A Nuffield Farming Scholarships Trust

Arden Report

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How farming can learn from science to optimise the nutritional value of food produced

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Contents

Disclaimer

Foreword

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My brief was to produce a report that would excite UK farmers about what science is developing with regard to improving the nutritional value of food. The timescale is over the next 5 -10 years, reviewing the benefits through the entire supply chain.

I have focused on plant-based improvements in nutritional value as my career to date has revolved around the fresh produce industry.

I have always been interested in plant breeding and genetics and this study has given me the opportunity to meet a far broader group of people around the world and highlighted how quickly the science of plant breeding, genetics, and genomics is developing into new areas of science like metabolomics.

I would like to thank The Frank Arden Memorial Trust, Mike Vacher and the Nuffield selection board for giving me the opportunity to participate in this study. In addition I would like to thank Caroline Drummond MBE, who has been on a similar journey of discovery as myself and with whom I have been honoured to share this award.

I have met many scientists around the world and I thank you all for your encouragement. I would also like to make note of new technology. I haven't been able to visit all the scientists mentioned in this report, but with Skype and social media I have been able to make contact with more people than I had thought possible.

Finally I must thank my wife Kelly and son Oliver for being so understanding during this last 13 months. There have been many occasions when I have been away from home, or alternatively have needed to lock myself away in a room to work on this study. Thank you for your patience and understand during this time.

1. Executive Summary

Introduction

Throughout my career I have been involved in working with and for farmers and food retailers, selecting new varieties for improved grower and consumer benefits. This has focused on improving taste, shelf life, appearance, yield and disease resistance. The next logical step would be to improve the nutritional value of the food we provide for consumers. With increasing instances of obesity, diabetes and heart related diseases as a consequence of a "Western style diet" we all need to act in synergy in developing more nutritious food for this and subsequent generations. It will be down to the food retailer to clearly market these messages to consumers and it will enable the progressive growers to differentiate their offer and improve their returns. My study has focused research on horticultural and arable crops, but these nutritional improvements and the knowledge gained should have wider applicability across the agricultural sector.

Aims

My key aim was to understand what the major plant breeders and food producers were researching with regard to optimising the nutritional value of the food that we produce and consume.

I wanted to understand where there are joined up approaches between scientists, farmers and retailers to ensure that benefits are for the entire supply chain.

I wanted to understand how the bioactives in food can benefit humans and further explore their importance in diet.

I wanted to explore the concept of personalised diets and the importance of internet food retailing for the future.

My study explored ideas and concepts that should make the reader think more laterally about sustainable food production and consider how important it is that we never lose sight of the consumer and what appeals to them.

Recommendations

To Scientists :

- **The age of plant breeding for the standard traits of yield and disease resistance is over. The next generation of varieties will include the traditional traits, but must also be better for us. This is demonstrated by examples like vital**vegetables® products from Plant & Food Research (PFR), Beneforte Broccoli by Seminis and new coloured potatoes from HZPC.

- Functional food development as shown by PFR provides a benchmark for improving the nutritional value of food.

- If scientists can establish that food produced from shorter supply chains is nutritionally better for us this will further strengthen the case for British farmers supplying the UK consumer.

- New science like metabolomics and hyperspectral imaging need to be applicable to as many areas of farming as possible to optimise the nutritional value of our food.

To Farmers :

- Never lose sight of the one thing that consumers are not willing to compromise on – **TASTE.**
- Genetic improvement is proven to be the most important element in improving the nutritional value of food within the farmer's control. Farmers must work closely with plant breeders to ensure that they have access to the best genetics.
- Improved agronomic techniques are becoming available to farmers. Be sure you are connected to the best agronomists and scientists throughout the world so you can be an early adopter.
- Farmers have a contract with society in producing their food. You need to produce higher quality more nutrient dense food as we are still not achieving "5 a day" in the population.

To Retailers :

- Delivery of improved nutritional value food requires a joined up approach through the entire food supply chain. The retailer must take responsibility for driving these improvements.
- As a food retailer we focus on "Normal but better" in product development. Historically this has been specifically around traits like taste, shelf life and appearance. The next trait will be improving the nutritional value. Initially these products will be niche lines, but before long they will become the new benchmark and hence help deliver the "Health by Stealth" strategy.
- When Henry Ford asked farmers what they wanted they said that they wanted a faster horse. So he created the car. Consumers are quite similar; they don't know what they want in future foods. It is up to the food retailers to educate and inform consumers about the exciting new products and provide the marketing support. Internet retailing provides even more touch points to reach consumers.
- The '5 a day' campaign still has a long way to go with UK consumers. Currently 64% of adults in the UK are overweight or obese and the overall health problems associated with being overweight or obese cost the NHS £5 billion per year. Food retailers have a collective responsibility to support and drive this government backed campaign through to consumers.
- Future product development should adopt a more scientific basis to maximise the opportunities to improve the nutritional value of food by all means possible.
- Nutrient density considers key nutrients as functions of the energy value of food (nutrients per calories). Food has become more energy dense and nutrient poor. Collectively we must all pull together to re-address this balance and focus on improving the quality of food by increasing its nutrient density.

2. Introduction

The Nuffield Farming Scholarships Trust

The Nuffield Farming Scholarships Trust invites enthusiastic individuals to explore topics of their own choice in agriculture, land management, horticulture or the food chain. It is dedicated to developing leadership in farming and the rural industries, and is recognised for the opportunities it provides to identity new knowledge and to apply it to practical and profitable industry outputs.

Funded by the agriculture and food industry, charities and trusts with agricultural objectives, and by past Scholars themselves, the Trust makes around 20 awards each year.

Frank Arden Memorial Award

This special Award is generously sponsored by the family of the late Frank Arden who established a fund for the study of key issues influencing the success of British farming.

The Award, administered under the auspices of the Nuffield Farming Scholarships Trust, is open to UK residents working in the fields of food, farming, forestry or other allied rural industries. There is no age limit. The bursary provided allows for reasonable research and travel expenses, both in the UK and abroad. The Nuffield Farming Scholarships Trust is indebted to the Crown Estate and Frank Parkinson Agricultural Trust for their generous support for this project.

Frank Arden CBE (1915-1979) was a legend in his own life time. He established a farming business in North Lincolnshire regarded as a showpiece for progress in agriculture. Throughout his career he continually sought new challenges and was always adaptable in his approach to meet market demands.

His vision and enterprise were rooted in extensive travel and the ability to embrace new technology. The Frank Arden Memorial Award was instigated by his family to continue to share his principles and passion for agriculture with others in the industry by funding key studies that address topics of importance to the UK agricultural industry.

3. Methodology

Throughout my career I have been involved in working both with and for farmers and food retailers, selecting new varieties for improved grower and consumer benefits. This has included improving taste, shelf life, appearance, yield and disease resistance. The next logical step is to improve the nutritional value of the food we provide for consumers.

My study was conducted over a 13 month period from February 2013 to February 2014. Due to the extensive nature of this topic it took a period of time and discussion to establish my key priorities. My background has been in the fresh produce industry and as a result my study is focused on plants rather than animals.

In March 2013 I attended the Contemporary Scholars Conference which was a combination of two days of visits in London and meeting the 2013 UK Nuffield Scholars, followed by a nine-day programme in Canada, split between Guelph and Niagara Falls. This provided me with the opportunity to meet all 67 Nuffield Farming Scholars from around the globe along with new associates that Nuffield is working with from Brazil and the Eisenhower Scholars from USA.

It also meant that Caroline Drummond MBE and I were able to spend some time together to discuss this Frank Arden Memorial Scholarship and to start discussing where we would be prioritising our efforts. Due to my role as Fresh Produce Development Manager at Waitrose I was keen to ensure that the study focused on consumer needs as well as the farmer needs. In doing so I was keen to look at what science is bringing to the consumer.

Over the past 13 months my study has become part of my day-to-day working at Waitrose and in all my interactions with external companies. My study has focused on regular visits to scientists, researchers, plant breeders and food businesses. I undertook detailed discussions about their particular research interest and subsequently reviewed recent publications, presentations and reports provided. I visited many institutions throughout the UK and across the whole supply chain. Within Europe I visited Holland, Belgium, Spain, Germany and Sicily. Outside of Europe I made a two week trip to New Zealand across both islands and I went to California for a week where I visited a number of businesses across the state.

I attended a number of conferences including one at Campden BRI on the future of GM foods. At Fruit Logistica 2013 and 2014 in Germany I met up with many global seedhouses and plant breeders. It was pleasing to see how much more research was being carried out on the nutritional value of fruit and vegetables between the 2013 conference and the one held in 2014. I used Skype and conference calls to connect with additional people whom I was unable to meet in person. Throughout my study I wanted to look for future opportunities that could be available to the entire food supply chain over the next 5 -10 years.

4. A short history of food

What are the biggest risks from food today?

- Pesticides or pollutant residues?
- Food-borne illness?
- Allergens?
- Additives such as artificial colours or flavours?

These are among the worries that are typically cited in opinion polls. One approximate way of comparing risks is to count the number of food-related deaths attributed to different causes. This is a little oversimplified but it does give an indication of relative risks. In the UK about 500 deaths per year are caused by food-borne illness and around 10 from food allergy. There are no deaths attributed to pesticide poisoning, GM food or additives. The biggest risk associated with our food is the contribution that our diet can make in influencing the development of major chronic diseases that between them will kill more of us than anything else: cancer, cardiovascular disease and stroke. The dietary contribution to death from these causes may be equivalent to in the region of 100,000 deaths per year *(Krebs, 2013)*.

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An early 16th century Swiss physician known as Paracelsus is generally recognised as the father of the science of toxicology. His key contribution was summarised in a sentence: "All things are poison, and nothing is without poison; only the dose permits something not to be poisonous." To illustrate this point, oranges are sometimes treated with a post-harvest chemical called imazalil, to prevent mould forming on the peel. Imazalil could in theory be a carcinogen. Based on experiments on rats, a potentially dangerous dose for humans would require eating over 12,000 oranges including the peel. But oranges also contain about 70mg of vitamin C per fruit, close to the recommended daily intake of this essential micronutrient. But as with imazalil, too much vitamin C is harmful. Extrapolating from rats, the number of oranges that could deliver a fatal dose of vitamin C is about 8,000. In short, vitamin C poses a bigger risk than imazalil (*Krebs, 2013*).

By 1941, thirteen vitamins essential for human health had been discovered. They play a range of vital roles. Vitamin A is required in the eyes, because the chemical compounds in the retina that turn photons of light into electrical signals to the brain are derived from vitamin A. Most vitamins help to power biochemical reactions in the cells of the body. For instance B1 and B2 are involved in the chemical pathways that generate energy, and vitamin C is important in the manufacture of collagen, the most abundant protein in the body. It also acts as an "antioxidant", meaning that it has the potential to protect cells against damage to their DNA. The human body cannot manufacture twelve of the thirteen vitamins, so they have to be consumed in food. The exception is vitamin D. The body can manufacture it as a result of exposure to sunlight; however, many people get their vitamin D from food.

In addition to twelve vitamins, there are about seventeen minerals, ten amino acids, the building blocks of proteins, and two fatty acids that we have to consume in our food because we cannot manufacture them ourselves. Serious deficiencies of essential nutrients are relatively uncommon in the developed world today, although there are some exceptions, as we will explore later in the report.

More recently, the search for specific plant components that convey health benefits has widened to encompass the vast range of compounds present in plant foods, and their potential to improve health. Evidence is growing that such plant constituents, belonging to the group termed **"Bioactive compounds"**, may help to promote optimal health and to reduce the risk of chronic diseases such as cancer, coronary heart disease, stroke and perhaps Alzheimer's disease.

The food supplements industry makes a lot of money from selling supplements that contain trace nutrients or other substances that have supposed health benefits. In 2010 the global market for fish oil supplements was worth about $2 billion. Cod liver oil, along with oily fish such as mackerel, sardines, salmon and fresh tuna, are good sources of the long chain polyunsaturated fatty acids (PUFAs) that are important components of the human body, especially the nervous system, including the brain. Unsaturated fats such as olive oil are liquid at room temperature and some of them are linked to a reduction in the risk of heart disease. The two unsaturated fatty acids that the human body cannot manufacture, both 18 carbon atoms long, are called α-linolenic acid (an omega-3 fatty acid) and linoleic acid (an omega-6 fatty acid).

It is not only an individual's diet that influences the risk of succumbing to the chronic diseases of developed nations. The mother's nutrition also has a significant effect. Professor David Barker, building on earlier work, discovered that the lower a baby's birth weight, the higher the risk of heart disease, stroke, and hypertension later in life. It is now widely accepted that if the mother suffers poor nutrition during pregnancy, this influences her ability to transfer nutrients to the foetus, which in turn affects the offspring's long-term health prospects *(Krebs, 2013).* Barker also found that if underweight babies rapidly gain weight after the age of two, their risk of later heart disease is increased.

During the late 20th and early 21st centuries a new global trend has emerged; people are getting fatter. The increase in the prevalence of obesity started in the rich countries, but has spread to middle and low income countries. Generally, in rich countries obesity is more prevalent among poorer people, while the reverse is true in low-income countries. The World Health Organization estimated in 2011 that about 1.5 billion, or 30%, of adults aged twenty or over in the world were overweight or obese, and of these 0.5 billion, or one in ten adults, were obese. The latest report in February 2014 by Public Health England highlights that 64% of adults in the UK are overweight or obese and that overall health problems associated with being overweight or obese costs the NHS £5 billion per year.

There is significant variation between countries in the prevalence of obesity. At the top of the league, (excluding some very small countries) is the USA, with around a third of adults classed as obese and over one third of children obese or overweight. In many rich countries, including Canada, Australia and New Zealand, a quarter to a third of adults are obese. In these same countries the equivalent level of children are obese or overweight.

What is the definition of obese and overweight? The internationally agreed measure is body mass index (BMI):

$$BMI = \frac{\text{Mass (kg)}}{(\text{Height (m)})^2}$$

The normal range is considered to be 18.5-24.99; overweight is 25-29.99 and obese is >30.

Between 1960 and 2000 the world's population approximately doubled, from 3 billion to 6 billion, and yet the amount of food produced per person increased by 25%. This was the result of the "green revolution". The productivity of agricultural land in many parts of the world, but especially in Asia and South America, was dramatically increased by a combination of four things: plant breeding to produce better varieties of major crops, irrigation, application of agrochemicals, and mechanisation.

There is no doubt that the green revolution was a huge benefit to mankind in the second half of the 20th century and saved many billions of people in the developing world from starvation. It also resulted in a decline in the relative price for food. In the UK, the proportion of household income spent on food decreased from an average of 30% in the middle of the 20th century to less than 10% in the first decade of the 21st century. Later in the report we will explore the current levels spent on food and drink by UK households.

No one doubts that the world's demand for food is going to increase sharply in the decades ahead. Experts estimate that the demand will have increased by 50% in 2030, and possibly doubled by 2050. This will be as a result of two things: the increasing number of mouths to be fed, and the increasing affluence in the developing world, which means that people eat more and eat the kinds of food that are more costly to produce in terms of water, energy, land and agrochemicals. As countries become wealthier, their populations tend to undergo a nutritional transition from a diet that is often largely plant-based towards an increased consumption of meat, especially beef. Each kilo of beef produced requires about 8 kilos of plant food, and fifteen times the amount of water as a kilo of wheat *(Krebs, 2013).* One estimate is that by 2050 the average per capita consumption of meat will rise from its current level of about 38kg to 52kg per person per year.

It is widely accepted that the global challenge for the first half of the 21st century is to produce more food, with more efficient use of energy, water and agrochemicals, while at the same time reducing greenhouse gas emissions, coping with a changing climate, and avoiding destroying natural habitats and their biodiversity. This has been described as the need for a "**doubly green revolution**" or the challenge of "**sustainable intensification**" of farming. Is it possible to grow more with less?

Harvard-based Kenyan political scientist Calestous Juma has argued that Africa could feed itself within a generation if it embraced new technologies, rather than adopting the dated technologies of the green revolution. He suggests that Africa should leapfrog to the next generation of technologies, including biotechnology, information technology, geographical information systems (digital spatial information), and nanotechnology. Precision agriculture, using satellite imaging and GPS can allow farmers to target their fertilisers and pest control chemicals, in precisely the amounts and locations where they are needed. This is evolving faster to look at the use of unmanned aerial vehicles (drones) to support precision agriculture. The internet could give farmers instant access to advice, weather forecasts, disease spread, and other crucial information. Nanotechnology, the manipulation of materials on the scale of individual molecules and atoms, is able to provide better pesticides, and more effective ways of processing food. But the most controversial technology is biotechnology.

Genetically modified (GM) foods often polarise opinion. For some, GM is both a modern, more sophisticated extension of the process of genetic modification of crops and livestock that started 10,000 years ago and will be a key contributor to sustainable intensification. For others, GM is anathema, dangerous to humans and nature, unnatural and unnecessary.

Genetic modification of crops involves inserting genes from another organism into the crop plant, with the aim of creating a new variety of the crop plant with a desirable feature such as resistance to insect attack, tolerance to drought, or improved nutritional quality. GM food crops, and some non-food crops such as cotton and tobacco, are grown worldwide on a large and rapidly increasing scale. The use of GM crops for food and cotton increased from 1.7 million hectares in 1996 to over 17 million hectares in 2012. In 2012, GM crops were grown by over 17 million farmers in 28 different countries, and more than 90% of these farmers were poor smallholders in developing countries *(Krebs, 2013).*

One of the key food crops is soya, grown as a source of protein for animals. In 2012, in Argentina 100% of the soya was GM, in Brazil 88%, and in the USA 93%. The EU imports a great deal of soya for animal feed and about 85% of it contains GM or GM-derived material. In addition to soya and cotton, the major GM crops grown worldwide are maize and canola (oilseed rape). There are many new GM crops in the pipeline, including foods with additional nutritional benefits such as "golden rice". Golden rice contains the precursor of vitamin A, and could help to prevent blindness caused by vitamin A deficiency in about 500,000 children each year in the developing world. A bit further down the line are crops that will be resistant to drought or salinity, enabling them to be grown in water-stressed areas, and cereals that are able to fix nitrogen from the air to reduce or obviate the need for fertiliser.

With these benefits, why isn't everyone enthusiastically welcoming GM foods? There is no simple answer. Different groups of objectors have different reasons for their views, but in summary they boil down to four main worries:

- GM may be risky to the environment
- it may be risky for human health
- it places too much power in the hands of big corporations that develop and own the intellectual property
- it is tantamount to "playing God" and therefore considered morally wrong.

An estimated 75% of all processed foods in the USA contain GM ingredients, mainly from maize, soya, or canola, but in Europe consumers have turned against GM foods and no food on sale should contain GM ingredients unless declared on the label.

What should we be concluding about GM food? The challenge of feeding 9 billion by 2050 will need all the technological, sociological and ecological knowledge that we can generate. GM is not a magic bullet, but it is already having a role to play and its importance may well increase as new genetic modifications come on stream. At the same time we need to carefully assess the risks as well as the benefits, case by case.

5. A short history of genetics

In February 1953 Francis Crick announced to a crowded Cambridge pub that he and James Watson had discovered the 'secret of life', the double helix structure of DNA. DNA is the molecule that carries genetic information from generation to generation.

Watson and Crick's double helix showed how the four molecules at the heart of DNA, adenine, guanine, cytosine and thymine, or A, G, C & T, can be paired up: A with T, G with C. This meant, they realised, that any stretch of DNA could be copied and duplicated. Over the next 30 years, molecular biologists learned how to identify and sequence stretches of DNA coding for genes for particular traits, and transferred snippets into other organisms to study them or to develop new breeds and products. This recombinant DNA technology is now widely used to make medicines and vaccines, as well as for new varieties of crops such as corn, cotton and soybeans.

> Within a decade, your personal genome sequence could be just part of your medical record

Genomics is the study of genomes: all the genetic material of an organism. While classical genetics zooms in on individual genes, genomics pulls back the focus, allowing scientists to see all the genes of an organism at the same time, then to comb through them for trends, associations and interactions. If genetics were rugby, the classical approach would be to know all about a single player. Genomics, on the other hand, means knowing something about all the players in every team in the league. Genomics is now being used to study crops like tomatoes, peppers and wheat; search for clues to cancer and autism; find ways to make new green fuels; and understand the microbes that live in, on and around us and make us healthy or sick.

It is predicted that genomics will have a big impact on agriculture, energy and even manufacturing by guiding the breeding of new crops and livestock, the development of new biofuels and inspirations for industrial materials. In agriculture, genomics could speed up the creation of new varieties for desired traits, such as tolerance for the effects of climate change. Instead of introducing single genes as in genetically modified crops, genomics allows breeders to see exactly which traits they are selecting. It will also bring about a more profound understanding of the microorganisms that are vital to agriculture, whether helping plants fix nitrogen from the air or allowing cattle to digest tough plant material.

In 1990, the USA launched the Human Genome Project, an international effort to determine the complete sequence of the DNA of a human being: about 3 billion letters of DNA code. The Human Genome Project, completed in 2003, cost $3 billion. Today, sequencing a human genome costs about $3,000, and the price is falling. Within a decade, your personal genome sequence could just be part of your medical record. Perhaps we will carry them around on a memory stick drive or store them in our smart phones.

This is expected to have profound effects on future health care and will enable personalised diets to be an opportunity for the future, something I will explore later in the report. Conditions like heart disease, diabetes and cancer arise from a combination of genetic predisposition and environmental factors. If you know the risk factors in your DNA, you can take steps to change the environment, avoiding certain foods to improve your chances of a healthier life.

High-throughput sequencing technologies have provided a powerful new set of tools to reveal genetic and epigenetic variation on a genome-wide scale and therefore new insights into the evolution of genomes and trait variation. Epigenetics is the study of heritable variation involving mechanisms other than changes in the DNA sequence of an organism. Fruit crop genomes that have been sequenced include :

- grapevine (*Vitis vinifera*)
- apple (*Malus* × *domestica*)
- diploid strawberry (*Fragaria vesca*)
- tomato (*Solanum lycopersicum*)
- banana (*Musa acuminata*)

These resources will underpin advances in the breeding of fruit crops by:

a) Greatly facilitating marker-assisted selection and allowing efficient cloning of genes underpinning quantitative trait loci (QTL's).

b) Providing the reference genomes for rapid allele mining in crop wild relatives.

c) Providing a guide for direct sequencing of monogenic mutants.

d) Maximising opportunities to optimise reverse-genetics tools such as targeting induced local lesions in genomes (TILLING) for gene functional studies.

In the future, high-throughput sequencing technologies will allow routine screening of crop epigenomes and therefore permit detection of epigenetic variation that impacts phenotypes. Additionally, translational biology from models to crop species has clear utility in enhancing important crop traits. Harnessing variation in crop wild relatives in combination with direct genetic modification provides a powerful route for a massive step change in crop improvement.

6. A short history of the human diet

The human genome evolved in the context of the diet prevailing before the introduction of agriculture and animal husbandry approximately 10,000 years ago, when humans were hunter-gatherers; diets were rich in fruits, vegetables, and protein and low in fats and starches *(Eaton et al., 1985).* For primates such as chimpanzees more than 75% of their diet by weight is fresh fruit, and the assumption is that our primate ancestors had similar diets. Fruit is also common in the diet of modern hunter-gatherers. The 10,000 years (~360 generations) since the first cultivation of cereals has not been enough time for humans to adapt to starchier, cereal-based diets with much higher amounts of fat and lower amounts of fresh fruit and vegetables, and it has been suggested that many chronic diseases result from our evolutionary discordance with modern diets *(Cordain et al., 2000).* Levels of phytonutrients in the diet have dropped significantly owing to a reduced variety of plants consumed (currently, just 17 plant species constitute 90% of the global human diet) and to selective breeding *(Willett, 2000).* For these reasons, most modern dietary recommendations include increased consumption of fresh or whole fruits and vegetables. Dietary intervention studies support the view that consumption of fruit (especially when replacing calorie-dense food) helps maintain a healthy weight and reduce the risk of a wide range of cancers *(Tohill et al., 2004)* and cardiovascular disease *(He et al., 2007).*

There is mounting evidence to suggest that the 'five a day' campaign's objective is scientifically sound and that there should be a shift toward increased fruit and vegetable consumption to reduce the risk of chronic disease

Plants are central to our survival, providing the oxygen we breathe, many of the raw materials for our dwellings and, directly or indirectly, all the food that we eat. Diet must be considered an important part of our environment, and it may have significant impacts on our growth and development when we are young and on our risk of disease, particularly chronic disease, throughout our lives.

Deficiency diseases usually result from malnourishment or overdependence on single staple crops. However, many chronic diseases, including diseases arising from metabolic syndrome and obesity such as type 2 diabetes, cardiovascular disease (CVD) and certain cancers, are heavily influenced by diet.

There is now strong evidence for the benefits of fruit and vegetable consumption in terms of protection against chronic disease, and epidemiological studies have linked diets that include abundant consumption of plant-based foods with decreased risk of developing CVD and various kinds of cancer. There is mounting evidence to suggest that the 'five a day' campaign's objective is scientifically sound and that there should be a shift toward increased fruit and vegetable consumption to reduce the risk of chronic disease *(Gingras & Beliveau, 2007).* The evidence suggests that we should be eating **at least "five a day"**.

Our ancestors were hunter-gatherers, consuming diets rich in lean wild meat or fish, with relatively high consumption of fruits and green leafy vegetables. Our modern diets, in contrast, are high in saturated fats and starches, added sugars with high energy load, and 'unnatural fats'. In modern US diets, foods unavailable to our ancestors, including dairy products, cereal grains, refined cereal flour, refined sugars, refined vegetable oils, and alcohol, on average make up 70% of total energy consumption. Americans currently consume less than 60% of the US Department of Agriculture recommendations for vegetables and less than 50% of the recommendations for fruits.

Fats, derived largely from dairy sources but also from plant oils, are a significant part of modern diets. The so-called lipid hypothesis suggests that low-density lipoprotein (LDL) cholesterol in plasma is the major risk factor for coronary heart disease (CHD) and that LDL levels can be influenced significantly by diet. The current thinking is that total fat intake is significantly less important than fat quality in terms of influencing obesity and the onset and progression of chronic disease *(Willett, 2012).* Since the 1950s, it has been commonly believed that consuming foods with a high proportion of saturated fatty acids is less healthy than consuming foods with a lower proportion of saturated fatty acids.

Diets rich in omega-3 PUFAs compared with omega-6 PUFAs are considered to be good choices. There has been a decline in consumption of omega-3 PUFAs linked with increased consumption of cereals which are low in omega-3 PUFA. This has been exacerbated by animal husbandry practices switching to cereal-based feed.

PUFAs are divided into two classes: medium chain and long chain. Medium-chain PUFAs are derived largely from plant sources, whereas long-chain PUFAs are derived largely from marine fish that acquire high levels from the algae on which they feed. Dietary campaigns to reduce saturated-fat consumption recommended replacement with medium-chain PUFAs such as linoleic acid (Omega-6 PUFA). Considerable evidence now exists that it is the composition of long-chain PUFAs, more than the total consumption that influences disease inception and progression. Consequently, current dietary recommendations include the consumption of significant amounts of fatty fish (such as salmon, anchovy, mackerel and tuna) to boost eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) levels.

Dietary carbohydrates come almost exclusively from plant sources. They are consumed as sugars or polysaccharides and contribute significantly to the energy load of the diet, glucose metabolism, and insulin signalling. Many nutritionists now believe that regulating carbohydrate consumption can have a greater impact on obesity and associated complications than limiting dietary fat intake does *(Martin et al., 2013).*

Starches can be divided into rapidly digested, slowly digested, and resistant. Rapidly digested starch is present in cooked starchy foods, leads to rapid elevations of blood glucose, and consequently has a high glycaemic load. Slowly digested starch is present in uncooked starchy foods such as raw cereals and cooked pulses; it is digested slowly to provide a slow and prolonged release of glucose, and has a low glycaemic load. Dietary sources of resistant starch include partially milled grains, potato and whole-wheat bread.

Foods with higher levels of resistant or slowly digested starch have been reported to reduce glucose and insulin responses and enhance satiety *(Bodinham et al., 2010).* The beneficial effects of switching from diets rich in rapidly digested starch to those rich in slowly digested starch and resistant starch could impact on obesity and associated chronic diseases.

Sugars were reasonably abundant in our ancestors' diets through fruits and occasionally honey. However, these types of sugars (largely fructose in fruits) are classified as intrinsic sugars. In modern diets, the levels of free (added) sugars are high, and consumption has increased more than fivefold over the past 60 years for the US population *(Martin et al., 2013)*. This large rise is attributable to increased consumption of beverages sweetened with high-fructose corn syrup, which consist of approximately 55% fructose and 45% glucose. The high fructose content in these beverages may contribute specifically to obesity because fructose is metabolised differently from glucose.

Figure 1 : Key bioactives in plants with examples and typical plant food sources.

Compound class	Examples	Typical plant food sources
Alk(en)yl-cysteine Sulfoxides	S-methyl-L-cysteine sulfoxide, S-propenyl-L-cysteine sulfoxide	Onions, garlic, leeks
Capsaicinoids	Capsaicin, dihydrocapsaicin	Chilli peppers, Sweet peppers
Carotenoids	Beta-carotene, lycopene, cryptaxanthine	Tomatoes, carrots, blocky peppers
(Dihydro)chalcones	Phloretin	Apples
Flavonoids		
Flavones	Apigenin, luteolin	Celery, parsley
Flavanones	Naringenin, hesperetin	Citrus fruits
Flavonols	Quercetin, kaempferol	Onions, tea, green beans, tomatoes
Flavan-3-ols	Catechin, epicatechin, procyanidin B1, procyanidin B2	Tea, cocoa, apples, berries, certain beans
Anthocyanidins	Cyanidin, delphinidin, pellargonidin	Blackcurrants, blueberries, strawberries
Isoflavones	Daidzein, genistein	Soy beans
Glucosinolates, Isothiocyanates	Glucoraphanin, sulphoraphane	Broccoli, cabbage, Brussels sprouts
Lignans	Secoisolariciresinol, matairesinol	Linseed, fruits and vegetables
Phenolic acids	Ferulic acid, salicylic acid	Coffee, cereal bran, fruits
Phytosterols	Campostanol, sitostanol	Wheat
Polyacetylenes	Falcarinol, falcarindiol	Carrots, celery, parsley
Stilbenes	Resveratrol, trans-piceid	Grapes, peanuts

Dietary fibre can reduce appetite and so contribute to weight loss. All dietary fibre comes from plants, but vegetables such as Jerusalem artichoke, chicory, aubergine, okra, asparagus, garlic, leek, and onion are particularly good sources. Resistant starch has properties similar to those of dietary fibre. The average modern diet includes 3–6g of resistant starch each day, and good sources are starchy fruits like banana and mango.

As part of the metabolic process within the body, oxygen is involved in toxic reactions. Free Radicals and Reactive Oxygen Species (ROS) 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 ageing including cardiovascular disease. The body has natural defences against these oxidants including a system of antioxidant enzymes and other compounds that act as antioxidants.

Many bioactive compounds present in foods from plants can be classified as antioxidants. It is estimated that 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.

How do we measure the antioxidant levels in food? ORAC is an abbreviation for Oxygen Radical Absorbance Capacity and was developed by the National Institutes of Health in Baltimore. ORAC units measure the antioxidant capacity of foods, the higher the better. If the ORAC rating is 1000/100g then the food is considered 'Rich' in antioxidants.

See Figure 1 on previous page: Key bioactives in plants with examples and typical plant food sources.

Although the antioxidant capacities of many bioactives have been claimed to explain their health-promoting properties *(Rice-Evans et al., 1997),* many dietary bioactives have a low bioavailability, making it highly unlikely that, once absorbed, they operate directly as antioxidants to promote health. Bioactives with strong antioxidant activity can be subdivided into hydrophilic and lipophilic antioxidants. The current dietary advice is to include both types of antioxidant to reduce the risk of chronic disease.

Many hydrophilic antioxidants in the diet are metabolised in the gut; although, once absorbed, their metabolites may also have significant antioxidant activity. Anthocyanins are plant pigments belonging to a subset of flavonoids with a particularly high antioxidant capacity and strong health-promoting effects. Anthocyanins are often present at relatively high levels in fruits such as blueberry, blackberry, strawberry, and raspberry.

Common lipophilic antioxidants in the diet are carotenoids, tocopherols, and tocotrienols. They protect lipids in the body from oxidation and so reduce membrane damage in particular.

Many health-benefit studies have been confounded because purified bioactives fail to have the same effects as they do in food. Three explanations can be offered for these observations:

- Bioactives may function in co-operation with other food components, giving rise to synergistic effects that are observed only in a whole food context.

- The food matrix may significantly impact bioavailability. Carotenoids are more easily absorbed from food if the food matrix contains fat.

- Supplements allow the consumption of very high levels of phytonutrients, which may reach toxic levels.

Most bioactives are subject to metabolism by the enzymes of the gastrointestinal tract and by the gut microbiota, and are usually metabolised further once absorbed. Each part of the gastrointestinal tract has a different microbiome and differs between individuals. However, in healthy adult individuals, the composition of the microbiome at most sites is stable over time. The human gut microbiome is subject to major changes in early life and is established by the age of three *(Yatsunenko et al., 2012).*

It should be possible to reduce the risk of a significant proportion of chronic disease by encouraging diets that :

- increase consumption of fruits and vegetables
- reduce consumption of meats (particularly high-fat meats) and saturated fats
- significantly reduce amounts of added sugars (particularly high-fructose corn syrup)
- and eliminate trans fats.

To accomplish these objectives, societies need to ensure greater access to fruits and vegetables at reasonable prices.

Consumption of the bioactives that promote health and protect against chronic disease might be encouraged if more research were invested in improving the phytonutrient content of fruits and vegetables, improving our understanding of their mechanisms of action and improving their taste and attractiveness to consumers.

7. Unilever research on diet

In August 2013 I made a visit to Colworth House, Bedfordshire, the flagship research location for Unilever in the UK. I was delighted to meet Professor Mark Berry who has been working for Unilever for over 30 years and is a member of their Strategic Science Group. Mark heads up Plant Biology and Plant Biochemistry for Unilever.

In addition to Mark I met a number of his colleagues who are working on all elements of food research and more recently have been looking at the Palaeolithic diet.

In May 2013 Unilever scientists released the results of a clinical study that suggests meals rich in nutrients and fibre inspired by our Palaeolithic ancestors are better at satisfying the appetite than a regular meal and could also help combat obesity and even type 2 diabetes.

> …. a clinical study that suggests meals rich in nutrients and fibre inspired by our Palaeolithic ancestors are better at satisfying the appetite than a regular meal and could also help combat obesity and even type 2 diabetes.

The study compared two meals using readily available ingredients: a healthy modern meal and a Palaeolithic-inspired meal - so called because its composition mirrored a range of foods our ancestors would have had easy access to. Both contained the same amount of protein, fat, carbohydrates and calories but crucially the second one incorporated a broader range of plant-based foods. These included nuts and spices - such as cinnamon - in addition to fresh fruit and vegetables.

The metabolism of the volunteers was monitored three hours after eating and those that consumed the modified meal felt much fuller. Furthermore, results showed they had significantly higher levels of PYY, a hormone that tells the brain we have had enough to eat.

Explanatory reasons for the results include that the Palaeolithic-inspired meal had a low energy density resulting in a physically bigger meal for the same amount of calories than the modern meal. This could account for the increased satiety levels. The meal was also designed using plant-based ingredients chosen to be both high in fibre and rich in phytonutrients.

Professor Mark Berry said: *“Initial findings from our study suggest we might do well to get back to basics and eat a diet for which our bodies have evolved. With its mix of lean meat, fresh fish and a very broad variety of plant-based foods, our ancient ancestors’ diet was different from what most of us consume today. Furthermore, the human genome has not had time to respond to radical recent changes in our diet and therefore human physiology is at odds with the vast majority of modern diets.”*

Professor Berry added: “*The great thing is we didn’t have to invent a time machine to do this study; all the ingredients needed for the Palaeolithic meal could be readily purchased.”*

Professor Gary Frost from Imperial College London said the initial findings could have other profound benefits: “*Up to now surgery has often been the only viable solution to tackle chronic obesity but this research has exciting future possibilities of opening up a genuine alternative to gastric surgery. The* *observation that Palaeolithic diet leads to an increase in PYY raises the possibility of designing a diet that would act as a sort of nutritional bypass."*

Dr Frances Bligh, Lead Scientist at Unilever said the team now plan to work with academic colleagues to investigate some of these effects further. "*We want to see if the findings could be applied to foods of the future."*

> ….. farmers will have the potential to exploit this production opportunity

What we can expect from these findings is that future product development from Unilever is going to need high quality raw materials and as a result farmers will have the potential to exploit this production opportunity.

8. How do we measure nutritional value?

The value of all nutrients in foods can be quantified in several ways, including the measurement of nutrient density and energy density. Fruit generally ranks highly in any system and it is these properties that make fruit an important component of a healthy diet. Fruit and vegetables are wholefoods and represent the most nutrient-rich food sources when compared to other foods; they form an essential part of a healthy diet.

There are a number of definitions used in relation to the average amount of specific nutrients required daily in order to support health. The sets of values are determined for specific populations based on scientific evidence, population studies and statistical analysis. Many countries have their own sets of values, reflecting differences in diet and ethnicity.

The reference values are also used as the basis for determining whether a food contains sufficient levels of a nutrient to justify making a content claim. In the EU, a food must be a source of a nutrient to make such a claim, where source is defined as having at least 15% of the Nutrient Reference Value (NRV) of the nutrient. To make a 'rich' claim the food must contain at least 30% of the NRV.

The reference intakes are typically given on the basis of gender and age group and the physiologic and growth requirements for those groups vary significantly. When referring to reference intakes, it is important to clearly state which group is being used and provide the correct reference. In addition to the range of values for age and gender, some countries including the EU set specific levels to be used as the reference for labelling purposes.

Energy density is a measure of the total amount of energy, (kilojoules (kJ) or kilocalories (kcal)) a food provides, as a function of either the serve size, or a specified weight, or volume. It may also be referred to as 'calorific density'. Foods with low energy density values are recommended as the main foods that should be consumed as part of a varied balanced diet.

Energy Density	Values	Examples
Low	<1.5kcal/g (or <7kJ/g)	Most fruit and vegetables, low-fat dairy options.
Moderate	1.6-3.0kcal/g (or 7-13kJ/g)	Lean meats, salmon, bread.
High	>3.0kcal/g (or >13kJ/g)	Fried foods, chocolate, cheese, many fast foods, nuts, oils, high-fat dairy options.

A balanced diet will include a selection of foods from all groups; most from the low energy group and only a small amount from the high energy-dense group. Not all energy-dense foods are 'unhealthy'; for example, nuts may contribute to a healthy diet so long as they are eaten in moderation.

> Fruit ..... ranks highly in any system and it is these properties that make fruit an important component of a healthy diet.

Nutrient density is the measure of the nutritional value of foods. It is a ratio that considers key nutrients as functions of the energy value of the food (nutrients per calories). In general, fruit and vegetables are amongst the most nutrient-dense foods as they contain a vast array of vitamins and minerals and have a low energy density. In contrast, many processed foods contain added sugars and fats making them energy-dense, whilst delivering fewer vitamins and minerals.

Nutrient density is a concept that underpins a healthy diet. Increasingly, as diets are westernised and become more highly processed, they tend to become more energy-dense, but nutrient-poor. This trend is exacerbated in many countries where the highly processed and energy-rich, nutrient-poor foods are more economically realistic options for consumers.

In contrast, many processed foods contain added sugars and fats making them energy-dense, whilst delivering fewer vitamins and minerals

There are several ways in which nutrient density may be determined. Globally, there is no 'official' method or standard. Commonly used calculation principles include:

> Direct measures of nutrients: where the amounts (in mg or g) of particular nutrients are calculated as ratios of the energy content of the food (kJ or kcal).
>
> An energy ratio: the energy from fat, protein or carbohydrate is given as a ratio of the total food energy and expressed as a percentage.
>
> Expression as a ratio of the nutrient composition of the food to the nutrient requirements of the human body: the nutrients used in this comparison may vary as well as the requirement basis.

Glycaemic Index (GI) is a measure of the rate and extent to which blood glucose levels rise after the consumption of a set amount of carbohydrate (glucose). It is measured in individuals following consumption of the test foods. High GI foods are rapidly digested and absorbed, and result in rapid, marked fluctuations in plasma glucose levels, whereas low GI foods are more slowly digested and absorbed, resulting in a gradual rise in plasma glucose response and insulin levels.

Foods are classified as either low GI (GI <55), moderate GI (GI 56-69) or high GI (GI >70) *(Brand-Miller et al., 2009).*

9. The state of the UK nation.

One of my first visits in the UK was to Nottingham University where I had the pleasure of meeting Dr Martin Broadley and his research highlighted the challenge that exists in the UK on basic mineral nutrition.

Human individuals require at least 20 inorganic elements (‘minerals’) for normal functioning. However, much of the world’s population is probably deficient in one or more essential minerals and at increased risk of physiological disorders. Addressing these ‘hidden hungers’ is a challenge for the nutrition and agriculture sectors. Mineral deficiencies among populations are typically identified from dietary surveys because minerals are acquired primarily from dietary sources and bio-assays of mineral status can be unreliable. While dietary surveys are likely to under-report energy intakes, surveys show that 9% of all UK adults consume Calcium (Ca) and Magnesium (Mg), and 14% of adults consume Potassium (K), at quantities below the UK Lower Reference Nutrient Intake (LRNI), and are therefore at risk of deficiency. LRNI values for protein, vitamins and minerals are set for each age/sex group at a level of intake considered likely to be sufficient to meet the requirements of only 2.5% of the population.

In a recent report Broadley & White (2010) assessed the impact of increased vegetable consumption and horticultural biofortification e.g. enhancing crop mineral content through breeding and agronomy, on intakes of the major minerals Ca, Mg and K. What they found was that *(continued on next* page)

Figure 2: see next page for description

Proportion of participants with average daily intakes of minerals from food sources only below the Lower Reference Nutrient Intake (LRNI), by age and sex

Aged 1.5 years and over — *2008/9 - 2010/11*

Mineral	**Sex and age group (years)**														
	Boys			**Men**		**Girls**			**Women**		**Total**				
	4-10	11-18	**Total Boys**	19-64	65+	4-10	11-18	**Total Girls**	19-64	65+	1.5-3	4-10	11-18	19-64	65+
	%	%	%	%	%	%	%	%							
Iron	1	6	4	1	2	1	46	26	23	1	7	1	26	12	1
Calcium	0	7	4	4	2	2	18	11	8	3	1	1	13	6	3
Magnesium	0	28	15	16	18	3	51	29	11	9	1	1	39	14	13
Potassium	0	17	9	11	14	0	31	17	23	18	1	0	23	17	16
Zinc	5	11	8	9	9	8	19	14	4	1	5	6	15	7	4
Selenium	0	22	12	25	31	1	45	25	52	54	1	1	33	39	44

despite low energy intake from horticultural crops generally, increased vegetable consumption and biofortification would significantly improve dietary intakes of Ca, Mg and K.

The basis in the UK for the concern is laid out in the 'Vitamins and Minerals' section of the rolling National Diet and Nutrition Survey (NDNS). I have included some key tables in my report to illustrate the concerns.

Figure 2 on previous page shows that over half the female population is deficient in one or more minerals (e.g. 51% of girls aged 11-18 have magnesium intakes below the LRNI for Mg; 52% of women aged 19-64 have selenium intakes below the LRNI for Se).

Figure 3 below shows the Reference Nutrient Intakes (RNI) and Lower Reference Nutrient Intakes (LRNI) for minerals, by sex and age.

Figure 3: Reference Nutrient Intakes (RNI) and Lower Reference Nutrient Intakes (LRNI)

Reference Nutrient Intakes (RNIs) and Lower Reference Nutrient (LRNIs) for minerals, by sex and age										
Mineral		**Age group (years)**								
		1-3	4-6	7-10	11-14	15-18	19-50	51-64	65-74	75+
Males										
Iron (mg/d)	RNI	6.9	6.1	8.7	11.3	11.3	8.7	8.7	8.7	8.7
	LRNI	3.7	3.3	4.7	6.1	6.1	4.7	4.7	4.7	4.7
Calcium (mg/d)	RNI	350	450	550	1000	1000	700	700	700	700
	LRNI	200	275	325	480	480	400	400	400	400
Magnesium (mg/d)	RNI	85	120	200	280	300	300	300	300	300
	LRNI	50	70	115	180	190	190	190	190	190
Potassium (mg/d)	RNI	800	1100	2000	3100	3500	3500	3500	3500	3500
	LRNI	450	600	950	1600	2000	2000	2000	2000	2000
Zinc (mg/d)	RNI	5.0	6.5	7.0	9.0	9.5	9.5	9.5	9.5	9.5
	LRNI	3.0	4.0	4.0	5.3	5.5	5.5	5.5	5.5	5.5
Copper (mg/d)	RNI[a]	0.4	0.6	0.7	0.8	1.0	1.2	1.2	1.2	1.2
Iodine (µg/d)	RNI	70	100	110	130	140	140	140	140	140
	LRNI	40	50	55	65	70	70	70	70	70
Selenium (µg/d)	RNI	15	20	30	45	70	75	75	75	75
	LRNI	7	10	16	25	40	40	40	40	40

The chart is continued overleaf

Figure 3 - continued

Reference Nutrient Intakes (RNIs) and Lower Reference Nutrient (LRNIs) for minerals, by sex and age

Mineral		**Age group (years)**								
		1-3	4-6	7-10	11-14	15-18	19-50	51-64	65-74	75+
<u>Females</u>										
Iron (mg/d)	RNI	6.9	6.1	8.7	14.8	14.8	14.8	8.7	8.7	8.7
	LRNI	3.7	3.3	4.7	8.0	8.0	8.0	4.7	4.7	4.7
Calcium (mg/d)	RNI	350	450	550	800	800	700	700	700	700
	LRNI	200	275	325	450	450	400	400	400	400
Magnesium (mg/d)	RNI	85	120	200	280	300	270	270	270	270
	LRNI	50	70	115	180	190	150	150	150	150
Potassium (mg/d)	RNI	800	1100	2000	3100	3500	3500	3500	3500	3500
	LRNI	450	600	950	1600	2000	2000	2000	2000	2000
Zinc (mg/d)	RNI	5.0	6.5	7.0	9.0	7.0	7.0	7.0	7.0	7.0
	LRNI	3.0	4.0	4.0	5.3	4.0	4.0	4.0	4.0	4.0
Copper (mg/d)	RNI [a]	0.4	0.6	0.7	0.8	1.0	1.2	1.2	1.2	1.2
Iodine (µg/d)	RNI	70	100	110	130	140	140	140	140	140
	LRNI	40	50	55	65	70	70	70	70	70
Selenium (µg/d)	RNI	15	20	30	45	60	60	60	60	60
	LRNI	7	10	16	25	40	40	40	40	40

[a] There is no LRNI for Copper.

The NDNS statistics highlight that even within the UK, a developed country, there are significant opportunities to improve the basic mineral nutrition of the population.

The recent Family Food report 2012, which was published in December 2013, has come up with some interesting findings and trends. The food manufacturing industry is the largest manufacturing sector in the UK. Taken as a whole, the agri-food sector contributes £97 billion to the economy and employs 3.8 million people. Food retail and food services of all types are part of our everyday life, from farmers' markets to 24-hour superstores. Food impacts our personal lives on a daily basis.

Figure 4 summarises the UK average energy and nutrient intakes from all food and drink from 2009 to 2012.

continued below chart on next page

Figure 4 : Family Food report 2012

		2009	2011	2012	% change since 2011	% change since 2009	Trend since 2009	% from food eaten out in 2012
Total energy and nutrient intakes [a]								*average intake per person per day*
Energy	kcal	2304	2245	2209	-1.6	-4.1	↘	9.9
	MJ	9.6	9.4	9.2	-1.6	-4.1	↘	9.9
Energy excluding alcohol	kcal	2233	2176	2143	-1.5	-4.0		9.5
Total Protein	g	78.6	77.2	75.9	-1.7	-3.4		10.7
Fat	g	95	92	91	-1.0	-4.5	↘	10.7
Fatty acids:								
Saturates	g	36.0	34.3	33.7	-1.7	-6.2	↘	8.8
Monounsaturates	g	36.0	35.8	35.5	-0.8	-1.3	↘	11.4
Polyunsaturates	g	17.2	16.2	16.3	+1.0	-4.7	↘	12.5
Cholesterol	mg	262	252	249	-1.1	-4.9	↘	12.9
Carbohydrate [b]	g	282	276	271	-1.9	-3.8	↘	8.2
Total sugars	g	129	124	120	-3.3	-7.4	↘	6.8
Non-milk extrinsic sugars	g	85	81	77	-4.0	-8.8	↘	7.9
Starch	g	153	152	151	-0.7	-1.0		9.4
Fibre [c]	g	15.2	15.2	14.4	-4.9	-4.9	↘	10.1
Alcohol	g	10.2	9.8	9.4	-4.0	-7.5	↘	22.9
Calcium	mg	983	955	937	-1.8	-4.7	↘	7.0
Iron	mg	11.9	11.8	11.4	-3.9	-4.3	↘	9.5
Zinc	mg	9.3	9.2	9.0	-2.3	-3.9	↘	10.3
Magnesium	mg	289	287	284	-0.8	-1.5	↘	9.0
Sodium [d]	g	2.82	2.74	2.72	-0.9	-3.7	↘	10.5
Potassium	g	3.23	3.21	3.16	-1.3	-1.9	↘	10.2
Thiamin	mg	1.67	1.62	1.78	+9.5	+6.1	↗	10.0
Riboflavin	mg	1.92	1.92	1.89	-1.9	-1.6		6.9
Niacin equivalent	mg	34.3	33.6	33.0	-2.0	-3.7	↘	12.0
Vitamin B_6	mg	2.5	2.4	2.1	-10.2	-12.8	↘	13.9
Vitamin B_{12}	µg	6.4	6.2	6.1	-2.0	-4.5	↘	8.5
Folate	µg	299	298	282	-5.2	-5.7	↘	12.5
Vitamin C	mg	79	77	82	+6.7	+4.3	↗	9.3
Vitamin A:								
Retinol	µg	530	533	521	-2.2	-1.6		7.6
β-carotene	µg	2191	2187	2557	+16.9	+16.7	↗	12.0
Retinol equivalent	µg	897	900	950	+5.5	+5.8	↗	9.5
Vitamin D	µg	3.07	3.10	3.06	-1.4	-0.2		10.0
Vitamin E	mg	12.22	12.33	12.17	-1.3	-0.4		12.0

The total energy intake per person was an average of 2209 kcal per person per day in 2012, 4.1% lower than in 2009. There is a statistically significant downward trend that confirms the longer term downward trend already apparent since the mid-1960s. Intake is still around 5% higher than the estimated average requirement. Another interesting point from this report is that the majority of measures are lower than in 2009. In some cases this is a good thing e.g. less fat and cholesterol; however, all the key minerals are seeing reduced intake and many of the vitamins are reduced, as well as fibre.

In 2012 the average household expenditure on all food and drink rose 3.6% to £41.37 per person per week (See *Figure 5 on next page).*

Taking inflation into account, this was 0.9% more than 2011, but 3.9% less than 2009.

Figure 5 : UK average expenditure on food and drink, per person per week.

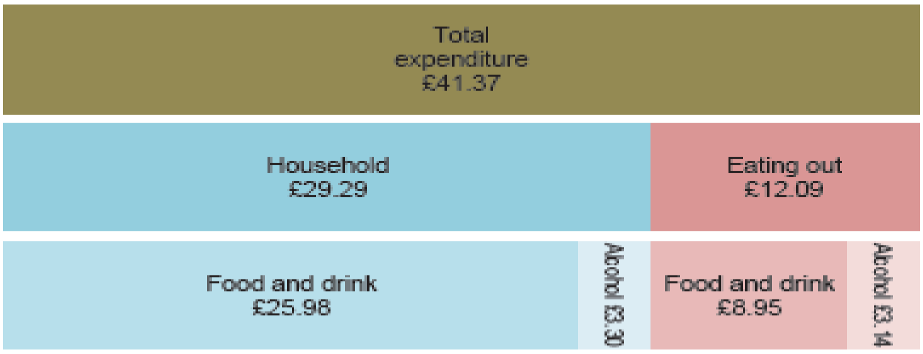


Figure 6 : Household purchases of fruit and vegetables.

Grams per person per week	2007	2008	2009	2010	2011	2012	% change since 2007
All households							
Fruit and vegetables excluding potatoes	2421	2317	2246	2240	2240	2193	-9.4
Fruit	1281	1199	1143	1133	1150	1107	-14
Vegetables	1140	1118	1103	1107	1090	1086	-4.7

Figure 7 : The recommended Eatwell plate.

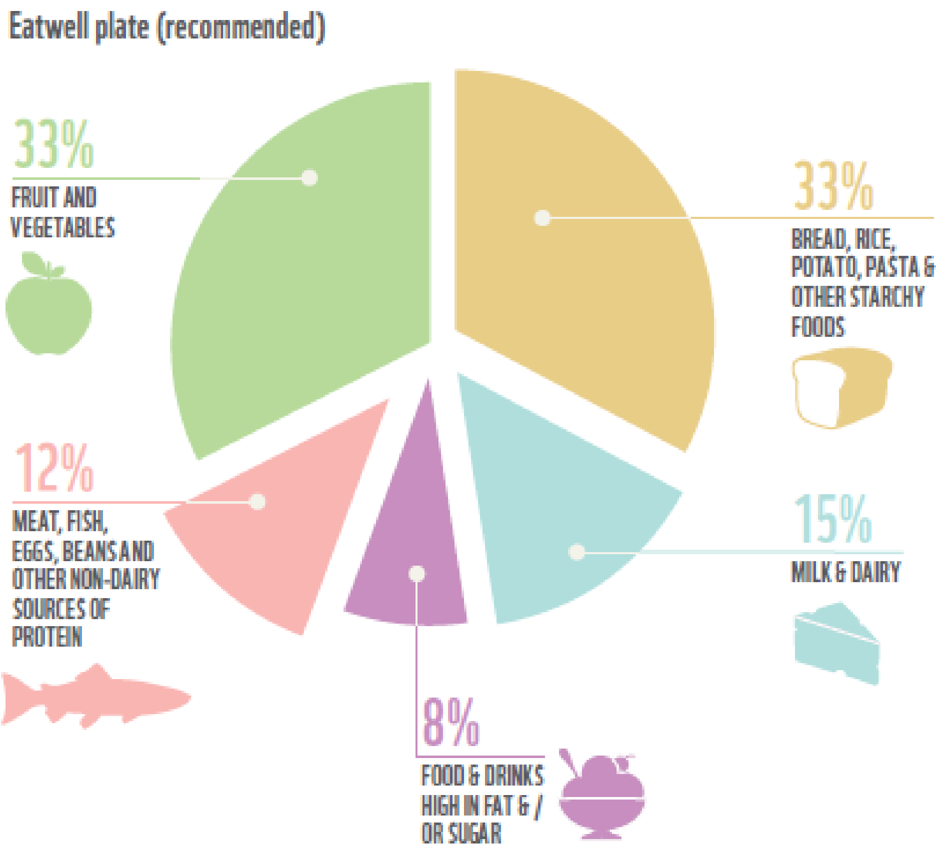


Figure 8 : Current differences between women and men

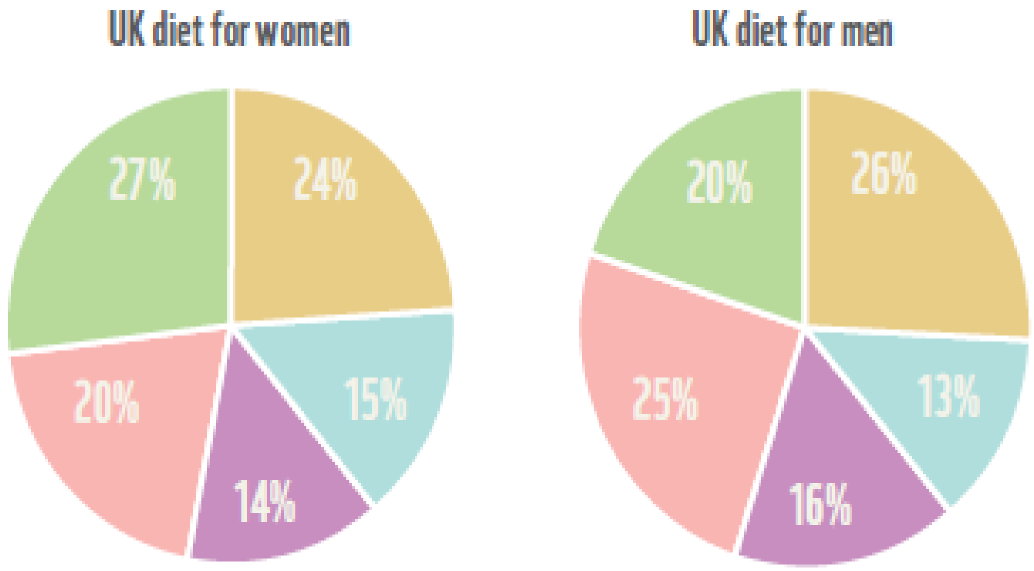


Figure 6 on previous page shows that:

- Fruit and vegetable purchases were 9.4% lower in 2012 than 2007.
- Fruit purchases have declined faster than vegetable purchases since 2007.

These findings are a concern as they are all suggesting that mineral nutrition is declining within the UK population and this all relates to food becoming more energy-dense, but nutrient-poor. The data also highlights that just eating less food isn't the answer. We need to be eating better quality food that is more nutrient-dense to address many of these challenges.

In 2011 the World Wildlife Fund (WWF) report was produced in collaboration with the Rowett Institute of Nutrition and Health at Aberdeen University. The report was entitled Livewell: a balance of healthy and sustainable foods choices.

The current situation and future direction of the report are summarised in the **charts 7 (on previous page) and 8 (above).**

The Family Food report 2012 focused mainly on trends over the period 2009-2012.

Figure 9 on next page shows that household food purchases do not generally match the Government recommended Eatwell plate proportions of the types of food which make up a well balanced diet (**Figure 7**). Both low income households and all households have a relatively similar diet in terms of the Eatwell plate categories, with the exception of fruit and vegetables, where all households consume more fruit and vegetables than the low income households.

As part of the WWF report in 2011 they wanted to research what a 'The Livewell 2020 diet' would look like that would meet the UK 2020 target for reductions in Greenhouse Gas Emissions while at the same time meeting the dietary recommendations for a healthy diet.

This Livewell 2020 diet is presented in **Figure 10 – see next page.**

Figure 9 : Eatwell plate comparison for low income and all households.

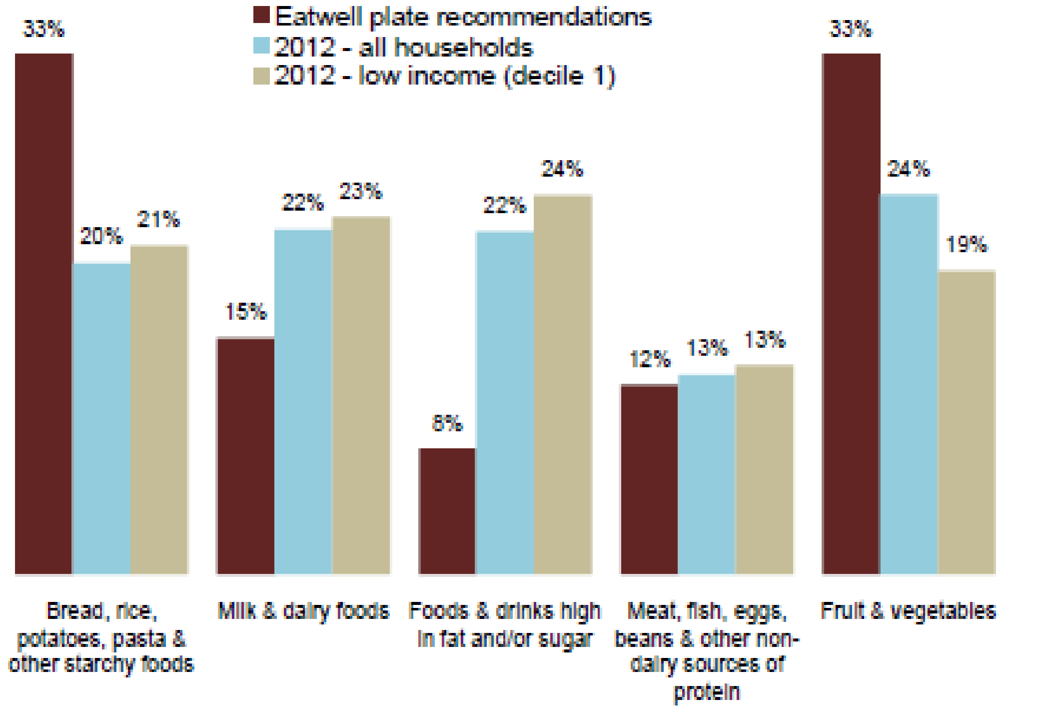
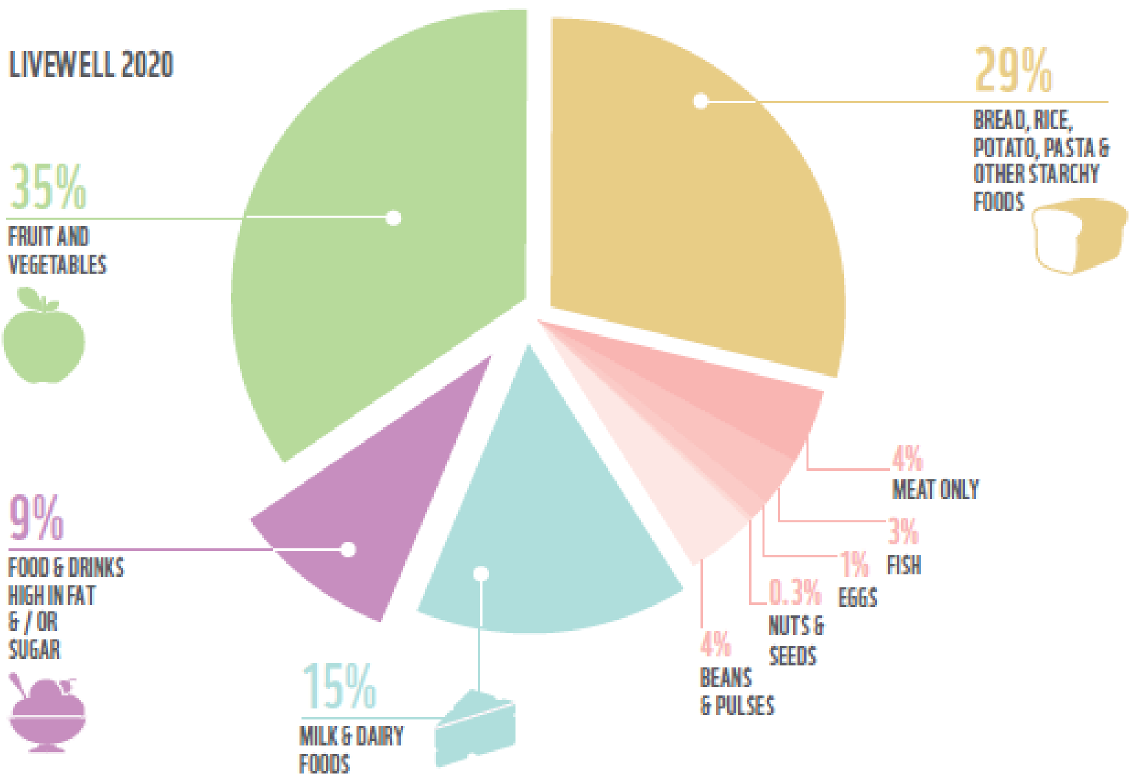


Figure 10 : Livewell 2020



When you consider the recommendations from the WWF report 2011, plus the findings from the Family Food report 2012, the UK continues to fall short in its overall consumption of fruit and vegetables, bread, rice, potatoes, pasta and other starchy food in particular. The report also shows how as a nation we consume far too many foods and drinks that are high in fat and/or sugars.

If we look at the Livewell 2020 guidance **(Figure 10 on previous page)** then we need to move a long way to reach a more balanced and sustainable diet for the UK population, when compared to the current situation for men and women of the UK shown in **Figure 8 (two pages back).**

In the next chapter I have explored how different countries in the Developing World compare to the UK.

…. we need to move a long way to reach a more balanced and sustainable diet for the UK population

10. What about the developing world?

The Gates Foundation believes that a 'sustainable' food system is one that provides the population with adequate food, both in quantity and nutritional quality, while minimising any loss or waste in the food supply. It is a system that can be maintained while the climate continues to worsen. It is one that helps communities flourish by empowering women and protecting the environment. The simple matter is we can only lift farmers out of poverty if we find ways to grow more food sustainably.

The Gates Foundation recently met to discuss the creation of a new set of development goals for post-2015. At the heart of its strategy is a strong focus on food security and nutrition for the following reasons:

"Enough food does not necessarily mean adequate nutrition for all. Improving agricultural productivity has to be much more than just increasing the amount of food that is available. To reduce malnutrition and enable all individuals to live healthy and productive lives, we must also be sure that a variety of nutritious foods are available and consumed in adequate amounts. There are settings where agricultural productivity has increased but child stunting has remained the same or even grown because the quality of diets has deteriorated. Less time has been devoted to feeding and caring for nutritionally vulnerable family members; or farm income has not been used to acquire nutritious foods in the marketplace. This leads us to believe that food security and nutrition must be tackled together and that future development goals should include measures of food quality as well as quantity, such as dietary diversity, to ensure sustainability."

The following article is from Steve Wiggins a research fellow in the Agricultural Development and Policy Programme at the Overseas Development Institute. I believe that it will be an eye opener to many of you and highlights the challenges that we are all under, but let's remember that out of every set of challenges there will always be a set of opportunities.

I quote from Steve Wiggins's report:

"If you believe growing waistlines are a problem affecting only rich countries, think again. The latest data reveals that the number of overweight and obese people in the developing world has more than tripled – from about 250 million in 1980 to almost a billion by 2008.

"The upshot is that there are almost twice as many overweight and obese people in the developing world than in industrialised countries, which are more commonly associated with piling on the pounds. Yet despite this rapid growth some 842 million people go to bed hungry, even though there is more food available than ever before.

"We are producing much more food from animals and have doubled the amount of fruit and vegetables being harvested per person in the past 50 years, yet we still live in a world that is unable to ensure everybody gets fed. Also, for many people who do have enough to eat there is not enough of a distinction between quantity and quality, and the weighing scales are bearing the brunt.

"The data yields a few surprises: Latin America, the Middle East and North Africa have obesity rates on a par with Europe, while South Africa's rate is higher than the UK's. In some countries, such as Mexico,

obesity rates have more than doubled within 30 years.

"What has led to the rapid growth of over-nutrition in the developing world? Higher incomes, falling real costs of many foods, thanks to increased harvests and more efficient logistics in supply chains; urban lifestyles with more sedentary habits and less time to prepare meals, increasing consumption of processed foods often dense in energy from refined carbohydrate, fats, oils and sugar, and the influence of advertising overwhelmingly of processed foods.

"It's a long list of factors that have combined to create urban environments where the temptation is to consume more food than a sedentary lifestyle requires.

"Diets matter. Stroll around a village in Mexico and you will see local shops packed with crisps, white bread and large bottles of fizzy drinks. As a result of the proliferation of junk food, two-thirds of Mexicans are overweight: almost double the proportion as in 1980. Now compare to the side streets of a Korean city, where eateries for ordinary people sell fish stews, and you will understand why the country has half the rate of overweight people as Mexico.

"Increased weight carries significant health risks for some. Apart from the personal misery of illness and early death, when played out across a population, health services can come under severe financial strain.

"Although the rising tide of overweight and obesity may seem difficult to counter, we should not be disheartened. There's sufficient variation in diets across countries and among individuals to suggest the trends in industrialised countries should not be seen as the inevitable fate of the emerging economies.

"The real problem is that few governments have taken decisive action to improve diets. However, the few that have put healthy eating on the agenda have made a significant difference. South Korea is a stellar performer, with the average citizen eating three times more fruit and 10% more vegetables in 2009 compared with 1980, thanks to a government-backed campaign that included teaching women how to prepare traditional low-fat meals.

"In Denmark, changes to the laws on trans-fatty acids have meant McDonald's has been forced to make its fries much healthier, while Mexico has recently imposed taxes on fizzy drinks.

"Countries undergoing a nutrition transition do not have to follow a pre-ordained path and end up with the rates of overweight and obesity we see in the US or UK. We need to learn about why countries with healthier eating habits, in the Mediterranean, Japan and East Asia for instance, have continued to buck the trends seen elsewhere.

"Governments need to explore the scope for combining small changes and incentives to improve diets. So far project donors and world leaders have taken little interest in the rising tide of obesity. It's time to work with developing countries to halt the advance of obesity."

This section of my own report highlights that these challenges are not just restricted to the UK. As a result I was keen to see how scientists around the world are adopting new strategies to tackle these challenges.

11. Global research strategies

During the course of my study I visited or made contact with a number of institutes that are adopting a more joined up strategy in tackling the issue of how science can improve the nutritional value of food produced.

The Plants for Human Health Institute in North Carolina was originally called the Fruit and Vegetable Science Institute. The name was changed to more accurately reflect the ground-breaking research approach the institute is undertaking. Institute research is focusing on identifying and making available to consumers bioactive compounds in plants that prevent and treat disease.

At the same time, North Carolina State faculty at the institute will work to determine how best to commercially produce plants containing bioactive compounds. Research will also focus on increasing yields, extending the North Carolina growing season, developing pest-resistant plants and enhancing pre and post-harvest technologies.

I had the opportunity to speak with Dr. Mary Ann Lila, an internationally known scientist who has devoted nearly a quarter-century to studying the biologically active properties of plants. Lila was on the faculty at the University of Illinois before being named to direct the institute. Eventually, the institute is expected to include 12 to 15 scientists, while the total staff will number around 150.

"The Plants for Human Health Institute will join together the expertise of scientists in genomics, metabolomics, pharmacogenomics, conventional and molecular breeding, post-harvest innovations and phytochemistry in order to capitalize on the benefits that key food crops can provide for health maintenance and human metabolic performance," Lila said.

Also housed on the Research Campus with the Plants for Human Health Institute is the Program for Value-Added and Alternative Agriculture, a North Carolina Cooperative Extension effort designed to transfer research knowledge and results from the lab to the field to improve agricultural production practices.

A novel project within the Lila laboratory is evaluating the functional and technical parameters surrounding Nutrasorb™, an innovative and cost-effective platform to manufacture good tasting, nutritious, and shelf-stable functional foods and ingredients. Nutrasorb™ is designed to deliver doses of phytonutrients within food structures to maintain health and wellness. The matrix is an all-GRAS (Generally Recognised as Safe) food material, effectively absorbing and concentrating phytochemicals and bioactive natural products from plant juices, teas and extracts. The enhanced matrix is then able to be processed into a wide variety of food or beverage products with enhanced nutritional value. The Nutrasorb™ matrix enables higher amounts of phytonutrient delivery compared to conventional plant servings. These products are being developed with particular focus on the developing world where malnutrition is an even greater problem.

My visit to New Zealand highlighted the joined up research approach undertaken by Plant & Food Research (PFR). There science is undertaken to support the development of foods with new functionalities, and they are targeting 'wellness'. Underlying food innovation research is a genetic base of New Zealand proprietary fruit, vegetable and arable cultivars.

The approach is multidisciplinary and summarised below:

Molecular and cellular technologies

Identify the wellness and health-promoting compounds within food and defining their delivery mechanisms.

Organic Chemistry

Scientists extract, fractionate and analyse samples to measure their chemical composition as well as identify unknown compounds. They are investigating enzymes and their activity to better understand the biosynthesis of these compounds.

Physical Chemistry

Understanding of physical chemistry helps them to develop technologies to maintain the bioactives through the temperature and pressure changes that can occur during processing and in human digestion.

Food Ingredients

Develop methods for the successful separation and fractionation of polyphenolic phytochemicals and carbohydrates and scale up these ingredients for industrial use.

The New Zealand Food Composition Database

Manage accurate provision of food composition information for product and diet analyses, Nutrition Information Panels, and marketing.

Post-harvest quality

Their knowledge and understanding of essential regulatory pathways of senescence, shelf life limitations and the role of cell walls in texture informs their development of elite cultivars and new technologies to deliver fresh, tasty products to global markets.

Sensory Science *(contd. at top of next column)*

Their understanding of sensory science and microbiology ensures these products taste great and are safe to eat.

Molecular Olfaction

The research involves the isolation and characterisation of elements in odour production and chemosensory reception systems.

During June 2013 UC Davis, California, established a World Food Centre to help feed and nurture people in the coming decades. This is a 'big picture' idea where the university has brought together the faculty of agricultural and environmental scientists, veterinary medicine, nursing, medicine, social sciences, engineering and management to solve humanity's most pressing problems of food, health and nutrition. One key target is to do this in sustainable ways. Located on the Davis campus in California it is amidst one of the world's most fertile growing regions. The World Food Centre will seek to connect with outside innovators, philanthropists, industry and public leaders to generate visionary research and practical policy solutions.

The global population is expected to hit 9 billion by 2050, and there's an urgent need to reform our food production to meet the rising demand. Through the World Food Centre, UC Davis intends to lead the way in developing sustainable agricultural practices and training the next generation of farmers.

The encouraging part of all three centres identified here is that they are trying to link a number of scientific disciplines that historically have not always worked together. As a result I hope that this collaborative effort can help deliver a 'doubly green revolution' with the nutrient density of food being as important as the energy density of food production.

12. Key food trends for 2014

One of your questions as a reader of this report might be: "How interested are consumers in naturally functional food?"

Julian Mellentin is one of the world's few international specialists in the business of food, nutrition and health. Julian is the owner and editor of New Nutrition Business, the leading source of industry and market analysis, which has focused solely on researching and forecasting the nutrition business since 1995.

Naturally functional products lead the top 12 food, nutrition and health trends for 2014 identified by New Nutrition Business in its latest update from December 2013, as outlined in **Figure 11 on next page.**

The other top four trends included:

- Dairy's rebirth as a natural wholefood
- Protein beyond the tipping point
- Energy: an unstoppable global trend
- Weight wellness.

"*Weight management is no longer a special category of foods*", said Mellentin. *"Consumers now think about weight as part of their everyday food choices and as a means of maintaining wellness. The most successful entrepreneurs are those who connect to consumers' desire for an individualised approach based on normal foods, and to the most important trends."*

The growing popularity of the slow energy trend reflected worldwide interest in products delivering 'slow release' or sustained energy, following the global success of Belvita breakfast biscuits.

"Although many companies are thinking about slow energy and blood glucose control in relation to diabetes, in fact the biggest opportunity for the food and beverage industry lies in providing sustained energy to the mass market," said Mellentin.

See Figure 11 on next page

Figure 11 : Twelve key trends in the business of Food, Nutrition & Health

13. Functional food development

New Zealand has been at the forefront of functional food development. Below I have outlined the current strategy adopted by Plant & Food Research, New Zealand, as set out in their strategy document.

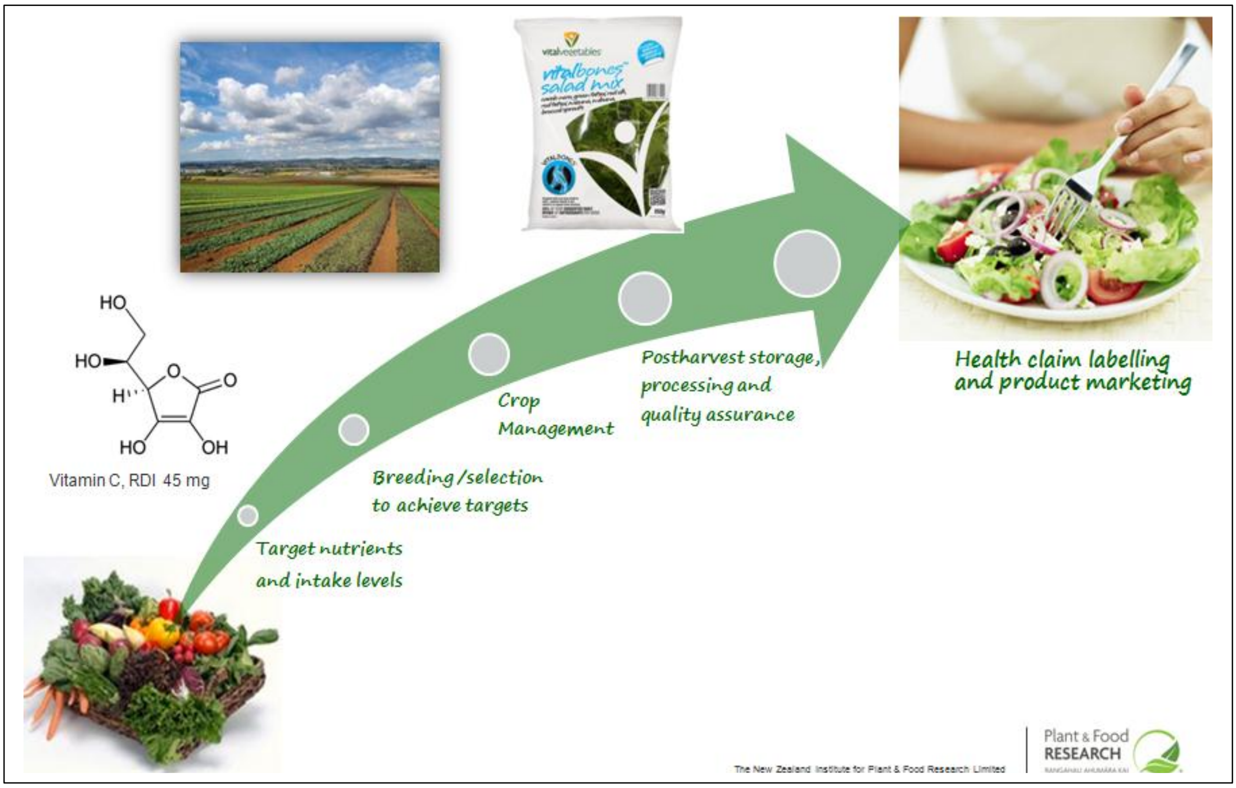
'To achieve products with naturally high nutrient levels, great taste, flavour and long shelf life we first established research principles and analytical methods that supported production of high health vegetables. Each step of production from seed selection, agronomy, harvesting, processing, packaging to distribution was investigated and optimised to ensure year-round product quality.'

Technologies in the form of agronomy and post-harvest protocols were taken up by industry partners during pre-commercial and commercial trials. The technologies were improved to fit the needs of commercial practice and embedded in product manuals for a suite of viable **vital**vegetables® products.

See their two posters below and on next page.

Different activities have been undertaken to ensure the final product is a functional food and meets the **vital**vegetables® standard:

- Product concept – The first thing we do is to define the product concept with our industry partners e.g. Baby leaf salad mixes
- Identify target nutrients of specific vegetables and the intake levels of those nutrients that will benefit human health
- Select germplasm (specific vegetable cultivars) that contain high levels of the nutrients
- Manage crop production to ensure the vegetables contain high levels of the nutrients
- Manage post-harvest handling and storage (including processing and packaging) to maintain the nutrient level
- Develop health claim messages for marketing purposes



Vitalvegetables® is a new category of vegetable products that has a strong focus on consumer health. **Vital**vegetables® products have been selected for their naturally high nutrient levels, great taste and flavour. Scientists have established how to grow and store the vegetables to ensure these levels are maintained from the day the plant is harvested until it reaches the consumer. The products are carefully monitored through every step of production; from seed selection, crop production, harvesting, processing, packaging to distribution. Their growing methods and selection of season-specific varieties ensure consistent year-round quality.

Scientists at Plant & Food Research in New Zealand and the Department of Primary Industries, Victoria, Australia, have spent ten years investigating these questions, resulting in the development of the **vital**vegetables® range. In addition to naturally high levels of nutrients known to be good for health, each serving of **vital**vegetables® contains at least 25% of your suggested daily intake of antioxidants.

The **vital**vegetables® research programme was funded by Horticulture New Zealand, Plant & Food Research and the Department of Primary Industries Victoria, with Horticulture Australia Limited matched funds from the Australian Government and support from the New Zealand vegetable sector.

Vegetables that contain higher levels of these nutrients can help us to reach our recommended intakes for these nutrients more easily. The trick is knowing which nutrients are linked to which aspect of health and which vegetables these nutrients are found in; finding the individual plant in a collection that has naturally higher levels than all the others; growing it so you optimise the levels of these nutrients; and packaging and storing it in such a way that you maintain these levels right through to the consumer.

The **vital**vegetables® program has four pillars for their products to fall under:

- vitalimmunity™
- vitalheart
- vitalbones™
- vitalsight™

The success of functional foods in the marketplace has led to intense interest in the discovery and the characterisation of plant-based bioactive compounds. Subsequent action is often directed toward maximisation of the concentration or bioactivity of the health-promoting compound, thus producing a food with inherent health-related 'functional' characteristics.

Epidemiological studies clearly show a relation between diet and health. Indeed, epidemiological studies that identify an association between a specific food or food group and lowered risk for a specific disease often lead to mechanism studies.

Typically for such studies, scientists focus on a single component of a food rather than a whole food. However, all too frequently, studies of individual components, or even mixtures of components, are found not to give the same effects as the whole food. Interactions between components are complex. Some component effects may be additive, but others may be synergistic, enhancing, inhibitory, masking, neutralizing or even opposing. A sound scientific basis is necessary if we are to integrate functional foods appropriately into the diet *(Jeffery, 2005).*

Challenges to overcome

Before we can provide useful, relevant information on functional foods to health professionals so that they may in turn inform the public, much work remains to be accomplished. We need to know how much of a food must be ingested to gain an effect, how it should be prepared, how frequently one should take it, and for which individuals this is likely to have the greatest impact. Both genetic and epigenetic factors can affect response to food components; dietary recommendations may need to be personalised *(Jeffery, 2005)*. A multitude of plant scientists and food scientists are working to analyse and to quantify bioactive components within foods. Likewise, nutritional scientists, physiologists, and cancer biologists are working to generate the sound scientific basis that provides the mechanistic assurance that certain food components can provide protection at the cellular level. This is an exciting time to be studying the health benefits of foods and food components. With diligence, cooperation and a clear vision of the steps that must be taken to reach our goal, we can make a difference both to the cost of health care and to the quality of life.

All this work highlights the opportunity for smarter product development in the future that enables us to provide consumers with highly nutritious products in whatever form they choose to buy them. It should focus our attention on how synergy exists between products and that the sum of the parts could be greater than the individual components. Future product development should adopt a more scientific basis to maximise these opportunities.

Key findings from visits

The next section reviews the findings from my key visits on a crop-by-crop basis and hopefully will provide the reader with an interesting exploration about science and its impact on nutritional value across a range of food crops.

14. Berries

Most berries contain sugars such as glucose, fructose and sucrose which contribute to their sweetness. All berries contain carotenoids, including components that are precursors of vitamin A. The levels of some vitamins are nutritionally significant e.g. blackcurrants can supply 40% NRV for vitamin K/100g. In addition, raspberries and strawberries can supply approximately 15-18% NRV for folate/100g *(McDougall & Stewart, 2012).*

Berries are best known for their accumulation of antioxidant components (mainly polyphenols, carotenoids and vitamin C) and have amongst the highest antioxidant capacity of commonly eaten foods. The amounts of these antioxidant components vary between berry species, between varieties, and can be influenced by growing conditions. For example, berry species differ greatly in their vitamin C content with blackcurrants containing levels that exceed the NRV in a single 100g portion. Carotenoids, in addition to those that act as precursors for vitamin A, contribute to the health benefits of berries *(Johnson, 2002).*

Total polyphenol content also can vary hugely between berry species, varieties and under different growing conditions. In addition, the levels of these antioxidant components can be heavily influenced by post-harvest treatments and processing *(Deighton et al., 2000)* so their levels must be validated in any product.

Although the primary driver for flavour in berries is sugar/acid balance, polyphenol components can influence taste or sensory perception. The presence of tannins, such as ellagitannins in raspberry or ellagitannins and proanthocyanins in strawberry, contributes the characteristic astringency of these berries *(de Freitas et al., 2012).* Flavonol components may also contribute the bitter undertones of certain berry taste profiles.

Berries have been implicated in health benefits relevant to a number of disease conditions. Much of the evidence has focused on the polyphenol components but other components (such as carotenoids, fibres and terpenes) may also have roles to play. It is clear that easy-to-measure criteria such as total antioxidant capacity, total phenolic content or total anthocyanin content may only be linked to efficacy in health benefits. Further research is only likely to extend the evidence for the health benefits associated with berry components *(McDougall & Stewart, 2012).*

The potential health benefits of berry consumption is now the subject of considerable investment by various bodies, public and private, following the success of the intervention programme in North Karelia, Finland *(Puska et al., 1990).* This initiative encouraged increased dietary intake of berries which then led to a reduction in the incidence of cardiovascular disease of around

60%. Berries, especially those with darker colours, are now sought by consumers globally due to the high antioxidant content *(Wu et al., 2004)* and the reported benefits on human health *(Stewart et al., 2007).*

The move towards higher quality fruit, with elevated content of specific components, is likely to remain for all berry fruit crops into the future. Already, cultivars are being selected solely on quality rather than agronomic traits by some end-users *(Brennan et al., 2008),* and as clinical evidence for the beneficial effects of berry fruit components on human health accumulates, the need by breeders to select appropriately enhanced phenotypes will increase accordingly. Fruit quality characteristics are key drivers for breeding programs and a greater under-standing of the processes and genes involved in quality will enable more targeted breeding in the future. Biotechnology has resulted in a fundamental shift in detecting and monitoring genetic variation in plant breeding and genetic studies. These advances have resulted in the development of genetic linkage maps and their use in variety development. Classical breeding, which selects parents and their desirable offspring based on an observable phenotype, is being integrated with techniques that can identify and manage genetic variability at the molecular level. The identification of quantitative trait loci (QTLs) and associated markers/genes linked to key traits is enabling breeders to select desirable phenotypes faster and with greater precision *(Brennan et al., 2008).*

As part of my research on berries I met up with Richard Harnden, Research Director for Berry Gardens and Rupert Hargreaves, owner of Hargreaves Plants. They both very kindly put me in touch with Dr Bruno Mezzetti who is the strawberry breeder at Ancona University in Italy. The programme started in 1993 with the aim of obtaining cultivars showing interesting agronomic characteristics. Great importance was given to the evaluation of fruit with improved nutritional quality (mainly total antioxidant capacity, Polyphenols, Anthocyanin, Vitamin C and Folate contents). With this aim they developed a breeding program involving wild genotype (F. *virginiana* ssp. *glauca*) and its back-crosses because of the high nutritional quality of such species. From this breeding program they have already licensed four strawberry varieties with high sensorial and nutritional attributes, cv. Sveva (2003), Adria (2003), Cristina (2010) and Romina (2010). These varieties have been involved in experimental studies to validate their high nutritional quality.

The study of offspring originating from different cross combinations showed that fruit nutritional quality can be considered an inheritable trait and that the variability of fruit nutritional quality among commercial cultivars can be improved by breeding.

Breeding and biotechnological approaches are currently used to increase the content of specific bioactive components of plants, but the manipulation of plant metabolism is still not easy to address. There is an increasing awareness that multiple genetic and environmental factors affect production and accumulation of bioactive compounds, but these factors are rarely taken into account when fruit is marketed. The assumption underlying 'functional fruit' is that bioactive compounds are efficacious for the improvement of health *(Finley, 2005).* The availability of high quality fruit (antioxidant-enriched), at an inexpensive and competitive price, will be a useful tool in the planning of healthy diets, especially when patients do not eat enough vegetables.

Consumers are now aware that consumption of fruits rich in health-promoting compounds is an appropriate strategy to enjoy their benefits, and the nutritional quality of fruit today is becoming an attribute as important as the organoleptic quality, even if it is still an extremely complex parameter.

Strawberry represents one of the most important sources of bioactive compounds with antioxidant activity, together with other berries. Several genetic and environmental factors affect the production and accumulation of bioactive compounds on strawberry fruits, and the effect of cultivar in affecting the nutritional quality of strawberry is well-known *(Wang & Millner, 2009).*

Black raspberry has not been studied in a great deal of detail within the UK and overseas. It is known to be a rich source of anthocyanins. Within the UK there are a number of raspberry breeding programmes that have looked to commercially exploit its potential health benefits by selecting new varieties suitable for the fresh market. Recently a UK retailer attempted to market "Black raspberry" too its customers, but the variety was quite small and had a short shelf life and as a consequence didn't look as appetizing as some of the conventional red raspberries. Research from around the world is highlighting the health benefits of black raspberry and that there is significant variability in the anthocyanin levels between varieties. We must remember that it must look attractive for the consumer and taste very good if they are to move to purchasing a new type of berry. The health benefits on their own aren't sufficient enough for consumers to change their habits.

In a study by PFR, New Zealand, they looked at the effects of blueberry consumption prior to exercise. The study has practical implications for all who turn to exercise and dietary antioxidant-rich supplements to maintain their health and performance. It is of potential relevance to all athletes who compete over successive days as well as to the general sporting community. Although the literature is divided as to the benefits of antioxidant supplements in affecting the initial muscle damage/inflammation and subsequent recovery of muscle function, this study supports the idea that blueberry consumption helped accelerate muscle repair and recovery of muscle strength. Follow-up studies are warranted with blueberry as a food to assist exercise and should focus upon dose and timing to ascertain important optimum parameters. Of interest also would be studies to determine whether repeated blueberry consumption with a specific exercise training strategy facilitates recovery between exercise sessions and/or improves the overall performance of athletes in competition *(McLeay, 2012).*

All this research is only going to further assist the soft fruit category, which is now the largest category in fresh produce sales within UK supermarkets. The blueberry category has been a phenomenal success over the last decade. A lot of this success was believed to be due to the health benefits, convenience and mass appeal of the fruit. If further research can show 'clinically proven' benefits of berries then I am confident that this category is only going to continue to grow. This will provide significant opportunities to UK producers as the majority of strawberries sold within the UK are grown by British producers and new research is already looking at further extensions to the UK season.

15. Blackcurrants

In September 2013 I made a visit to the headquarters of GlaxoSmithKline (GSK) to meet up with Rob Saunders and Dr Jonathan Gilkes who both work within R&D and specifically on the Ribena brand. In addition to visiting GSK I went to the James Hutton Institute (JHI) in Dundee to meet scientists working on a range of crops but also to meet Professor Derek Stewart and Dr Rex Brennan who manage a bespoke blackcurrant breeding programme for GSK. One of the interesting findings was that there are ten different blackcurrant varieties used to make Ribena.

Functional drinks containing enhanced levels of proven health-promoting bioactive compounds are receiving extensive interest. Food companies are currently focusing efforts on the development of functional drinks which contain significant amounts of distinct types of bioactive compounds, as the global functional drinks market is forecast to have a value of $62 billion by 2015, an increase of 29% since 2010 *(Anon, 2011).* Blackcurrants (*Ribes nigrum*) are widely grown for juice processing. However, it is reported that their anthocyanins are somewhat sensitive to process degradation *(Hollands et al., 2008),* and therefore some of the health beneficial properties may be lost during processing. Consequently, introducing additional anthocyanins into blackcurrant products from other sources is one strategy to maintain and/or increase health beneficial properties in blackcurrant juices and other products. As a result of their high and diverse anthocyanin content, wild berries are a very interesting source of incorporating polyphenols into blackcurrant and other berry products.

Crowberry (*Empetrum nigrum*) is a particularly interesting wild berry due to its high levels of different anthocyanins *(Koskela et al., 2010).* The data showed that adding crowberry containing different types of polyphenols into blackcurrant juice doubled the polyphenol content and improved glycaemic control in healthy subjects *(Torronema et al., 2008).*

Within the PFR program a lot of work is looking at sports nutrition. Most current sports nutrition products focus upon hydration, rehydration and energy supply. Scientists at PFR feel that some fruits, and in particular berries and currants, may be able to assist and promote physical wellbeing. Outcomes could be controlling stress, less muscle damage or pain, speedier recovery, train for longer and harder, enhanced performance and a reduced risk of infection. They would like to consider that berries and currants may enhance the natural benefits of exercise.

They have developed a platform for evaluation of human health benefits from exercise through feeding studies, and volunteers undergo exercise regimes. They developed two models:

- An oxidative stress type of exercise, rowing, in which volunteers row for 30 minutes maintaining a rowing rate that is at 80% of their maximal heart rate.
- A muscle damaging and repair model, in which volunteers perform 4 sets of 10 squats with weights to point of failure.

They evaluated the benefits of two powdered blackcurrant extracts from New Zealand. Research showed that consuming the blackcurrant powder markedly prevented the exercise-induced oxidative stress. Muscle damage was slowly increased in response to the exercise, as expected, and the blackcurrant extracts significantly impaired the oxidative stress response rate.

In another study by PFR they have shown that an extract of New Zealand blackcurrants enriched in anthocyanins can help people stay more alert, reduce mental fatigue and work with greater accuracy whilst under significant mental stress. In the randomised, double-blind study, 35 healthy young participants were asked to complete 70-minute computerised assessments designed to demand attention and to be mentally fatiguing. The trial found that, compared to placebo, after taking the extract from 'Just the Berries Limited' participants worked more accurately without slowing down, and felt more alert and less mentally-fatigued after the test.

"We know that there are compounds in dark berry fruits, like blackcurrants, that have real effects on people's health and wellbeing," says Dr Arjan Scheepens, the study leader. *"We found that, compared to a placebo, taking an enriched blackcurrant extract before performing stressful mental tests helped trial participants maintain accuracy, and that their mental fatigue was significantly reduced. Our next stage is to identify exactly which compounds are creating this effect, and using this knowledge to develop new whole and processed foods or ingredients that deliver optimised performance."*

Just the Berries have since launched the product in May 2013 under the brand delcyan™ and market it as both a validated functional food ingredient and as a consumer product.

Another aspect of research has been assessed to look at the effects of fungicides on the nutritional value of certain crops. In addition to their antifungal activities, the strobilurin group of fungicides have been shown to modulate plant physiology and biochemistry, resulting in yield increases and improvements in crop quality. It has been suggested that many of the impacts of strobilurin fungicides are related to their capacity to alter antioxidant metabolism in plant tissues via effects on the mitochondrial electron transport chain *(Nwankno et al., 2011).*

Given the well-documented impact of strobilurins on product quality and antioxidant systems in cereals, a study was undertaken to determine the impact of fungicide treatment on blackcurrant fruit quality *(Nwankno et al., 2011).* The study looked at the impacts of fungicide treatment on antioxidant compounds in addition to other key quality parameters including sugars and organic acids. There was an indication that fungicide application could improve juice quality with respect to both sensory characteristics and potential health benefits of juice consumption. The observation that phytochemical impacts were dependent on harvest year and previous application suggests an interaction between fungicide treatment and growing environment, and the potential for additive effects which require further investigation *(Nwankno et al., 2011).*

This example shows the impacts of agronomic practice on the overall product quality. With close collaboration with your customer, examples like this can benefit the whole supply chain, particularly in crops where the producer is paid on the quality produced.

This research poses some interesting opportunities. Currently Ribena is a mainstream brand and GSK use 10 different blackcurrant varieties to produce a consistent product. In the future it could be possible to produce a more functional blackcurrant drink that is based on a single variety of blackcurrant, possibly bred by JHI. This type of concept has been done in New Zealand, will the UK follow? If it does then it will produce an interesting opportunity for UK growers to produce a more functional blackcurrant crop.

Within the blackcurrant category the Blackcurrant Foundation website has posted some interesting information and below I have included two tables. The first, **Figure 12** comes from the 'Superfruit' wheel and compares the %NRV per 100g for a range of fruit crops. **Figure 13** looks at antioxidants and the impact on key health areas.

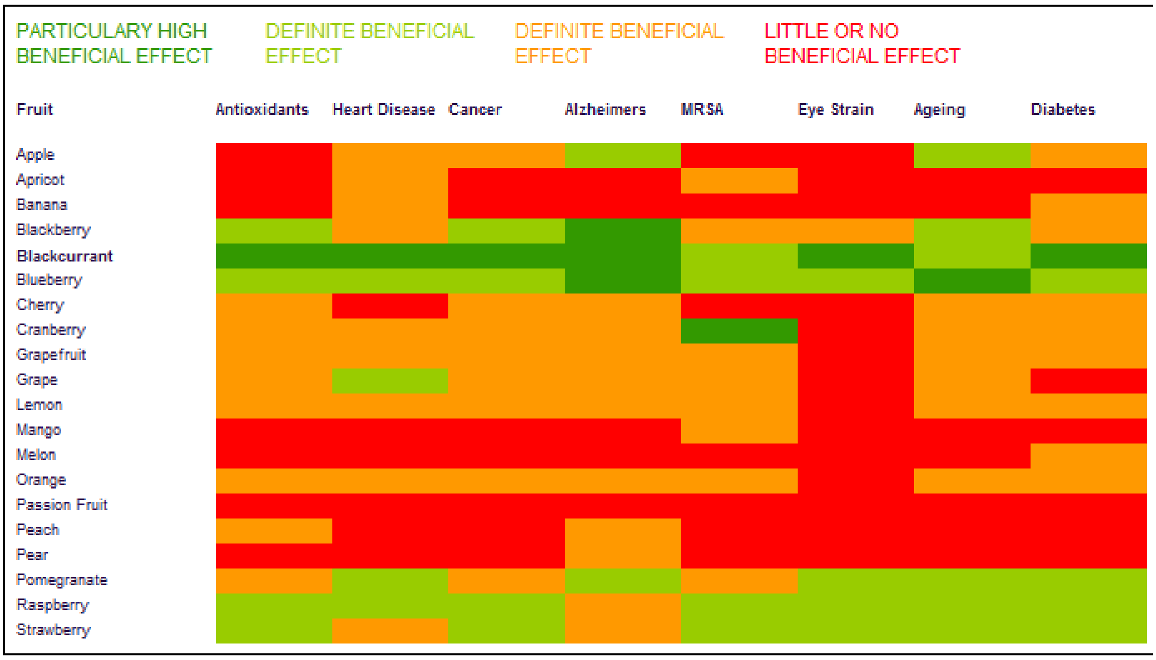
Figures 12 & 13 (13 is on next page) highlight the power of the internet in modern day living and show that customers have never had so much information readily available to them. The challenge is ensuring that the information that we provide them with is from trusted sources. We need to understand how this can benefit the farmer and the rest of the supply chain in a joined up fashion.

Figure 12 : "Superfruits" % NRV per 100g

HIGH LEVEL   MODERATE LEVEL   LITTLE OR NONE PRESENT

Fruit	Energy	Fibre	Vit C	Vit B2	Vit E	Vit K	Calcium	Iron	Phosph.	Potass.	Selen.	Zinc
Apple	9.2	12.8	37.5	0.8	14.3	100	0.4	1.1	1.9	3.7	100	0.0
Apricot	6.8	11.7	12.5	4.2	14.3	0.0	2.0	8.8	4.4	8.1	0.0	4.6
Banana	16.6	15.0	25.0	2.5	8.6	30.0	0.7	4.4	5.5	10.2	100	trace
Blackberry	7.7	23.9	37.5	0.0	25.7	0.0	3.9	5.5	7.5	7.6	100	4.6
Blackcurrant	8.8	32.2	100	5.8	62.9	100	10.3	13.3	11.7	9.7	100	4.6
Blueberry	9.1	46.7	25.0	2.5	54.3	100	2.7	6.6	4.0	3.1	100	3.1
Cherry	9.8	6.7	25.0	1.7	2.9	100	2.9	5.5	3.2	7.1	100	1.5
Cranberry	3	23.3	37.5	0.8	0.0	100	3.7	4.4	4.2	0.7	100	3.1
Grapefruit	5.7	7.8	100	1.7	14.3	trace	3.0	1.1	4.0	4.7	trace	trace
Grape	12.2	12.2	7.5	0.8	17.1	100	2.0	3.3	1.8	5.8	100	trace
Lemon	2.3	10.0	100	1.7	22.9	20.0	1.4	1.1	1.8	5.5	trace	trace
Mango	4.3	5.6	100	5.0	28.6	0.0	2.0	2.2	4.6	4.1	trace	trace
Melon	5.4	3.3	80.0	1.7	5.7	100	1.1	trace	2.4	6.1	100	trace
Orange	8.8	10.0	100	2.5	2.9	0.0	5.3	1.1	3.6	4.4	100	trace
Passion Fruit	7.0	18.3	57.5	10.0	14.3	40.0	0.6	2.2	2.6	7.9	100	trace
Peach	6.7	7.8	17.5	1.7	20.9	100	0.6	2.2	2.4	5.1	100	trace
Pear	8.9	11.7	10.0	0.8	2.9	100	0.9	1.1	2.2	3.2	100	trace
Pomegranate	15.2	18.9	17.5	1.7	17.1	100	0.4	3.3	1.6	7.4	100	1.8
Raspberry	6.3	20.6	95.0	5.8	25.7	100	5.0	12.2	7.5	6.3	100	6.2
Strawberry	4.4	12.2	100	2.5	11.4	100	2.1	5.5	5.5	5.2	100	trace

Figure 13 : Antioxidant and impact on key health areas



16. Tomatoes

Tomato fruits are an important dietary source of antioxidants for humans due both to the high intrinsic levels of these compounds and the high consumption by the western population. The main antioxidants found in tomato fruits are ascorbic acid (vitamin C), lycopene, carotenoids, phenolics, and vitamin E *(Frusciante et al., 2007).* Tomatoes have the potential to be one of the greatest benefits to the human diet as they are the most important crop in the world by volume consumed and are part of so many meals that we eat.

Shelf life is an important quality trait for many fruits, including tomatoes. A recent report *(Zhang et al., 2013)* showed that enrichment of anthocyanin, a natural pigment, in tomatoes can significantly extend shelf life. Processes late in the ripening process are suppressed by anthocyanin accumulation, and susceptibility to *Botrytis cinerea*, one of the most important post-harvest pathogens, is reduced in purple tomato fruit. They showed that reduced susceptibility to *B. cinerea* is dependent specifically on the accumulation of anthocyanins. The increased antioxidant capacity of purple fruit likely slows the processes of over-ripening. Enhancing the levels of natural antioxidants in tomato provides a novel strategy for extending shelf life by conventional breeding or genetic engineering.

One of the interesting discussions during my Nuffield Farming study arose during a meeting with a major multinational business. The question posed was "How do you make money out of health and nutrition?" This is a question that business has been pondering for a number of years. Fruit and vegetables are inherently healthy and how will it resonate with consumers if you have something even-healthier? The view was that it may not be a trait to command a premium from, but what if the whole market shifts to focus on this trait? Then it could just be about protecting your market share within that crop.

An interesting example of this is high lycopene tomatoes. This nutritional trait also gives tomatoes a more intense coloration, and consumers like these varieties due to the fact that they have better appearance on shelf and don't look pale and under-ripe. The fact that high lycopene could be better for us was secondary in the purchasing priorities of the consumer, especially because the majority of consumers don't understand what high lycopene means. This is also due to the fact that 'high lycopene' isn't a health claim that could be acceptable under current EFSA (European Food Safety Authority) rules within the EU. However, for the consumer they are getting these health benefits because more of the new tomato varieties have intense coloration due to high lycopene. This is my first example of 'Health by Stealth' and I expect this to occur in many categories.

Like so many things in life we must focus on the commerciality of what we are doing. Within the same meeting we discussed the following two scenarios:

> Use conventional breeding to produce a vine tomato but with the intense flavour of a baby plum tomato with the associated higher sugars and bioactives.

> Use conventional breeding to produce a vine tomato with 50% more vitamin C than the standard vine tomatoes.

Which breeding target should we focus on and which one is the more commercial proposition? The reality is that in any business our budgets are limited and we need to focus on research and development (R&D) that we believe will deliver the best commercial pay-back. In fresh produce it is worth considering how the profit gets split down the chain. If you are plant breeder then you will need to sell a certain quantity of seed to offset the cost of breeding that new variety. So in the initial R&D brainstorming you will want to focus on the areas where you believe you can make the biggest wins to ensure the business is profitable and hence sustainable. It is only after you have good sales on core lines that you can consider developing more niche options.

Beauty will be a key trend for Hazera Genetics in the future. The Israel-based seed breeder is aiming to develop peppers and tomatoes with high levels of vitamin E, which has been proven to improve skin. The recent 'ACE' pepper, high in vitamins A, C and E, will come under the beauty driver, as will other products in the Hazera Lifestyle range, including high-lycopene tomatoes.

Dr Alon Haberfeld, tomato product manager at Hazera, said the following: "We know that antioxidants and vitamin E are good for our skin and consumption should reinforce that. A lot of research on the effect of vitamin E on the skin is being carried out because we have to make sure it is scientifically viable before we can make any claims. But a couple of years' more research needs to be done".

"If you can tell your daughter to eat fruit and vegetables because they are good for you it is one thing, but you could get a better response if you tell her it will make her pretty," he added. *"The only fresh product that is naturally high in vitamin E is the pepper and, while you can get the vitamin from meat and nuts, their fat content is also high*."

The UK is involved in lots of tomato crop research. My study highlighted strong collaboration between many institutes including the John Innes Centre, Nottingham University and Royal Holloway University. These organisations are working collaboratively with a number of industry partners. I visited all these organisations. Much of the work is being done by classical breeding but modern equipment and the use of metabolomics are providing new information that will undoubtedly mean that tomatoes could be the model crop for optimised nutritional value in the future.

Research at Royal Holloway is looking at the production of the ketocarotenoids (astaxanthin) in tomatoes. Astaxanthin is used as a colorant in feed within the salmon and poultry industry. Currently it represents 20% of the total cost of aquaculture and is produced by chemical synthesis ultimately relying on crude oil.

Figures 14 & 15 show a GM tomato plant with increased levels of astaxanthin. As you can see the production of this ketocarotenoid is so high that it has changed the entire colouration of the plant.

Figure 14: GM tomato plant with increased levels of astaxanthin

Figure 15: GM tomato plant with increased levels of astaxanthin

These are the types of development that could lead to a more sustainable future and provide opportunities for new types of high value functional crops and reducing our reliance on non-renewable sources of energy.

However, it brings us back to the question of: will GM foods be accepted within the EU?

17. Brassicas

Brassicas are rich in antioxidants; 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 synthesized 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 antioxidants.

Broccoli contains one of these natural compounds, called glucoraphanin. The Institute of Food Research (IFR) has been working with the John Innes Centre (JIC) and Seminis seeds (Monsanto) for many years developing a new range of broccoli called Beneforte. From identifying a high-glucoraphanin broccoli relative in the 1980s, it has taken many years of plant breeding, field trials and studies into potential health benefits to deliver Beneforte broccoli to the consumer. **Beneforte has even more of a good thing as it contains 2-3 times more glucoraphanin than standard broccoli varieties.**

As part of my study I visited Sicily in January 2014 where the wild type broccoli with high levels of glucoraphanin was originally found. I met researchers at Catania University where they are researching the local land races and trying to understand their nutritional benefits. The local population really enjoys the vegetables from the locally produced land races. They are using more wild type crops in breeding to try and incorporate these traits into commercial crops. The researchers are keen to see how they can exploit opportunities for future development with seedhouses using their native land races. Although it will take a long time, this approach is likely to produce more varieties along the lines of the Beneforte broccoli.

Dietary studies suggest that having regular intake of the glucosinolates may help our bodies to keep functioning well. When we eat glucosinolates they are converted into chemicals known as isothiocyanates. In our digestive system, this is converted to an isothiocyanate called sulphoraphane. Sulphoraphane enters our bodies' cells and switches on our 'antioxidant' genes. These genes are part of our natural defence system which helps to protect us from environmental toxins but are also important in ensuring that we can combat a wide range of common diseases and keep us healthy as we get older.

As well as the increased levels of glucoraphanin, Beneforte also contains all of the nutrients found in standard broccoli varieties. Broccoli is high in fibre and a good source of vitamins A and C, as well as folate and calcium. The strongest evidence for the health-protecting effects of eating certain foods comes from **human intervention trials,** where a group of human volunteers have their diet supplemented with the food being tested and the effects compared with a similar group who do not receive the supplementation.

IFR has conducted a small-scale human intervention trial. This observational study was in men at risk of developing prostate cancer and showed there were more positive changes in gene expression amongst men who were on the broccoli-rich diet, and these changes may be associated with the reduction in the risk of developing prostate cancer. IFR is now carrying out a much larger study, funded by the Prostate Cancer Foundation looking at the protective effects of broccoli consumption against prostate cancer.

IFR is still carrying out research to work out how much we need to eat to get the health benefits. Some studies suggest we need to eat the equivalent of one portion of ordinary broccoli every day, while other studies suggest we can eat less. This may be because the levels of glucoraphanin in broccoli can be quite variable. This is why they developed Beneforte broccoli, to guarantee that you get your glucoraphanin.

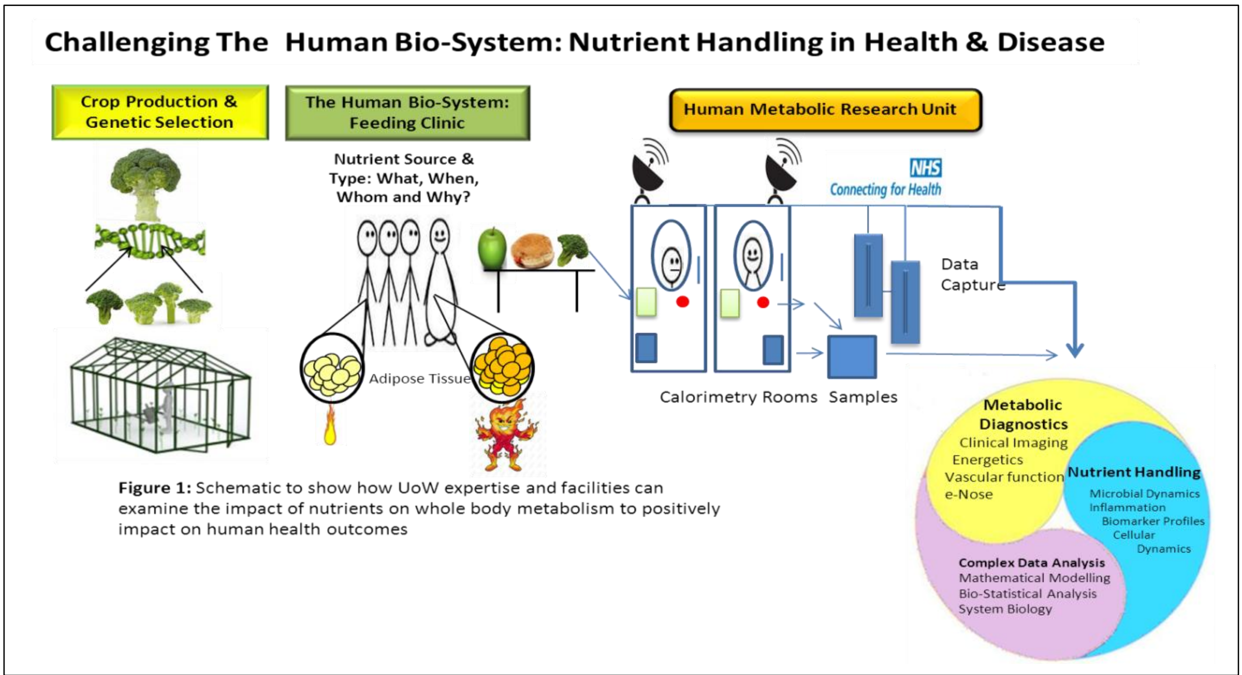
Beneforte broccoli is still relatively new in the UK retail market with Marks & Spencer being the first UK retailer to launch the product. What is unclear at these early stages is: will Beneforte be the 'normal but better' new benchmark for broccoli in the UK or will it remain a niche at a premium retail price? It has the potential to deliver in a 'Health by Stealth' strategy, but will the economics work through the supply chain?

Warwick University has recently started a project with the aim of building a strategic, multi-departmental, collaborative team able to formulate an optimal 'Functional food' and to examine its impact to improve metabolic function and energy expenditure with direct human health application. In their initial work they will be using a broccoli hybrid developed by the University. **Figure 16 (below)** shows the systems approach that they will be using.

Not everybody is willing to purchase fresh broccoli so it was great to hear about research being undertaken at Illinois University looking at ways to improve the nutritional value of frozen broccoli. I was very kindly put in touch with Professor Elizabeth Jeffery at Illinois University and was able to discuss her work on broccoli via Skype!

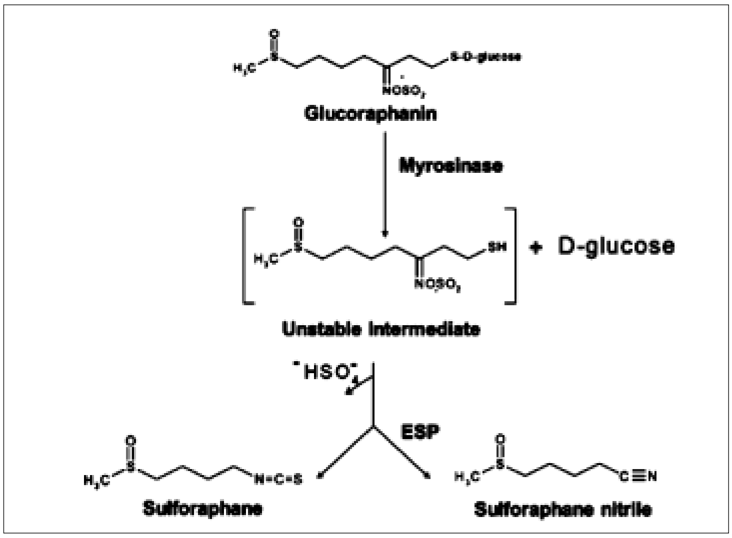
Commercially frozen vegetables undergo blanching prior to freezing, a process utilising hot water or steam to inactivate enzymes that otherwise cause degradative changes, limiting

Figure 16: Warwick University systems approach



shelf life severely *(Andress & Harrison, 2006).* With an increase in blanching time and temperature, not only does the cost increase, but there is also greater loss of nutrient content *(Lim et al., 1989).* This suggests a potential benefit in the use of lower temperatures during processing. Nutrient availability from foods is sometimes dependent upon enzymatic activity, requiring a balance between destruction of enzymes with negative impact on food quality, while maintaining beneficial enzymes. An example is seen in the broccoli enzyme myrosinase, which releases bioactive sulforaphane from its parent glycoside glucoraphanin *(Jeffery & Keck 2008).* This thermally labile enzyme shows 90% degradation when held at 60°C for 10 minutes *(Van Eylen et al., 2007).* Yet typical blanching protocols for processing broccoli prior to freezing often exceed the limit of myrosinase stability *(Lund, 1977).*

Figure 17 : Biochemical pathway showing the production of Sulforaphane. (Image courtesy of Jeffery & Keck, 2008)



In the project they blanched and froze broccoli in a manner typical of commercial blanching protocols, and determined that decreasing the blanching temperature by 20° still successfully inactivates (>93%) the degradative enzyme lipoxygenase, while leaving active the majority (>87%) of peroxidase. This change in temperature protocol also preserved 82% of broccoli's capability to form sulforaphane. The addition of daikon radish (0.25% or 0.5%) as an external source of myrosinase yielded 74% of the sulforaphane, even after microwave cooking. Visually, the addition of 0.25% or 0.5% radish resulted in no change in appearance compared to no radish *(Dosz & Jeffery, 2013).* Furthermore, current studies show that myrosinase activity is stable under frozen storage at −20°C for at least 90 days *(Rungapametsry et al., 2008).* A sensory study should be performed to confirm the palatability of the broccoli after the addition of different amounts of radish.

Recent research *(Ku et al., 2013)* has looked at the effect of pre-harvest methyl jasmonate (MeJA) and post-harvest 1-methylcyclopropene (1-MCP) treatments on broccoli floret glucosinolate concentrations and quinone reductase (QR, an *in vitro* anti-cancer biomarker). Activity was evaluated two days prior to harvest, at harvest and at 10, 20, and 30 days of post-harvest storage at 4°C.

MeJA treatments four days prior to harvest of broccoli heads was observed to significantly increase the glucosinolate levels in florets but also increased ethylene biosynthesis resulting in chlorophyll catabolism during post-harvest storage and so reduced product quality.

Post-harvest treatment with 1-methylcyclopropene (1-MCP), which competitively binds to protein ethylene receptors, maintained post-harvest floret chlorophyll concentrations and product visual quality in both control and MeJA-treated broccoli. This research showed that the **combination** of a pre-harvest MeJA treatment which increased the glucosinolate levels in the broccoli floret and the post-harvest 1-MCP treatment which prevented the ethylene biosynthesis maintained the enhanced glucosinolate levels meaning that we can improve the nutritional value to consumers.

This work conducted by Professor Elizabeth Jeffery and her team highlights that in future product development there could be synergies between different crops that will improve the nutritional value of the overall food and that pre- and post-harvest technology can also play a significant role in improving the nutritional value of the crop.

With so much of this work we shouldn't underestimate the importance of marketing. Waitrose launched the 'Kid friendly' Brussels sprouts in December 2013 (See **Figure 18 & 19**). The message was that these Brussels sprouts were sweeter, making them more appealing to children. The reality was that Waitrose, through working with key seedhouses and its farmers, had selected varieties that were lower in glucosinolates. This meant they had less perceived bitterness and hence they were perceived to be sweeter by consumers. However, if Waitrose had marketed them as "Lower Glucosinolate" Brussel sprouts they would have not attracted so much attention and this wouldn't have been appealing to children. Even though they were lower in glucosinolates these varieties still had good levels of the other minerals that we would expect in this crop.

There is a great opportunity to further develop this market and, as so many Brussels sprouts are grown in the UK, then the opportunity exists through the British supply chain.

Figures 18 & 19: Brussels sprout marketing by Waitrose (December 2013)

18. Apples

The fruit of the domestic apple (*Malus* x *domestica*) is a popular and important source of nutrients, and is considered one of the top 'functional foods'. The pigmentation of typical red apple fruits results from accumulation of anthocyanin in the skin. However, numerous genotypes of *Malus* are known that synthesise anthocyanin in additional fruit tissues including the core and cortex (flesh) (**Figure 20**). Red-fleshed apple genotypes are an attractive starting point for development of novel varieties for consumption and nutraceutical use through traditional breeding and biotechnology *(Nocker et al., 2012).*

Figure 20 : Red-fleshed apple

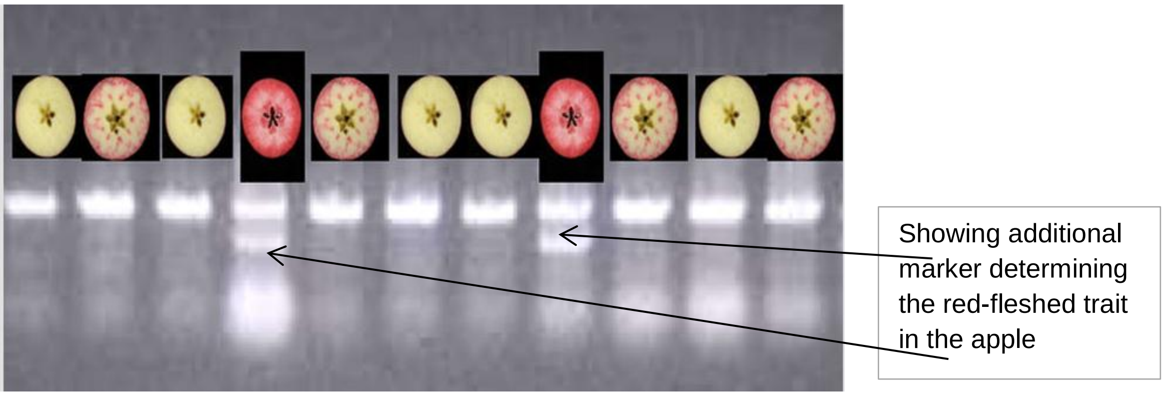
The scientists at PFR were particularly interested in red-fleshed apples because of their possible health benefits. Apples are healthy anyway (they are high in vitamins and antioxidants and are associated with reduced risk of some diseases), but it's possible that red-fleshed apples could be even healthier. This is because anthocyanins are present in large amounts in red-fleshed apples (a several hundred-fold increase in red flesh compared with white flesh). So is it likely that red-fleshed apples will have a greater health benefit than white-fleshed apples? Well, it's difficult to predict, but what can be shown is that these red-fleshed apples have an increase in anthocyanins, and if we think that anthocyanins are likely to be good for us, then that has to be a good thing.

Researchers at PFR and other breeders have identified a large number of DNA markers within the apple genome. These short sequences of DNA act as signposts and can give researchers information about functional DNA sequences nearby. Markers can provide information about which allele(s) of a gene a seedling probably carries. For instance, there is a marker for red flesh, which is very closely linked to the gene shown by PFR scientists to control apple flesh colour. Scientists can use the marker to tell which allele(s) of the gene a seedling probably carries and therefore whether it will produce red-fleshed apples. PFR scientists also use markers to check whether seedlings have disease-resistance alleles.

Some markers are known to be associated with complex traits (such as apple firmness), which are usually controlled by several genes. However, the genetic basis of complex traits is not yet well understood.

Figure 21 (Marker assisted selection in apples) – see next page - shows that the two red-fleshed apples have different markers to the rest of the population and this enables them to be detected at a laboratory level rather than having to grow trees to establish whether they are red-fleshed or not. This enables the plant breeder to speed up the process and only plant out trees that they know possess the red-fleshed trait.

Red-fleshed apples haven't yet reached the consumer; however, when they do they could arrive in many forms. We could have fresh apples, apple pies, apple juices, apple ciders as well as opportunities in prepared fruit.



In addition to PFR there are many other breeding programmes developing this fruit and I am sure it won't be long before consumers see these new products.

What has also become apparent in the apple business is that, in selecting for size, crunchiness, storability and other commercial attributes, we have inadvertently been eroding the nutritional value of the fruit. This may be because many of the polyphenols have bitter or acidic attributes, but this doesn't explain it entirely *(Paynter, pers comm., 2013).*

A voluntary organization, the Tree Crops Association in NZ, tested every variety they could get their hands on and reported on this information in 2006. **Figure 22 (on next page)** provides some interesting results.

Many heritage or cider apples have very high levels of antioxidants relative to their commercial peers. With some improvements in texture it could be possible to produce a commercial apple with 3 or 4 times the levels of key compounds. The two most promising polyphenols are epicatechins and procyanidins. The latter have some quite powerful anti-cancer properties. Most of these compounds have low levels of bioavailability for humans but there are still some clear impacts on the digestive tract that are exciting, particularly with regard to colon cancer. Curiously it seems bioavailability may improve when taken with alcohol, which apart from being great news, has some real positives for the cider industry *(Paynter, pers comm., 2013)!*

An interesting finding is that antioxidants seem to increase with controlled levels of stress on the tree, but a relative assessment can still be made at a young tree age. The next age of breeding will not just be focused on better commercial apples but those that are better for you *(Paynter, pers comm., 2013).*

What we can see from the data in **Figure 22 (on next page)** is that for the plant breeder there is value in maintaining a wider range of germplasm as trends change over time and in the case of apples the differences in skin and flesh total phenolics could be valuable in future apple breeding.

Throughout the world there are a number of plant breeders looking at red-fleshed apples. The challenge is getting these higher levels of anthocyanins into varieties with good appearance, texture and most importantly flavour. If all these targets can be met with the appropriate agronomic traits then there is a huge opportunity for this fruit. If all of this can be achieved then the old adage of **'Eat an apple a day, keep the doctor away'** could have even more clinical significance to consumers.

(see chart on next page)

Figure 22 : Comparison of the top NZ apples cultivars against other commercial cultivars

	Total Phenolics							
	Skin (µg/cm²)				**Flesh** (µg/g FW)			
Commercially Grown*	**Hawkes Bay**	**Nelson**	**Central Otago**	**Mean**	**Hawkes Bay**	**Nelson**	**Central Otago**	**Mean**
Braeburn	319	467	274	**348**	337	395	388	**368**
Cox's Orange	208	231	392	**277**	578	448	565	**530**
Granny Smith	278	307	510	**330**	485	533	998	**597**
Pacific Beauty	550	546	543	**546**	816	630	1001	**815**
Pacific Queen	292	666	720	**612**	719	775	1103	**895**
Pacific Rose	439	479	665	**500**	819	735	1089	**840**
Pink Lady	306	305	471	**376**	395	489	728	**564**
Red Delicious	750	861	808	**806**	864	832	750	**815**
Royal Gala	484	380	461	**441**	556	485	610	**550**
Jazz	442	460	427	**443**	582	444	590	**544**
Mean	***423***	***539***	***543***	***497***	***590***	***579***	***752***	***638***
Top Cultivars Tested								
Otoko House No.1				**1832**				**6657**
Monty's Surprise				**1676**				**3773**
Fuero Rous				**1664**				**11078**
Knotted Kernel				**1534**				**11586**
Hetlina				**1475**				**4154**
Otoko House No.2				**1432**				**4882**
Bisquet				**1358**				**11305**
Makaranui Apple				**1155**				**3420**
C'huero Ru Bienn				**963**				**8747**
Sweet Alford				**734**				**4707**
Commercially Grown Mean				***497***				***638***
Monty's Surprise Comparison				**1676**				**3773**
Factor Difference				***3.4***				***5.9***

19. Oats

Oats are a multifunctional crop with end uses as healthy human food, high quality animal feed or a grain with industrial applications. The health benefits of oats are increasingly recognised and are the subject of a recent EU health claim for reducing the risk of coronary heart disease, primarily due to the soluble fibre beta-glucan found in oat grain. Increasing the levels of beta-glucan in both spring and winter husked oats whilst improving agronomic performance is a current breeding target. Various studies have shown a satiety effect when eating oats. In a society where obesity is contributing to numerous health problems this is an area of considerable public interest. Understanding the mechanisms involved in this process is an important step in identifying traits associated with this effect and how selection for these traits might be incorporated into the breeding programme *(Green, 2013).*

Oats are also recognised as a high value animal feed. Considerable progress has been made in the development of high yielding, high oil, naked oat varieties that have a good oil and protein content with a good distribution of the essential amino acids that are particularly suited for inclusion in poultry rations.

Aberystwyth University has been breeding oats since the formation of the Welsh Plant Breeding Station in 1919. They have developed molecular markers associated with a number of key traits including grain oil, beta-glucan content, flowering time and height and these are being used to tailor varieties to specific end-users.

'Ready to Eat' cereals may still be the dominant feature of the cereal aisle in supermarkets, but it is porridge and particularly the instant brands which are setting the growth trends. The healthy credentials of oats are very much in line with consumer trends and have led to gluten-free varieties of porridge and mueslis being launched aimed at coeliac disease sufferers.

Figure 23 (below) is an example of recent marketing of the benefits of oat-based porridge in your diet.

Figure 24 : Impact of "Oatso Simple" on overall cereal market share

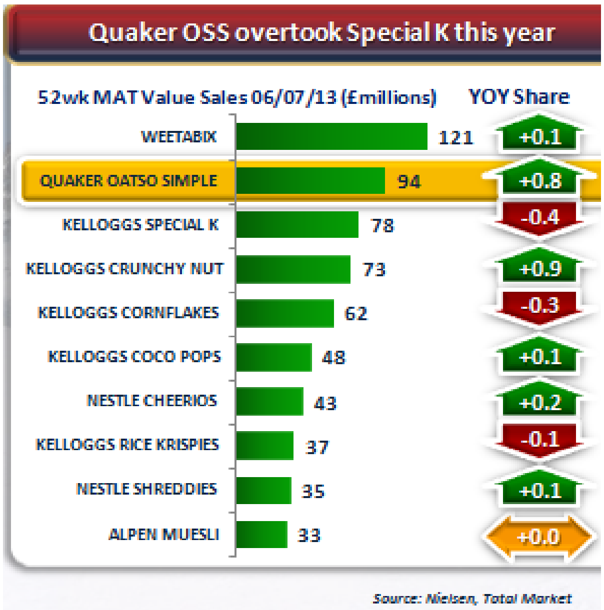


Figure 25 : Value change in Quaker porridge sales

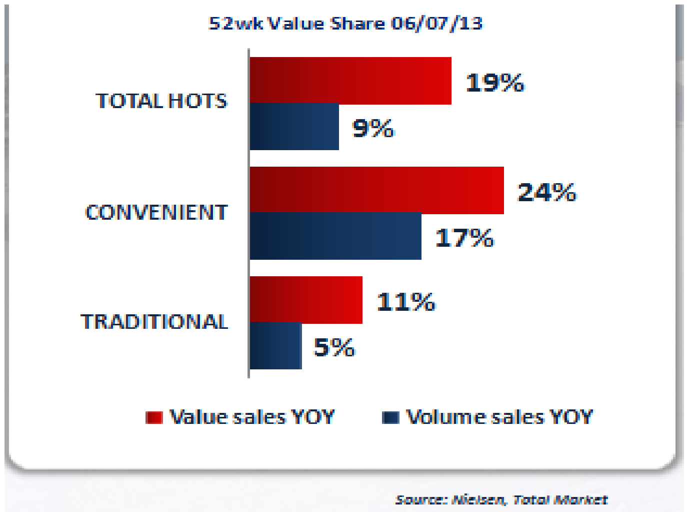


Figure 24 shows data from Nielsen on the market share of the big breakfast cereal brands. Quaker Oatso Simple achieved significant market share gains over that 52-week period and is now only second to Weetabix in value market share.

Figure 25 shows where the growth in the category has been occurring. Porridge has continued to deliver good value and volume growth. However, what you can see is that most of the growth is now occurring in the convenience segment. The convenience segment means the 'pots' and 'sachets' that are now available. There is big growth in 'Out of Home' breakfast occasions; people are now making their own porridge at work and the convenience formats are driving this.

Bear in mind that the traditional format of porridge in boxes is a mature product and this is still achieving significant value and volume growth. So overall being involved in the oat supply chain should be positive.

Oats and components of oats have the potential to positively impact our health. In the EU approved health claims are required to communicate specific health benefits of foods and ingredients to consumers. The role of oat β-glucan in modifying cholesterol levels and glucose responses, and of oat fibre in improving faecal bulk are approved health claims. Further clinical studies that meet EFSA criteria are required to support the role of oats in influencing satiety and weight management. Oat phytochemicals are associated with anti-inflammatory and antioxidant activity; however it is a challenge to confirm their effects in clinical trials and thus to achieve health claims.

Research by Campden BRI has established that a health claim has more chance of being accepted by consumers if consumers are familiar with the functional ingredient and/or the base carrier and together they convey a message of naturalness. Consumers are more likely to take notice of health messages, including nutrient and health claims, if they resonate with their personal circumstances. Claims need to use easy to understand, nonscientific language. Consumers are more familiar with 'risk reduction' claims than 'function' claims. Consumers don't necessarily recognise or understand the functional ingredient providing the health benefit.

Note the power of words: 'clinically proven', 'actively lowers' and 'proven'.

The words 'clinically proven to' were considered more powerful and credible than the words 'proven to' because it gave the impression that research had been conducted at a hospital, the assumption being that research carried out at a hospital must be scientifically robust and adhere to rigorous testing protocols to ensure that the product works before being launched on the market.

In 2013, Campden BRI conducted a consumers' preference for health and/or nutrition claims on breakfast cereal packs. Participants were given eleven statements that are typically found on breakfast cereal packs. They consisted of seven nutrition claims, three claims and a Guideline Daily Allowance (GDA) statement. Participants were instructed to select five statements that were most important to them.

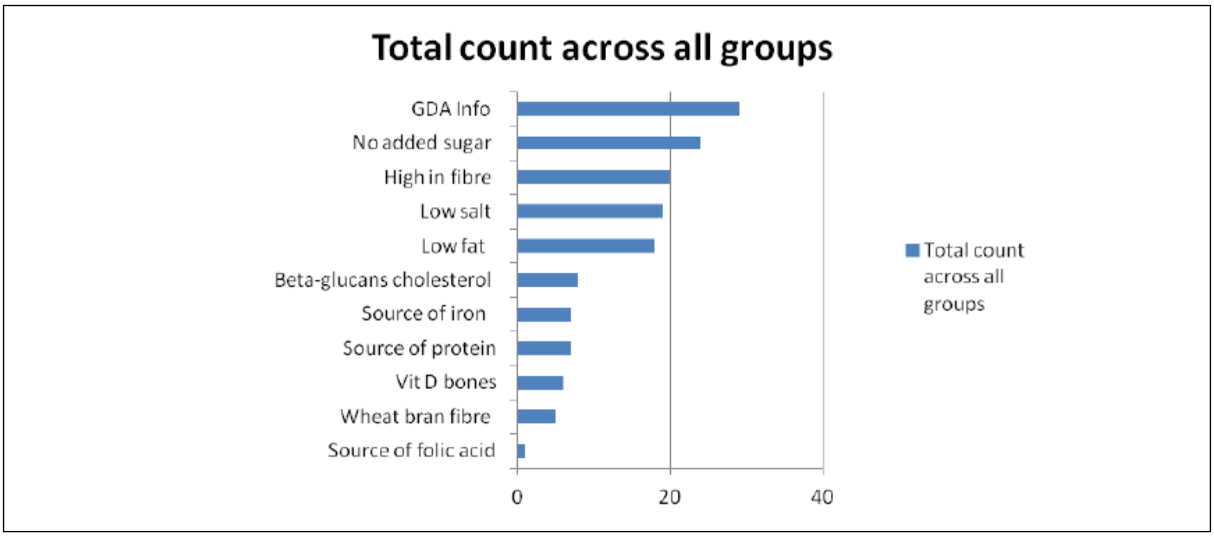
Figure 26 shows that the majority of participants (29 of 36) selected the GDA display as one of the most important statements to go on the front of a cereal pack. This is because it presents a summary of the main nutrients consumers are most concerned about (fat, sugar and salt content) in an easy to read and understand format.

Two of the health claims *'consumption of beta-glucans from oats contribute to the maintenance of normal blood cholesterol levels'* and *'source of vitamin D to help build strong bones'* were mainly selected due to personal relevance.

This research highlights again that the simplest messages are the most effective. Overall, consumers are more aware of and see the relevance of nutrition claims on packaging rather than health claims.

There is discord between the stringent controls enforced by EFSA regarding the use of health claims and the perception and interpretation of these claims by consumers. In order to improve health it is important that evidence continues to be generated to support new health claims, but also that this evidence is understood by consumers. Dialogue between nutritionists, product

Figure 26 : Count Data for each statement selected across all groups (*Campden BRI,2013)*

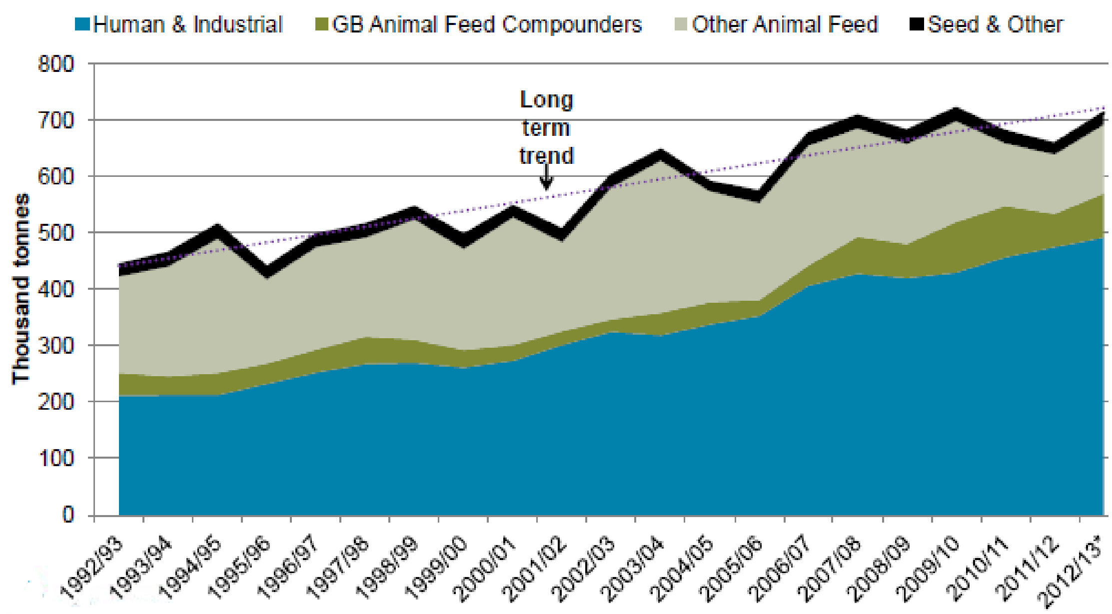


developers and consumer researchers may help to bridge this gap.

Figure 27 (below) is data from the AHDB showing the increased production of oats from 1992 – 2013 in the UK.

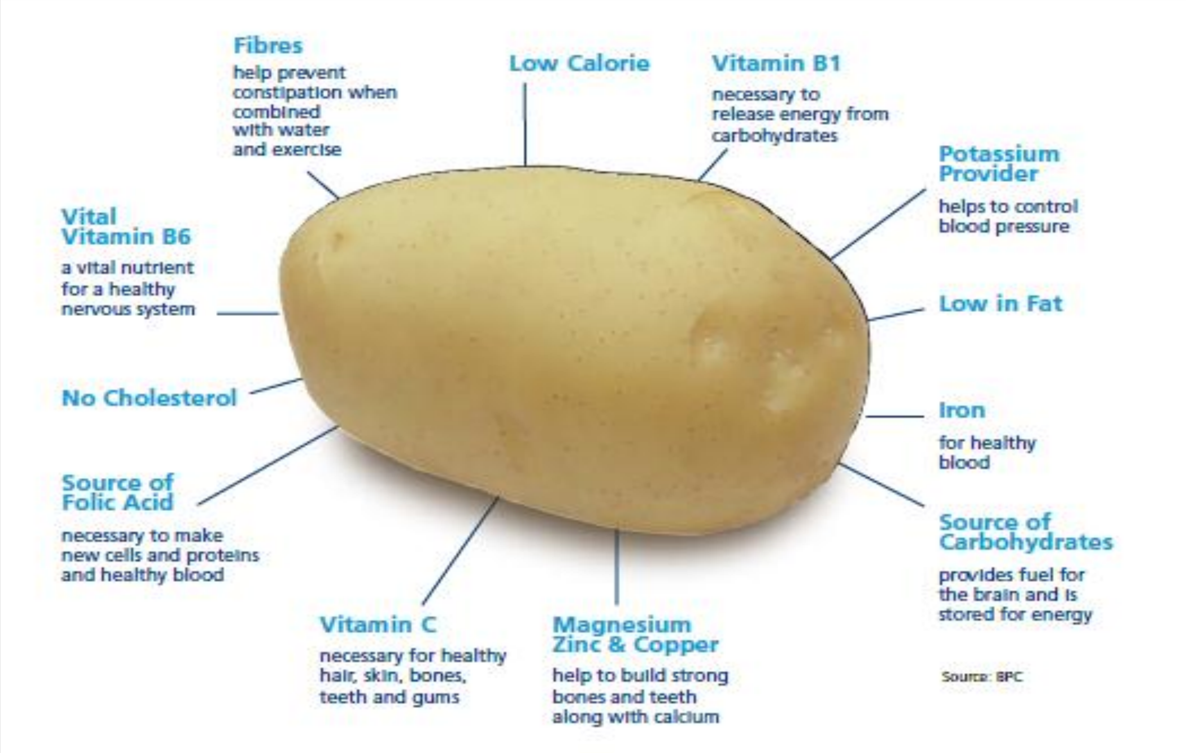
2013 was an unusual year because, due to the 2012 weather conditions, more oats were planted in spring 2013 and as a result 2013 was the biggest UK oat harvest for 40 years. What is encouraging is the steady rise in volume required for human consumption. It is worth bearing in mind that oats still only contribute 3% of all cereals grown in the UK, so the crop is still quite limited in terms of overall cereals.

Figure 27 : UK production of oats 1992-2013 (*Source AHDB*)



20. Potatoes

Figure 28 : The nutritional facts on potatoes (Source BPC).



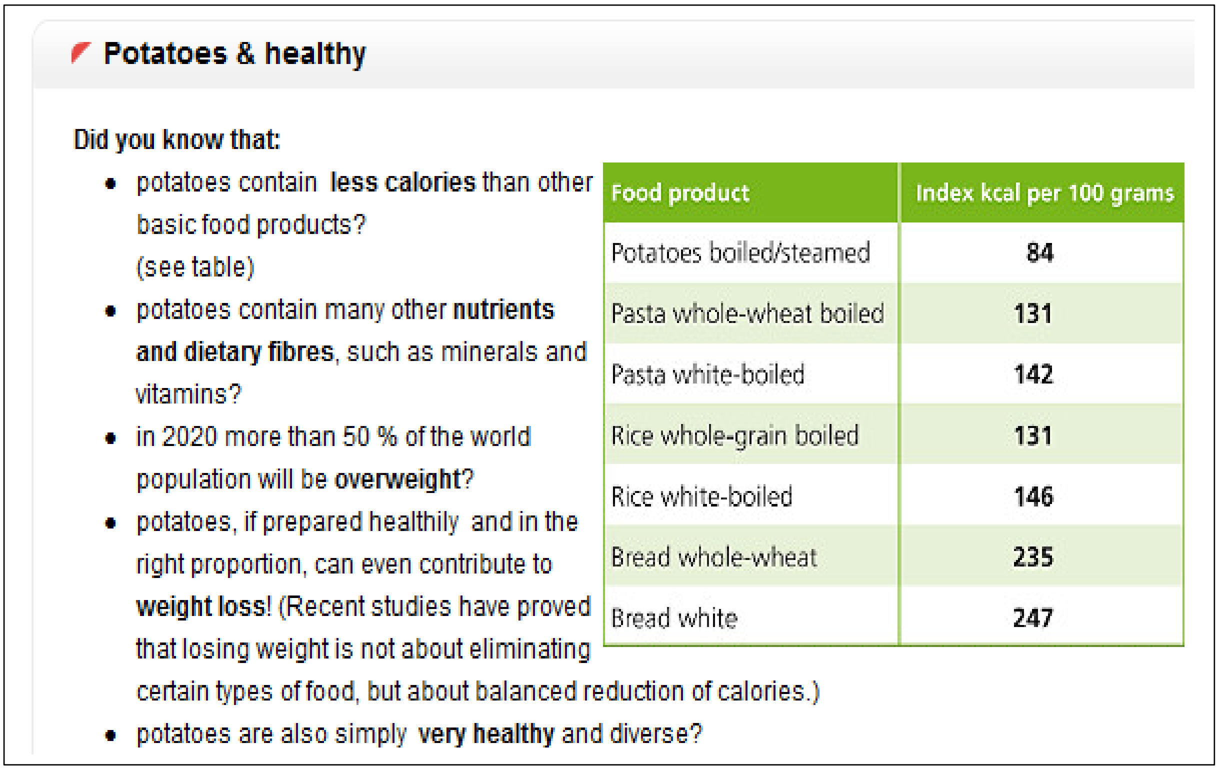
Despite their reputation for being the silent, strong type of the vegetable world, the humble potato - or *Solanum tuberosum* - has more attributes than you might think. What might be surprising is that there are more than 5,000 varieties in the world.

Over recent years Agrico, one of the Dutch potato breeders, has been working on a new 'Low GI' potato variety. You can select your potato on the basis of colour, size and texture or whatever you need but the one thing that most potatoes have in common is a high GI rating.

For the last few years, a new variety of potato called Carisma has been grown in Australia. The common exterior characteristics belie a trait that has the potential to revolutionise the reputation of the potato. When Carisma first tumbled out of the earth, no-one would have thought it to be different from any other potato. In the case of Carisma, beauty was certainly more than skin deep. It was in the laboratory for routine testing, when scientists discovered Carisma was different. It contained all the goodness of a regular potato, but also boasted a low GI rating. Carisma is the only potato in Australia to carry the official low GI symbol from the Glycaemic Index Foundation (**Figure 29** below).

The claim on the packaging tells you that goodness not only fills you up, it gives you long lasting energy. The way you cook your Carisma potato makes all the difference to maintaining its low GI, helping you to fight

Figure 31 : Potatoes & health (*Source HZPC)*



Potatoes & healthy

Did you know that:

- potatoes contain **less calories** than other basic food products? (see table)
- potatoes contain many other **nutrients and dietary fibres**, such as minerals and vitamins?
- in 2020 more than 50 % of the world population will be **overweight**?
- potatoes, if prepared healthily and in the right proportion, can even contribute to **weight loss**! (Recent studies have proved that losing weight is not about eliminating certain types of food, but about balanced reduction of calories.)
- potatoes are also simply **very healthy** and diverse?

Food product	Index kcal per 100 grams
Potatoes boiled/steamed	84
Pasta whole-wheat boiled	131
Pasta white-boiled	142
Rice whole-grain boiled	131
Rice white-boiled	146
Bread whole-wheat	235
Bread white	247

post food fatigue and enhancing its flavour. What makes the Carisma low GI? The variety, how it is grown (optimal soil conditions) and the way it is cooked. Most importantly, eating low GI makes us feel fuller for longer and offers sustainable energy.

In addition to a 'Low GI' potato another Dutch potato breeder, HZPC, has bred a potato variety that is termed 'Low Carb' (See **Figure 30 below**). This is because it has <58kcal/100g fresh weight. This means that it can be officially termed as 'Light'. These potatoes are specifically grown and tested to ensure that they have <58kcal/100g fresh weight. When you compare this value to a typical value and then to other sources of carbohydrate in **Figure 31 above** it highlights the benefits of potatoes as a good source of carbohydrate with lower calories than some other carbohydrates.

Figure 30 – Sunlite 'Low Carb' potato (*Source HZPC*).

Within the HZPC breeding programme they are looking at three key areas for nutritional optimisation in potatoes.

- Low Carbohydrate
- High Antioxidant
- High Carotenoid

The Sunlite potato is the example of a low carbohydrate potato and in discussion with HZPC there appear to be a number of key points to ensuring the variety meets the <58kcal/100g fresh weight value. The variety is a key part, the field selection is important and the agronomy model of production and pre-harvest management are crucial. The variable out of their control is the environment. They have estimated that the environmental factors can contribute to ~10% of the effect so the genetics and agronomy are the major contributors to this beneficial trait.

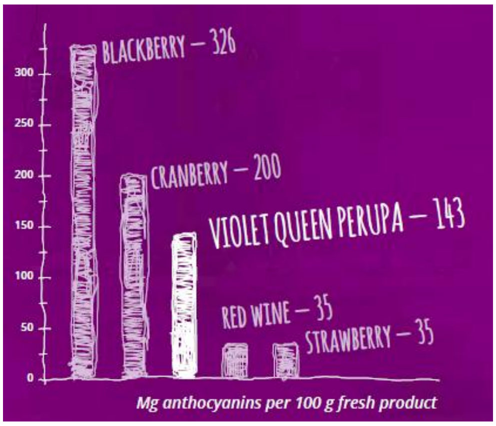
Figure 32 (below) shows the new range of red-flesh and blue-flesh potatoes being developed as specialties by HZPC. It isn't just the fact that they have coloured flesh, but the particular anthocyanins are key to their nutritional value and there are some similarities with the berry sector.

With high carotenoid varieties HZPC now have a number of molecular markers for this trait and they will be able to use this in their future breeding.

In all these areas we come back to bioavailability and what can the body utilise and also a new term of 'Bioeffective'. It is extremely expensive to undertake human intervention studies to establish 'Bioeffectiveness'. Initial studies show that these antioxidants in potatoes are able to lower blood pressure. During the forthcoming years, further studies will prove this. *"I have to think about my blood pressure so I will eat purple potatoes twice per week".* **Soon consumers will not only visit the pharmacist, but also the greengrocer or supermarket for solutions to their health.**

What it does highlight is that within the potato sector there is plenty of work being undertaken to look at its nutritional value and in this case higher isn't always better as some of the examples show. What it also means is that these positive attributes could cascade into many other potato-based products important for consumers and this will create opportunities to those producers involved in those particular markets. It isn't beyond the realms of possibility for chips to become healthier based on more nutrient dense lower carbohydrate varieties cooked in healthier oils. Once again this type of scientific development provides more opportunities for 'Health by Stealth'.

Figure 32 below shows a new range of potatoes that HZPC are launching in 2014. (Source *HZPC, Fruit Logistica 2014.)*



21. Oilseeds

The health benefits and the functionality of oils are inversely correlated as **Figure 33 (below)** shows.

Figure 33 : functionality and Healthiness of oils (*Source Bayer Crop Science)*

As a result of this, the development of High Oleic acid, Low Linolenic acid (HOLL) oils have been an important development for canola and oilseed rape crops.

Figure 34 : HOLL oil constituents. (*Source Bayer CropScience*).

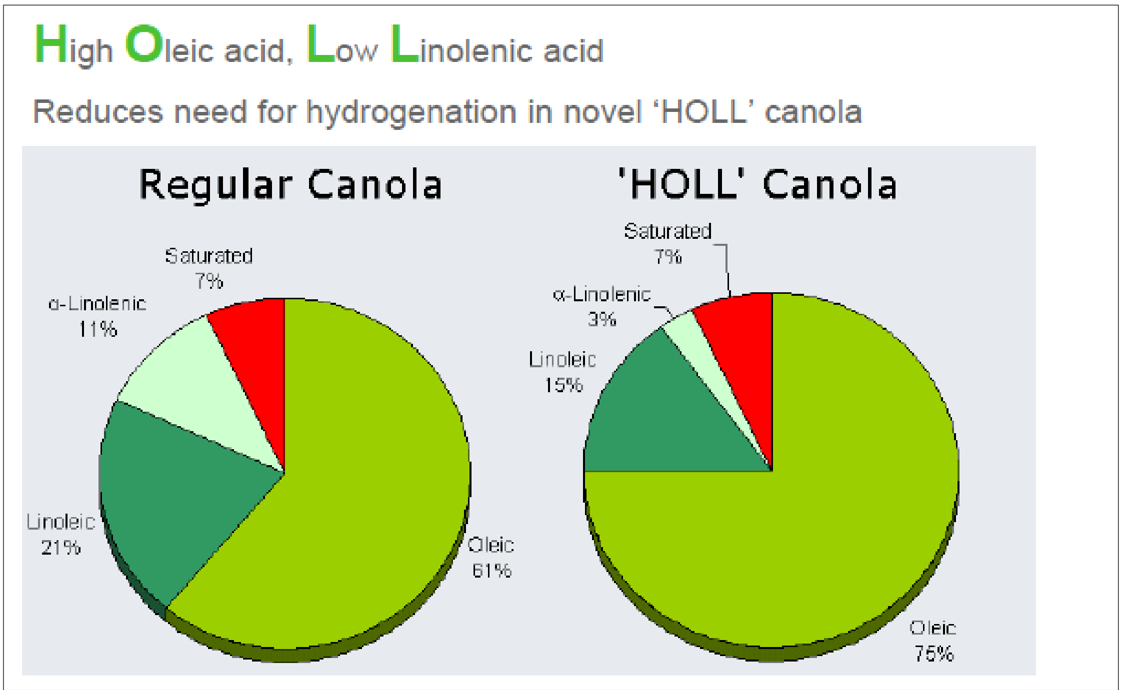


Figure 35 : Bayer / Cargill seeds oilseed segmentation.

Product	Classic	Health*	Nutrition*	Bio-D*
Saturates	7	<7	<7	<7
Oleic	60	65-85	40-50	65-85
Linoleic (Omega 6)	22	10-18	10	10-18
Linolenic (Omega 3)	11	<3	>30	<3
Oil is main reason for Rapeseed – BCS has ability to change fatty acid profile for Functionality & Health. Can react to changes to consumer demand	Normal Commodity. Leading InVigor varieties and major market for food, feed and fuel. Main focus of BCS.	Market has not developed as fast as predicted, but remains valuable segment with potential.	Longer-term: Omega-3 EPA and DHA for animal and fish feed. Seen as future alternative for sustainable demand to replace fishmeal.	High erucic or high oleic. Cooperation with UND (Jet fuel & for benzene and toluene. Cooperation with BMS for bio polyols.

Many companies have developed their portfolio of varieties to address these opportunities. **Figure 35 (above)** is an example of a range of products that Bayer has developed with Cargill seeds and shows the segmentation in the marketplace.

Oilseeds globally are of huge economic importance and even within the UK oilseed rape has seen significant growth over the last decade. What we are now seeing is that cold pressed oilseed rape oil is being sold in a similar way to extra virgin olive oil. This is enabling segmentation within the oilseed category and adding value to a product that was historically a commodity. With further work in breeding and more functional uses identified I believe that there will be further opportunities for producers of this crop.

Omega-3 long chain polyunsaturated fatty acids (LC-PUFAs) have been shown to be beneficial for human health and the primary dietary sources of these fatty acids are marine fish either wild stocks or farmed fish (aquaculture). The increasing demand for fish oils puts pressure on the natural marine resources and highlights the need to identify alternative sustainable sources of Omega-3 LC-PUFAs. Rothamsted Research scientists have successfully engineered the metabolic processes in the seed of false flax (*Camelina sativa*) to produce up to 12% EPA and 14% DHA. These amounts are very similar to those found in fish oil *(Lopez et al., 2014).*

The Omega-3 LC-PUFAs that are beneficial for health are eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). They modulate both metabolic and immune processes and confer the health benefits in areas of Cardiovascular Heart Disease (CHD) and neurodevelopment. Plant sources of Omega-3, e.g. flax seed, do not produce EPA and DHA; instead they produce shorter chain Omega-3 fatty acids such as α-linolenic acid (ALA). ALA does not confer the health-beneficial properties associated with EPA and DHA, despite the former also being an Omega-3 fatty acid. The primary source for Omega-3 EPA and DHA are marine algae and diatoms and other photosynthetic organisms that comprise the phytoplankton. They are consumed by fish and this is how fish accumulate these oils.

Dr Olga Sayanova, Rothamsted Research scientist funded by BBSRC said: "*In this work we used as a starting point a plant that is rich in ALA which is the building block that is used to produce EPA and DHA Omega-3 oils.*" Having identified in marine algae and other photosynthetic marine organisms the essential genes required to make these beneficial oils, they assembled them together and introduced them to the *Camelina* plant. In the first instance, they introduced five genes and on average 24% of the total oil content in the plant seed was EPA. Then they introduced seven genes and in that case on average 8% of the total oil content in the seed of the plant was DHA and 11% EPA. They had instances that these percentages were 14% and 12% respectively. The average accumulation of these oils in the transgenic *Camelina* plants is comparable to those found in fish oil but *Camelina* makes none of these naturally.

Professor Johnathan Napier, lead scientist of this project at Rothamsted Research, said: "*We are very excited with the results that we have achieved with this work. We have managed to generate a plant that can provide terrestrial sustainable sources of fish oils and this achievement can have potential benefits for our health and the environment. Scientifically, it has been a great achievement as we had to understand really well the fundamental processes that underpin oil synthesis in seeds of plants in order to be able to reconstitute the synthesis of EPA and DHA in the seeds of Camelina*".

This very recent report from Rothamsted Research highlights some extremely interesting work that could have the potential to revolutionise the nutrition of consumers in the UK and overseas. However, this has only been possible through the use of biotechnology. I have already highlighted views on biotechnology earlier in the report. Could this be the type of consumer-focused biotechnology that could start to change the UK's view on this technology?

22. Citrus

Red (or blood) orange (*Citrus sinensis* (L.) Osbeck) is a pigmented sweet orange variety typical of eastern Sicily, California, and Spain. The red orange is noteworthy for its excellent orange flesh colour and the consistent appearance of red coloration. The red coloration of red orange is mostly caused by the presence of water-soluble anthocyanin pigments not usually found in other citrus fruits. The three most common types of red oranges are the *Tarocco*, the *Moro* and the *Sanguinello.* The *Tarocco* variety is a medium-sized seedless fruit and is perhaps the sweetest and most flavourful of the three types. It is referred to as 'half-blood', because the flesh is not accentuated in red pigmentation as much as with the *Moro* and *Sanguinello* varieties. The *Moro* is the most colourful of the red oranges, referred to as 'deep blood orange', with deep red flesh and a rind that has a bright red blush. This fruit has a distinct, sweet flavour with a hint of raspberry.

Evidence from a recent study *(Grosso et al., 2013)* assessing red orange juice has shown that red oranges demonstrate both potent antioxidant activity and also have cytoprotective effects that reflect their substantial role in reducing chronic conditions such as cardiovascular diseases and many forms of cancers. The supply of natural antioxidant compounds through a balanced diet rich in red oranges might provide protection against oxidative damage under different conditions and could be more effective than supplementation of an individual antioxidant.

Work is being conducted in collaboration with the John Innes Centre to understand the genetics behind the red pigmentation in these oranges. Currently the pigmentation develops under diurnal fluctuations and cool nights are required, hence the limited geographical representation of these varieties. If scientists can understand the genes that are turned on and can have them constantly on irrespective of the temperature conditions then there could be an opportunity to produce a more plentiful supply of red fleshed oranges and their health benefits could be available to more people.

Whilst visiting a number of producers of blood oranges in Sicily one visit highlighted an important agronomic element affecting the levels of anthocyanin in the Tarocco orange fruit (**Figure 36**). This key element was the choice of rootstock. Although the UK doesn't grow citrus it does have a number of crops where the rootstock is a consideration and with the development of red-fleshed apples, rootstock choice could be an important consideration in ensuring we maximise the nutritional value of any variety.

Figure 36: Effect of rootstock on anthocyanin levels in Tarocco orange

23. Agronomy

During the course of my study I have met many people across a range of crops and they all reference the importance of agronomy in maintaining or increasing the nutritional value that they can achieve within the particular variety and crop. I haven't gone into great detail on aspects of soil science as this could be a Nuffield Farming Scholarship in itself. However, through this report I have tried to explore a range of agronomic techniques that are supposed to make the reader think more broadly about agronomy and how it could affect their own farming operation.

For years many people have been treating soils with a lack of respect. Soil has been viewed as something to use and abuse and then when you have pillaged the soil you can move to a new location and buy some more. I am pleased to say that people are now starting to treat soils with the respect they deserve and that soil scientists are now being treated with respect and the industry is starting to listen to them. However, this is not a simple matter and relies on many inter-related factors, but the fact that people are re-focusing their effort on improving the overall quality of soil is only going to help the quality of food produced in years to come. The key message is that soil is the building block of so much of what we do in food production and ensuring that we do everything possible to improve it for the next generation will be key to a sustainable future with nutrient rich food.

Throughout the world we are losing organic matter and topsoil at a rate of knots. January 2014 in the UK has highlighted the challenges of flooding. The weather we have experienced has washed more top soil away, washed out organic matter and nutrients from the soil aside from all the damage it has done to soil structure and soil porosity. I am sure that this will have ramifications for the years ahead and will re-iterate that we must look after our soils and do everything in our power to improve their quality.

Within the UK at East Malling Research (EMR), Dr Mark Else continues to excel in the field of resource management and is continuing to develop his team to research more crops and methodologies as the resource efficiency for crop production lead. One of his key research interests is in improving water use efficiency and product quality using irrigation management techniques. Mark has led work in Partial Root zone Drying (PRD) and Regulated Deficit Irrigation (RDI) on a range of horticultural crops. **Figures 37 & Figure 38 on next page** show how the irrigation treatment is conducted on strawberry plants.

Figure 37 : Regulated Deficit Irrigation (RDI)

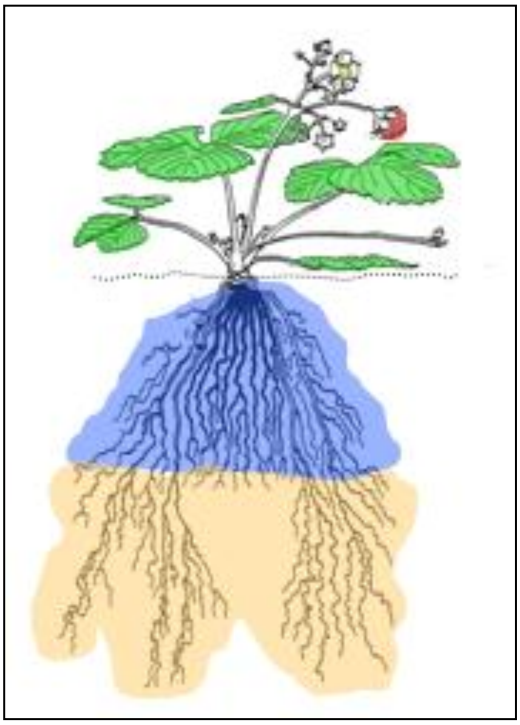
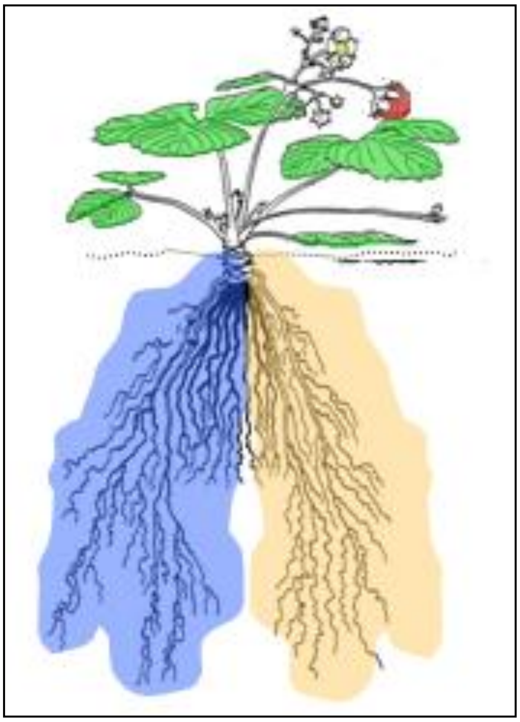


Figure 38 : Partial Root Zone Drying (PRD)



In addition to being able to save water in these crops they have identified improvements in product quality. This has included shelf life, eating quality and also the antioxidant capacity.

Figure 39 : Irrigation treatment effect on the level of phenols in strawberries.

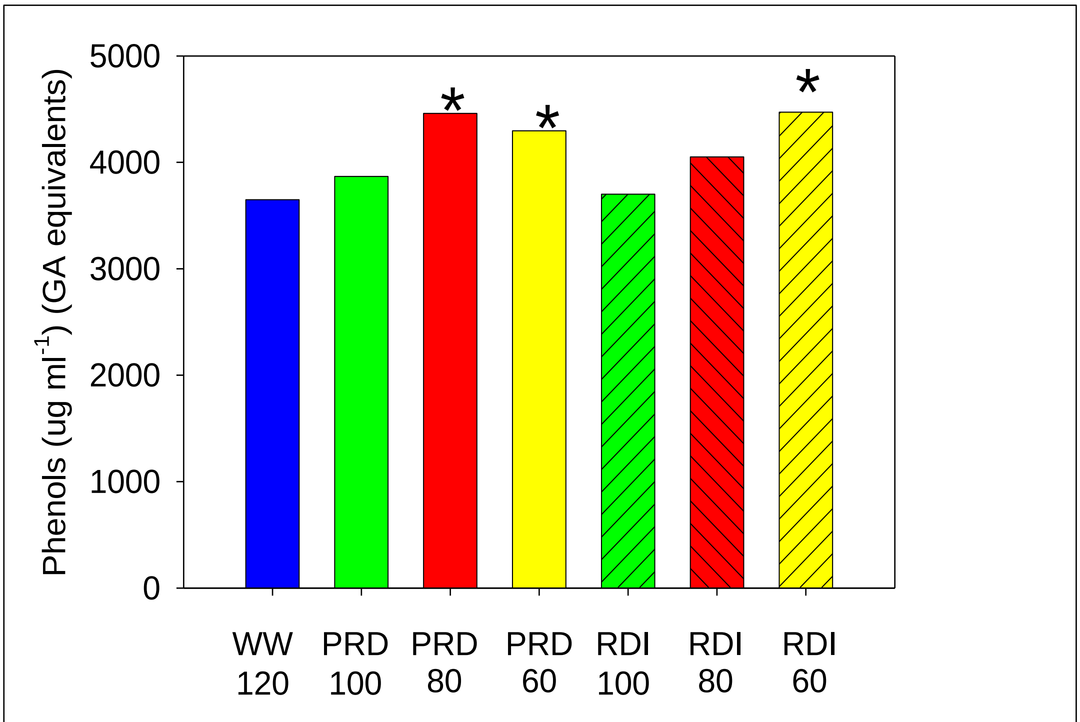


Figure 39 shows the different effects of irrigation on the levels of phenols present in strawberries. The data shows that increasing the levels of stress on the plant both by PRD and RDI statistically increases the levels of phenolics in strawberry fruit compared to the well-watered (WW) control. This science shows farmers how controlled levels of stress on a plant can improve the nutritional value of the fruit, whilst at the same time not negatively impacting productivity.

A new technique called hyperspectral imaging is starting to gather momentum in agriculture. Hyperspectral imaging involves dividing light into thousands of small bands to gain detailed information. Every pixel has a complete spectrum within it and this can be used for a variety of applications including mineralogy, agriculture, astronomy, and surveil-lance. Lightweight hyperspectral imaging systems can be mounted on fixed-wing aircraft and small UAVs to capture data over very large areas.

These systems can effectively monitor the health of crops, 'seeing' water and nutrient levels and the presence of hard-to-spot diseases. Hyperspectral imaging has enabled many advances in precision agricul-ture. Looking at the spectral content in the pixels, hyperspectral solutions can detect chlorophyll or very small colour-changes on foliage.

For many years the top fruit industry has used mineral analysis of apples to assess the keeping quality of fruit and this has been closely associated with the potential for the crop to be affected by physiological disorders. Farmers have been used to taking soil and leaf analysis in their crops as a means to mitigate nutri-tional deficiencies and disorders. Traditionally these have primarily been carried out to prevent yield reductions and to reduce disease incidence which can be more prevalent when the plant is under stress.

> Within farm shops one of the key consumer drivers is the feeling that they are supporting the local producers. What we need to understand is: what does freshness mean when it comes to crop nutrition?

I don't believe that farmers have been focused on doing these assessments to optimise the nutritional value in the crop for consumer benefits.

Ultimately however, if the farmer grows a healthy crop that isn't deficient in the essential minerals then this will undoubtedly be passed on in the finished product to the consumer.

What opportunities exist for the farmer regarding improving nutritional value? A lot could be considered with the supply chain itself. If the supply chain is shorter, which can be the case with local producers supplying the domestic market, then can we put a scientific value to freshness? Within the **vital**vegetables® programme one of the pillars was having local producers supplying the raw materials.

Within farm shops one of the key consumer drivers is the feeling that they are supporting the local producers. What we need to understand is: what does freshness mean when it comes to crop nutrition? There is currently very little information available to support the claim that fresher is better. If we can undertake research on this then it could support the producer with freshness providing better nutritional value to the consumer. As we have discovered elsewhere we have to harness the food being both good for you nutritionally and even more importantly tasting great.

In Asia and particularly Japan the consumer is very positive about nutraceuticals and purchasing products for health benefits, this is highly evident with how they hold 'Green tea' in their diet.

Tea is an interesting plant as it is constantly being wounded as the tea pickers pick the fresh leaves. This process gives a different range of phytochemicals within the plant. So when you prune the plant can you affect the phytochemical profile and, more broadly, when we prune other crops can this impact the nutritional value of the plant? If this is the case then there are opportunities for science to look at these impacts on the overall quality of the food produced after pruning or 'wounding' in a broader sense.

24. Personalised diets and the future

So what sort of opportunity could personalised diets present us in the future? If individuals get to a 'tipping point' in their life then they may change their views and alter their purchasing habits. Currently and unfortunately the triggers to these events are more often than not the diagnosis of a condition that means that the individual has to make lifestyle changes. An opportunity for the industry at all levels is: can we provide more prevention of issues rather than trying to cure issues, which is often harder, less cost effective and can have more significant side effects? Remember, the latest report in February 2014 by Public Health England highlighted that 64% of adults in the UK are overweight or obese and that overall health problems associated with being overweight or obese cost the NHS £5 billion per year.

Life stage brings other dietary requirements to bear. Typically as people get older their senses start to decline and they get increasingly numbed. This means that food becomes less appealing, so one of the key questions relating to this is how do we make food more attractive to elderly people so that the elderly actually consume all of what they need? This creates a development opportunity. Can we get **'**More from less', e.g. pack those portions with even more nutritional value so that even if they only eat a small portion they receive the full complement of nutrition?

This concept would also be advantageous to many parents. Often as parents we are concerned by the lack of fruit and vegetables that our children eat. So if we can only get them to eat a small portion, but that portion has intense nutritional value, then we would all be happier. One of the next opportunities will be providing more nutrition in less food.

An interesting example of this was seen in Sicily. **Figure 41 (below)**shows a new blood orange citrus variety that had ten times the level of antioxidants of a standard blood orange (**Figure 40**). It was still in the development stage, but this type of variety could be an interesting 'More from less' fruit for the future. This could provide a number of commercial opportunities. It could be sold as an individual fruit or could be an addition to standard juicing oranges to make a more nutritional orange juice.

Figure 40 : Tarocco Blood orange

Figure 41 : High Antioxidant Blood orange

Whilst considering consumption of fruit and vegetables by children shouldn't we be thinking of ways to make these products more fun and interesting? There are a range of more unusual varieties that as adults we may consider strange, weird and not normal. It is worth remembering that as we get older we often are more averse to change and become more set in our ways. However, if we want to get our children more engaged in consuming fruit and vegetables couldn't making them more fun be beneficial? There are many unusual coloured varieties that have been developed, for example orange and purple cauliflower, purple tomatoes, pink tomatoes, red potatoes, blood oranges to name but a few. In most cases these varieties have health benefits associated with their more unusual coloration. The flavour is often as good as the conventional product and in some cases can be even better. Wouldn't we all rather provide our children with these 'fun' fruits and vegetables rather than a collection of 'e' numbers in other sugary products? Maybe we should all give ourselves permission to have some more fun when we shop for food!

So how important is the internet to UK grocery now? In 2012, 8% of the UK population used the internet to do grocery shopping. In early 2013 this figure had moved to 30%. By the end of 2013, 50% of all grocery shopping was conducted in the UK using a Smart phone *(Ocado, 2013).*

Before too long we will be able to shop relating to our health needs.

The scenarios could be as follows:

If I am a diabetic what food is best for me?

> I will apply a 'Diabetic' filter to the retailer's website and all products that will assist in my diet will be filtered out and highlighted. This then means that 'Low GI' products will be highlighted and you could then shop based on the personal needs of the family.

I would like to lose 1kg of body weight this week, what should I eat?

> The retailer's website could then provide you with a complete range of ingredients, amounts and recipes for the week and an exercise plan to ensure that you meet your desired target.

The development of functional foods and foods with improved nutritional value could create a huge opportunity for consumer engagement and provide a strong pull through the supply chain for these products.

One of my biggest concerns regarding internet retailing is the importance that it puts on product consistency. Currently when we shop we visit the superstore and shop with our eyes. We have intentions on what we think we want to purchase; however, if we get to the fixture and that product, pack or variety doesn't meet our expectation we pick up something different. We undergo our own selection process to ensure that as far as possible we select the best products for our household.

When it comes to internet shopping we look at the image on the Smartphone, tablet or computer and build up our list of items based on exactly what we want. This can and will bring more challenges in areas like fresh produce, but could also provide many new opportunities.

If we visited the store we may not have decided to pick up that punnet of blueberries because for whatever reason they visually turned us off. However, with internet shopping they are delivered to our home and we expect that everything we ordered will be of top quality. If they are not then we are disappointed and may complain, may not buy them again for a while, or may choose to shop elsewhere for them.

In the internet scenario the product stays in our 'Favourites' list and this provides a huge opportunity for significant volume and value growth in the product. The end result is that consistency of product quality becomes even more paramount to the success of that complete supply chain.

Too often people choose to eat foods that don't match their lifestyles and energy needs. This can result in a number of problems such as weight gain or loss, inability to concentrate, and energy levels that are too low or too high, which in turn can lead to other problems, such as diabetes and heart disease. The Lifestyle Foods research programme run by Plant & Food Research, New Zealand, has a vision for the future where food choice is matched to energy needs.

> Too often people choose to eat foods that don't match their lifestyles and energy needs. This can result in a number of problems such as weight gain or loss, inability to concentrate, and energy levels that are too low or too high, which in turn can lead to other problems, such as diabetes and heart disease.

A key aim of Lifestyle Foods is to match foods to energy requirements. To do this, you need to know what effect a food has on the energy available after digestion. This is measured by measuring the levels of sugar released into a person's blood as the food is processed.

It's the year 2020 and your favourite snack is a great tasting blueberry bar. The bar comes in several 'Lifestyle' varieties. Each variety has the great blueberry taste, smell, and texture that you love, but has a different energy level.

When you play sport, you choose to eat the high, rapid energy blueberry bar because your body needs large amounts of energy quickly. But if you are watching TV you choose the low, sustaining energy blueberry bar because your energy needs are lower. The blueberry bar allows you to eat what you like at times when you need different energy levels.

25. Conclusions

1. During my travels I have visited and come across a number of institutions that have encouraged closer multidisciplinary collaboration between scientists. Most noticeable was Plant & Food Research in New Zealand. Through the principles adopted in developing the **vital**vegetables® programme I can see a clear strategy in how science can provide improved nutrition in the food produced. The new World Food Center at UC Davis, California and the Plants for Human Health Institute at Kannapolis, North Carolina is now adopting a similar type of approach. Encouragingly there is more evidence of this now occurring within the UK.

2. There needs to be a conceptual shift away from the view that chronic disease is the realm of pharmaceutical treatments only. The potential impacts of such shifts in science, society and policy are enormous. In the near future, healthcare insurers and food producers will work increasingly closer, the objective being to make people aware of the importance of healthy eating. This is all about targeting the rising levels of obesity and diabetes globally.

3. The message that individuals should try to consume a variety of food products that are rich in phytonutrients on a daily basis is generally accepted. However, the scientific basis for improving health through diet is largely missing because of the imprecision with which the contribution of individual phytonutrients is understood *(Martin et al., 2011*). What is needed are precise dietary recommendations based on understanding the scientific basis of the link between dietary phytonutrients and health, the levels at which they offer the best protection, the phytonutrients that are best, how best to consume them and whether one phytonutrient-rich food is equivalent to another *(Martin et al., 2011).*

4. One of the most alarming facts to emerge from the 5-a-day campaign is that despite putting out dietary recommendations to consume at least five portions of fruit and vegetables a day for the past 25 years, still <25% of the adults in the UK achieve this level of intake and even more alarming <10% of children achieve the recommended levels. This means that despite broadly disseminated public information programmes on how to eat healthily, people are eating less well than they did in the past. It is extremely difficult to get people to change their diets; therefore, it is vital to target dietary improvement to the young and to look at 'Health by Stealth' as a method to meet these challenges. 'Health (*continued on next page*)

by Stealth' is likely to be fundamental in the development of improved nutritional value foods. Products like Beneforte broccoli, high lycopene tomatoes and red-fleshed apples could just become the new benchmark and if this is the case then people's habits won't have to change to get more nutrient dense, better quality food.

5. What can farmers actually do about it all? As consumers we make choices on a daily basis and that is some way removed from the farmer. However, what is clear is that producing high quality, nutrient dense, sustainable food is in the farmer's control. There is plenty that farmers can do to meet the challenge of optimising the nutritional value of the food produced; be it from ensuring that the fields are nutritionally in balance before they plant, to seeing there are no deficiencies during production of the crop and using the latest technology. However, one of the biggest decisions is the selection of the variety that they choose to plant. The genetics that you put in the ground has so much impact on the potential nutrition of the food produced.

6. Within the potato category, HZPC have scientifically established the relative % that was contributing to the nutritional value of the final product. They believed that 60-70% was the genetics, 20-25% was the agronomic and post-harvest practices on the farm and through the supply chain, and the remainder were the environmental factors out of their control. This type of knowledge will enable the selection of better quality genetics that will benefit the consumer.

7. Functional foods will continue to 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. Successful functional foods are likely to be those that are presented to consumers in a form that meets their expectations in respect to traditional food characteristics, that communicate the additional health benefits that consumers can expect to obtain, and in a context to which they can relate.

(continued overleaf)

8. Throughout my study many organisations highlighted the importance of focusing on the key consumer attributes. Consumers continue to look for convenient, attractive, tasty food with good shelf life and we need to ensure that developments in improving the nutritional value are not at the cost of the above. Please don't ever forget about the one thing that consumers are not willing to compromise on. Consumers are not prepared to compromise on **taste** even if they can perceive the health benefits.

9. I have referred to GM technology in a number of examples. GM technology can provide the **'proof of concept'** and allow plant breeders to combine the appropriate natural variation into elite genetic lines to provide improved nutritional value by classical breeding methods.

10. We are all responsible for our section of the global food supply chain in the optimisation of nutritional value in the food we produce and consume. All the above can be considered as the challenge of the 'doubly green revolution' with sustainably produced nutrient dense food for the world being the opportunity.

26. Recommendations

1. To Scientists :

a) **The age of plant breeding for the standard traits of yield and disease resistance is over. The next generation of varieties will include the traditional traits, but must also be better for us. This is demonstrated by examples like vital**vegetables® products from Plant & Food Research (PFR), Beneforte Broccoli by Seminis and new coloured potatoes from HZPC.

b) Functional food development as shown by PFR provides a benchmark for improving the nutritional value of food.

c) If scientists can establish that food produced from shorter supply chains is nutritionally better for us this will further strengthen the case for British farmers supplying the UK consumer.

d) New science like metabolomics and hyperspectral imaging need to be applicable to as many areas of farming as possible to optimise the nutritional value of our food.

2. To Farmers :

a) Never lose sight of the one thing that consumers are not willing to compromise on – TASTE.

b) Genetic improvement is proven to be the most important element within the farmer's control of improving the nutritional value of food. Farmers must work closely with plant breeders to ensure that they have access to the best genetics.

c) Improved agronomic techniques are becoming available to farmers. Be sure you are connected to the best agronomists and scientists throughout the world so you can be an early adopter.

d) Farmers have a contract with society in producing their food. You need to produce higher quality more nutrient dense food as we are still not achieving "5 a day" in the population.

(continued on next page)

3. To Retailers :

a) Delivery of improved nutritional value food requires a joined up approach through the entire food supply chain. The retailer must take responsibility for driving these improvements.

b) As a food retailer we focus on "Normal but better" in product development. Historically this has been specifically around traits like taste, shelf life and appearance. The next trait will be improving the nutritional value. Initially these products will be niche lines, but before long they will become the new benchmark and hence help deliver the "Health by Stealth" strategy.

c) When Henry Ford asked farmers what they wanted they said they wanted a faster horse. So he created the car. Consumers are quite similar; they don't know what they want in future foods. It is up to the food retailers to educate and inform consumers about the exciting new products and provide the marketing support. Internet retailing provides even more touch points to reach consumers.

d) The '5 a day' campaign still has a long way to go with UK consumers. Currently 64% of adults in the UK are overweight or obese and the overall health problems associated with being overweight or obese cost the NHS £5 billion per year. Food retailers have a collective responsibility to support and drive this government backed campaign through to consumers.

e) Future product development should adopt a more scientific basis to maximise the opportunities to improve the nutritional value of food by all means possible.

f) Nutrient density considers key nutrients as functions of the energy value of food (nutrients per calories). Food has become more energy dense and nutrient poor. Collectively we must all pull together to re-address this balance and focus on improving the quality of food by increasing its nutrient density.

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