmers they offer a 56 marker test for tenderness, feed efficiency and marbling and quote reliabilities of 49%, 30% and 26% respectively.

The use of genetic markers is probably least useful where existing progeny testing offers a very high level of reliability. There is little to gain. It is of greatest potential use in relation to traits that are difficult to incorporate into existing progeny tests such as those traits that are difficult to measure or are associated with more mature animals.
One effect of genomic selection may be a more appropriate balance in the direction of genetic gain. Currently in the dairy industry large gains are made in production traits whereas gains in fertility are small – due in part to the lower accuracy of fertility EBV (Estimated Breeding Value) and because production and fertility are unfavourable correlated. A major impact from genomic selection should be increased gains in these hard-to-select for traits. (Hayes et al: 2009)
Incorporating genomic information into the international comparisons among proven sires, as currently calculated by Interbull, will be a very challenging task owing to different sets of SNP being used between and within countries, different prediction equations, and the presence of marker × environment interactions

In future markers might be used not just for breeding programmes but also for

- Animals might be bought and sold based on estimated phenotypic values (EPV) derived from the markers.
- Animal products, such as meat and milk, might be paid for based on genetic markers.
- Animals might be allocated to management options or environments based on genetic markers.
- Animals might be mated to achieve favourable non-additive gene combinations
- DNA markers could be used to determine pedigree.
- DNA markers could be used to trace animals and their products. (Goddard: 2007)
- Genetic markers could also be used to avoid inbreeding

Transgenic animals – traditional breeding and marker assisted breeding are limited by the genetic variation within the species. However the possibility exists to introduce genes from other species to produce livestock with attributes that could not be produced using conventional breeding. Potentially we could produce a cow that produces lactose free milk.
Transgenic livestock are produced using pronuclear injection. A solution containing the DNA is directly injected into one of the pronuclei of a freshly fertilised single cell embryo. A new technique called Nuclear targeting is also used. This technique involves manipulating stem cells. Both techniques are hugely expensive and many embryos fail.

Transgenic animals are principally used for producing donor organs and a variety of pharmaceuticals. The mammary gland is a particularly useful ‘factory’ for pharmaceuticals due to its large capacity for protein production and ease of harvesting the product. A gene for human protein used to treat cystic fibrosis has been inserted in to a line of transgenic sheep. The gene is expressed in the udder of those sheep, so the protein is secreted in to the milk and can be filtered out from there. This provides a supply of the protein that can be used to treat cystic fibrosis suffers. (LIC: 2003)
Transgenic animals could have a future in improving production, food quality, disease resistance and efficiency but the prohibitive costs suggests that the immediate future will centre on the uses outlined above.
There are also huge ethical issues associated with transgenic animals and they are unlikely to represent an opportunity for UK farmers in the foreseeable future.

Case Studies

DNA Proven Sires

The Livestock Improvement Company – LIC – in New Zealand have commercialised livestock genomics in their DNA Proven Sires programme.

The Dairy sector has an advantage over the other livestock sectors in that it has a huge historical data base from which it can draw data. Going back over several decades the sector has abundant phenotype data for the key production traits of milk yield, butterfat, protein and somatic cell count. The progeny testing programmes and breed societies classification systems also provide significant quantities of information on the animals physical make up. The industry was able to take this data and analyse it alongside the genomes of the various AI sires that had been used during that period.

LIC started work on genome selection in 1995. Over the next 8 years they built capability in the technology and identified a number of specific genes for specific functions. The business successfully patented two specific mutations –

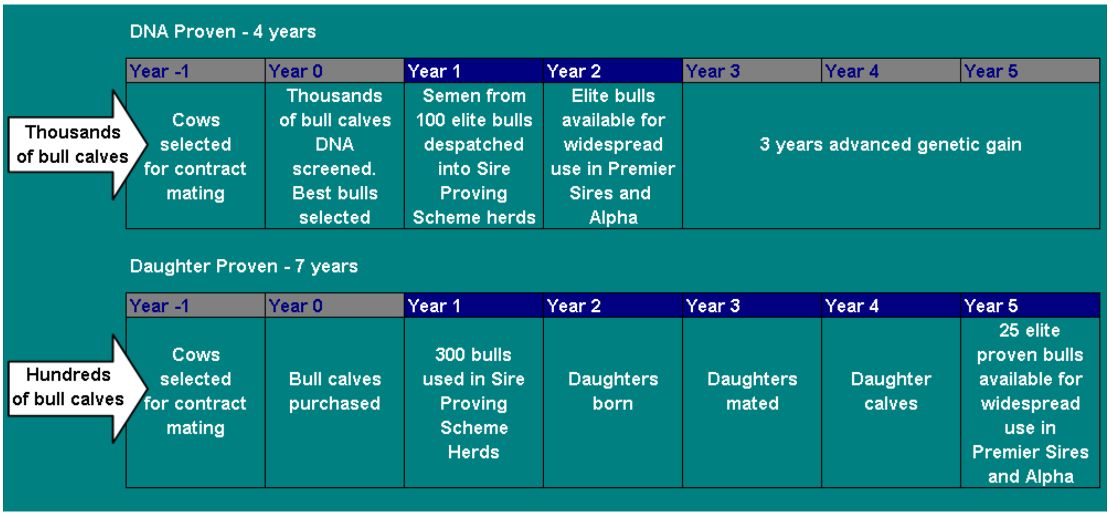
The Dgat gene – which has an impact on fat and protein production
Growth Hormone Receptor gene – that also impacts on fat and protein

They have since identified two further SNPs –

One associated with liveweight and
One associated with once a day milking

In 2003 LIC started to work on WGS (whole genome selection or marker assisted breeding). At this point the cost of running a 50000 chip had come down to the point where they felt it was time to invest. The business analysed their archive of data to establish links between the marker SNPs and various traits. The business was suitably encouraged by the results and in 2007 launched their first group of bulls with a proof based on just their genome. LIC continue to offer bulls based on a traditional progeny test on their Daughter Proven Sires programme.

LIC believe that the reliability associated with the DNA Proven Sires programme is in the order of 55% in comparison with about 80% for the Daughter Proven Sires. The DNA Proven Sires will be put through a traditional progeny test in due course to verify the reliability and provide feedback on the whole process. However as the business moves to analysis based on a 500000 chip the reliability can only improve and the business is already thinking about the prospect of costs declining to the point where they can put the whole genome through the process and pick up individual mutations associated with key traits. One of the key benefits of Whole Genome Selection is that it allows the whole process of genetic improvement to be speeded up. In the time it takes to put a sire through a traditional daughter progeny test almost two generations can be put through a Genome test. In theory the DNA Proven Sires should be of higher genetic merit than the Daughter Proven Sires which can be offset against the lower reliability.



Another key benefit it that it Whole Genome Selection is lower cost than traditional progeny tests.

There is also the prospect that in the future Whole Genome Selection will be a more reliable tool than traditional progeny testing.

The Genome Proven Sires have just been made available to UK farmers. They will be of interest to those farmers running a grass based system similar to those in New Zealand.

Muscling in sheep

Two genes have been identified that have a major impact on muscling in sheep. The Myostatin gene and the Callipyge gene.

The research team at the Centre for Reproduction and Genetics at Invermay in New Zealand have led the World in the development of Commercial Genetics tests for the sheep industry. Their premium product is MyoMAX which is marketed by Pfizer Animal Genetics. The Agresearch laboratory at Invermay conducts the test.

MyoMAX is a test for the myostatin gene that influences carcase weight and muscle yield on the leg and rump.
The myostatin gene is one that has a negative impact. It suppresses muscle growth in all breeds except the Texel. The MyoMAX test ensures that the animal is carrying the desirable gene. The team have recently identified the causative mutation associated with this test and this has improved the accuracy of the test. In the past they occasionally produced an incorrect result.

The test is used by the breeders of terminal sires. By a process of back crossing the desired gene is incorporated it into local indigenous breeds and the test is used to ensure its presence.

First Cross Texel (MM) X Indigenous Breed (mm)

Second Cross M x m X M x m

Offspring from 2nd Cross M x M M x m m x M m x m

25% of the offspring of the second cross carry two copies of the desirable Myostatin gene although the animal will be only 50% Texel. These animals are identified and then used as terminal sires. The commercial lambs that they produce are guaranteed to carry the desired gene and will be 25% Texel /75% Indigenous Breed. The impact on the carcase is significant.

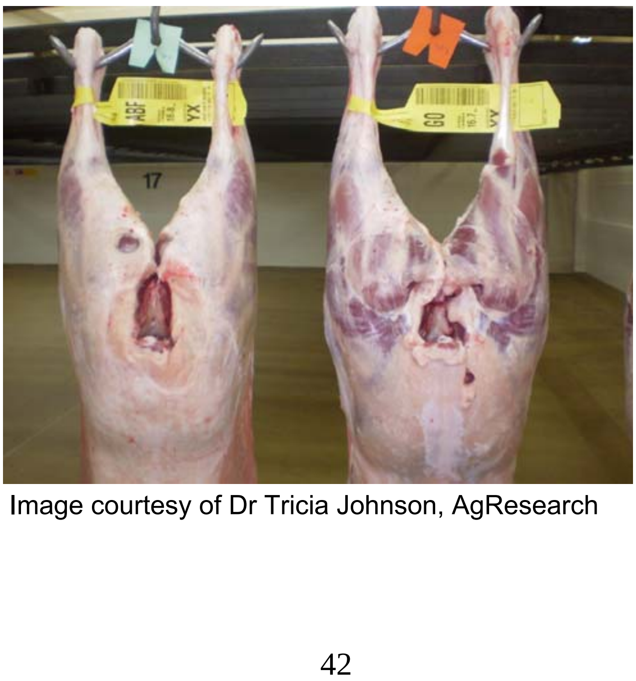


Image courtesy of Dr Tricia Johnson, AgResearch

The team at Invermay have produced a number of other genetic tests that are available to farmers. These include parentage tests, worm resistance, prolificacy and loin muscling. A small number of UK farmers are already using the testing service at Invermay.

The team are about to introduce a test for Whole Genome Selection based on 50000 SNPs. It will test for liveweight, parasite resistance, no of lambs born and lamb survival. In due course meat yield, meat quality, wool growth, adult live wt, longevity, residual feed intake, and methane emissions will be added. All of these are in various stages of development. This test will focus on local breeds and will probably not be of use to UK farmers.

Farmers in New Zealand are helped by specialist advisers from businesses such as Abacusbio to develop the genetic merit of their flocks and these advisors are now starting to incorporate genomics into their service.

The Callipyge gene is a mutation that first appeared in a Dorset Horn ram in 1982. The gene was identified in 2002. It also produces significantly greater muscling and reduces fat content in the carcase. It can also be incorporated into other breeds by back crossing.
Remarkably the gene only works when it comes from Sire

Sire	Dam	Lamb
C	C	Normal
C	c	Double muscled
c	c	Normal
c	C	Normal

Image courtesy of Dr Kreg Leymaster, MARC

However there is a problem with the Callipyge gene. Whilst it increases muscling it also makes the meat very tough. Scientists at the US Meat Animal Research Centre have produced animals with both the Callipyge gene and the Myostatin gene and have achieved increases in rump width, leg scores and rib-eye area along with a reduction in fat. They believe that genomic approaches to investigate the toughness issue should be pursued, but acknowledge that the development and release of improved germplasm is a long-term project. One to watch for the future.

Conclusion – gene technology has not yet delivered what was expected 20 years ago but our understanding of the genomes of our cultivated plants and our animals has now developed to the point where vast numbers of valuable genes have been identified. Scientists are using this knowledge to track desirable traits through their breeding programmes and to genetically modify plants with desirable characteristics.

The case studies demonstrate the wide variety of ways in which this technology can be used from breeding new characteristics into our existing cultivars to increasing the speed of genetic gain in our livestock populations. The future promises further developments in this technology offering farmers improved performance, new traits and improved disease resistance.

Functional Foods

Functional Foods - are an important part of a healthy diet. Foods are not medicines but a healthy diet can promote well being and reduce the risk of developing certain non-communicable diseases. A diet can only be healthy if the combinations of individual foods is good and is not just about limiting foods that contain components of concern such as fatty acids but is also about including elements that can provide extra benefits.

In today's Society there is a growing problem with obesity along with an increase in the prevalence of chronic, non-communicable diseases such as high blood pressure, cardiovascular disease and type 2 diabetes. Aspects of lifestyle, diet and physical activity all play a role in the incidence of these diseases and it has become clear that diet can play a role in reducing their incidence and improving long term health. Foods can have a positive influence that goes beyond providing basic nutrition.

Defining a functional food is not always straight forward and there is a grey area where functional foods and medicines merge. The EC Concerted Action on Functional Food Science in Europe (FUFOSE) have produced the following working definition of a functional food –

- A food that beneficially affects one or more target functions in the body beyond adequate nutritional effects in a way that is relevant to either an improved state of health and well being and/or reduction of risk of disease

- Not a pill, a capsule or any form of dietary supplement

- Consumed as part of a normal food pattern

From a practical point of view, a functional food can be:

- o A natural, unmodified food

- o A food in which one of the components has been enhanced through special growing conditions, breeding or biotechnological means

- o A food to which a component has been added to provide benefits

- o A food from which a component has been removed by technological or biotechnological means so that the food provides benefits not otherwise available

- o A food in which a component has been replaced by an alternative component with favourable properties

- o A food in which a component has been modified by enzymatic, chemical or technological means to provide a benefit

- o A food in which the bioavailability of a component has been modified

- A combination of any of the above (Howlett: 2008)

Functional food science works from knowledge of the key processes that result in optimal health or the risk factors that result in the development of disease. Functional foods can have an influence on the following aspects of well being and health –

Early development and growth

Regulation of energy balance and body weight

Cardiovascular function

Defence against oxidative stress

Intestinal function

Mental state and performance

Physical performance and fitness

This is not an exhaustive list and other areas of physiology also have the potential for the development of functional foods.

Early Development and Growth – pregnancy and the first postnatal months are critical periods not just for growth but also for the development of the risks associated with high blood pressure and heart disease, intestinal growth, the development of the nervous system, the development of the immune system and skeletal development. A variety of essential nutrients, minerals, vitamins and other food ingredients are important during this period. These include polyunsaturated fatty acids, folic acid, iron, zinc, iodine, antioxidant vitamins, pre-biotics, pro-biotics and many others. All of these are important functional food ingredients.

Regulation of energy balance and body weight – the epidemic of obesity is recognised as one of the major health challenges facing the developed world. Obesity is associated with an increased risk of heart disease, type 2 diabetes, high blood pressure and some forms of cancer.

Diabetes results from impaired insulin secretion or reduced insulin action. Insulin is the main hormone that controls blood glucose levels and the disease is characterised by increased glucose levels in the blood. Type 1 diabetes usually develops in young people and is associated with the body’s inability to produce insulin. Type 2 diabetes usually develops in overweight and/or older people. Its onset is slow and it is associated with a resistance to insulin resulting in increased glucose levels. It also results in changes to the metabolism of fats which increases the risk of coronary and other cardiovascular diseases.

This area offers opportunity for functional foods. Some foods cause a slow absorption of glucose into the bloodstream and help control glucose levels. The term ‘low glycaemic index’ is reserved for foods with carbohydrates that are absorbed in the gut but which cause only a slow and small rise in blood sugar levels. Examples of such foods are bread and pasta with whole grains, legumes and foods enriched with certain types of dietary fibre.

Cardiovascular function – cardiovascular diseases (CVD) are a group of degenerative diseases of the heart and circulatory system and include coronary heart disease, peripheral artery disease and stroke. They are major problems in most developed countries. There are a number of risk factors associated with these diseases including high blood pressure, inflammation, inappropriate lipoprotein levels, insulin resistance and control of blood clot formation as well as factors such as genetic disposition, smoking and levels of physical activity.

Diets low in saturated fatty acids and trans-unsaturated fatty acids reduce the risk of CVD. Functional foods enriched with cis-unsaturated fatty acids with 18 carbon atoms – oleic (mono-unsaturated), linoleic and alpha-linolenic acids (polyunsaturated) can be used to reduce the risk of CVD. The long chain, highly unsaturated fatty acids found in fish oil can promote improvements in arterial health, counteract blood clotting and reduce blood pressure.

The risk of CVD can also be influenced by certain types of dietary fibre, by antioxidants, by plant sterols and by reducing sodium intake and increasing potassium and calcium intake.

Defence against oxidative stress – as part of the metabolic process within the body oxygen is involved in toxic reactions. Free Radicals and Reactive Oxygen Species are formed within the body. They are the body’s own poisons. They act as oxidants and are thought to be contributors to ageing and many of the diseases associated with aging including cardiovascular disease, cancer, cataracts, age-related decline in the immune system and degenerative diseases of the nervous system, such as Parkinson’s and Alzheimer’s. Oxidants can damage the structure of DNA. (See Appendix 2 for more details on Free Radicals and Reactive Oxygen Species).

The body has natural defences against these oxidants including a system of antioxidant enzymes and other compounds that act as antioxidants. Antioxidants de-activate oxidants and render them harmless. Selenium, copper, manganese and zinc are important components of some of these enzymes and if their supply is inadequate the body’s defences may be impaired. ‘Oxidative stress’ occurs when the body’s antioxidant defences are unable to cope and are overwhelmed by oxidants.

The body’s natural defence system can be supported by functional foods containing a wide variety of antioxidants. These include vitamins C and E, carotenoids and polyphenols including flavonoids. They either directly reduce oxidants or assist the body’s own antioxidant defences. Most are of plant origin. Plants create a wide variety of antioxidants to protect themselves from exposure to ultraviolet light and other forms of radiation.

It is estimated more than 5000 individual antioxidants have been identified in fruits, vegetables and grains. Antioxidants differ widely in composition between fruit, vegetables and grains and often have complementary mechanisms to one another. (Liu: 2007). Trials to date have shown no benefit associated with the consumption of single antioxidants and it maybe best to consume a wide variety of antioxidants to ensure a benefit is obtained.

Intestinal function – the colon is a highly metabolically active organ that contains a complex microbial ecosystem. The gut micro flora provides the basis for a barrier that prevents infection and plays a major role, at an early age, in developing the immune system. It also has a major influence on stool characteristics.

The gut is sterile at birth and is colonised during delivery and shortly thereafter. This is heavily influenced by diet and each individual has their own specific gut micro flora. All the species of micro flora that are present in the gut have not been identified but molecular genetics have revolutionised their identification and characterisation.

The gut micro flora play an important role in gastro-intestinal infections, constipation, irritable bowel syndrome, inflammatory bowel diseases and, possibly, colon cancer.

The main substrates for bacterial fermentation in the colon are dietary fibre and mucus. The consumption of dietary fibre is an important aspect of maintaining gut health.

Pro-biotics and pre-biotics are functional food components that influence the activity of gut micro flora.

Pro-biotics are live microbial food ingredients. Various species of bacteria are used as pro-biotics in yogurts and fermented dairy products. They can alleviate lactose intolerance and reduce the incidence and severity of gastro-intestinal infections. They may also have an impact on reduce the risk of some cancers. Pro-biotic bacteria do not persist in the gut and regular consumption is required to maintain their effects.

Pre-biotics are non-digestible food ingredients that stimulate the growth or modify the activity of bacteria that are already present in the gut with the result that the host's health is improved. To succeed pre-biotics must pass through the small intestine in significant quantities and must be a selective substrate for one or more beneficial bacteria that are stimulated to grow. Various possible benefits associated with pre-biotics are being investigated including their impact on the immune system and on other colorectal diseases.

Mixtures of pro-biotics and pre-biotics are called synbiotics.

Mental state and performance – some foods have a significant impact on mood and mental state. They can affect appetite or the feeling of satiety, cognitive performance, mood and vitality and an individual's reaction to stress with consequent changes in behaviour. There are large differences in response to different foods amongst different individuals and age, weight and sex have a significant influence in the level of response. In some cases adaptation can occur so that with repeated ingestion the effects may be diminished or lost.

Aspects of behaviour that can be affected by foods include performance in mental functions (such as vigilance, memory, attention, and reaction times) and aspects of eating behaviour (such as eating frequency, food preferences, and dietary selection). Some effects are immediate, such as reaction time, attention focus, appetite and satiety and short term memory. Others are longer term such as changes in memory and mental capacity associated with ageing.

Functional foods can prevent a dip in vigilance in the post lunch period; others can improve the intellectual performance of students sitting exams. Functional foods can lift the mood of individuals at a low point and others can improve memory in old age. It is important to specify the needs of the individual when considering suitable functional foods to improve mental performance.

Glucose improves working memory, decision time and information processing. Caffeine is well recognised as a food that improves reaction time and vigilance. Meals high in carbohydrates produce feelings of sleepiness and calm. Sweet foods may ease stress in young infants and may reduce perceptions of pain in members of the general population. Meals high in protein reduce hunger and increase satiety and may help body weight control.

Physical performance and fitness – diet can have an impact on physical performance during exercise and can influence recovery after intensive training. During training and competition the body uses significant quantities of energy and exerts significant stresses on the musculoskeletal and hormonal systems. Functional foods can improve recovery during training and improve performance at competitions.

Oral rehydration products were one of the first functional foods. They offer rapid absorption, improved physical performance and delayed fatigue. Exercise induced loss of nitrogen, minerals, vitamins and trace elements need to be replenished by the diet. Specific carbohydrates with moderate to high glycaemic index and with protein have been shown to influence physical performance and enhance recovery. This offers the potential for the development of functional foods. (Howlett: 2008)

Issues with Anti-oxidants! – as outlined above antioxidants are substances that deactivate the body's own poisons. They have a huge impact on health and slow down the degeneration associated with ageing. As we now live longer the results of long term damage to body tissues associated with ageing has become more apparent. Many of us eat a diet that provides inadequate antioxidants.

Antioxidants include –

Carotenoids –
- Beta-carotene – in green veg, yellow & orange fruit and veg
- Lycopene – in tomatoes, watermelon, many pink fruits
- Lutein – in leafy vegetables

Vitamins –
- Vitamin C – in fruit and veg especially citrus and berry fruits and potatoes
- Vitamin E – in grains, nuts, watermelon, and vegetable oils

Flavonoids and other phenolics-
- Anthocyanins – in red wine, red grapes and berry fruit
- Phenolic acids – in most fruit and vegetables
- Isoflavones – in pulses, especially soya beans
- Flavonols – in onions and asparagus
- Catechins – in tea and chocolate
- Flavones – in citrus fruits

Sulphur compounds –
- Allium sulphur compounds – in garlic, onions and leeks
- Glucosinolates/isothyocyanates – in brassicas: broccoli, cabbage & cauliflower

Trace elements –
- Selenium – in seafoods
- Zinc – in seafood, lean meat, milk, grains, lentils and nuts

Others –
- Lignans – in linseed, sesame seed, bran, whole grains, beans & vegetables
- Lipoic acid – in green vegetables, tomatoes and rice bran
- Coenzyme Q (ubiquinone) – in meat, fish, vegetable oils, wheat germ and rice bran

Scientists have accumulated evidence that suggests that antioxidants are good for us. They have conducted population studies, population trials and laboratory experiments. An example of this research is the 'Seven Countries Study' which investigated the relationship between coronary heart disease and cancer with the intake of flavonoids in 12000 men aged between 40 and 59 in seven countries over 25 years. The study demonstrated that coronary heart disease was 5 to 10 times less prevalent in Greece, Japan and Italy than in the USA, Finland, Holland and Yugoslavia. These differences correlated with variations in the intake of flavonoids. This particular study found no correlation between flavonoids and cancer but a variety of studies have established associations between the consumption of antioxidants and various cancers.

Scientists and nutritionist also grapple with 'the French Paradox'. The French eat a lot of saturated fat but have a comparatively low incidence of heart disease. Scientists believe that this is related to other aspects of their diet that counter balance the negative impact of the saturated fat.

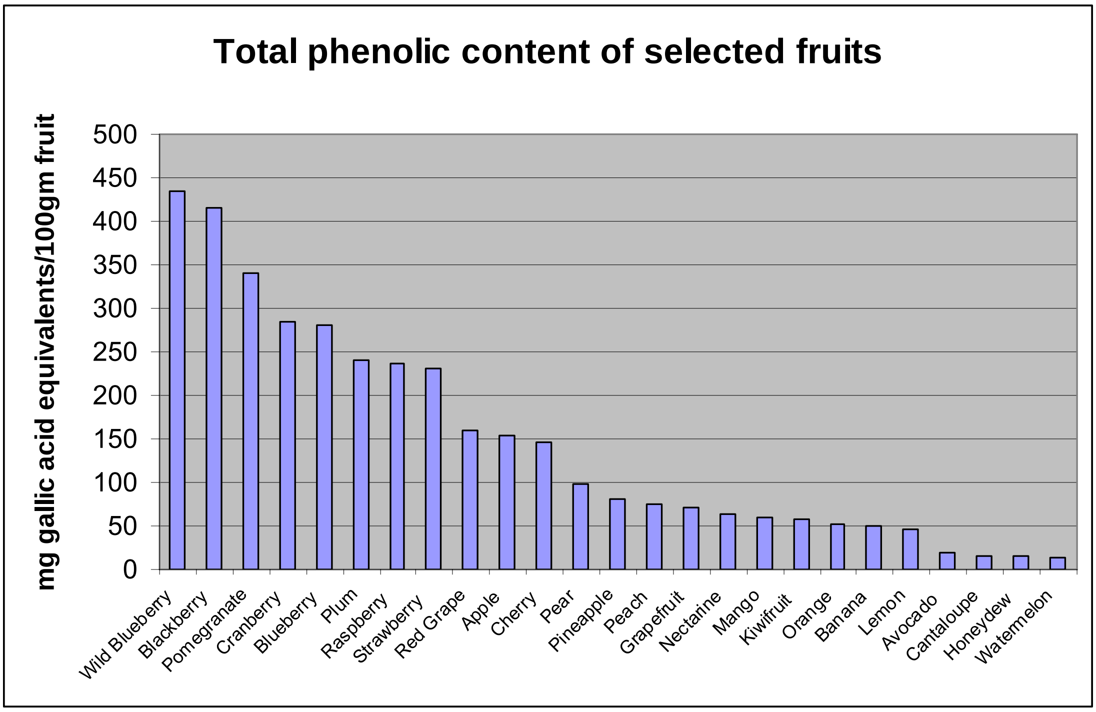
Studies and trials have built up a picture of the benefits of increased antioxidant intake through dietary changes rather than taking supplements. Evidence suggests that the various antioxidants work together as though they are a team and that studies testing the effects of just one or two antioxidants are of limited use. A wide range of unrefined natural foods tends to contain a wide range of antioxidants that together promote better health across a wide variety of issues.

Vitamin C is known to be a powerful antioxidant, it scavenges almost all free radicals. It is thought to help prevent cancer except ovarian and prostate cancers. Vitamin E is though to help prevent heart disease and its effectiveness is increased by Vitamin C and carotene. Carotenoids make carrots orange, tomatoes red and broccoli dark green. There are over 600 carotenoid compounds and they are thought to reduce cancer. Their availability is influenced by how they have been processed and the absorption of some of them is enhanced by fat in the diet. Flavonoids influence the colour, flavour and aroma of fruit. They mop up reactive oxygen and heavy metals, help prevent oxidant formation and protect other antioxidants such as Vitamin C. They are thought to reduce the risk of cancer and heart disease. The flavonoids in red wine may explain 'the French Paradox'; they are mitigating the effect of consuming saturated fats. Micro elements such as Selenium are not antioxidants in their own right but are important components of antioxidant enzymes. Selenium is the most important micro element. It is incorporated into antioxidant complexes that may deactivate very powerful free radicals. Allium sulphur compounds and glucosinolates are both thought to prevent cancers. Glucosinolates appear to have an impact on breast and prostate cancer and may also be strongly synergistic with other antioxidants.

Many antioxidant substances have beneficial biological activity that is quite separate from their antioxidant behaviour. They are involved in cellular signalling, the expression of genes and in influencing regulatory enzymes.

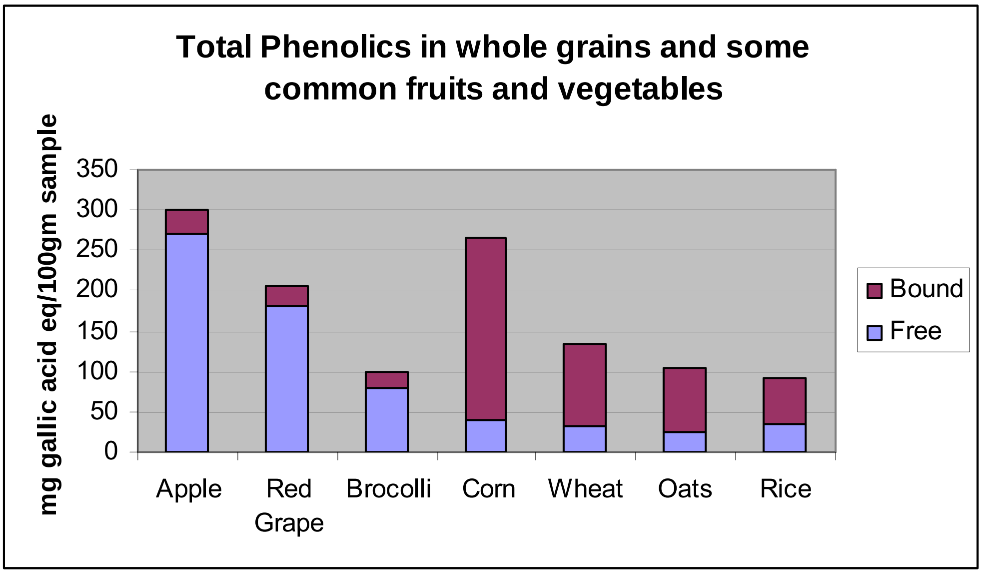
Anti-oxidants appear in a wide variety of fruits, vegetables and grains. Particularly good sources of antioxidants include asparagus, beans, berry fruit (especially blackcurrants and blueberries), broccoli and other brassicas, fruit juices (especially grape and blackcurrant juice), onions and garlic, peppers, prunes, raisins, red wine, spinach, tea, watercress, whole grains and whole meal bread. Colour is a good guide to antioxidant content, particularly where colour occurs right through fruits and vegetables and not just on the skin. (Lister: 2003)

The total phenolic content of a variety of different fruits appears in the chart on the following page which demonstrates very big differences between different fruits.



(Source: Wolfe et al: 2008)

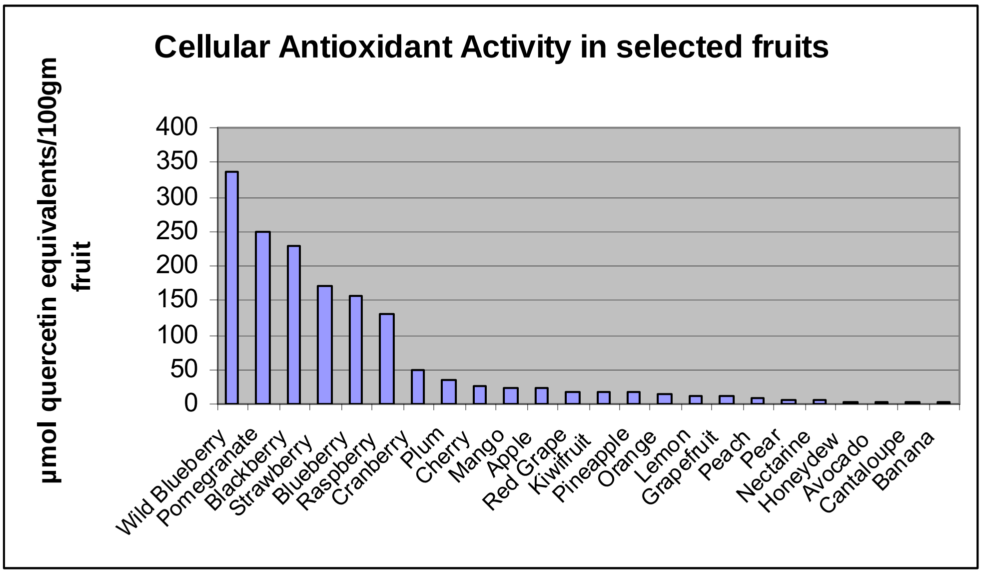
Recent work has also shown that whole grains contain significant quantities of antioxidants. It would appear that the antioxidant content has been underestimated by 70 to 80% in the past. This is because most phenolic compounds in grain are bound tightly to cell wall materials and are only released during processing. These compounds are largely found in the bran and germ and some are different to those found in fruits and vegetables offering the prospect of complimentary action.



(Source:Liu:2007)

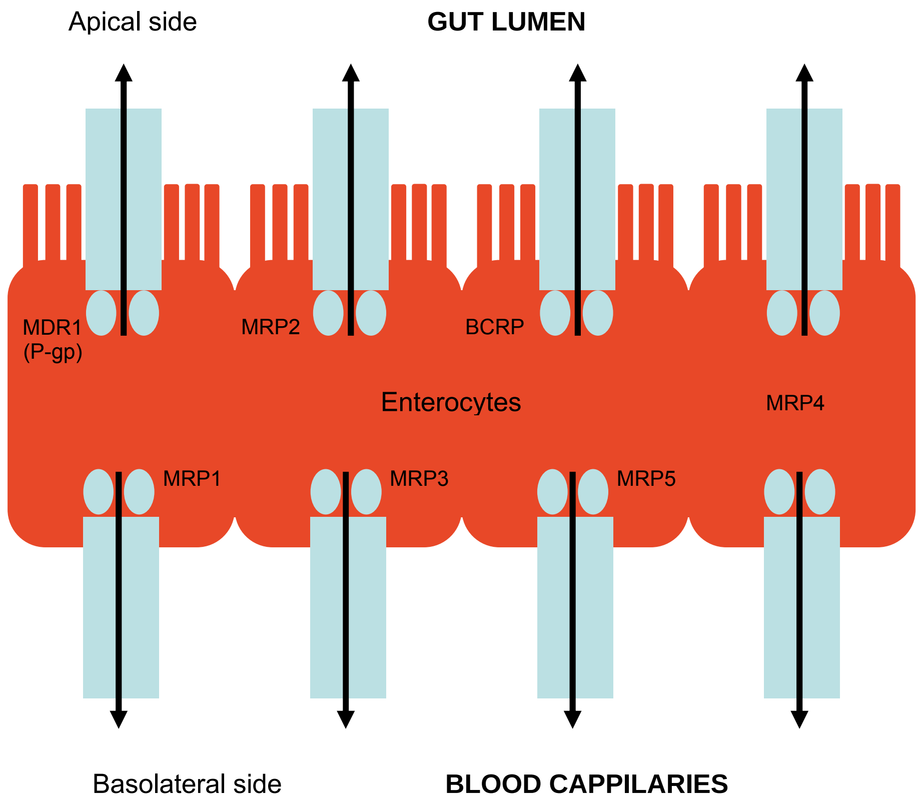
These antioxidants may explain the reduced risk of colon cancer associated with whole grains and whole grain products. Cell wall materials are difficult to digest and may survive upper gastrointestinal digestion and reach the colon. Colonic digestion of these materials by microflora may release the bound phenolic compounds to exert their health benefits locally. Some of these compounds are known to be absorbed into the blood. (Liu:2007)

Total phenolic content doesn't necessarily translate into cellular antioxidant activity. There are a number of different tests that can be done in the laboratory to assess antioxidant activity. The chart below shows cellular antioxidant activity using the 'no PBS wash' protocol in a variety of fruits.



(Source: Wolfe et al: 2008)

Berries have high activity whereas the melons have low activity. Measuring antioxidant activity in cell culture is important in screening for potential bioactivity but further testing is needed to confirm the relationship between cellular antioxidant activity and the modulation of oxidative stress in the body. (Wolfe et al: 2008). Although many phenolics have been shown to have specific and potent health promoting properties in the laboratory and when injected directly into experimental animals very few have been shown to have any effect when ingested orally. Indeed some scientists have suggested that in nutrition it is unrealistic to extrapolate results from laboratory studies to a protective effect in the human body. This is because they have very poor bioavailability. Bioavailability describes the concentration of a given compound or its metabolite at the target organ. (Holst et al:2008). The body doesn't absorb them or it breaks them down before they reach the target. Consumed phenolics are treated as poisons by the body and must over come many barriers, including enzymatic and chemical modification during digestion and absorption, to reach their sites of action. Tests in the laboratory do not take into account the bio-availability in the body and can lead to false-positive and false-negative interpretations. For example if a compound that has performed well in the laboratory is not absorbed by the body or is quickly broken down and excreted a false-positive will be recorded. Scientists are aware that the effective concentrations of these compounds in the laboratory are rarely found in the blood plasma after digestion. Indeed the gut wall actually has various 'efflux pumps' that reject chemicals it perceives to be poisons, they actively transport phenolics back into the gut contents.



Various 'efflux pumps' are located in the gut epithelial cells. P-glycoprotien (Pgp/MDR1), MDR2 and BCRP are localised in the apical membrane, effluxing compounds back into the gut lumen; whereas MRP1, 3 and 5 are localised in the basolateral membranes pumping substrates into the blood stream. MRP4 is present in both the apical and basolateral membranes of the gut epithelia. (Scheepens et al: 2009)

There are also a variety of enzymes in the gut wall and liver that act as a significant defensive barrier to invading phenolics. Some phenolics do get through this barrier and sometimes metabolites of the phenolics appear in the blood plasma. The beneficial effect of these metabolites is largely unknown but in some cases they have been shown to have equivalent or greater activity than the original phenolic compound. (Scheepens et al: 2009)

The complexities associated with understanding the antioxidant issue is illustrated by a project being undertaken by Plant and Food Research in New Zealand on the health benefits of blackcurrants. The research team have been reviewing the various blackcurrant varieties that are grown in New Zealand and the many compounds that are found in them. There are dozens of compounds found in these varieties at very varying levels.

The team have then run tests on just 4 anthocyanins. Three of these get through the gut in very, very small quantities but the fourth one gets through in much bigger quantities although the levels found in the blood plasma are still only a small percentage of what was in the fruit. However the team believe that the test is imperfect and probably underestimates the quantity present in the blood plasma. The current test is thought to detect just 20% of what is in the blood. This test is due to be replaced by a new test that should pick up 80% but this test is in its infancy.

There are other chemicals that we don't know what they do and others that we don't even know are there. There is clearly so much that is unknown and scientists debate amongst themselves how antioxidants work. Some scientists believe that antioxidants work on the basis of 'toxic shock'. The body perceives them as a poison and responds by producing antioxidants of its own. Some antioxidants are known to increase the expression of genes that produce enzymes involved in antioxidant functions. And like a drug a very small amount can have a big impact on the body.

Phenolics appear to have a considerable potential to regulate the inflammatory aspect of CVD. They are also thought to have a direct impact on the growth of cancer cells and to protect neuronal cells beyond their antioxidant effect. They also have a role in regulating the absorption of nutrients from the gut that can potentially lower the glycaemic index of a meal and may also benefit gut health. (Stevenson et al: 2007)

It is clear from a variety of studies that chemicals found in fruit, vegetables and whole grains can have a wide range of beneficial effects on the body but effects vary between different cultivars. So how can we make claims about 'a fruit' without testing a particular chemical from a particular cultivar?

Scientists are starting to explore the possibility of designed synergies to increase the availability of phenolics. The concept of designed synergies involves consuming a phenolic along with another compound that interferes with the body's defence mechanism with the result that the phenolic gets past the defence system in tact. This concept has been successfully applied to the design of pharmaceuticals which the body also tries to reject. The best known example of designed synergy is the use of the traditional medicine Ayahuasca by South American Amazon people. It comprises two plants, each containing specific bioactives that if taken separately have no effect. However if taken together they have a powerful hallucinogenic effect that lasts three days. One plant inhibits the enzymes that break down the hallucinogenic compounds found in the other plant and allows them to pass the defensive mechanism. Scientists believe they will be able to find similar synergies that will improve the performance of phenolic compounds. These synergies offer an exciting new tool for the creation of future functional foods. (Scheepens et al: 2009)

There is so much still to learn about antioxidants and the significant complexities that surround them. They are thought to work in combination as a team. Exact guidelines on daily consumption of antioxidants change as new research emerges and current advice is to eat a healthy balanced diet. It seems unlikely that in the foreseeable future there will be any change to the basic advice of 'five a day fruits and vegetables' but specific pieces of research are likely to change our view on individual fruits and vegetables as evidence emerges of their performance within the human body.

Personalised diets – there is growing interest in the concept of personalised diets. A diet that is designed for an individual based on their own specific problems or risk factors. Recent years have seen the growth of food markets associated with a variety of specific dietary needs including gluten free diets, diets for people with lactose intolerance and others. But diets can also be tailored to address known risk factors, for example where there has been a family history of a specific disease. Diseases such as Celiac disease are genetically related. Scientists are in the process of building the capability to understand the interactions between diet and the human genome. This is a relatively new scientific discipline and is called Nutrigenomics. An early target has been Crohn's diseases. There is a genetic link between Crohn's disease and the genome. When one identical twin develops the disease there is a 50% probability that the other will go on to develop the disease whereas in non-identical twins the probability is only 5%. There are thought to be 30 genes associated with this disease. Many more people carry the genes than have the disease and the concept behind nutrigenomics is that those people without the disease but carrying the genes would personalise their diet to reduce the probability of the disease developing. Other diseases that are attracting interest include arthritis and Type 1 diabetes. The availability of Direct-to-Consumer DNA tests can provide insights into personal genetic traits and disease risks that have been previously unavailable. Genetic testing can improve lifestyle choices and increase preventative screening. Direct-to-Consumer genetic tests are easy to get. Users order a test on-line, provide a saliva or cheek swab and with a few weeks 500 000 to 1 000 000 of their DNA markers are scanned. (This is the same process that livestock geneticists use to identify markers associated with desirable traits in animals – see pages 23 and 37). The service provider then calculates a set of disease risks based on the customer's specific combination of markers. (Ng et al: 2009).

The current accuracy of Direct-to-Consumer genetic tests has been questioned. Different companies use different markers and some individuals have reported getting different predictions from different companies for the same disease. A recent study compared the predictions from 23andMe and Navigenics for five individuals. It found consistent predictions for some diseases but inconsistent predictions for others depending on which genetic markers the companies chose to use.

Predictions for Disease Relative Risks for Five Individuals					
Disease	Female A	Female B	Female C	Male D	Male E
Breast Cancer	↑↑	↑↑	↓↓		
Coeliac Disease	↓↓	↓↓	↓↓	↓↓	↓↓
Colon Cancer	==	==	=↓	↑↑	=↓
Crohn’s Disease	↓↑	↓↑	↓↓	↓↓	↓=
Heart Attack	↓↓	=↓	=↓	=↓	↑↑
Lupus	↑↓	↓↓	↓↓	↑=	↑=
Macular Degeneration	↓↓	↓↓	↑=	↓↓	↓↓
Multiple Sclerosis	↑↑		↓↓	↓↓	↓↓
Prostate Cancer				↑↑	↓↑
Psoriasis	↓↑		↑↓	↑↑	↓↓
Restless Leg Syndrome	=↓	↑↑	↓=	↓↑	↑↑
Rheumatoid Arthritis	↑↑	↑↑	↓↓	↓↓	↑↑
Type 2 Diabetes	↓↓	=↓	↓↓	↑↓	=↓
↑ increased risk (Relative Risk RR> 1.05), ↓ decreased risk (RR< 0.95), = average risk. First prediction is from 23andMe, second prediction is from Navigenics. Different predictions are highlighted in red					

Source Ng:2009

In the same way that the reliability of using genetic markers for livestock breeding is expected to improve there is every reason to believe that the reliability of using genetic markers for predicting human disease will also improve in the future.

Scientists are also starting to look at the Genome and peoples likes and dislikes. There are subsets of the population who can’t taste certain flavours and odours. For example some people can’t detect bitterness. Although this work is in its infancies it raises some interesting possibilities. In future all babies may be genotyped at birth to establish their disease risks and the food industry maybe able to market baby foods to the baby’s parents in the knowledge that the baby will eat a particular flavour!

One of the scientific challenges of developing nutrigenomics is proving functionality – how do you establish the personalised diet works without conducting a huge long term study that includes a control group where the disease is allowed to develop? At present research is focused on confirming which genes are important and developing high throughput assays. Animal models and human trials will follow. In time we will build up an understanding of how food modulates the bio-chemical system.

All this creates exciting opportunities for food producers and food manufacturers. The market place is going to develop new segments, lots of new segments. Groups of people with specific dietary needs. Businesses that effectively target those segments as they emerge can look forward to successfully exploiting niche markets. The possibilities offered by function foods looks to be endless!

Legislation – has recently been introduced in relation to health claims made on foods. This legislation exists to inform and educate consumers as well as to protect them. It is to ensure that health claims do not mislead. The relevant piece of legislation is Regulation (EC) No 1924/2006 of the European Parliament and of the Council of 20 December 2006 on Nutrition and Health Claims made on foods.

Legislation covers labelling presentation and advertising. It covers the claims that can be made, offers a list of generally accepted claims, the authorisation of new claims, the claims that are prohibited and foods that cannot make claims. Claims are allowed based on generally accepted scientific evidence or based on newly developed scientific data. New claims based on an applicant's own data will be protected for 5 years. Specific regulation covers claims relating to the reduction of disease risk and to the health and development of children.

Specifics relate to claims involving content of food – for example in relation to fibre content

- Source of fibre (>3g/100g or >1.5g/100kcal),
- High fibre (>6g/100g or 3 g/100kcal)

Similar levels are made for energy, sugar, sodium, fat, protein and vitamins and minerals

Other substance content claims (Omega 3 fatty acids, phenolics, etc) are subject to approved claims that food manufacturers can use.

The EU has produced a list of over 4000 generic claims that can be used by the food industry. For example 'Fibre helps maintain healthy digestion'. These are based on generally accepted scientific data from the literature and well understood by the average consumer (Rowland: 2007). They are open to all operators.

Products with an 'undesirable' nutrient profile are not allowed to make claims. So a product that is full of fat and sugar cannot claim to be 'Low in salt'

Claims are subject to a process called PASSCLAIM (Process for the Assessment of Scientific Support for Claims on Food). This involves a set of criteria for scientific substantiation. These criteria relate to the characterisation of the food or food component, appropriate methodology for human studies, the use of markers and to the evaluation and use of the totality of the data in weighing the evidence. (Binns: 2007). Each claim must be evaluated on a case by case basis making an intelligent interpretation of the evidence.

The list of generic claims was published in the winter of 2009/2010 and the food industry is still in the process of adapting to this new legislation. There remains significant uncertainty about what claims can be made and some areas have yet to be clarified. Claims along the lines of 'X% less fat than standard' are not yet understood. The legislation is already a problem for the functional food industry but removing spurious claims from the market place should improve the commercial prospects for food products that do meet the required standard.

Case Studies

Low Saturated Fat Milk – Excessive consumption of saturated fat is believed to be a major contributor to cardiovascular disease. In the UK the Department of Health recommend a target intake of saturated fat of no more than 11% of total energy intake. Studies in the UK have suggested that this target is exceeded by 22% by men and 20% by women. However the average UK adult fails to achieve the tentative target for monounsaturated fat. (Henderson et al: 2003). Milk and dairy products are the single largest source of saturated fat in the UK diet. They contribute 40% of all saturated fat. Cheese is the biggest source followed by butter (Hulsof et al: 1999)

The replacement of saturated fat by both monounsaturated fat and polyunsaturated fat is desirable for improved health. There is also evidence that increased milk consumption can provide cardio-protective and other benefits (Elwood et al: 2004). Milk and dairy products are also significant sources of monounsaturated fats and other key nutrients including calcium and vitamin B_{12}. Simply reducing milk consumption may not deliver the desired benefits associated with reducing saturated fat. However manipulating the fat composition of dairy products to replace some saturated fat with monounsaturated fat may prove a valuable means of reducing saturated fat intake while retaining the wider benefits associated with milk consumption. The health benefits of this strategy have been supported by a limited number of human studies.

Scientists at Reading University have successfully demonstrated that the saturated fat content and composition of milk can be manipulated by changing the cow's diet. They compared the fat composition of milk produced from diets containing rapeseed in various forms with a diet containing a commercially available fat supplement that was manufactured from palm oil. (Givens et al: 2009)

The cows involved in the trial were fed a diet based on maize silage, grass silage and concentrates. Treatments consisted of a control diet containing 49g/kg of calcium salts of palm oil distillate or the same basal diet with 49g/kg of fat derived from whole rapeseed, milled rapeseed or rapeseed oil. The four experimental diets had a similar DM, CP, NDF, starch and ME contents but replacing the palm oil distillate with milled rapeseed or rapeseed oil resulted in a marginally lower dietary water-soluble carbohydrate concentration. The whole rapeseed and milled rapeseed diets had slightly lower total fatty acid content than the other two diets and there was a significant difference in the specific fatty acids that made up the different diets. (See Appendix 1 on Fatty Acids for an explanation of different fatty acids)

	Treatment			
	Control	**Rapeseed Oil**	**Whole Rapeseed**	**Milled Rapeseed**
Ingredients (g/kg)				
Maize silage	375	375	375	375
Grass silage	125	125	125	125
Wheat straw	10	10	10	10
Milled rapeseed	0	0	0	100
Whole rapeseed	0	0	100	0
Rapeseed oil	0	49	0	0
Megalac®	49	0	0	0
Rapeseed meal	100	100	45	45
Soyabean meal	60	60	60	60
Molassed sugar beet feed	76	76	76	76
Milled wheat	100	100	100	100
Wheat feed	20	20	20	20
Maize Gluten Meal	20	20	20	20
Soyabean Hulls	20	20	20	20
Calcined magnesite	10	10	10	10
Minerals and Vitamins	15	15	15	15
Blended molasses and urea	20	20	20	20
Composition (g/kg DM or as stated)				
DM (g/kg fresh)	428	444	424	444
CP	165	160	168	165
Neutral detergent fibre	359	342	357	347
Starch	170	162	170	171
Water soluble carbohydrates	43	39	44	34
ME (MJ/kg DM)	11.0	12.1	11	11
Key Fatty Acids				
16:0	31.5	8.0	6.9	7.0
18:0	8.9	3.5	3.7	4.5
18:1*cis*-9	18.2	32.4	30.8	29.9
18:2n-6	12.3	21.8	17.9	17.0
18:3n-3	3.1	6.5	6.3	5.9
Total Fatty Acids	75	72	66	64

Ingredients and chemical composition of experimental diets (g/kg DM or as stated)
(Source: Givens et al: 2009)

Cows were fed twice each day and milked twice each day. Results from the trial are shown in the table below.

	Treatment			
	Control	**Rapeseed Oil**	**Whole Rapeseed**	**Milled Rapeseed**
Dry matter intake (kg/day)	22.8	21.3	24.2	23.4
Milk yield (kg/day)	36.2	37.1	34.3	38.1
Fat %	3.85	3.37	4.20	3.95
Protein %	3.21	3.05	3.24	3.18
Fats (g/100g fatty acid)				
Total Saturates	69.6	55.6	71.7	61.5
Total *cis*-MUFA	22.7	29.2	21.4	27.7
Total *trans-MUFA*	4.4	10.5	3.5	6.8

(Adapted from Givens et al: 2009)

There were differences in dry matter intake, yield, fat % and protein % most of which were not statistically significant although some of the bigger differences were significant. There were significant differences in the total saturates and monounsaturates in milk between the milled rapeseed and the rapeseed oil in comparison with the control. This did not apply to the whole rapeseed and this may indicate that the seed coat reduced the bioavailability of the oil. The reductions in saturated fats associated with the milled rapeseed and rapeseed oil was mainly due to a reduction in short and medium chain fatty acids. It is thought that the inclusion of long chain unsaturated fatty acids in the diet reduces the synthesis of shorter chain fatty acids in the mammary gland. The way in which these various fatty acids are modified by the rumen or pass through without alteration is also thought to have an impact on the eventual fatty acid composition of the milk.

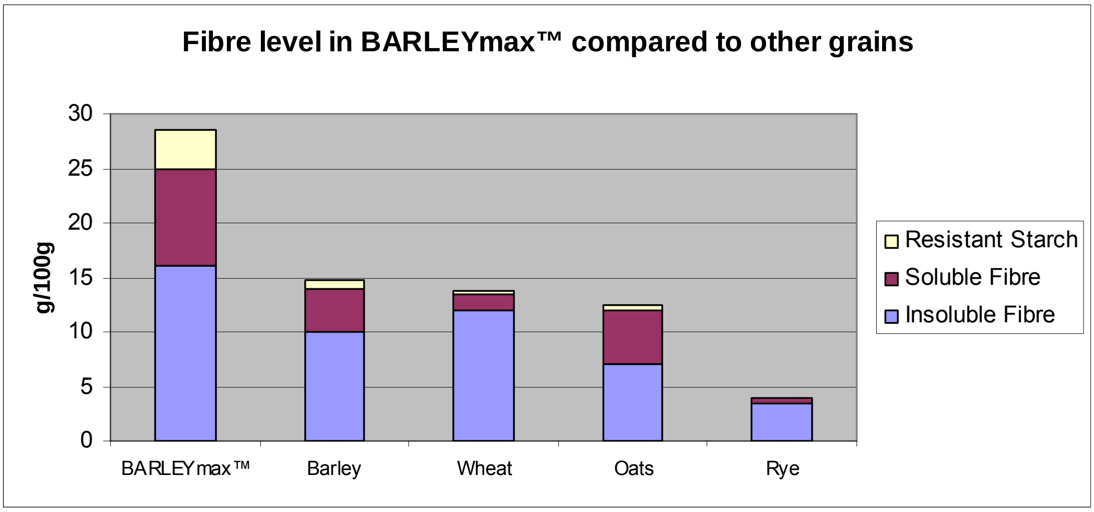
Overall, the inclusion of milled rapeseed appeared to offer the best compromise with respect to reducing saturated fat and increasing monounsaturated fat in the milk whilst maintaining animal performance. Milk from animals fed milled rapeseed or rapeseed oil could make a significant impact on the health of society as a whole if it replaced typical milk available today. The team at Reading have commenced modelling the health benefits that the project could deliver. They are targeting the cheese market although they have not yet conducted taste tests on the product. They are developing an adoption plan and have formed a consortium of companies and have presented the proposal to potential partners. Producers who adopt the feeding regime in the immediate future may be able to exploit a niche market associated with those consumers who are eager to reduce the impact that dairy products have on their health.

Research is also being conducted by CSIRO into reducing the saturated fat content of meat products. Diet and genetics are being explored as potential routes to improve the fatty acid profile of meat.

BARLEYmax™ – is the first novel grain to be launched on to the market by the CSIRO Future Grains project. The project is part of the CSIRO Food Futures National Research Flagship. The objective of the programme is not just to improve the texture and flavour of food but also to improve its nutritional quality. Foods produced with BARLEYmax™ as their key ingredient have a low glycaemic index and also produced positive changes in a range of biomarkers of bowel health.

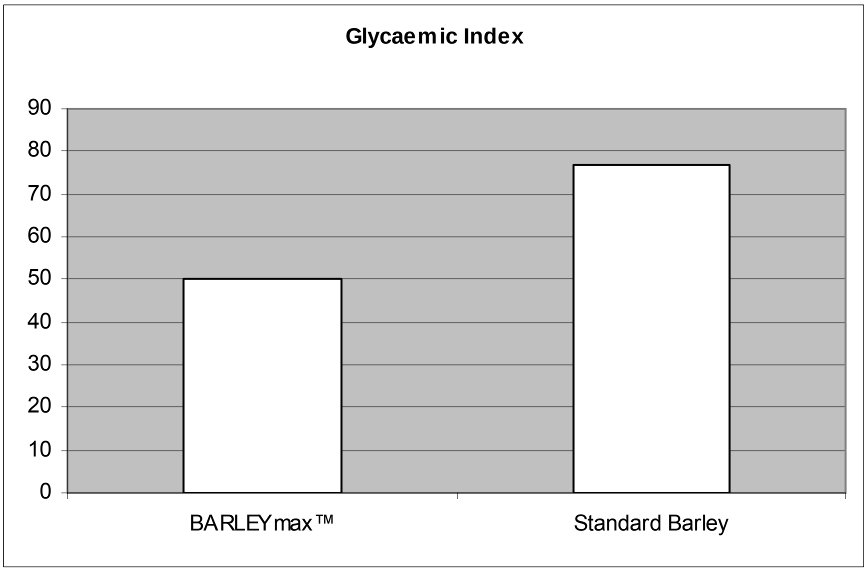
In the very late 1990s the research team started the development of new grains. They developed a series of new barley grains through a process of mutagenesis. Grains were treated with sodium azide to mutate the DNA and see what characteristics developed as a result. This is not GM technology. From this process came a new type of barley in which the gene that codes an enzyme which synthesises the amylopectin starch polymer is inhibited. This new barley went on to become BARLEYmax™ and the altered gene is a reliable marker for it.

The health benefits of whole grain foods are well understood and are mentioned on page 53. These include the potential for lowering the risk of heart diseases, colon cancer and Type 2 diabetes as well as improving bowel health. Fibre is an important factor associated with these benefits and BARLEYmax™ has superior quantities of soluble fibre, insoluble fibre and resistant starch.



Resistant starches are digested in the large bowel by the resident bacteria, producing short chain fatty acids (in particular butyrate) which promote intestinal health and are believed to contribute to lowered disease risk, including colon cancer (Ridlon et al: 2006). However, a direct protective effect of these acids in human colo-rectal cancer is yet to be shown. Soluble fibre is thought to lower LDL (bad) cholesterol levels (National Heart Foundation of Australia: 2006) while insoluble fibre is known to promote regularity and protect against diverticular disease.

BARLEYmax™ also has a low glycaemic index which can have an impact on both the management and the prevention of Type 2 diabetes. The glycaemic index is significantly lower than standard barley.



BARLEYmax™ was launched successfully onto the Australian market in 2009. Products are licensed to use the brand. It is currently included in breakfast cereals but has potentially wider application as an ingredient in bakery products, breakfast bars and other convenience foods. License agreements will be framed to ensure that BARLEYmax™ foods will give consumers the greatest health benefit by ensuring that they are formulated to meet nutritional guidelines.

BARLEYmax™ is available to be licensed into the European market although its attributes would probably have to be back crossed into local barley varieties which will take time.

The Food Futures Grains research team together with its commercial partners are now developing a high amylose wheat that will complement BARLEYmax™ and expand the range of foods that improve bowel health and reduce disease risk.

Hyperimmune Milk – A team of Scientists at AgResearch in New Zealand have developed milk that contains antibodies that can be used to prevent and treat certain medical conditions. They have also demonstrated that their process can be successfully scaled up into an industrial process for potential commercial exploitation. (Hodgkinson et al: 2007)

All dairy farmers are very aware that calves are born with no immunity from infection. No immune factors pass to the calf in the uterus and the new born calf is dependent on the high immunoglobulin content of its mother's colostrum in the hours following birth. These immunoglobulins provide the young animal with passive immunity. Immune factors in colostrum and milk are also important in the defence of the mammary gland itself. The udder has a complex, well developed and highly effective barrier against pathogens integrating both innate and acquired immune responses. If effectively detects and eliminates harmful pathogens using a wide range of immune related components.

Immunoglobulin antibodies are the main immune components of the acquired immune system that are present in colostrum and milk. The most abundant immunoglobulin class in cows milk is IgG. In contrast IgA and IgM are present in much smaller concentrations. However the predominant immunoglobulin in human milk is IgA.

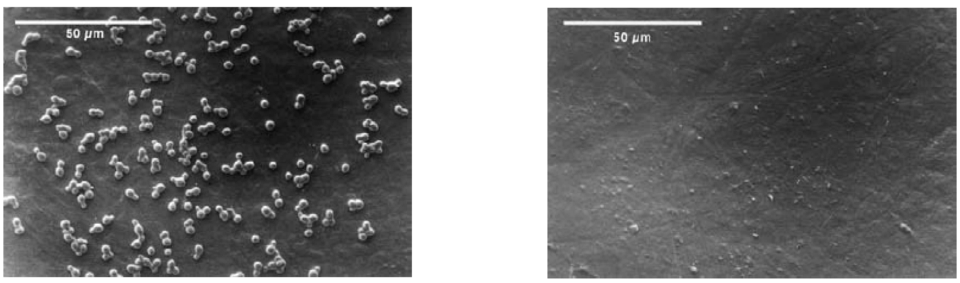
		Concentration, mg/ml		% of total immunoglobulins	
Species	Immunoglobulin	Colostrum	Milk	Colostrum	Milk
Bovine	IgG_1	47.60	0.59	81.0	73.0
	IgG_2	2.90	0.02	5.0	2.5
	IgA	3.90	0.14	7.0	18.0
	IgM	4.20	0.05	7.0	6.5
Human	IgG	0.43	0.04	2.0	3.0
	IgA	17.35	1.00	90.0	87.0
	IgM	1.59	0.10	8.0	10.0

(Butler:1973)

The presence and concentrations of immune components in milk vary depending on the stage of lactation with very high concentrations found immediately following birth. The immune components of colostrum can make up 5% of its total content at this time. In addition to immunoglobulins both colostrum and milk also contain a host of other immune related components including cytokines, antimicrobial proteins, and peptides such as lactoferrin, defensins and cathelicidins. A detailed understanding of these proteins and peptides offers great potential to add value to the dairy industry. They have applications in pet food, cosmetics, personal care and health promotion. A number of these chemicals have been commercially exploited. Lactoferrin has been extracted for its antimicrobial and antiviral properties and is a valuable ingredient in infant formula. There can be a 20-fold difference in the concentration of some of these components between individual animals. Such significant differences suggest there is an opportunity to select for animals that are high in immune factors and establish special herds for commercial exploitation. (Stelwagen et al:2008)

The team at AgResearch in New Zealand have recently developed a proprietary procedure to boost the immunoglobulin content of milk using vaccination. This concept is not new. Hyperimmune colostrum from cows vaccinated with rotavirus has been successfully used to treat babies with rotavirus-caused diarrhoea and the IgG content of milk has also been boosted using vaccination. However the most common immunoglobulin in human colostrum is is IgA and the team have developed a vaccination procedure that significantly raises the concentrations of IgA and IgG for *candida albicans* or thrush in cow's milk. The antigen-specific activity of IgA is also significantly enhanced. The cows are only vaccinated in the dry period and the immunoglobulins remain elevated throughout the whole of the following lactation.

The team have showed that hyperimmune milk protein concentrate effectively prevented the development of *candida albicans* or thrush on a tooth surface model.



Scanning electron micrograph of *Candida albicans* cells bound to tooth surface after pre-incubation of cells – the tooth on the right was treated with immune milk protein concentrate
Images courtesy of Dr Kerst Stelwagen, AgResearch

Analysis of milk from immunised and control cows demonstrates the rise in both IgA and IgG –

	Titres of anti-Cand. albicans IgA (kTU)		Titres of anti-Cand. albicans IgG (kTU)	
Days after calving	Control Cows	Immunised Cows	Control Cows	Immunised Cows
1	0.39±0.12	26.22±7.83	0.22±0.07	16.24±2.30
28	Not detectable	6.42±1.14	Not detectable	0.41±0.08

(Hodgkinson et al : 2007)

The team have also tested the industrial production and storage of the hyperimmune milk and found that milk that is spray dried and freeze dried remains effective even though the spray dried product lost some of its activity.

The commercial exploitation of immune components in milk offers an exciting opportunity for the dairy industry to add value. Vaccination procedures to boost the natural concentrations of these immune components offers great potential in the development of hyperimmune milk derived products for both preventative and curative medicine.

Brassicas rich in anti-oxidants – the consumption of brassica vegetables has been shown to be associated with a reduction of cancer risk (Higdon et al: 2007). These vegetables are a rich source of bioactive compounds with protective properties including glucosinolates, flavonoids, folate and carotenoids. Glucosinolates are sulphur containing phytonutrients responsible for the sharp taste of cruciferous vegetables and are primarily synthesised by the plant as part of a defence mechanism against insect predators (Aggarwal et al: 2006). Scientists at a number of institutes have been exploring the opportunities to develop new cultivars and growing techniques that will offer brassicas with enhanced levels of anti-oxidants.

Booster Broccoli™ and the Vital Vegetables® programme – a partnership between Australian and New Zealand scientists at the Department of Primary Industry Victoria and the New Zealand Institute for Plant & Food Research Limited, with support from Horticulture Australia Limited, Horticulture New Zealand, Ausveg, leading seed companies and the Vital Vegetable Marketing Partnership has developed the Vital Vegetables® programme. It was clear to the research team that certain varieties of vegetables contained more natural occurring antioxidants. By researching a huge number of varieties the team have selected and bred new cultivars that naturally produce higher levels of anti-oxidants. All Vital Vegetables® are selected and bred using traditional breeding techniques, they are not Genetically Modified. The first new cultivar that the team have recently brought to the market is ‘Booster Broccoli™’

Booster Broccoli™ has over 40% more active anti-oxidants than standard varieties of broccoli. It has significantly higher levels of the glucosinolate sulforaphane which is a long lasting anti-oxidant that is believed to offer a variety of health benefits including protecting the body against DNA damage and tumour formation. It is thought to trigger enzymes that help eliminate free radicals and enhance the body’s own defence system. Regular consumption of foods containing sulfuraphane is believed to have a preventative effect on heart disease as well as a range of cancers. During development the anti-oxidants were tested successfully in the laboratory and were also found to help prevent cancer in rats. Studies have suggested that 70gms of Booster Broccoli™ should be consumed at least three times a week to maximise its health benefits. (Vital Vegetable website: 2010)

Booster Broccoli™ was developed by selecting for high levels of glucosinolates and screened against other varieties grown in Australia and New Zealand. Growing protocols are also involved to ensure that the crop delivers the required levels of anti-oxidants. This includes both a grower's protocol and a post harvest protocol. These are held by marketing partners and kept to just participating growers.

The crop has been launched in Australia with the slogans 'Nurtured by nature – Created by science' and 'Is it real?' The development team are concerned that the crop consistently delivers in its current environment before it is rolled out further. Booster Broccoli™ could be grown in Europe but a local laboratory will be required to test that the crop is delivering what it promises and local growing protocols will have to be developed. The Vital Vegetables® team are excited about the opportunities that the programme will offer and are developing other products including tomatoes rich in capsicums.

Rocket – has also been the subject of scientific research. A team at Reading University have investigated the antioxidant composition of both Salad Rocket and Wild Rocket in different growing environments. Rocket has a rich, peppery taste and is exceptionally strongly flavoured for a leafy green crop. It is believed to contain high levels of Vitamin C, glucosinolates, flavonoids and phenolics.

The research team grew Salad Rocket and Wild Rocket under differing light intensities for a period of six weeks. They wished to investigate if pre-harvest stress associated with high light intensity would affect quality or quantity of key antioxidants. They also studied the effect on the expression of genes associated with glucosinolate metabolism. (Jin et al: 2009)

The plants grown under higher light intensities had smaller leaves and appeared to accumulate anthocyanins. This is a common response to environmental stress including extremes of heat, light and cold. The plants of both cultivars became thickened as a result of low light intensities which is a typical response to shading. The two cultivars were analysed for total glucosinolate and flavonoid content. The plants grown in the high light intensities had significantly higher levels of antioxidant capacity. Indeed the high light environment led to flavonoid levels up to 15 times higher than the low light environment. This is consistent with work on other species that has shown that antioxidants are increased by environmental stress.

The leaves were then subjected to cold stress in store. A controlled atmosphere of 4˚C resulted in an increase in total antioxidants and total phenolics. However the Wild Rocket showed much greater accumulation of cyanadin (the flavonoid linked to anthrocyanin production) during storage in the leaves from the high light environment than the Salad Rocket. This could be because the wild cultivar has retained its capacity to produce protective chemicals under stress to a greater extent than the domesticated salad rocket which has not been selected for survival strategies such as cold tolerance.

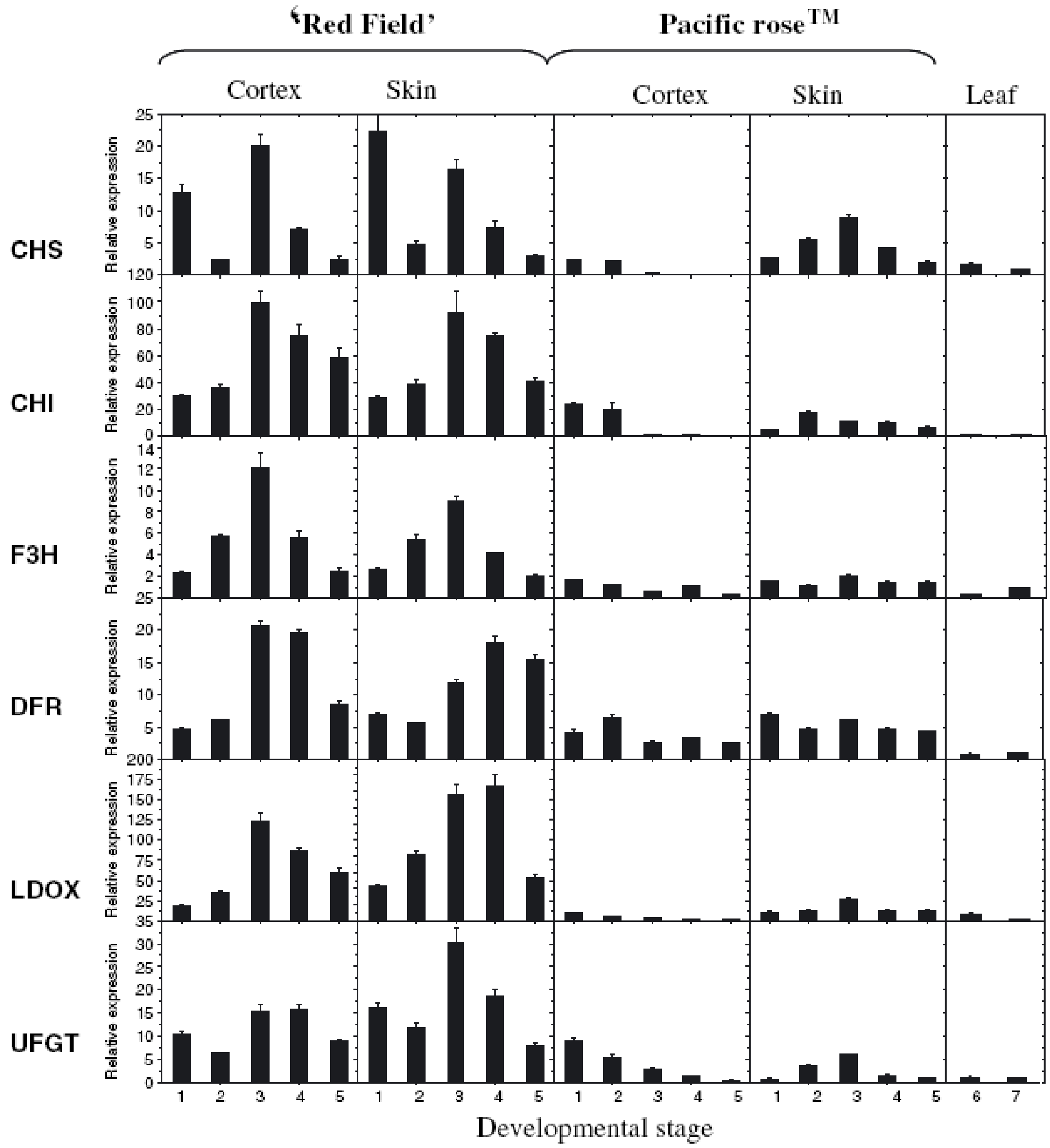
The research team then took extracts from both cultivars to test their antioxidant capacity in the laboratory. The Salad Rocket appeared to have a greater protective effect than the Wild Rocket and may have a greater potential to have a positive impact on human health. (Jin et al: 2009)

The research team have successfully demonstrated that flavonoid profiles vary with genotype and environment and that controlled environmental stress during both the growing period and during storage can have a beneficial effect on the accumulation of valuable antioxidants in plants that can make a positive contribution to the human diet. The research offers opportunities to both plant breeders and growers to develop new lines of vegetables.

Red Apples – the accumulation of anthocyanin in apples is important in terms of fruit quality. Anthocyanin is an important antioxidant but also gives the fruit its red colour. This colour is usually restricted to just the skin of the apple but there are varieties with red flesh although these are not commercially grown. The development of a red fleshed apple would offer consumers a potentially 'healthier' apple but would also represent a novel element in the market. Market research has suggested that such an apple would be well received.

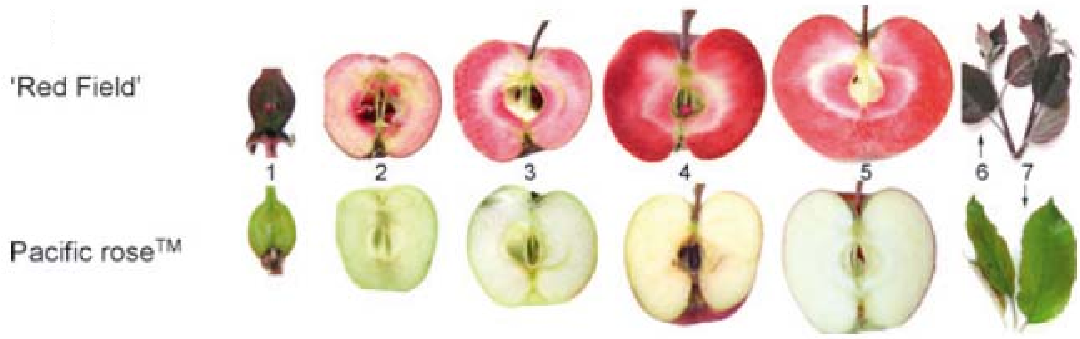
A group of scientists at Plant and Food Research in New Zealand believe they have identified all the genes associated with the development of red flesh in an apple. They compared two apples; the commercial white fleshed variety 'Pacific Rose™' and the red fleshed variety 'Red Field'. (Espley et al: 2007)

The group were able to compare the expression of six major anthocyanin genes. Clear differences were observed. The genes were expressed much more strongly at all stages of development in both the skin and flesh of the 'Red Field' apple with a peak 102 days after full bloom. This correlated with the degree of pigmentation observed during tissue sampling. The gene expression and pigmented tissue were sustained right through to fruit maturity in late summer. In contrast the 'Pacific Rose™' showed very little expression in the cortex and some moderate expression in the skin as the skin developed colour as it matured.



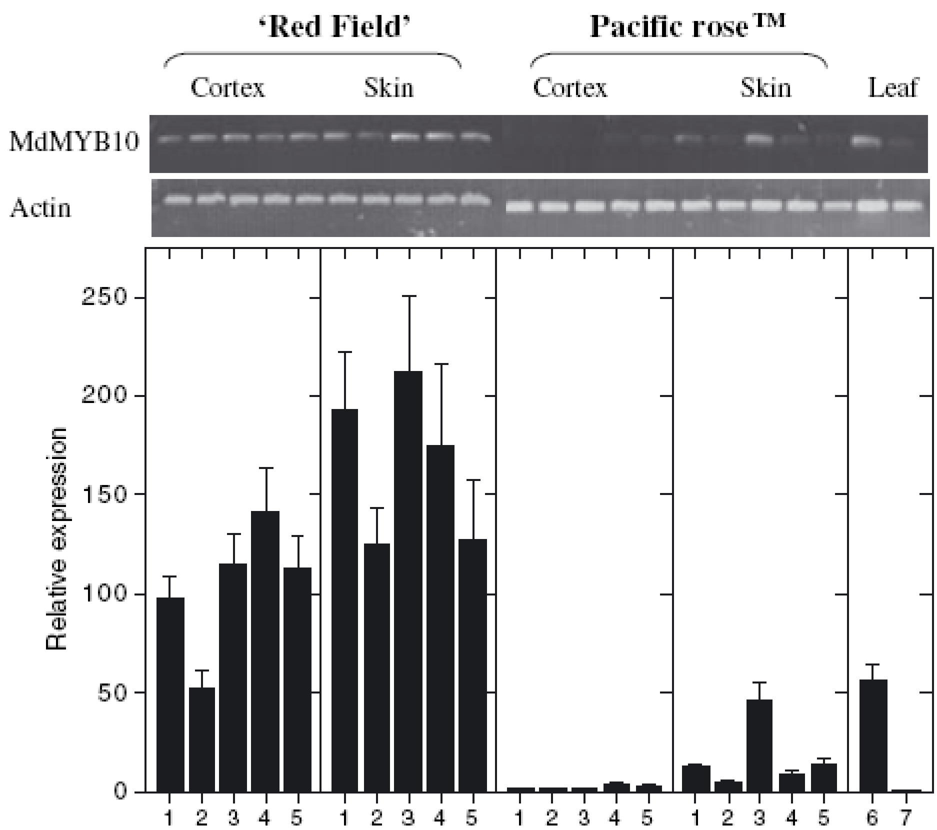
Expression profiling of apple anthocyanin genes. Data from qPCR analysis of the apple anthocyanin biosynthetic genes in the cortex, skin and leaf of the apple cultivars 'Red Field' and 'Pacific Rose™'. CHS, chalcone synthase; CHI, chalcone isomerise; F3H, flavanone 3β-hydroxylase; DFR, dihydrflavonol 4-reductase; LDOX, leucoanthocyanidin dioxygenase; UFGT, uridine diphosphate (UDP)-glucose:flavonoid 3-*O*-glycosyltransferase. Samples were taken at 1 – 40 days after full bloom (DAFB), 2 - 67 DAFB, 3 – 102 DAFB, 4 – 130 DAFB and 146 DAFB.

All graphs and images courtesy of Dr Richard Espley, Plant and Food Research



Fruit development and leaves of 'Red Field' and 'Pacific Rose™'.

The group then went on to identify a transcription factor (called *MdMYB10*) that was responsible for the expression of these genes. A transcription factor is a protein that binds itself to a specific DNA sequence and then controls the transcription of genetic information from DNA to mRNA. (See page 19 for an explanation of transcription).The gene associated with this transcription factor appears in both white fleshed apples and the red fleshed 'Red Field' however it is the degree to which this gene is expressed that appears to control the expression of the anthocyanin genes that produce the anthocyanin in the apple. The expression of *MdMYB10* follows a very similar pattern to that observed for the six genes associated directly with anthocyanin accumulation. The team have identified a mutation in the *MdMYB10* gene that controls the degree to which it is expressed.



Expression analysis of the transcription factor *MdMYB10* in the cortex, skin and leaf of the apple cultivars 'Red Field' and 'Pacific Rose™'

The scientists were able to use the model plants Arabidopsis and Tobacco to confirm their findings. (See page 25 for an explanation of model plants)

The group believe that they have developed a full understanding of the transcriptional regulation of anthocyanins and that the identification of the mutation in the gene responsible for the transcription factor associated with this process is a crucial step forward. It is important progress towards the development of a red fleshed apple. They are now using their understanding of this process to develop a commercial red fleshed apple although they believe they are still 5 years away from bringing this novel apple to the market place.

Conclusion – functional foods offer exciting opportunities for farmers and growers. The development of groups of consumers with particular health concerns and the concept of personalised diets will lead to a marketplace that will segment. New niches will develop that entrepreneurial businesses will be able to exploit. In addition some large markets will develop for added value grains and other primary foods. Successful functional foods are likely to be those that are presented to consumers in a form that meets their expectations with respect to traditional food characteristics, and that communicate the additional health benefits consumers can expect to obtain in a context to which they can relate (Binns et al: 2007)

The
non-food use
of
agricultural produce

excluding energy

Agricultural produce can be used for a whole variety of purposes beyond food. Indeed as fossil fuels decline agriculture will become an increasingly importance source of renewable materials and chemicals. There has been significant interest in the use of agricultural produce to produce energy. The last Frank Arden Study considered the Carbon Footprint of UK agriculture and Julian Morgan covered many of the renewable energy technologies available to UK farmers in his report. As a result energy crops are excluded from the scope of this report. In the long term there are alternatives to agricultural crops to replace our fossil fuels including nuclear, wind, wave and solar power. However replacing the raw materials we currently source from fossil fuels will inevitably come from agriculture and forestry. Mankind has spent over 100 years manipulating crude oil to produce a wide variety of raw materials but we have only recently started to study in depth the various chemicals and fibres that agriculture can offer. A vast amount of scientific research is taking place around the world to discover and develop new and novel uses for our agricultural produce. Indeed the basic raw materials that agriculture produces offer a bewildering range of possibilities in terms of their potential uses.
Agricultural produce falls into a number of broad areas for alternative uses. These are –

Oils
Carbohydrates
Fibres
Specialist uses including pharmaceuticals and cosmetics

There are significant market opportunities for oils, fibres and carbohydrates but the markets for some specialist crops are limited and could easily be over-worked.
Manufacturing industry recognises the benefits of agriculturally derived products as raw materials in that they are more sustainable, non-toxic and bio-degradable. However such materials must meet functional specifications as well as being competitively priced and available in sufficient quantities. (IENICA: 1999)

Oils - The seeds of over 1400 plant species are rich in oil largely composed of triacylglycerol (triglyceride), offering enormous potential for exploitation in both the chemical and pharmaceutical industries. Over 500 different fatty acids are found in plants but most are only found in the storage oil of a few species. On the other hand a relatively small number of ‘housekeeping’ fatty acids are present in all plants in both the storage and membrane lipid.

The main oilseed crop currently grown in the UK is oilseed rape with linseed sunflower, borage, evening primrose and crambe being grown in small quantities.

The value and use of different vegetable oils depends on the composition of their constituent fatty acids, particularly carbon chain length, the degree of saturation and the nature and position of functional groups. Thus short chain fatty acids (C8-C10) can be used in soap and cosmetics, medium chain lengths (C12-C14) can be processed into oils and greases and long chain lengths (more than C14) are needed for industrial lubricants and polymers.

The principle uses for oil crops are –

- Lubricants – reputed to have better lubricity, reduced deposits and a lower environmental impact. Success is dependent on tailoring molecular structure to the end requirements. There are issues with plant derived oils at high and low temperature. They are particularly useful as lubricants where spillage may occur, for example, on drilling rigs.

- Surfactants – are used as basic ingredients in cleaning materials and are also used as facilitators in a wide range of industrial processes ranging from textiles and fibres through to plant production and pest control. Most surfactants could be derived from plants, however few occur naturally. Consequently raw plant materials must be chemically processed in order to manufacture surfactants.

- Surface coatings – vegetable oils can be used in paints, resins and varnishes and in printing inks. They are attractive as printing inks because they are less damaging to the environment than traditional inks. This has become increasingly important as more paper is recycled.

- Polymers – whilst most polymers are derived from petroleum some products do include vegetable oils and there appears to be considerable scope for an expansion of their use in polymer production. Genetic engineering offers the opportunity to produce oilseeds that synthesise polymers in the plant.

- Functional additives and reactive agents for industrial manufacture can also be derived from vegetable oils. (IENICA: 1999)

Fibres – produced on agricultural land have the potential to make a major contribution to world fibre supply. These fibres might be residues or they may come from dedicated fibre crops but to succeed they must be competitive with supplies of fibre from forestry and developing world countries.

The main fibre crops of interest in the UK at present are hemp, flax and miscanthus. The latter is now grown quite widely for fuel in the UK. It is a C4 crop with enormous potential and produces a fibre that is similar to hard wood. The UK also produces a significant quantity of fibre in crop residues particularly from the cereal and oilseed rape crop.

The properties of end products are ultimately dictated by the properties (ultrastructure) of the raw materials (fibres) from which they are manufactured. In addition, the properties of the raw materials themselves are often of crucial importance in determining the costs associated with processing and manufacturing products, which in turn ultimately determines the economic viability of a given raw material. Important ultrastructural properties include: tissue structure (types and arrangement of cell/fibre types); fibre length; fibre strength; chemical composition.

The principle uses for fibres are –

- The wood based panel industry to be used as an alternative to create composite boards - particleboard/chipboard and medium density fibreboard (MDF),.

- Pulp and paper including packaging materials that can replace products such as polystyrene

- Textiles - including industrial textiles such as insulation quilts, and geotextiles. Particularly useful where bio-degradable materials are required.

- Filters and absorbents - surface chemistry and large surface area should make fibres ideal as filters. Modified fibres can be used to absorb heavy metals and oils.

- Fibre composites – reinforced plastic composites where plant fibres can, for example, replace glass fibre. Natural fibres offer a strong, low cost and lightweight alternative.

- Cellulose-based ion-exchange

- Novels uses for items such as car panels. (IENICA: 1999)

Carbohydrates - produced in the UK are primarily in the form of starch and sugar. The principle sources of starch are wheat and potatoes with barley, oats, peas and novel crops such as quinoa as potential alternative sources. In plants, starch appears as small granules, insoluble in cold water. Sugar beet is the principle source of sugar but it can also be produced from the hydrolysis of agricultural wastes and starch.

There are already some substantial well established industrial markets for starch and sugar and environmentally friendly products are opening up new market areas. Wheat is the UK's principle crop and the physical, chemical and genetic modification of its starch represents the greatest potential source of renewable raw materials for industry with a wide range of products. Indeed the cereal starch industry produces over six hundred products.

Uses for starch include –

- Paper and board - starch is added at the pulping stage to promote internal cohesion. Greater use of recycled paper in the pulp calls for greater use of starch to counter fibre quality deterioration. Most of the starch, however, is used to reinforce surface fibres and provide a smooth finish.

- Detergents - several of the 15 or so chemical constituents of detergents could be derived from starch.

- Pharmaceuticals, cosmetics and personal care products – starch derivatives are quite extensively used in their manufacture

- Adhesives, surfactants, paints and agrochemicals – can also involve the use of starch derivatives

- Plastics and polymers – starch can be used in the manufacture of plastic. New polymers are considered to be a highly attractive innovation with a wide range of potential applications.

- Specialist fibres – electro spinning starch can produce very fine fibres. Starch is also used to improve the performance of ordinary textiles.

Uses for sugar include –

- Fermentation and chemical synthesis are used to manufacture a wide range of chemicals that are used in pharmaceuticals, health care products, polymers, agrochemicals and printing inks.

- Plasterboard, concrete and glazes and tile manufacture – can all use sugar in their manufacturing process. (IENICA: 1999 and 2005)

Specialist Uses of Agricultural Produce – centres on the use of specialist crops and animal products for the production of pharmaceuticals, health care products and cosmetics. These specialist uses are associated with new technology, niche markets and added value.

A wide variety of potential specialist crops are available to the farmer including Pot Marigold (*Calendula officinalis*), Gold of Pleasure (*Camelina sativa*), Woad (Isatis tinctoria) and Honesty (*Lunaria annua*) along with many others. The emphasis is on aromatic, essential oil and extract crops. They are often grown and bred by smaller companies with lower overheads and offer the potential of on farm and regional processing. Cold pressing, steam distillation, hydrocarbon solvent extraction and supercritical extraction techniques are involved. Novel extraction technologies offer new options for products.

Plant metabolism gives rise to a wide range of extractable products, for example secondary metabolites and essential oils. These have many uses as natural flavourings, fragrances and remedies, medicinal drugs in pharmacy, cosmetic preparations, perfumes, aromatherapy, herbal beverages and other novel uses e.g. dyes, nutraceuticals, sprouting/weed suppression, pest control and antioxidants. They are often difficult to synthesis economically. In many plant species the quality and proportions of desired plant-derived molecules vary according to geographical location and method of growing as well as the time of day, stage of physiological maturity and harvest method.

Considerable promise is seen for improvement through new varieties, by improving varieties grown overseas and adapting them to UK conditions, and by exploiting and/or domesticating non-crop plants. (IENICA: 1999 and 2005)

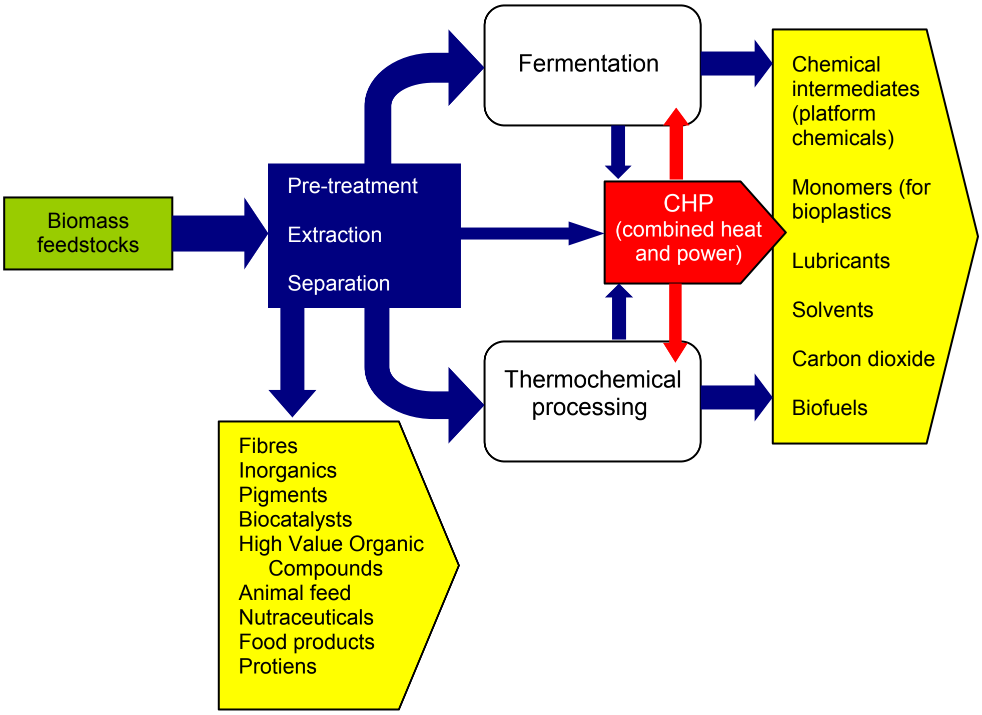
The livestock sector also offers a wide range of potential chemicals for science to investigate to be used for specialist uses. The various tissues all contain specialist materials that can be the foundation for novel high value pharmaceuticals and health care products.

Many of the products above are produced by large scale industrial processes that extract and modify plant products before turning them into useful products and raw materials. Technology is improving these industrial processes to widen the range of agricultural produce that can be utilised and to develop more novel uses for the end product. This point is illustrated by bio-refining and by the fermentation process in particular.

Bio-refining and 'platform chemicals' – many of the above products are created by bio-refining. A bio-refinery converts biomass into purified materials and molecules that result in usable products such as chemicals, fuels and fibres.

Feedstocks (from cereals to miscanthus) are fractionalised through various processing techniques into lignin, cellulose, hemicellulose and starch. These fractionalised components can be converted using a combination of state-of-the-art biological and chemical processing technologies into useful products and chemical intermediates. These processes include fermentation and thermochemical methods such as gasification and pyrolysis. The process also gives rise to a number of useful by-products.

A generic advanced bio-refinery is shown below -



(Chemistry Innovation Knowledge Transfer Network: 2009)

First Generation Bio-refineries – process the 'valuable' part of a crop such as the grain or sugar beet and discards the unwanted parts such as the straw and chaff

Second Generation Bio-refineries – process the whole crop. They are still in development with demonstration plants being built but have the potential to process crops such as grass and miscanthus. In time second generation bio-refineries should dominate the market because of their ability to generate a higher yield by utilising the whole crop.

There are two fundamental types of bio-refinery.

Fermentation – processes are well understood and first generation systems produce bio-ethanol from sugars and starches. The process can be adapted to produce other 'platform chemicals'. These are simple functionalised molecules that can serve as building blocks for further chemistry. The evolving second generation processes can produce a similar range of platform chemicals by processing cellulose and lignin as well as sugars and starches. They require additional stages to breakdown the plant's structural materials, using micro-organisms or chemical treatment, into sugars that can be fermented.

The fermentation process has the potential to produce a wide range of different platform chemicals. Those that have the potential to be economically important are included in the chart below -

Carbon Number	**Platform Chemical**	**Applications**
2	Acetic acid Ethanol	Fuels and fuel additives Polythene and PVC Solvents Ethylene oxide and glycols Polymers Bleaches Antimicrobials Chemical intermediates
3	Lactic Acid 3-Hydroxpropionic acid 1,3-Propanediol	Solvents Packaging, fibres and textiles Coatings, adhesives, sealants & elastomers Plasticisers Lubricants Surfactants and cosmetics Antifreeze Water treatment and papermaking Pharmaceuticals and agrochemicals Engineering plastics
4	Succinic acid Fumaric acid Aspartic acid 1-Butanol 1,4-Butanediol	Fibres and textiles Engineering plastics and nylons Polyurethanes and elastomers Food additives and sweeteners Solvents (THF in particular) Lubricants Fuel oxygenates Dyeing Water treatment and corrosion inhibitors Detergents Plasticisers Chemical intermediates

5	Xylose / Arabinose Levulinic acid Furfural	Explosives Sweeteners Antifreeze Solvents Fuel oxygenate Plasticiser Pharmaceuticals and agrochemicals Resins, elastomers and polyurethanes Chemical intermediates
6	2,5-Furandicarboxylic acid Sorbitol 5-Hydroxymethylfufural Adipic acid	Polyesters, polyamides and polyurethanes Sweetener, humectants, emulsifiers and antioxidants Surfacants and cosmetics Cosmetics Phenolic resins Solvents, lubricants and plasticisers Fibres
Lignin	Benzene, Toluene, Xylene, Phenol, Aryl ethers, Vanillin, Cersols, Catechols, Resorcinols, Quinones	

The final line of the table shows materials that could in principle be derived from lignin. Lignin is an important structural polymer within plants that is not degradable to sugars and not fermentable.
(Chemistry Innovation Knowledge Transfer Network:2009)

Thermochemical – processing is very different from fermentation in that it uses heat to breakdown the biomass into a gas containing hydrogen and carbon dioxide (known as 'syngas'). This method is known as gasification and produces a mixture that can be processed using well established technology widely used in the petrochemical industry. Indeed this process can duplicate all of the products from the conventional petrochemical industry. Other thermochemical technologies are used as pre-treatment steps for biomass prior to gasification. The current focus for thermochemical technology is on the production of fuel rather than raw materials for industry.

Bio-refineries cost several hundred million pounds and are therefore well outside the scope of farmers. Indeed one of the features of this sector is that in most circumstances industrial processing facilities are involved in transforming oils, starches, fibres and other agricultural produce into useful materials. They represent an additional market to farmers and sometimes the opportunity to grow a new crop but the farmer is usually a supplier of commodity biomass into the process and struggles to capture the added value.

However there are opportunities in this sector to process on farm and capture added value. They are often associated with niche markets and the speciality area sometimes lends itself to on-farm processing. These are opportunities that require a real entrepreneurial spirit. The case studies that conclude this section highlight just three truly diverse uses for agricultural produce. One of these involves on-farm processing and is an opportunity for those willing to take a risk and diversify.

The **research effort** associated with alternative uses for agricultural produce centres on –

- The growing, harvesting and storage of specialist crops grown for non-food uses
- The viability (technical and economic) of 'new' alternative crops
- Physiology, biochemistry and cell biology
- The physical and chemical modification of raw materials
- The industrial acceptability and performance of products
- The properties and processability of products
- Processing technologies and manufacturing techniques
- Environmental assessment methods and cost benefit analysis
- Novel uses for products
- Breeding programmes to develop new varieties; disease resistance, and materials with improved quality, quantity and characteristics
- Plant biotechnology including the genetic modification of plants to synthesise chemicals directly or improve the quality of the raw materials they produce which has the potential to widen the scope of this area significantly. Some of the potential associated with non-food uses of agricultural produce will only be realised through the development of genetically modified organisms.

Case studies

Farm Produced Ultrathin Lightweight Packaging

This project successfully produced novel biocomposite food packaging from crop residues that is non-toxic, strong, will maintain the integrity and shelf life of the food, is affordable and acceptable to users. It produced punnets, trays and pizza bases from straw in a manufacturing process that could be used on the farm. Indeed the process represents a business opportunity for farmers to add value to their straw crop. It has particular relevance to farmers who have redundant buildings on the farm and spare labour during parts of the year.

The project was funded by the Technology Strategy Board. It was lead by the Bio-composite department of Bangor University and the consortium included Valueform, C-Tech, Sintamesh, Ciba, Reading University, Imperial College and the Co-operative.

Straw for the process needs to be clean, dry and bright and stored in good weather proof conditions. The process involves grinding and pulping the straw, putting additives into the pulp, moulding the pulp into the desired shape and then drying the finished product. The process has successfully produced food grade packaging at a cost that is competitive.

The pulping drum – making adjustments to this process was key in improving the technical performance of the pulp

Picture courtesy of Robert Elias, Bangor University

The project faced a number of significant challenges. These included –

Creating a pulp from various crop residues that would form into the desired end product with sufficient strength and an acceptable finish. It was also a key objective to keep the amount of processing to a minimum. The crop residues have to be washed, soaked, milled and sieved and various techniques were used to help improve the technical performance of the resulting pulp. Adjustments were made to the pulping process including adding plates and baffles to the mixing drum to improve blending. The design of the milling plates had a huge impact on the finished pulp and the way in which the straw was fibrillated to open up the ends. The pulping process had to be precise to produce viable fibres from the raw material, just enough to break the interfibre hydrogen bonding. The pulping process was also designed to partially gelatinise the starch-hemicellulose which would then act as a binder, minimising the need to add starch or other ligand during the moulding process. A variety of crop residues were tested and characterised including wheat, barley and oat straw, bean haulm, silage maize and onion skins. Wheat straw, barley straw and silage maize offered the highest yield of pulp and barley straw offered the finest quality of finish. The research team were determined to find ways of making up for the deficiencies in the raw materials. Straw has lignin on the cellulose fibres and the team wished to avoid bleaching the straw and removing the lignin.

Creating a barrier between the finished packaging and the packaged food was a significant challenge. The team used a variety of different additives to create a punnet or tray that would hold fruit or meat products for a number of days without become wet and losing its integrity. The packaging had to be resistant to both oil and water. The packaging didn't require a very long shelf life but it did need to survive a number of days before it started to deteriorate. A variety of different additives were tried including starches that are biodegradable. A hydrophobic coating was successfully created that would meet the shelf life requirements.

Moulding and drying the product in a small scale on-farm environment was also a challenge. The product is vacuum moulded and the moulds have to work consistently without blocking and the team used a unique drying process that incorporated both hot air and radio waves. The product was 98% water going into the mould, 60% water coming out the mould and 10% water when dried. Retaining the strength and shape of the finished product were the key objectives of the drying process. Drying also plays a role in sterilising the finished product. A conveyor oven is envisaged as the drying solution to on-farm manufacturing facilities. Very little waste water is created by the process and it contains no serious contaminants. It should be possible to spread it back on the farm.

Pizza base – early prototype before trimming

Picture courtesy of Robert Elias, Bangor University

The team have successfully met the technical challenges associated with producing food grade packaging that meets the market requirement. Its competitors are packaging manufactured from plastic and paper pulp. Plastic uses oil and usually goes to land fill for disposal. Paper pulp involves cutting down trees because recycled paper is usually contaminated with unacceptable printing inks. The packaging produced from straw utilises a waste stream and can be produced locally with a reduction in transport. The team also believe that the manufacturing process they have developed uses only a fraction of the energy used for the production of either plastic or paper pulp packaging.

For the farmer this project represents an opportunity to add value to what is currently a waste stream. Straw does have a value when ploughed back into the soil but it is small. Paper pulp sometimes has a value of £1300/t which gives a feel for the value that can be created from the straw. The product that the farmer produces will be of very high value. The pizza base weighs just 26gms and a manufacturing plant will have the potential to produce 6 million bases per year from just 150 tonnes of straw. They will have a sale value of 3.5p each or £210000 in total. The farmer has the opportunity to set up an on-farm manufacturing facility of food grade standard.

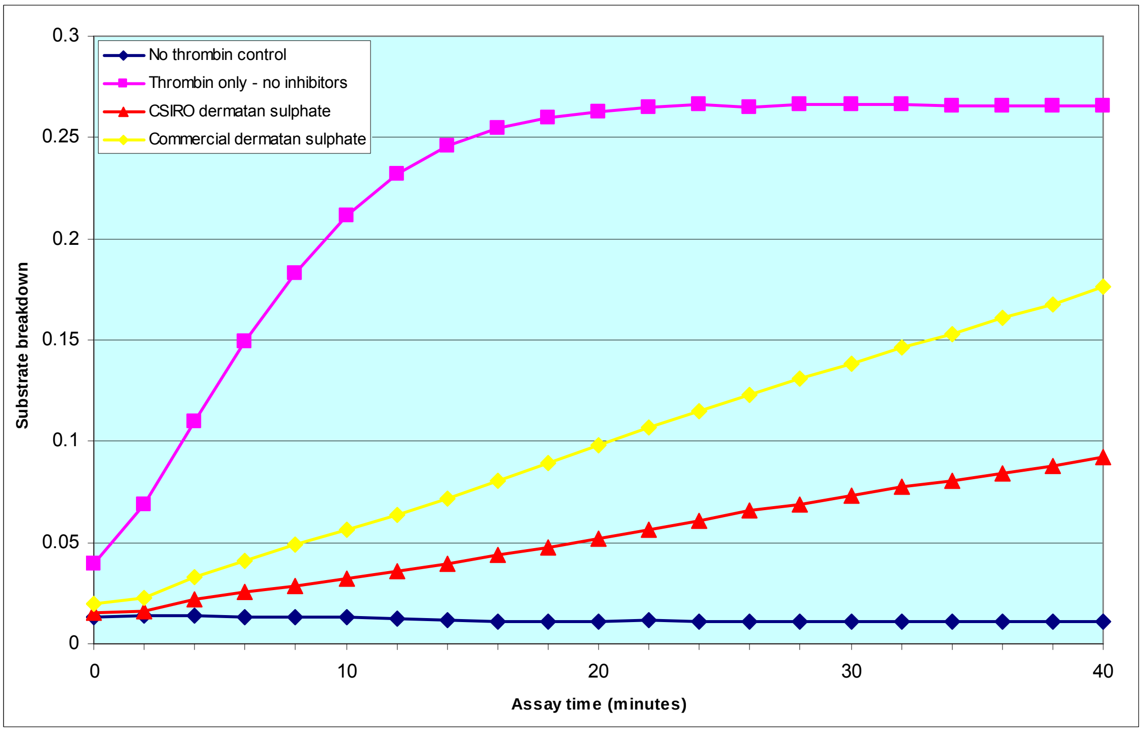
The research team are now going on to consider what other applications the technology could be used for. Hospital trays, horticultural products and industrial packaging are all potential opportunities. They all have their own challenges. Horticultural hanging basket liners for example will have to absorb water rather than repel it. In time these will offer the entrepreneurial farmer the opportunity to expand his production facility into new market places.

New Pharmaceuticals being developed from Animal By-products

CSIRO Livestock Industries scientists at the Queensland Bioscience Precinct specialise in developing nutraceuticals and pharmaceuticals from animal by-products. Their purpose is to add value to animal waste streams. The vast number of different tissues in animal offal gives them a huge number of potential molecules to investigate.

They have recently achieved a break through with the identification of a potential new anti-coagulant that is cheaper to produce than Heparin, the current standard product, and offers additional benefits. The team were initially involved in the extraction of chondroitin sulphate. This chemical is used to promote joint health and has a market value of about £60/kg. It is extracted from livestock tracheas in a labour intensive process that involves the offal being shipped to China for processing. The team developed a process to automate the removal of chondroitin sulphate and reduce the cost of the finished product.

They then turned their attention to another chemical that they had identified called dermatan sulphate. They discovered that the process they had developed to extract chondroitin sulphate from tracheas would also extract dermatan sulphate. They then established that dermatan sulphate has an anti-thrombin activity that impacts on the formation of blood clots and is a potential treatment for preventing deep vein thrombosis (DVT).



The chart above demonstrates how the dermatan Sulphate (in yellow) inhibits thrombin activity when used in a complex with heparin co-factor II in an *in-vitro* experiment.

The team then went on to conduct *in-vivo* experiments with rabbits. The rabbits were treated to stimulate blood clot formation and then dermatan sulphate was orally administered in two different formulations and compared with clexane (the heparin standard) and saline solution as a placebo. The results were very favourable.

The team followed this trial up with an investigation into how quickly the product was absorbed into the blood stream in comparison with both heparin and the saline placebo. The results showed absorption of the dermatan sulphate into the blood steam.

Dermatan sulphate is much cheaper to produce than heparin and the team have also identified a number of other key benefits that it offers over the heparin standard but these are subject to confidentiality until all the intellectual property issues have been resolved. The results of the research will be published as soon as these issues are resolved.

The product and process that extracts it are ready for commercialisation. The dermatan sulphate should have a value of about £2500/kg. A plant to extract it will cost between £750K and £2M and there is no shortage of animal waste stream to process. An opportunity exists for an entrepreneurial meat processor to seek out a drug company to conduct the human trials and register the new drug for use and then take the product into commercial production. The team are now going on to investigate the available molecules in blood which is another valuable resource that often goes to waste.

Using starch to create light weight concrete

Scientists at WRRC in California have really demonstrated how agricultural produce can be put to the most extra-ordinarily diverse uses with a product that is used to create light weight concrete.

Concrete is widely used in construction because it offers tremendous compressive strength and is very durable. However it is very heavy and in some circumstances that weight is a liability. Lightweight concrete has lower density and unique sound proofing and thermal properties. It has many useful

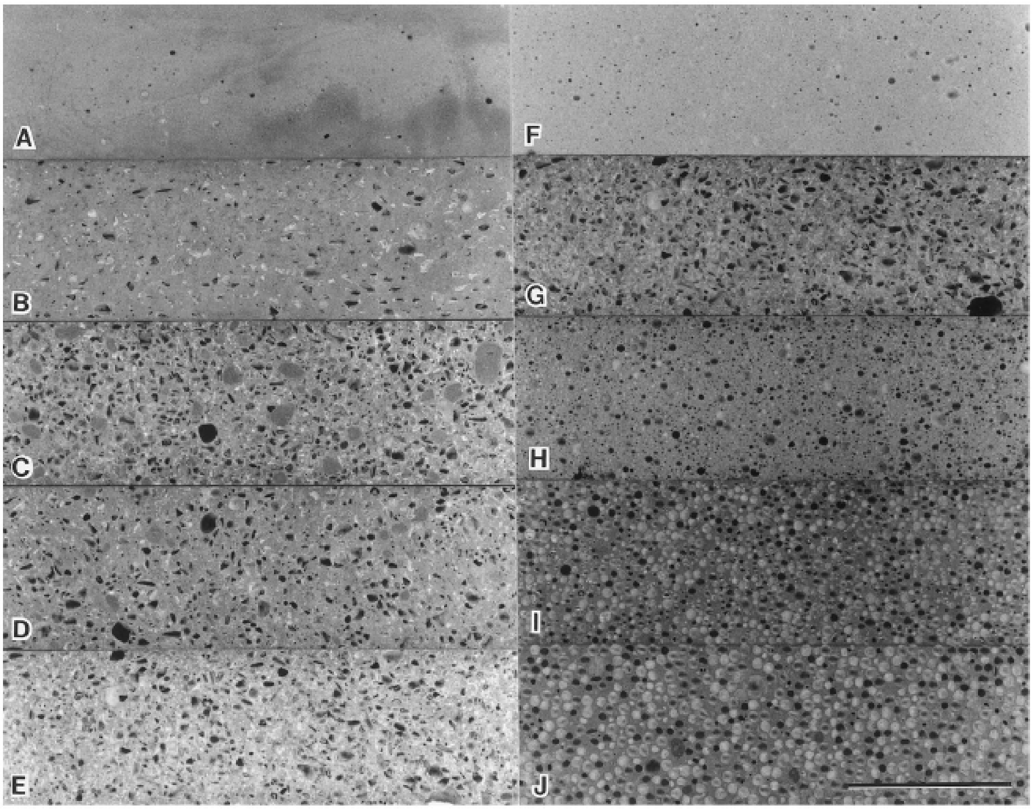
applications including floors fills, roof decks, sound barriers and insulative fill around fireplaces. Lightweight concrete is usually made by incorporating a lightweight aggregate or by entraining air into a concrete mixture. Both these are effective ways of reducing the density of concrete but they have drawbacks. These include the local availability of low cost lightweight aggregate and the instability of air-filled bubbles. (Glenn et al: 1998)

The research team at WRRC have developed an alternative process to create lightweight concrete that uses starch based aquagels. Various challenges have been overcome over a number of years to develop an aquagel that offers satisfactory performance in the aggressive alkaline environment of a concrete mix. (Glenn et al: 2004)

Aquagels are semi-rigid gels that contain mostly water and a small amount of solids that act as a gelling agent. To be effective they must be strong enough to remain in tact during the mixing process. Once the aquagels are mixed uniformly through the concrete mixture, the concrete is poured into place where it hardens and encases the aquagel. Void spaces then develop around the encased aquagels as the cement cures and dries.

Initially the research team tested four types of aquagel; High Amylose Corn Starch (HACS) aquagel, Wheat Starch aquagel, Agar aquagel and Algin Acid aquagel. The aggregate Perlite was tested as an example of an alternative lightweight concrete. The aquagels were tested at four different inclusion rates and it was found that they had an impact on the moisture content of the mix and setting time. The ideal aquagel for making lightweight concrete is one that behaves inertly when mixed with the cement and releases little or no water until the concrete has hardened. This ideal isn't achieved in practice.
Water clearly moves out of the aquagels and into the concrete during mixing.

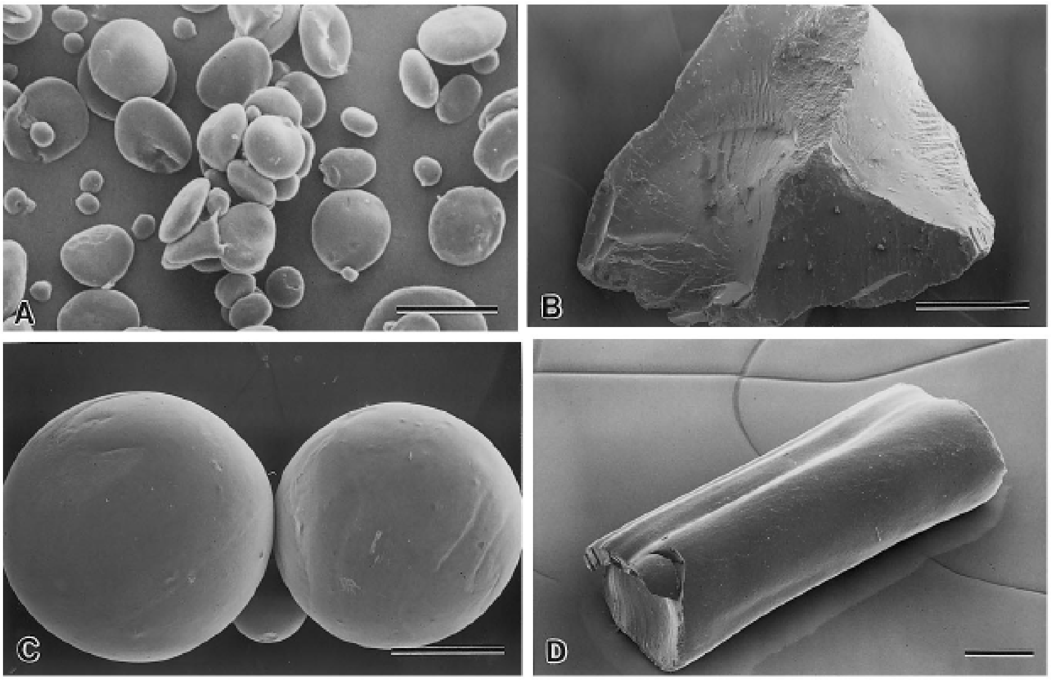
Crossectional views of the resulting concrete revealed a uniform distribution of pores throughout the profile of the concrete with each pore containing a small particle of dried starch surrounded by a void space. The aquagels had remained intact during the mixing process and become encased during the setting process.



Cross sectional views of concrete samples. The control sample (A) had only occasional pores from small air pockets trapped within the sample. The number of pores increased with greater proportions of wheat starch aquagel (B – E). Note the angular pore shape formed by the wheat starch aquagel. Samples F to J are concrete samples manufactured from perlite, wheat starch aquagel, high amylase corn starch aquagel, algin aquagel and agar aquagel respectively. The pore size of the perlite sample is too small to see with the unaided eye.

As the amount of aquagel increased the density deceased, the thermal conductivity deceased and the compressive strength decreased. It was clear that aquagel could be used to easily formulate concrete of desirable densities and uniformity. (Glenn et al: 1998)

The team then went on to test if the shape of the starch particles had an impact on the quality of the concrete. Raw starch granules were tested along with angular, spherical and cylindrical particles. Concrete made with the raw starch granules and the cylindrical particles had high compressive strength but cracked when oven dried. They were considered unsuitable for making light weight concrete. However spherical aquagels proved to be the preferred shape because they resulted in a greater compressive strength than angular aquagels. Compressive strength was also improved by using smaller aquagel particles rather than large particles. The team also concluded that the source of the starch had no significant effect on the physical and mechanical properties of the concrete. (Glenn et al: 1999)



Scanning electron micrographs of wheat starch granules (A), angular particles (B), spherical beads (C) and extruded cylinders (D). These starch preparations were fully hydrated in water at 23˚C before being added to a concrete mixture. Scale bar = 25µm for A and 500µm for B, C and D
Images courtesy Greg Glenn ARS USDA

A further challenge remained. The starch aquagels were unstable in the strongly alkaline conditions typical of Portland Cement based products that are widely used commercially. The alkalinity interferes with the setting process. Seeking potential solutions the team researched five different polymers at three different inclusion rates that could be blended with the aquagels. They discovered that a blend of starch with 30% PVOH (poly vinyl alcohol) was resistance to the impact of the alkaline in the cement although careful control of the moisture content and short mixing times were important in ensuring consistent setting times. The compressive strength of the aquagel concrete was approximately 10% of the control made with only concrete and on this occasion the size of the aquagel particles had only a minor impact on that compressive strength. (Glenn et al: 2004)

The team at WRRC have demonstrated how agricultural products can be put to the most unexpected and extra-ordinary uses. The product has been patented but is still waiting to be exploited commercially. At present in the USA the economics associated with the various components of aquagel concrete are not favourable in comparison with the alternatives.

Conclusion – agricultural produce can be put to a wide variety of uses. The oils, carbohydrates, fibres and specialist chemicals in our agricultural crops offer a bewildering number of opportunities and new technology is constantly developing further uses for agricultural produce. Their processing usually involves industrialised facilities and this limits the opportunities for farmers who will invariably become just commodity suppliers of raw biomass.

However opportunities do exist from time to time to grow novel crops on the farm and engage in on farm processing. Specialist crops have an emphasis on aromatic and essential oils. These are often grown by smaller companies and offer the potential for on farm processing. Whilst the opportunities in this area of technology are limited for the individual farmer the case study on light weight packaging demonstrates that there are innovations that will appeal to the entrepreneur.

Robotics and Smart Engineering

Developments in engineering and computer based technologies offer huge opportunities for agriculture. Many tasks in farming are dull and routine and involve huge gangs of labour performing repetitive tasks. These mundane tasks can potentially be replaced by robots. Farmers also require information about their operations in order to manage them effectively and developments in new sensing technologies offer opportunities to produce more timely data and information that has to date been uneconomic to collect.

Robots have the potential to undertake a wide variety of operations on the farm including cultivating, seeding, spraying, nutrient application and harvesting. The drivers for introducing robots on to the farm are economic and the poor availability of manual labour. There is the potential for robots to complete tasks at lower cost and possibly to higher standards. Robots don’t get tired and will complete the one thousandth task as effectively as the first. The farming industry has suffered with a lack of available labour. In recent years the UK industry has relied on willing workers from Eastern Europe but that probably won’t be available for ever. However for many years the USDA had a moratorium on funding research into robotics because of the threat to employment. That moratorium was only lifted 3 years ago.

The development and use of robots in agriculture is still in its infancy. The robotic milker is becoming established with numerous installations across the UK. Lely believes that 20% of all new installations in the UK are now robots (Dunn: 2009). The robotic milker has been developed over the last 30 years and is a sophisticated machine. The accurate placement of the cups on the teat was a significant challenge but the machine also had to rise to the challenge of mastitis detection and to maintaining milk hygiene standards. All these issues were overcome and a small group of pioneer farmers then brought the machines into commercial use.

Columnar trees make harvesting easier for robots

The good robotic engineer has to be capable of thinking outside the box to solve problems. The starting point in developing suitable robotic technology is understanding the problem. What is it that has to be done? And are there opportunities to adapt what is done to make the robotic solution easier? For example growing strawberries on table tops presents fruit to a robot in a much more acceptable way than growing strawberries on the ground. Can fruit trees be grown to present fruit to a robot in a way that will make picking much easier? Apple breeders at Cornell University are using genetics to develop 'columnar' trees that will present a 'fruiting wall' to robots for harvesting – an easier environment than searching for fruit in the canopy. 'Re-positioning' the problem is often a significant part of the solution for the robotics engineer.

The engineer also has to understand the economic environment that the machine is going to work in. Indeed this is a fundamental issue in technical development, does the engineer solve the problem and then try to reduce costs or does he work at low cost and then work his way up to solve the problem.

As in most fields of R&D robotic engineers work at different levels. Some engineers work at a theoretical level developing novel sensors, control systems and tools for which they don't have an immediate need. They create the 'new science' that is then used by those engineers who are closer to the market place to develop marketable machines. The military are a key driver in the development of robotics and smart engineering. They don't have the same cost constraints as the commercial world and can develop concepts that are then used by commercial engineers. Once the technical problems are overcome bringing down the cost usually follows. GPS is a good example of this process, once it was developed both the physical size of the GPS units and their cost came down quickly. This model works over and over again.

Robots consist of a number of key components –

Sensing systems – to see, locate and feel

Power units – to provide the power

Control systems including a CPU (Central Processing Unit)

The mechanical machine that actually does the work

Sensing systems – robots make use of a number of different sensing systems including machine vision. Machine vision is used to help robots locate where they are working and also for a wide variety of other applications including locating produce for harvesting, plants for spraying and animals for condition scoring. Machine vision is based on a variety of different sensors that can include -

Colour cameras
Infra-red cameras
Cameras tuned to specific light frequencies
Radar
Lasers
Ultra sound

Often stereo cameras are used to help create a 3 dimensional image and sensors can also be fitted with motors so that they nod and scan a field of vision. I some cases a number of different sensors is used to create reliable image.

These images are then combined using complex algorithms to create a picture of the surrounding area. It is important that the sensing system can detect the ground and any vertical surfaces so it can place objects into that space.

Sensors on a vehicle that is travelling on bumpy ground represent a particular problem. They have the potential to produce ‘noisy’ images. The CPU has to be capable of taking these images and producing clear images. It also has to be capable of synchronising images coming from different sensors.

These cameras can take thousands of pictures a second and the processing units must be capable of processing that data in real time to produce an image of the working environment.

One of the challenges of vision systems is coping with shadow – areas of dark and light. This can be overcome by using double exposures that the CPU then processes in real time to produce a single image but it is costly. This helps to ‘see’ objects in the shade. The human eye and brain is particularly good at doing this.

Work done by the National Centre for Engineering in Agriculture at the University of South Queensland demonstrates how lighting can be used to aid computer vision. The research team wished to develop a computer aided system for assessing the yield of macadamia nuts. The pictures below show how working in an environment of structured light can make the target easier for the computer to identify in comparison to uniform light.

Pictures Courtesy of Cheryl McCarthy - NCEA

Robots also use sensors other than machine vision to locate where they are. The disadvantage with machine vision is that it can only locate position relative to a feature and it doesn’t work in an unstructured environment. Alternatives include -

GPS (Global Positioning System) – with which most farmers will now be familiar. GPS signals are used to pin point exactly where the machine is. Systems associated with the very high levels of accuracy required for field operations are still expensive and the signal can be lost, particularly under tree canopies.

Wheel encoders – can be used to track vehicle position. They are electro-mechanical devices that measure the rotation of an axle and calculate how far the vehicle has moved from a known starting point.

IMU – inertial measurement units – is an electronic device that measures and reports on a vehicle's velocity, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes. They are commonly used in aircraft. These measurements are likewise used to calculate how the vehicle has moved from a known starting point.

Both wheel encoders and IMU use a process known as dead reckoning to calculate vehicle position. Position is calculated from a known starting position based on speed over a period of time. A disadvantage of dead reckoning is that since new positions are calculated solely from previous positions, the errors of the process are cumulative, so the error in the calculated position grows over time. In a fixed environment such as an orchard these errors can be corrected using 'high precision way points' that the vehicle uses to adjust its calculated location.

Arial photo graphs can also be used to help a machine locate its position and some research has been done into using cameras positioned high above working areas to help locate position. (Zhang et al: 2009)

Sound isn't widely used on robots for sensing. It has been used by the military to 'listen' for gunfire but has limited value in an agricultural setting.

Touch is a particularly challenging sense to imitate. Force feed back can be used where the electrical current required to pick something up can be measured. Tactile sensors are useful in unstructured and changing environments and play a major role in grasping objects. Imitating the human hand is particularly difficult in terms of robotic development – it is very expensive. Humans use vision and touch to handle objects – we locate the object with vision but then use touch to actually handle it.

Other sensors that are used in robots include tilt and stability sensors.

Control systems – robots require effective control systems based around a CPU. These include -

High Level Controllers – for mission decisions, path planning, safeguarding, specialty sensors and user interfaces that handle large amounts of information

Low level controllers – for steering, engine and implement control

The two systems must effectively communicate in a timely and fail safe manner. An architecture is required for this. (Cameron et al: 2009) Cooling the CPU can be a problem.

Power units – a number of different options are available to the robotics engineer. These include –

- Many types of batteries including –
  - Lithium Ion batteries that offer good power density and can be shaped to fit into any space. They require recharging and if mishandled they can explode.
  - Wet Lead Acid Batteries that are heavy, lack power density and also require recharging.
- Electricity through a power lead which is low cost and light weight but lacks freedom of movement
- Petrol and diesel engines that work for a long time on a tank of fuel but produce vibration, noise and heat.
- Hybrid power where engines are used to recharge batteries. Electricity has good power characteristics and the engine smoothes the power requirement.

Cooling the power units can be a potential problem

The mechanical machine – uses a variety of solutions to solve 'doing' the task including -

Hub electric motors that offer great torque and are easy to design into a machine. They have no direct drives and very little loss of energy.

Hydraulics which results in a loss of power if used to drive the vehicle. However they are easy to design in. Hydraulics can also be used to move components like mechanical arms.

Pneumatics that are 'soft' in their operation. Gases can compress and take shocks which can be very useful in controlling some mechanical operations. They are also easy to design in.

The movement of robot is usually accomplished using wheels but tracks can be used and some robotic engineers have worked with 'walking' machines in certain applications. When wheels are used a wheel can be put onto each corner of the robot with the possibility of using four wheel steer and four wheel drive. Turning circles can be made tighter using braking control. (Idia et al: 2009)

'Safeguarding' is an important feature of any robot. Invariably this involves creating images to detect dangers. Safeguarding needs to be conservative in its operation and should detect false positives, that is, it should stop when there is nothing there. Typical obstacles in a farm environment include – telegraph poles, trees, people, animals, other vehicles, irrigation pipes and pumping stations. When a machine stops it can send an image that highlights the obstacle back to a supervisor who decides if he should override it. (Moorehead et al: 2009)

Machine learning is a key component of robot development. The robot adjusts its own software based on previous experience. The algorithm learns patterns from the data sets and then uses them in a predictive manner. The robots perception is improved.

For example if the robot is fitted with long distance vision sensors and short distance vision sensors it may ‘ see’ something in the distance but may not know what it is. The short distance sensors may then recognise that object as a tree when it gets close to it. Next time the machine ‘sees’ a similar object in the distance it will recognise it as a tree. Or when it hits an obstacle it remembers what it saw and then next time it recognises it as an obstacle.

Robots can use this process to reset its own parameters in a new environment and as such it saves programmers huge amounts of time and cost.

Machine learning was used in the development of an oestrus detection aid that LIC in New Zealand have developed. The system that is commercially available is designed for large herds. It uses a camera to ‘read’ Kamar heat detectors. Creating an algorithm that could read the Kamars was difficult and eventually a blue Kamar was produced to overcome the problem but machine learning was used to refine the software during the development of this product.

LIC are also investigating using machine learning to analyse data for individual cows. For example each milk cluster could be adjusted based on the machines previous experience.

BRAIN in Japan - The driverless machine is a reality

Most robotic engineers currently envisage a future based on groups of small robots under the control of a single operator. Such a system will require a supervisory system with a communications infrastructure. In the future the operator might be a ‘mothership’ controller with sophisticated systems to control the smaller machines along with an infrastructure to refuel and replenish them. The driverless machine is a technical reality and its uptake appears to be limited by legal issues rather than technical ones - who will be responsible when the machine drives through someone’s living room? Smaller machines will limit the potential damage that might occur and could also be more easily retained by a series of ‘tank trap’ ditches around the working area.

Developments in sensor technology are creating a revolution in the information that is available to farmers (Singh et al: 2009). A plethora of sensors and communication systems are being developed that can be used for applications as diverse as –

Identifying crop stress

Identifying crop disease
Measuring the nutrient content of plant leaves in situ
Estimating crop yields
Identifying internal defects in produce
Measuring body condition score in livestock
Measuring livestock activity

These will help farmers react more quickly and to make more informed decisions.

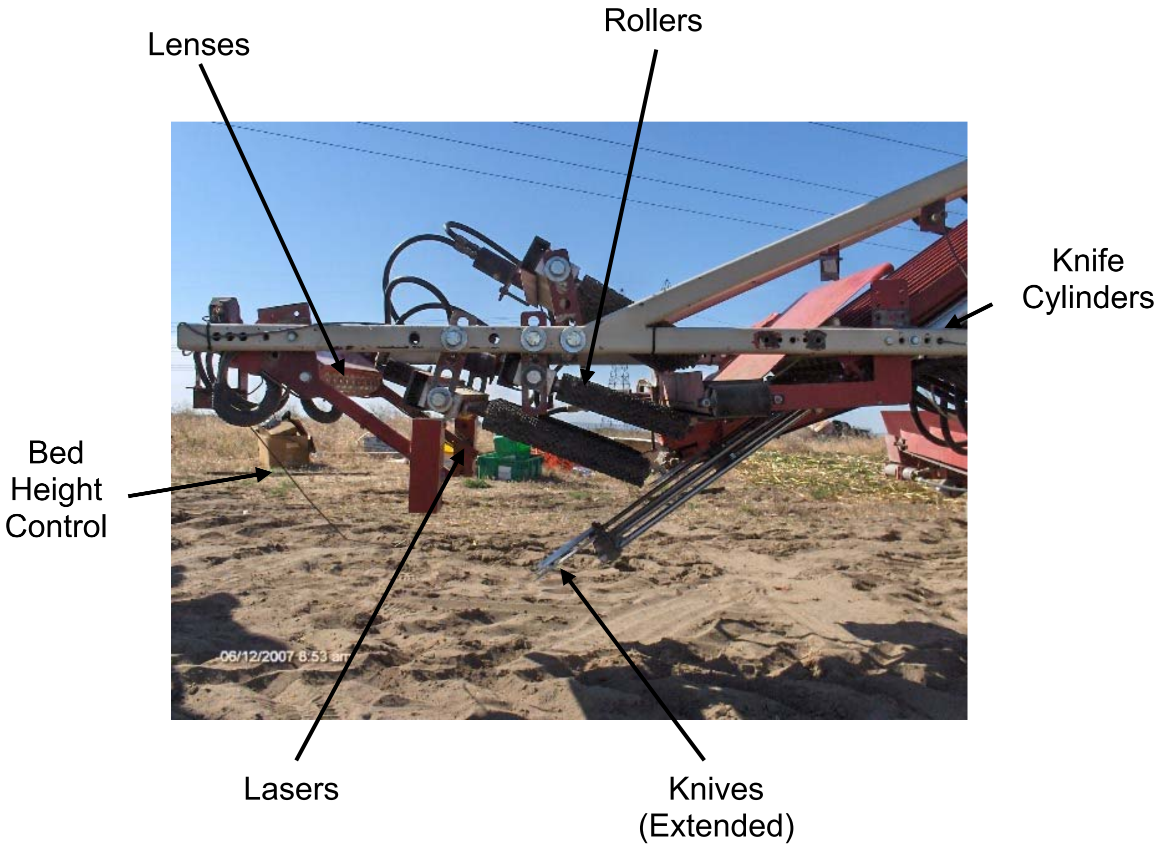
Case studies

Asparagus Harvesting – Geiger-Lund Engineering in California have successfully developed a robotic asparagus harvester that is now ready for the market (www.asparagusharvester.com).
Harvesting asparagus with a robot is not easy. The crop is selectively harvested and cut below ground. Any automatic harvester has to be capable of identifying the spears that are ready to harvest and then cleanly cut and collect them without damaging the spears that are developing. The machine has to be quick and reliable because during the peak harvesting season the crop is cut on a daily basis.

Bill Lund first started building prototype harvesters in the very early 70s and persevered throughout most of the 1980s before putting the project aside. He returned to developing the machine in 2000 as a result of renewed interest in automated harvesting and technical developments that offered the potential to overcome the obstacles that had been encountered over a decade earlier. The development of the machine has been slowed because there is only one short season each year in the Western United States to develop and test it.

The machine uses two laser beams along with a series of sensors to identify where the spears to harvest are, it then uses pneumatically fired knives to cut the spears and finally uses rollers to collect the spears and deliver them onto a conveyor. The cut spears are then manually packed into trays.

A variety of sensors were tried over the years. An early video camera was tried as were small flappers that touched the spears. It quickly became clear that any sensor that touched the spears was unacceptable. Spears that leaned over also represented a problem in terms of detecting exactly where to cut them. The chosen sensing system uses two laser beams. The higher beam is used to determine if the spear is ready to harvest. If the spear is lower than the beam then it doesn't get cut. The lower beam is used to determine where to cut. The beams create a red spot on the spears that is 'seen' by optical sensors that sit behind a series of lenses. There are two sensors behind each lens; one focused on the top laser beam and one on the lower laser. Each sensor then has its own micro controller with its own programme running. The laser is modulated and the sensors detect a rapid change in intensity. The sun doesn't interfere with the system.



The header is constantly kept at just the right height above the bed using a simple rod that moves and activates a pair of proximity switches. Earlier versions had mechanical switches, ultrasonics and laser distance detection but they proved to be unreliable or unsatisfactory. Where a harvester has more than one header they will all move independently. Farmers grow asparagus on differing widths and heights of bed and machines will be custom built to suit the farmer's requirements.

Cutting the asparagus is a real challenge. The machine has to calculate just the right spot to cut. If the machine is moving at one mile per hour it moves almost 2 inches in a tenth of a second. The knives have to be very accurately targeted to cut the spears. The harvester has a shaft encoder on the axle that calculates the machines speed every tenth of a second. The CPU then calculates when to 'fire' the knives to cut in the right spot.

The knives are 2 inches wide and fitted to the end of 20 inch stroke pneumatic cylinder that can fire 5 times each second. The knife has 100lbs of force and reaches full velocity within an inch of starting to move. It takes just 0.07 of a second to go down. The cylinders had to be custom built to provide ports that were big enough to allow a big enough airflow to meet the performance requirements. Its movement is cushioned by a small pneumatic cylinder that ensures the cylinder rod doesn't strike the cylinder case at the top of its stroke. On the down stroke the cylinder reverses direction before it bottoms out. Early versions of the cylinders shook themselves to pieces. Rods that held early cylinders together stretched and fittings shook themselves apart. Lock nuts and lock tight were tried without success. Cylinders that are welded together with tapered fittings provided a reliable solution. The current cylinders have a one inch bore with a centre-to-centre spacing of one and three quarters inches.

The width of the knives and cylinders has been reduced as the machine has been developed. The knives were 5 inches wide. They cut the asparagus well but did far too much damage to spears that were developing around the spear that was harvested. They were having a negative impact on the overall yield across the season. As targeting was refined their width was progressively reduced. Sometimes two knives are fired at once if the sensors detect that a spear sits in the margin between the two knives.

There are three sets of rollers that pick the spears up and carry them into the conveyer. The first set starts to grip the spear before it is cut. The rollers then 'pass' the spears from set to set and lift the spears well out of the way of the knives before putting them onto the conveyor. The rollers have been developed so they don't damage the spears.

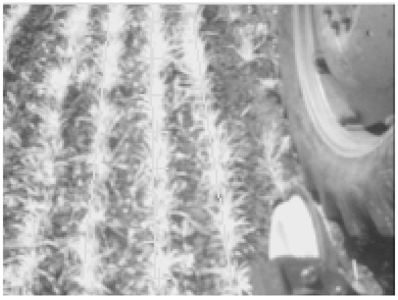
The machine is finally ready for the market place and Geiger-Lund expects to sell one into Australia in 2010. The cost is expected to be in the region of £150K for a machine with three headers. In a commercial environment the machine should be able to work at 2 miles per hour.

Images courtesy of Bill Lund

To date no study has been done comparing the machine in its current form with a manual team cutting the crop but it is envisaged there will be a small yield penalty associated with its use.

Weed Control – is an area where alternatives to conventional spraying are being pursued by a number of research groups. Our existing spraying techniques result in potential risks to the environment and the possibility of product contamination. In Europe many agrochemicals are being removed from the market and in some cases alternatives are urgently required. Possible solutions are robotic weeding and targeted spot spraying.

Dr Nick Tillett of Tillett and Hague Technology has been working on alternatives to conventional spraying for over twenty years and his success in this area demonstrates how frontier technology develops over a period of time. As long ago as the late 1990s he and his colleagues had developed a tool carrier that could steer itself through a field of row crops using machine vision. This developed into the first Robotic weeder, the Robocrop, which was launched in 2001. A number of different techniques were tried to differentiate between the crop and the weeds. Colour differences between the crop and the weed were found to constantly change and were insufficient to successfully differentiate. Leaf shape was tried but it required very high definition cameras and too much computational capacity. The solution was found by using the planting geometry to identify where the crop rows were. Colour cameras were able to quite easily distinguish between the green crop and the background soil. A band pass filter tuned to the known row spacing was then used to create an image of the rows that the hoes could follow.



Unfiltered image

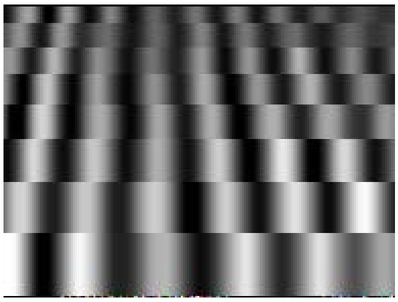


Image after filtering

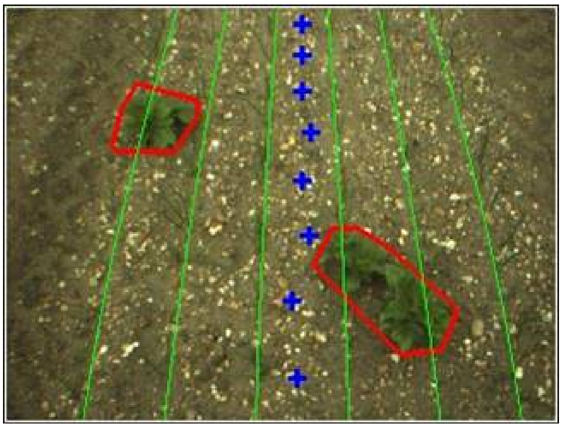
The machine tracks crop rows from image to image and uses knowledge of the tractors forward motion to ensure reliability. This solution was found to very robust in terms of identifying the rows and even worked reliably when the tractor was deliberately driven badly. The Robocrop found a market with vegetable farmers and organic cereal farmers and sales have risen to about 50 machines each year. The research team continued to refine the machine over the next few years but their attention moved on to the next challenge.

Weeding in between vegetable plants within the row as well as between the rows was the next problem to be addressed and overcome. This required both vision innovation and mechanical innovation. Once again knowledge of the geometry of the crop is the basis on which the machine works. The camera produces 30 images each second and the machine predicts when a plant will appear at the top of the image. It then refines the location of the plant as it moves across the image and rotating hoes are then run around each plant as the weeder passes over them. When an unusually large gap exists between two plants the hoe can be clearly seen to hesitate before it sweeps through the gap.

The Robocrop in row – hoes weed around each individual plant

The Robocrop InRow was successfully launched in 2007 and offers a real alternative to spraying in precision drilled or transplanted vegetable crops where large gaps exist between individual plants. Once again the research team moved on to a fresh challenge.

Using the technology to identify individual weeds and spot spray them is the current focus at Tillett and Hague Technology. The particular challenge that they are addressing in a collaborative HortLINK project is volunteer potatoes in onions and carrots. The current agrochemicals used for this task may well be withdrawn in the near future and they have a reputation for checking the crop. On the prototype machine the camera looks forward and down across a 1.8 meters wide bed. Once again it differentiates between plant material and the background soil on the basis of greenness. The potatoes are identified based on a weighted combination of their distance from the crop row, their size and their shape; that is their aspect ratio (width divided by height) rather than the leaf shape. The algorithm then identifies spots to be sprayed.



Potatoes identified for spraying

This project has involved solving the problem of spot spraying the weeds as the machine passes. The sprayer has to turn on and off very sharply with no drift at very low flow rates. This has been achieved with Glyphosate where quite large droplets have been used to give good drift control and targeting. However these may not be suitable for all other chemicals. The machine is now an advanced prototype and is probably 2 years from becoming commercially available. One of the problems to overcome is a legislative one; there is no approval for using Glyphosate in onions and carrots.

Control plot alongside a crop that has been spot sprayed. Between 75% and 95% of potatoes have been removed in one pass in trials with very low levels of crop damage
Pictures courtesy of Tillett & Hague

A research team at the National Centre for Engineering in Agriculture in Australia have successfully used colour differences to identify different weeds. They managed to identify weed grasses in Sugar Cane using the ‘blueness’ of the leaf. Accuracy of detection was over 90%. Although this is not directly applicable to the UK it does demonstrate that there are potentially alternative ways of identifying weeds to the one outlined above. Indeed it may well be that individual solutions have to be found for particular weeds in particular crops.

A really futuristic approach to chemical application is being researched at Washington State University. The programme is seeking to use cold plasma to accurately apply chemicals to fruit crops. The long term aim is to apply pesticides to just the part of the crop that requires treating – so when the apples need spraying they will get coated in pesticide but not the leaves. Once again vision technology is used and cold plasma is used to apply an even film across the target. It may be many years before this technology is available to use in the orchard but it could be available much sooner for applying materials to harvested crops in the store or pack house.

Smart engineering for livestock farmers – progressive dairy farmers have been aware for many years that locomotion scores and body condition scores for their cows are valuable information that can improve management but obtaining this information through manual assessment is laborious and interpreting it to produce meaningful trends has not been easy. IceRobotics in Edinburgh have developed technical solutions to gathering and interpreting this information and are due to launch an animal activity recorder onto the dairy farm market that will not only produce locomotion scores but a variety of additional management information in relation to both individual cows and the whole herd.

IceRobotics expertise is in sensing technology. They have already developed an activity recorder that monitors, records and reports detailed animal activity. Called the IceTag3D it is based on an accelerometer that picks up the forces of gravity in 3 dimensions – up/down, forward/backwards and left/right.
It records information 16 times each second and transmits the data wirelessly. This is a progression from the pedometers that have been on the market for some time that record just stepping activity. Software interprets the raw data into the animal's activity patterns rather than just recording step count.

The IceTag3D is currently used by animal scientists to support research into animal health and welfare. Typically, devices are attached to animals for the experiment period and then removed and the data downloaded wirelessly to the researchers' computers.

A new system is being launched at the Precision Dairy Management Conference in Toronto in March 2010 to enable much larger longitudinal datasets to be collected to support research. Called theCattleGrid, the IceTag3D is being combined with automated data download on the farm and internet connectivity. This will allow devices to stay on animals for several years and the researcher to access the data remotely. Oestrus detection will be available to participating farms through the system.
A system is also being launched in Autumn 2010 that is being designed specifically for commercial dairy farmers. This will be based upon a localised system but will be internet enabled to allow for downloading updates and to benchmark with other herds. Initially this will provide monitoring and alerting for oestrus and lameness. IceRobotics have been holding farmer focus groups to develop an understanding of exactly what information farmers want from a commercial system.

IceTag3D on grazing cow

Image courtesy IceRobotics

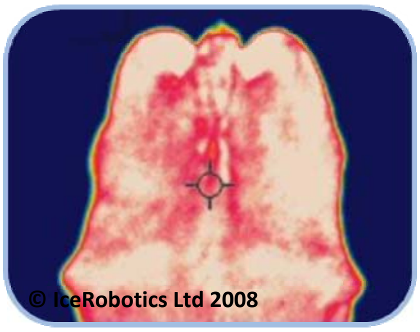
The accuracy of the information generated is currently being validated to ensure that the system is accurate whilst minimising the detection of false positives. In addition to individual cow monitoring, the system will also produce whole herd information; how long cows are spending lying down, how long do they spend just standing. This will allow farmers to assess the impact of management changes on the behaviour of the herd. Has a ration change resulted in the cows spending more time standing at the feed face? This should lead to the development of 'time budgets' that the farmer can use to maximise the time his cows spending eating and lying rather than waiting to be milked. It should allow good management practices to be scaled up.

The IceTag3D incorporates battery saving technology that gives its batteries a prolonged life and it sits within a tough plastic housing that can tolerate life on a cow's ankle.

The concept of gathering information from sensors on the animal can be further developed. Researchers in Japan have collected data automatically on the number of bites an animal takes when feeding. It should be possible to put a bolus into the animal that would take temperature readings. All this information could be linked back into sensors in the milking system and in the future it should be possible to gather a wide variety of data that will give us new insights into individual cows and whole herds.

IceRobotics has also been involved in the development of automatic body condition scoring. They have developed a system demonstrator that uses a thermal imaging camera to assess the shape of a cow. At present body condition scoring is manual and subjective. It is time consuming and requires trained labour. Very few farmers consistently measure body condition scores although many recognise the value of the information associated with the practice.

The system developed by IceRobotics works by determining the presence of the animal and then taking an image of the back of the cow from above. The data is then analysed to identify certain points on the animal's back. The angles associated with these are then calculated and the appropriate resulting body condition score generated.



Thermal image of cow's back from above

Image courtesy IceRobotics

Studies to date with the system have demonstrated its effectiveness, although it still requires some refining before full commercialisation.

Automatic body condition scoring could also be used to select animals for slaughter in beef feedlots.

At present the cost of thermal imaging cameras is prohibiting the commercialisation of this approach to automated body condition scoring, but technology is constantly comes down in cost and there is every prospect that this technology will be available of the farm in the future.

Fruit Harvesting – a significant challenge for the robotics engineer – a number of research groups around the world are working on this difficult issue. A group of Universities in the USA including Washington State University and Pittsburgh University are working on an orange and apple harvester, Washington State University are working on a Cherry harvester and BRAIN in Japan are working on a strawberry harvester.

The challenges associated with harvesting fruit are considerable but the most significant was probably summed up by Marvin Pitts of WSU 'If I touch a fruit, I bruise a fruit'.

The robotic fruit harvester has to navigate and power its self around the orchard, it has to see the fruit to be harvested, differentiate between fruit that is ripe to pick and fruit that is still immature, restrain it to grab it, remove it from the tree or plant and then put it into a tray or bin. It has to do that economically and a large part of doing it economically means doing it quickly.

Locating the fruit is made difficult because it grows on a plant that is not uniform. Fruit can be hidden behind branches and leaves. To locate red fruit a colour camera is probably the lowest cost option but green fruit against green leaves creates problems. In this case neo-infra red, ultrasonic or laser scanners may be the best option. The machine will have to reach and grab the fruit. As the fruit gets further away from the robot this becomes more difficult. The machine has to be able to judge distance and to grab fruit that is moving in the wind. Of course one possible solution to this is that the trees are trained. As discussed above columnar trees may have a big role to play in this respect if they are used to create a 'fruiting wall'.

Having located the fruit the next challenge is too handle it. Robots are often built to mimic humans. When we reach out to pick an apple we use vision to guide us to the point of grabbing the apple but then touch takes over. Touch is a very difficult sense to mimic. Indeed it would appear that nobody has yet produced an effective robotic finger tip. That finger tip would require a number of sensors – 3, 20 or 100? It would then require very rapid feedback loops from the sensor to the mechanical actuators to stop the 'finger' bruising the fruit before it had stopped moving. Progress is being made here. Until recently the fastest actuator took one tenth of a second too respond; to slow to prevent damage. This has been reduced to one two hundredth of a second – 20 times quicker. The 'hand' that grabs the fruit has to be soft but not so soft it won't work. If it grabs too firmly it will bruise but if it isn't firm enough the fruit will slip within its grasp and scratch.

The 'hand' that grasps the apple could consist of 3 fingers, or 4 fingers or may make use of suction. Will one device handle all sizes and shapes of fruit?

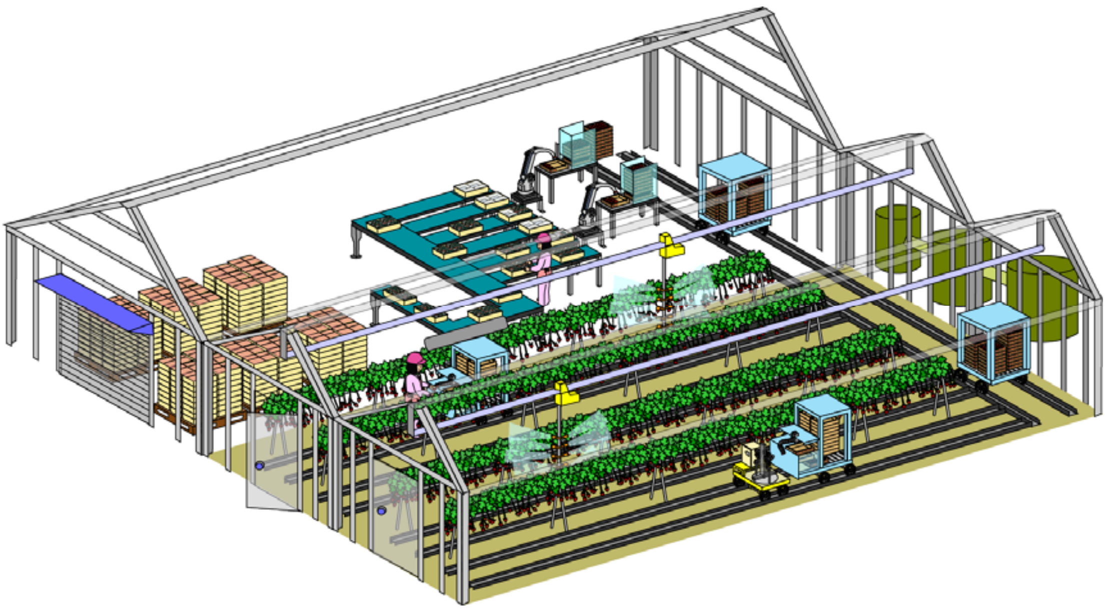
The fruit will then have to be moved back to the tray or box. Will that be done with the picking arm? If so can it be quick enough? Can it be done through a vacuum tube? Without bruising the fruit?

Any harvester will have to be reasonably straight forward to operate and calibrate.

Power options include electrics through a cable, batteries and engines. Traction systems could include rails, wheels or tracks. On a slow machine

working in a confined space an umbilical system on rails may well be the preferred option.
GPS could be used to guide the machine around the orchard but trees interfere with the signal. A portion of the signal bounces back.
In developing a robotic harvester the design parameters are important. What is the specification? What is the tolerance level in terms of bruising?
However technological break throughs could make a huge impact. If someone develops an effective ‘touch sensor’ next week development could be much faster than we might expect.

Strawberry Harvesting – research engineers at BRAIN in Japan have produced two prototype robots that will harvest strawberries. The eventual goal is to develop a complete automated harvesting and packing operation based around strawberries grown on table tops in either greenhouses or poly tunnels.



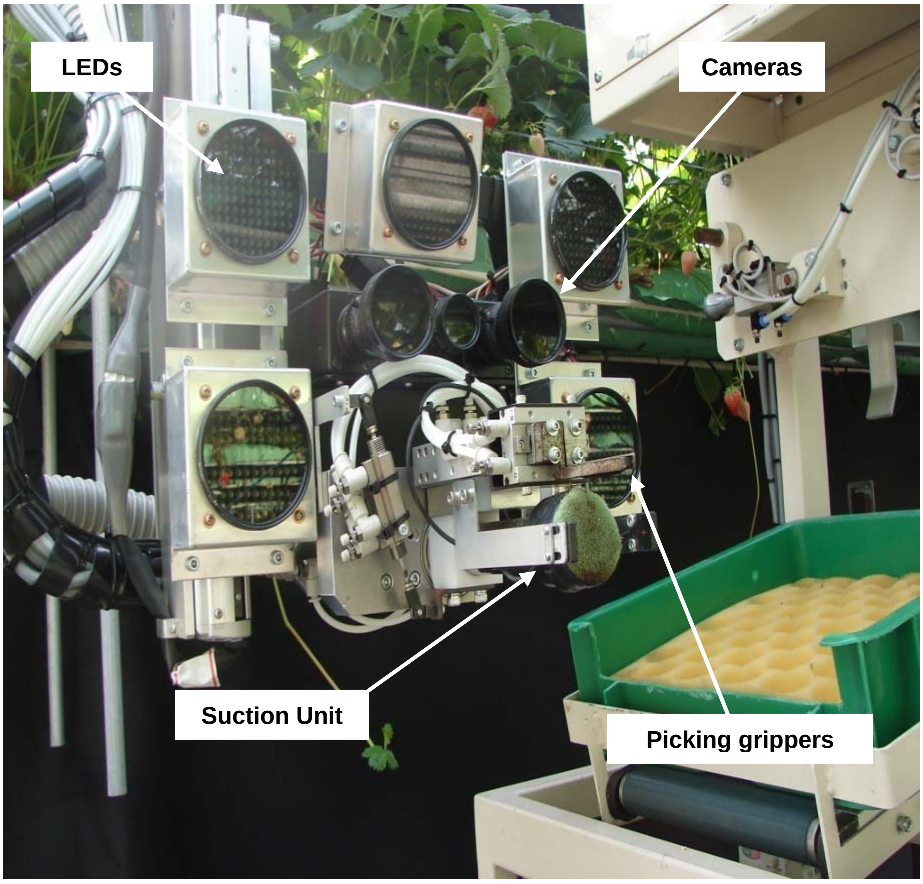
The robots are designed to work at night when shadow doesn’t interfere with the machine vision. The robots travel on rails, are battery powered and work under LED lights. Cameras are used to identify the fruit and an algorithm calculates the proportion of the fruit that is white at the top to determine if the fruit should be picked.

The team have developed two prototypes -

A cylindrical type robot that picks just from the aisle side of the plant

An articulated type robot that picks from both the aisle and the bed side of the plant

The cylindrical machine uses machine vision based around 5 LEDs and three cameras. The centre camera is used to detect the peduncle and the two side cameras are used to create a 3 dimensional image.



The picking arm reaches out and picks the strawberry at the peduncle. The fruit itself isn't actually touched. This has over come the problem of damaging the fruit when it is touched. The machine has been fitted with a small suction system to hold the fruit stable as it is picked and has been tested with and without this in operation.

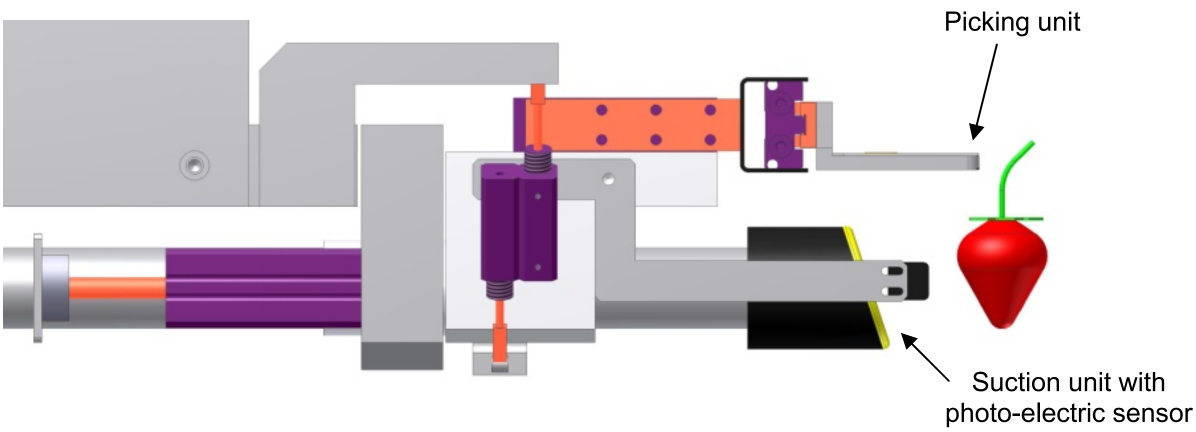


Diagram of the picking arm

The Articulated machine uses machine vision based on two cameras and one LED. It also handles the fruit by the peduncle but can approach the fruit from both the aisle side and the bed side.


Working from the aisle side


Working from the bedside

All Images Courtesy of BRAIN

The machines have been tested. They don't pick all the fruit and do pick some fruit that isn't ripe. Indeed it seems likely that for the foreseeable future a feature on robotic fruit harvesting will be that a manual picking team will have to follow the robots to pick what has been missed. Results have been as follows –

	Success rate(%)	Execution time (s/fruit)	Mature fruit left (fruit/10a)	Immature fruit harvested (fruit/10a)	Damaged (%)	Test length (m)
Target	60 <	< 10 [1)]	< 1440 ~ 2880 [2)]	< 216 ~ 432 [3)]	0	-
Cylindrical (Suction)	41.3 (7.7 ~ 75.8)	11.5	1491	558	0	684
Cylindrical (Non-suction)	34.9 (18.0 ~ 61.5)	11.5	1188	500	0	360
Articulated	49.1	11.6	1836	1443	0	23

1) Theoretical working hours per 10a
10[s]×7200[fruit/10a]×0.6 = 43200[s/10a] =12[h]
10[s]×3600[fruit/10a]×0.6 = 21600[s/10a] = 6[h]
2) Mature fruit: 3600～7200 fruit/10a
3) 10% of harvested fruits

The results show that the robot has created no damage which is a significant improvement on manual picking where figure bruising is a problem. The machines don't quite meet the target execution time and at present pick too much immature fruit. Improvements to either the vision systems or fine tuning the algorithms will be required to solve the latter problem. The team also haven't yet solved the problem of automatically moving the machine around the greenhouse from the rails in one row to the rails in the next row. They are going on to produce a third prototype and believe that a commercial strawberry harvesting robot is still about 5 years away from the market.

Conclusion - developments in engineering and computer based technologies are set to make a huge impact on agriculture. A number of complex robots are already on the market and more are set to follow. Driverless machines fitted with GPS and machine vision are a technical reality and legal issues appear to be the greatest obstacle to their commercialisation. Harvesting fruit is a particular challenge to the robotic engineer. Locating it and handling it without bruising is difficult but a research team in Japan have created a prototype strawberry harvester and teams elsewhere are working on apple and cherry harvesters. An important feature of robotic development is to rethink the problem to make the task easier for the robot. In this respect plant breeders and geneticists have a role to play in changing the structure of the crop to improve the presentation of the fruit.

Sensing and communication technologies are creating a revolution in the information that is being made available to farmers to improve their decision making processes. Information that was historically difficult to collect can be created automatically and analysed to help fine tune management and spread best practice.

The requirement for further research – the technologies that have been reported on in this study are set to remain 'frontier' technologies for many years to come.

Genetics is a technology that has not delivered what was expected twenty years ago. Genes and how they are regulated has proven to be far more complex than was anticipated by the early pioneers. Indeed an appreciation of what we don't know seems to grow faster than what we do know. The depth of knowledge has grown to a point where there is good reason to be excited about what the technology will deliver in the near future and the new opportunities that are available to the farmer will need revisiting on a regular basis.

Functional Foods is another area that is clearly very complex. Exactly how foods interact with all the biological processes in the human body is an area where there is so much still to learn. As that knowledge develops it will inevitably create new niche markets that offer opportunity. The entrepreneurial farmer will be keeping a watching brief on this area of scientific research.

The non-food uses of agricultural produce will continue to develop. The wide variety of fibres, oils, carbohydrates and other specialist chemicals that the farming industry produces ensures that novel uses will continue to emerge. The development of platform chemicals will offer an expanding market for farm products but there will also be scientific effort put into developing uses for agricultural produce that involves as little processing as possible to reduce cost. Many of the developments in this area will not be applicable to the individual farmer but occasionally new technology will emerge that does offer opportunity on the farm.

Robotics and smart engineering is perhaps the area that farmers relate to most readily. There is every reason to believe that new machines and gadgets will continue to appear in the market place. Some will be applicable across wide parts of the industry whilst others will be very sector specific. Selective fruit and vegetable harvesting remains a major challenge for the robotics engineer but early adopters will be constantly researching the engineering industry to identify new prototype harvesters that are about to hit the market place.

But what other 'frontier technologies' are there that warrant further research.

Soils are an area in which there is renewed scientific interest. The biological processes that take place in the soil are not well understood. Exactly how the plethora of microbes in the soil interact with each other and the plant is an area where new research is emerging. Some of this research is being driven by environmental concerns but it will create opportunity for farmers. For example there is interest in developing our understanding of how plants can access the minerals in our soils.

The biological processes in the Rumen are also and area that is attracting scientific attention. Again much of this interest is being driven by environmental concerns. Genetic profiling of the rumen microbes will develop a deeper understanding of how the rumen works and how its performance can be improved.

Scientists are also seeking to develop an understanding of how different chemicals integrate. Are there marriage values associated with using two chemicals together?

These are all areas that will require further research to bring new innovations to the attention of the farming community and without doubt there are and will be others. On going research into ‘frontier technologies’ is clearly required!

Conclusion – new technologies being developed around the world have the potential transform UK agriculture. However only some of these technologies will have an impact across the industry. Clearly advances in plant and animal breeding that improve performance will be widely applied as will some new engineering technology but many of the applications associated with the technologies outlined in this report will only be adopted by entrepreneurial businesses. Some specific attributes that the plant breeders will develop in their crops will relate to niche markets and the functional food market is one that will create a segmented market that will appeal to the entrepreneurial spirit. This is a significant departure from the science that was developed in the post war period when new research on conventional husbandry techniques was driving the performance of the industry forward in leaps and bounds. The new research in conventional husbandry is incremental in its nature rather than transformational. New markets will emerge as a result of some of these technologies and some farmers will capture these markets at the right time and develop big businesses as the market grows. The opportunities for the entrepreneurs in the industry are fantastic.

The connection between scientists and farmers remains a problem. Over the last 25 years the Government funded extension service in the UK has been eroded and the loss of Government funded extension is a compliant amongst scientists across the Globe. There are some scientists in the UK who believe that we have lost the basic skills that interpret science on behalf of farmers. The interpretation of science has become more difficult as science has become more complex. Food and agricultural science has moved way beyond the dose response trials and feed intake trials that so successfully transformed agriculture during the post war 'Green Revolution'. Today's science is concerned with the very complex nature of the detail associated with how living things work. The research effort also appears to be very fragmented with bits being done in various places as scientists pursue funding opportunities that fit their skills. All too often research is not organised into groups of related projects that are presented under a theme. A key feature of some very impressive projects elsewhere in the World is that they are organised into themes. The best example of this is probably the Future Grains project at CSIRO. A number of projects are being conducted around a common theme. The team have delivered projects into the market place and clearly have others in the pipeline that are going to deliver. Making a connection between the research team and farmers must be much easier when related projects are brought together in this manner.

Most scientists are judged on the number of peer reviewed papers they get published in academic journals. These papers are very technical in their nature and difficult for the farmer to interpret. They are probably also difficult for scientists from unrelated disciplines to interpret! However they are important. They safeguard the quality of the science and ensure that experimental design is robust. Abandoning the scientists focus on published papers may appear attractive to those outside the scientific community but it has a serious downside.

A number of initiatives to improve the links between scientists and farmers are being tried around the World.

Some scientists are required to spend a certain percentage of their time on extension activities. Whilst this has its attractions there are some excellent scientists who just don't have great presentational skills. Pushing these individuals out in front of a farming audience may well do more harm than good. A possible solution is that each institution has to spend a proportion of its time on extension activities and it can then allocate its best communicators to liaise with local farmers.

Some scientists are now being judged on impact. They are required to demonstrate that their research has made an economic impact in the industry. Whilst the calculations associated with demonstrating an impact might be contentious this approach does have some significant merits. It focuses attention on activities that are relevant to the industry, that have the most potential to make an impact and then drives the roll out into the farming community.

Many farmers are involved with local industry groups. This serves two purposes. It enables the scientist to communicate what he has done but also allows him to assess research needs.

Some scientists work exceptionally well with industry bodies. This works particularly well where very strong industry bodies exist. Zespri in New Zealand is a good example of an industry body that connects very well with the scientific community.

In Canada awards exist for extension activities. The public recognition of excellence can only help to promote the importance of communicating well with farmers and raise the status of extension in the scientific community.

Improving the connection between scientists and farmers in the UK may help roll UK research out into the farming community but it won't help UK farmers connect with research that is taking place around the world. At present there is very limited resource to facilitate this process. Organisations such as TAG and Kingshay can play a roll as indeed can Nuffield. The Agricultural and Horticultural Development Board could also take a lead here. They do have a significant resource at their disposal and contacts throughout the agricultural community.

Farmers also have to take some responsibility for seeking out new technology and applying it on their farms. The time that farmers have available to them has been eroded by a wide variety of issues including an ever growing burden of regulation but the individual farmer has a responsibility to keep his business up to date. The web has opened up new avenues for farmers to delve into what is going on else where in the world. The author found the following websites to be particularly informative and inspirational –

AgReseach in New Zealand - www.agresearch.co.nz

Agricultural Research Service in the USA - www.ars.usda.gov
CSIRO in Australia - http://www.csiro.au
National Agricultural Research Organisation in Japan - http://www.naro.affrc.go.jp
Plant and Food Research in New Zealand - www.crop.cri.nz

There are many other fascinating websites that can bring new ideas straight into the farm office including those that carry the Scientific Journals. Perhaps this study will inspire UK farmers to browse the web occasionally on a wet afternoon or a winter evening in search of the technological breakthrough that will transform their business.

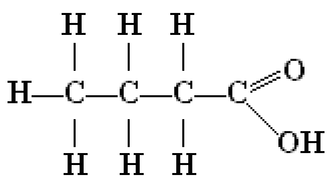
Appendix 1

Fatty Acids

Fatty acids consist of carbon (C), hydrogen (H) and Oxygen (O) and come in a number of different forms. Some forms have a negative impact on human heath whereas others are beneficial. They are structural components of the brain and cell membranes.

Fatty acids consist of carbon chains with a carboxyl group (-COOH) at one end.

Saturated fatty acids have no double bonds between the carbon atoms and carry all the hydrogen atoms that the carbon can hold.



Butyric Acid

Monounsaturated fatty acids have a single double bond between one pair of carbon atoms.

Polyunsaturated fatty acids have more than one double bond along the chain of carbon atoms.

Common fats include –

Name	Carbon Atoms	Double Bonds	Sources
Butyric acid	4	0	butterfat
Caproic Acid	6	0	butterfat
Caprylic Acid	8	0	coconut oil
Capric Acid	10	0	coconut oil
Lauric Acid	12	0	coconut oil
Myristic Acid	14	0	palm kernel oil
Palmitic Acid	16	0	palm oil
Palmitoleic Acid	16	1	animal fats
Stearic Acid	18	0	animal fats
Oleic Acid	18	1	olive oil
Ricinoleic acid	18	1	castor oil
Vaccenic Acid	18	1	butterfat
Linoleic Acid	18	2	grape seed oil
Alpha-Linolenic Acid (ALA)	18	3	flaxseed (linseed) oil
Gamma-Linolenic Acid (GLA)	18	3	borage oil
Arachidic Acid	20	0	peanut oil, fish oil
Gadoleic Acid	20	1	fish oil

Arachidonic Acid (AA)	20	4	liver fats
EPA	20	5	fish oil
Behenic acid	22	0	rapeseed oil
Erucic acid	22	1	rapeseed oil
DHA	22	6	fish oil
Lignoceric acid	24	0	small amounts in most fats

(Scientific Phychic: 2010)

Fatty acids are often referred to by the notation such as C18:2 which indicates that the fatty acid consists of an 18-carbon chain with 2 double bonds.

***Cis* and *Trans* Fatty Acids** - describe the configuration of the hydrogen atoms with respect to the double bond. A *Cis* configuration means that adjacent hydrogen atoms are on the same side of the double bond and this results in the chain being bent at each double bond. A *trans* configuration means that the next two hydrogen atoms are bound to opposite sides of the double bond and this results in a straight shape that is similar to a saturated fatty acid. Most naturally occurring fatty acids are of the *cis* configuration although ruminant fats including milk are about 4% *trans* fatty acids. Most *trans* fatty acids are created as a result of processing.

Trans fatty acids always have a detrimental effect on human health. They create denser cell membranes that alter the normal functions of a cell. They are associated with increased risk of heart disease, diabetes and hypertension. They also have a detrimental effect on the brain and nervous system. (Scientific Phychic: 2010)

Some typical fat contents are shown below –

	Saturated	Monounsaturated	Polyunsaturated	Cholesterol
	g/100gm	g/100gm	g/100gm	mg/100gm
Butter	54.0	19.8	2.6	230
Sunflower Oil	11.9	20.2	63.0	0
Rapeseed Oil	5.3	64.3	24.8	0

Essential fatty acids – are linoleic and alpha-linolenic acid (ALA). They are polyunsaturated fatty acids and are the parent compounds of the omega-6 and omega-3 fatty acid series. They are essential in the human diet because the body is unable to synthesize them. Essential fatty acids are used to produce hormone-like substances that regulate a wide range of functions, including blood pressure, blood clotting, blood lipid levels, the immune response, and the inflammation response to injury infection.

Omega-3 fatty acids - have their first double bond on the third carbon-carbon bond from the terminal (or Omega) end. Omega-6 fatty acids have their first double bond on the sixth carbon-carbon bond from the terminal (or Omega) end.

The Omega-3 group of fatty acids includes the following –

α-Linolenic acid	ALA	18:3 (n-3)
Stearidonic acid	SDA	18:4 (n-3)
Eicosatrienoic acid	ETE	20:3 (n-3)
Eicosatetraenoic acid	ETA	20:4 (n-3)
Eicosapentaenoic acid	EPA	20:5 (n-3)
Docosapentaenoic acid	DPA	22:5 (n-3)
Docosahexaenoic acid	DHA	22:6 (n-3)
Tetracosapentaenoic acid		24:5 (n-3)
Tetracosahexaenoic acid (Nisinic acid)		24:6 (n-3)

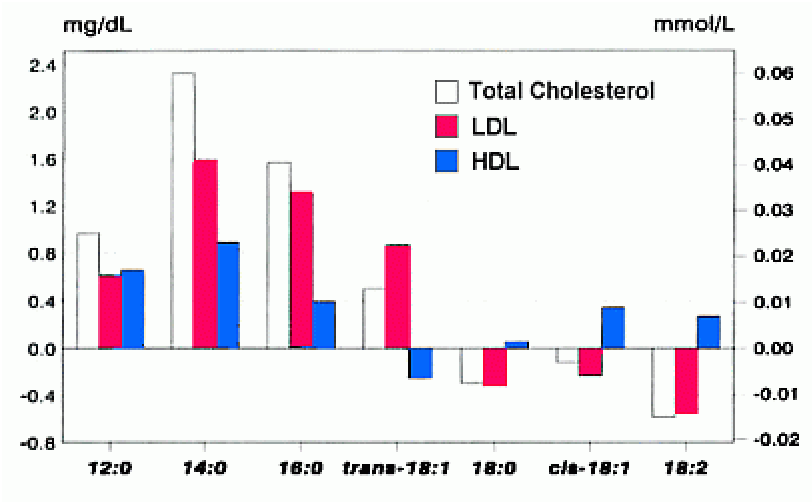
DHA has 22 carbon atoms with 6 double bonds. The n-3 refers to the double bond on the third carbon-carbon bond from the end. Omega-6 fatty acids are suffixed n-6.

DHA and EPA are the long chain Omega-3s associated with fish oil and significant health benefits. The consumption of fish oil is recommended because the body only converts ALA to these longer chain fatty acids to a limited extent.

Both Omega-6 and Omega-3 fatty acids are essential for good health but it is believed that current Western diets provide ratios of between 10:1 and 30:1 – heavily in favour of Omega-6. Healthy ratios are thought to be between 4:1 and 1:1.(Wikipedia: 2010)

The consumption of polyunsaturates should be 3 times that of monosaturates and trans fats should be avoided.

Effect of fats on blood cholesterol levels – saturated fats and trans fats raise blood levels of low-density lipoprotiens (LDL or 'bad' cholesterol) increasing the risk of coronary heart disease. Trans fats also reduce the level of high-density lipoproteins (HDL or "good cholesterol"). Blood cholesterol levels can be lowered by reducing the sources of dietary cholesterol, increasing the amount of fiber in the diet, and by consuming oils high in polyunsaturated fatty acids while reducing the intake of saturated fats.



The chart above shows the effects of individual dietary fatty acids on Total Serum Cholesterol, LDL cholesterol, and HDL cholesterol when l% of the energy from carbohydrates in the diet is replaced by 1% of energy of the specific fatty acids. (Katan et al: 1994)

Appendix 2

Free radicals, Reactive Oxygen Species and Antioxidants

During respiration sugars are oxidised with oxygen from the blood producing energy, carbon dioxide and water. This process of oxidation is constantly going on inside the living cells of our bodies. It is essential to life as molecules are built up and broken down in our cells and during this process some highly reactive particles are produced that attack parts of living cells including lipid membranes, proteins and DNA. They harm the circulatory system leading to heart attacks and strokes. They generally hasten the aging process and have been linked to more than 100 diseases ranging from cancer to Parkinson's disease. These particles are called free radicals, reactive oxygen species, reactive nitrogen species and reactive chlorine species.

Free radicals are molecules with one or more unpaired (and therefore reactive) electrons. They seek out extra electrons and will take them from fats and proteins which become damaged as a result. Free radicals include –

Reactive Oxygen species including -

> Superoxide anion ($O_2^{\cdot -}$) – a by-product of respiration leaking from mitochondria. They are also associated with ionizing radiation and pollutants. Causes intracellular damage
>
> Hydroxyl radical ($HO^{\cdot}$) – the result of the breakdown of hydrogen peroxide. Causes intracellular damage of many kinds. The most reactive of all the free radicals
>
> Lipid alkoxy radical/Lipid peroxyl radical/ Lipid carbon-centred radical ($LO^{\cdot}$, $LO_2^{\cdot}$) – caused by a chain reaction when fats are attacked by other oxidants

Reactive Nitrogen species including -

> Nitric oxide ($^{\cdot}NO$) – comes from phagocytes, nerve tissue, cells lining the arteries, ionizing radiation, some pollutants and cigarette smoke. It controls blood pressure by relaxation of blood vessels but excess behaves like an oxidant – it reacts with superoxide to produce a more highly reactive form.
>
> Nitrogen dioxide ($NO_2^{\cdot}$) – the result of an unwanted reaction of nitric oxide with oxygen. Also comes from air pollution. It initiates the peroxidation of lipids, causing damage to membranes.

Non-radical oxidants don't have unpaired electrons but still seek out extra electrons. They work in the same way as free radicals and cause damage to other molecules. Non-radicals include –

Reactive Oxygen species including -

Hydrogen peroxide – which is a result on respiration and a product of phagocyte activity. It easily crosses cell membranes and reacts directly as an oxidising agent. Also causes production of hydroxyl free radicals. May initiate activity of virus genes.

Singlet oxygen – caused by the absorption of energy from, for example, UV. Results in cholesterol oxidation and lipid peroxidation if decomposed by metal ions.

Reactive Chlorine species -

Hypochlorous acid – comes from the oxidation of chloride by neutrophilis. It destroys bacteria and damages cells.

There are also a number of environmental factors that initiate free radical reactions including –

Sunlight – which generates highly reactive OH initiating free radical reactions and damages DNA

Quinones, polycyclic aromatic hydrocarbons – which come from food, some drugs and environmental contaminants. They generate oxidants.

Transition metal ions (Iron and copper) – that come from various sources including the diet. They promote free radicals from hydrogen peroxide

Ionizing radiation – from X-rays. It initiates free radical reactions including lipid peroxidation and DNA damage

Ozone – comes from photochemical reactions, oxygen and petrol vapours

Antioxidants are substances which deactivate free radicals and oxidants rendering them harmless. They are in effect antidotes to some of the bodies own poisons. By counteracting these poisons they make for better health and slow down the degeneration associated with aging. Some prevent the formation of new reactive oxygen species and others work by combining with reactive oxygen species before they have time to attack a cell. This process is called scavenging. Because we now live longer the results of damage to body tissues become more apparent and many people eat a diet that provides inadequate dietary antioxidants.

There are a number of naturally occurring antioxidants and antioxidant mechanisms in the body. These include –

Preventative antioxidants – that prevent the formation of new reactive oxygen species. These include albumin, ferritin and transferrin that are found in the blood plasma. They bind to metal ions that would otherwise promote oxidant and free radical production

Repair enzymes – that repair or remove damaged molecules. They can restore the integrity of damaged DNA

Scavenging antioxidants including –

> Enzymes – Glutathione (GSHpx), superoxide dismutase (SOD) are synthesised in cells. They remove hydrogen peroxide and require micronutrients as co-factors
>
> Small molecules – in plasma, fats and water throughout the body: carotanoids, vitamin E, vitamin Q10 (ubiquinione), lipoic acid (fat-soluble); flavoniods, vitamin C, uric acid (water soluble) come from our food but some are manufactured in the body. Antioxidants in our diet are covered in more detail in the main body of the report on page 51.

(Lister:2003)

Glossary

Accelerometer - a device that measures magnitude and direction of the acceleration

Algorithm – a method of solving a problem using a finite sequence of instructions. Used for calculation, data processing, and many other fields

Alzheimer's disease - a progressive degenerative disease that alters the brain, causing impaired memory, thinking and behaviour

Amino acid - An organic compound containing an amino group (NH_2), a carboxylic acid group (COOH), and any of various side groups, especially any of the 20 compounds that have the basic formula $NH_2CHRCOOH$, and that link together by peptide bonds to form proteins or that function as chemical messengers and as intermediates in metabolism

Assay – an analysis or examination

Arthrogryposis multiplex - congenital disorder that is characterized by multiple joint contractures and can include muscle weakness and fibrosis

BLAD - Bovine Leukocyte Adhesion Deficiency. A genetic disorder that affects the immune system

Cellulose-based ion-exchange – used for isolating chemicals in a production process. For example used for isolating proteins from liquors and waste streams

Chromosome - an organized structure of DNA and protein that is found in cells. It is a single piece of coiled DNA containing many genes, regulatory elements and other nucleotide sequences

Cisgenic – genetic modification that involves moving a whole gene from the same species – including the promoter and stop switch

Coeliac disease - a lifelong condition of the small intestine where gluten causes the immune system to produce antibodies that attack the delicate lining of the bowel

Cold plasma - plasma is a gas in which a certain portion of the particles are ionized. The presence of a non-negligible number of charge carriers makes the plasma electrically conductive so that it responds strongly to electromagnetic fields. Plasma therefore has properties quite unlike those of solids, liquids, or gases and is considered to be a distinct state of matter. Plasma is referred to as being cold if only a small fraction (for example 1%) of the gas molecules are ionized

Colostrum - is thick, yellowish milk with a high concentration of antibodies that is secreted by a mammal in the first several days after delivery

DNA - deoxyribonucleic acid. Stores genetic material and is like an instruction manual. It contains the information that plants and animals need to grow and function

Geotextiles - are permeable fabrics which, when used in association with soil, have the ability to separate, filter, reinforce, protect, or drain

Glycaemic index - a measure of the effects of carbohydrates on blood sugar levels

Gyroscope - a device for measuring or maintaining orientation

Hydrocarbon solvent extraction – method of extracting essential oils using solvents such as petroleum ether, methanol, ethanol or hexane

Infra-red - is electromagnetic radiation with a wavelength between 0.7 and 300 micrometres

Intragenic - genetic modification that involves moving part of a gene from same species

In-vitro - the manipulation of organs, tissues, cells, and biomolecules in a controlled, artificial environment, for example in the laboratory

In-vivo - characterization and analysis of biomolecules and biological systems in the context of intact organisms, for example in the human body.

Lasers - Light amplification by stimulated emission of radiation (LASER) is a mechanism for emitting electromagnetic radiation, typically light or visible light, via the process of stimulated emission

Mannosidosis - neurological disease characterised by tremors of the head, ataxia, and aggression

Microphthalmia - Congenital defect resulting in an abnormally small eye or eyes

mRNA – messenger ribonucleic acid. A molecule of ribonucleic acid encoding a chemical "blueprint" for a protein. Derived from DNA it is part of the transcription process that creates protein

Mutation - damage or a change to DNA in a gene in such a way as to alter the genetic message carried by that gene

Neuropathic hydrocephalus - a lethal genetic condition that results in dead calves with an extremely large cranium with little or no brain material or spinal cord

Parkinson's disease - a degenerative disorder of the central nervous system that often impairs the sufferer's motor skills, speech, and other functions

Phenotype - an observable characteristic or trait of an organism including its morphology, development, biochemistry or physiological properties, or behaviour. Phenotypes result from the expression of an organisms genes as well as the influence of environmental factors and possible interactions between the two

Pre-biotic - non-digestible food ingredients that stimulate the growth or modify the activity of bacteria that are already present in the gut

Pro-biotic - microbial food ingredients

Radar - an object detection system that uses electromagnetic waves to identify the range, altitude, direction, or speed of both moving and fixed objects

Steam distillation - used in the manufacture and extraction of essential oils, the botanical material is placed in a still and steam is forced over the material

Supercritical extraction techniques - process of separating one component (the extractant) from another (the matrix) using supercritical fluids as the extracting solvent. Carbon dioxide (CO_2) is the most used supercritical fluid, sometimes modified by co-solvents such as ethanol or methanol

Transgenic – genetic modification that involves moving a gene or part of a gene from a different species

Ultra sound - cyclic sound pressure with a frequency greater than the upper limit of human hearing. Used to penetrate a medium and measure the reflection signature. The reflection signature can reveal details about the inner structure of the medium

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