Genetically modified crops: how attitudes to new technology influence adoption

Dana Sanchez
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GM crops: how attitudes to new technology influence adoption

Genetically modified crops have been designed to increase crop yield, food quality and reduce the use of pesticides and herbicides. At present there is scientific evidence that genetic modification of crops is a safe and useful technology, but those opposed to the technology have been able to exert great influence on its adoption. This paper examines the factors that create such divergent views and examines how attitudes have influenced the development, adoption and regulation of genetically modified crops.

1. Introduction

Food security is a high priority for governments and communities around the world. Although Australia does not have a problem feeding its population, food security in this country has been linked to the political stability of the region, consumption, trade, climate and environmental challenges that may affect food production (PMSEIC 2010).

The Food and Agriculture Organization of the United Nations (FAO) defines food security as:

> *when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.*[1]

About one in eight people in the world suffer from chronic hunger and are unable to get access to enough nutritious food to live an active and healthy life. The challenge of food security includes issues of food availability, economic and physical access to food, inadequate food intake resulting in poor health outcomes, and the vulnerability of farmers and poor consumers (Food and Agriculture Organization of the United Nations 2013). Improvements in food security by measures including increasing crop yield, improving agricultural practices, reducing waste, changing diets and expanding aquaculture will require multidisciplinary cooperation (Godfray, Beddington et al. 2010).

Genetically modified crops alone will not solve the problem of food insecurity, but they do have the potential to play an important role in a broader food security strategy. The technology has the potential to increase crop yield, food quality and nutrient composition, but crops produced through genetic modification technology continue to be a subject of controversy. This is partly because of the perception that modifying plant genes is a new phenomenon, when in fact humans have been breeding and selecting crops for 10 000 years.

Our beliefs, and our perceptions of risk, heavily influence our opinions about new technologies, including genetic modification of crops. Despite scientific evidence to the contrary, there are still concerns that the introduction of genetically modified crops to the food chain will harm the environment and human health, and will badly affect the livelihoods of farmers, in particular those in developing countries. Social activists point to the potential for food industry monopolies when a small number of multinational corporations control an increasing share of agricultural supply and distribution globally.

As a result of public concern, regulatory authorities in Australia and most of Europe have been cautious in their approach to regulating genetically modified crops. Regulation is heavily influenced by the process and attitudes instead of assessment of crop traits, scientific evidence and risk.

[1] From FAO's *Post-2015 Development Agenda and Millennium Development Goals,* http://www.fao.org/post-2015-mdg/14-themes/food-security-and-the-right-to-food/en/

2. Agricultural practices

The perception that any given product, process, or technology is new is an illusion. Technologies develop from each other, usually gradually and incrementally, with long periods of development before reaching the market. Scientific discoveries and technological developments have always played an important role in food production (Figure 1).

Most of the concerns surrounding the food we eat are not new in the history of crop and food production. There is a long history of human intervention in the evolution of plants. At some time in history, crop plants grown today were selected and bred by humans. Our ancestors have chosen a relatively small number of plants to transform into cultivated crops. A little over 100 crop species are now grown intensively across the world (Prakash 2001).

Agriculture began with the selection and breeding of the wild grasses that were the precursors of modern staples such as wheat, rice and maize. Through these mechanisms human actions have modified crop plants and animals over thousands of years. Well before there was any scientific understanding of genetics, farmers were selecting for desirable traits such as shorter growing season, larger fruit and seeds, increased resistance to pests and diseases, higher nutritional content, and better adaptation to local conditions.

Current agricultural practices for plant breeding can be categorised in three ways:

- **organic** – the production of food and fibre without the use of synthetic chemical fertilisers, pesticides, herbicides or genetically modified organisms. It focuses on healthy soil as the basis for sustainable productivity, and relies as much as possible on natural processes and cycles for managing pests, diseases, weeds and crop nutrition (Department of Envrionment and Primary Department of Environment and Primary Industries 2011).
- **genetically modified (GM)** – the alteration of genetic material of a plant or other organism using genetic engineering techniques.
- **conventional** – the kinds of practices that dominated the 20th century and account for most of the farming practices used today. Conventional farming can include traditional plant breeding techniques, induced mutation and DNA diagnostics.

Conventional farming can include crops referred to as non-GM, and shares many methods and processes with both organic and GM methods. Conventional practices will not be explored in this paper.

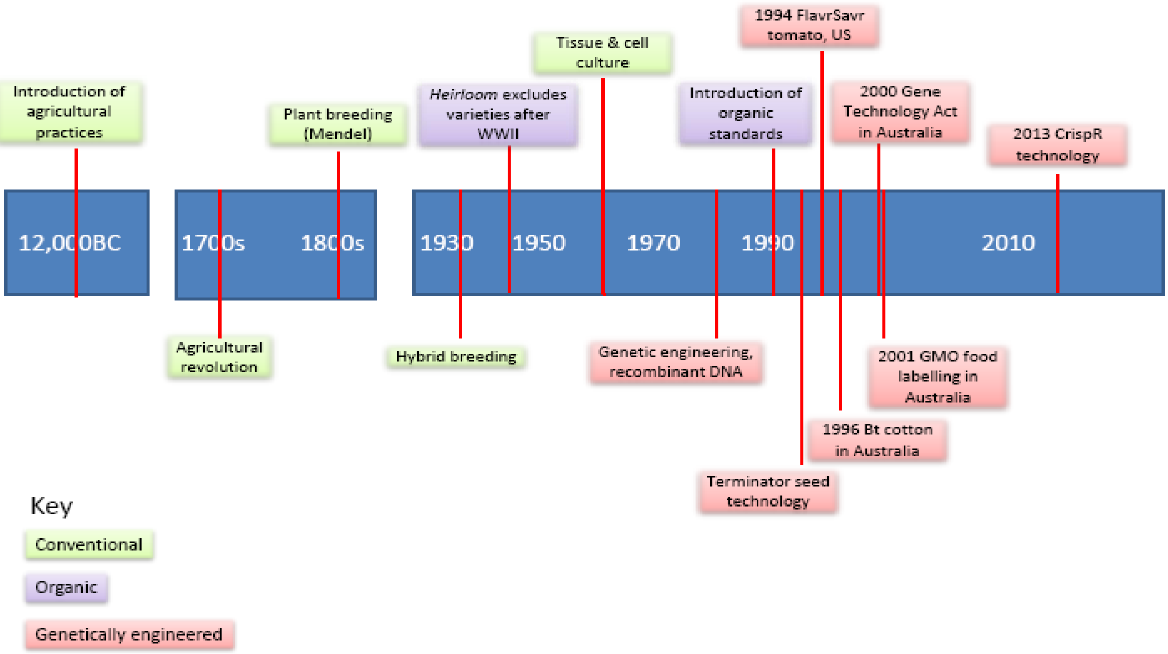

Figure 1 Timeline of key agricultural methods and technological developments

2.1. Genetic modification

Genetic modification refers to the mutation, insertion or deletion of genetic material. Plant biotechnology techniques can transfer genes from one organism to another to introduce a new trait into a plant in a targeted and controlled manner. For example, insect-resistant GM cotton uses a gene from a naturally occurring soil bacterium to provide the cotton with built-in insect protection. GM does not necessarily mean that a gene from another organism has to be used to create the genetically modified organisms (GMOs); it can also mean that the organism's own genes are changed.

In 1973 Stanford biochemist Paul Berg and colleagues created the first recombinant DNA molecules by joining fragments of DNA molecules from different organisms creating a molecule that shared properties from the original fragments. This set the scene for the creation of transgenic organisms (Jackson, Symons et al. 1972). In 1994 the United States Food and Drug Administration approved the first commercially available transgenic fruit – the Flavr Savr tomato (also known as CGN-89564-2) – for marketing. The plant was modified to slow down the tomato's ripening after picking (James and Krattiger 1996). In 1996, Monsanto commercialised herbicide-resistant soybeans, known as 'Roundup Ready', followed by alfalfa, corn, cotton, spring canola, sugar beets and canola (Monsanto). That year a partnership between Monsanto and CSIRO resulted in the first Bt cotton crop grown in Australia. Bt cotton is genetically modified so that the plant itself produces a naturally occurring insecticide.

Initial attempts at DNA sequencing began in the early 1970s and the technology rapidly developed. Next generation sequencing allows thousands or millions of sequences to be processed concurrently. The demand for sequencing resulted in high throughput technologies which in turn lowered the cost of DNA sequencing (see Attachment 1: GM crop technology). Next generation sequencing now allows thousands or millions of sequences to be processed at once.

Genetically engineered crops can be made by inserting genes from the same species or closely related species, or by interchange of genes between different species. New biotechnology methods that offer precise genome editing by site-specific integration, deletion and mutation of genes are expected to radically affect plant biotechnology. Advanced bioengineering methods such as the CRISPR[2] genome-editing system allow for precision editing of genes within the original organism. One implication of these new techniques is that plants can be genetically modified without the addition of foreign genes. Critics of biotechnology might be more accepting of genetically modified crops if they are not transgenic. This could result in less scrutiny and regulation, reducing the time and expense it takes to commercialise GM products (Rotman 2013).

One of the concerns expressed by those opposed to genetically modified crops is about the use of foreign DNA to transfer traits. What constitutes a species is often open to debate (even when one is not engineering organisms). Targeted genome modification using engineered nucleases may require that regulation frameworks be reconsidered. In 2012, an article in *Nature Biotechnology* revealed that

> *the US Department of Agriculture had been quietly informing crop trait companies that plants made with certain novel approaches to genetic modification would not require regulatory oversight.*

One such crop that did not require oversight was GM corn developed using a zinc-finger nuclease (ZFN) technique was exempt from regulation (Waltz 2012).

The US Department of Agriculture is authorised to regulate organisms which are used to deliver foreign genes into plant genomes. But advanced technologies do not involve genes from plant pests. Instead of adding foreign DNA, plant genes are being altered through endogenous site-specific mutagenesis techniques. This might have implications for the detection of GM content in crops. Crops resulting from many of these new techniques cannot be distinguished from conventionally bred crops (Waltz 2012), which provides further support for the argument that the product should be tested, not the procedure.

2.2. Organic principles and practices

The concept of organic farming and organic produce began in the 1940s. Organic farming was introduced in response to the health and environment concerns over the increasing reliance on fertilisers and pesticides in conventional crop production. Organic methods endeavour to use sustainable practices which maintain a balance between productivity and have a minimal impact on the environment. Organic farming is currently a niche activity accounting for about 0.86% of agricultural land across the world (Organic World 2013). In some areas organic farming is a necessity because farmers do not have access to affordable herbicides and pesticides. The total value of the organic marketplace internationally in 2010 was estimated at A$60bn (Swinburne University of Technology 2012). The organic industry has experienced solid growth in demand for certified organic products in Australia and globally. The total value of the organic industry in Australia was estimated at $1.276bn in 2012.A study of Australian consumers found the perceived benefits of organic foods were that it is chemical-free (89% of people), additive-free (88%), more nutritious (88%) and better tasting (85%). ‘Free from’ aspects were the key perceived benefits. Four of the five leading benefit attributes revolve around what organic food ‘does not contain’ (Bruce and Critchely 2013). In order

[2] An acronym of ‘clustered regularly interspaced short palindromic repeats’.

to qualify as organic, plants must be grown using certified organic conditions. The National Association for Sustainable Agriculture Australia Limited (NASAA) Organic Standard sets the general principles for organic agriculture in Australia, providing (for example) acceptable levels and application rates of pesticides, herbicides and fertilisers. The standards specifically prohibit the use of synthetic chemicals and GM products.

The *National Standard for Organic and Bio-Dynamic Produce, 2013* outlines when a seed is considered to be organic.

> *New seeds and new vegetative reproductive material shall be considered organic when grown in accordance with the provisions of this Standard for at least one generation or, in the case of perennial crops, two growing seasons.* (Organic Industry Standards and Certification Committee OISCC 2013)

This means that conventional crops can transition to organic crops after they are grown using organic conditions for at least one generation. This does not apply to plants derived from genetically modified seeds. The standard specifically prohibits the use of any genetically engineered seeds regardless of growing conditions or number of generations from the parent crop. In a landmark case discussed in the *Section The effect on early adopters of GM technology*, an Australian organic farmer claiming his crop was contaminated by genetically modified crop from a nearby farm had his NASAA organic certification retracted (ABC News 2014).

In general, the plant breeding techniques used in conventional breeding – including combination breeding, crossing varieties, grafting, hybrid breeding and exposure of plants to temperature, irradiation and chemical agents – are acceptable in organic farming. DNA diagnostic tests which enable selection at DNA level are acceptable in both conventional and organic breeding because the technique does not involve genetic modification of the DNA in its pursuit to induce variation.

A 2012 study published in *Nature* showed that, overall, organic yields are lower than conventional yields. The yield differences are highly contextual. With good management practices, particular crop varieties and good growing conditions, organic systems can nearly match conventional yields, whereas under other circumstances they cannot. The study concluded that factors limiting organic yields need to be more fully understood, including assessments of the many social, environmental and economic benefits of organic farming systems (Seufert, Ramankutty et al. 2012).

3. Genetically modified crops: what does the science say?

Genetically modified crops are engineered to increase yield, reduce pesticides and herbicide use, increase nutritional content in food and provide economic benefits to farmers. A report by the International Service for the Acquisition of Agri-Biotech Applications (ISAAA), *Global Status of Commercialized Biotech/GM Crops: 2012,* outlined the benefits of biotech crops to the global community during the period 1996 to 2011. The crops led to:

- increasing crop production valued at US$98.2 billion
- saving 473 million kg active ingredient of pesticides
- reducing CO_2 emissions by 23.1 billion kg
- saving 108.7 million hectares of land.

The report concludes that 'biotech crops are essential but are not a panacea and adherence to good farming practices such as rotations and resistance management, are a must for biotech crops as they are for conventional crops' (ISAAA 2013).

A report from the Australian Centre for International Agricultural Research notes that farm yield of crops (measured as average yield given in kilograms or metric tonnes per hectare) must linearly increase by a minimum rate of 1.1% pa to meet the predicted global food demand in 2050. The report strongly supports crop intensification as a solution to delivering higher crop yields. One of the main benefits to crop intensification is reduced pressure to clear new land for agriculture, which is environmentally desirable (Fischer, Byerlee et al. 2014).

Increasing global crop yield depends on two main factors: on-farm adoption of crop management best practice, and plant breeding methods to advance potential yield (biological limits to crop yield are reported not to have been reached yet). Conventional breeding continues to deliver improvements in potential yield and can be assisted by new molecular tools. The report notes that genetically modified crops are yet to show consistent increases in yield globally, although the technology has provided benefits to the agricultural system in other ways, such as decreased use of pesticides and herbicides. The report concludes that a multidisciplinary approach to the issue of food security is the key to success. Crop yield can be increased by improving crop management, training, rural infrastructure and effective adaptive research (Fischer, Byerlee et al. 2014).

3.1. Economic performance of GM crops

The potential disruptive impacts of new technologies can at times be overestimated. One can find literature that both supports and refutes the economic benefits of genetically engineered crops to farmers. In 2011, Berlin’s Ecologic Institute reviewed 721 studies to provide an overview of economic performance of GM crops. The institute compared the performance of GM crops with that of conventional crops for yield, gross margin, seed cost, pesticide cost and labour/management costs.

The review of studies indicated that on average Bt cotton, a genetically modified variety of cotton producing an insecticide, shows an economic advantage over conventional cotton. However, the results obtained were vastly different in different countries, mostly due to pest management practices. Countries with well established pest management, such as Australia, had lower yields but got benefits from reduced pesticide costs. Bt maize yield exceeded that of conventional maize in most countries, but the results were affected by the seasons and regions in which the crop was grown.

In addition the study found that the people who conducted the study had an influence on the outcome of each study. Perhaps unexpectedly, yield levels observed by biotech companies were generally lower than those reported by public research, except for Bt cotton, where the reverse was true. The study concluded that the ability of GM crops to increase yields and deliver economic benefit to farmers varies widely between crops, varieties, regions, countries and farming practices. It is particularly difficult drawing comparisons when different methodologies are used to gather and analyse data (Kaphengst, El Benni et al. 2011).

A study of the socio-economic impact of GM crops in 1996–2011 performed by the UK company PG Economics also found that crop biotechnology has resulted in improved productivity and profitability, although benefits vary widely between and within regions. The study found that crop biotechnology delivered economic and environmental gains through a combination of inherent technical advances and the role of the technology in facilitating more cost-effective and environmentally friendly farming practices. Gains from the GM insect-resistant crops include yield improvements, reduced production risk, and decreased use of insecticides. The study found that GM herbicide-tolerant crops enabled farmers to move to lower tillage systems, reducing the amount of labour and tractor fuel required. It also found that GM crops had made important contributions to increasing the world production of soybeans, corn, cotton and canola. GM canola and cotton grown in Australia did not show higher yield from using the technology. The primary benefit to Australian farmers is derived from lower costs of production, i.e. easier weed control, less tillage and a shorter production cycle (Brookes and Barfoot 2012).

3.2. Health and safety of GM crops and products

Some of the concerns about the possible impact of GM foods on human health relate to the creation of new allergens or toxicity in foods. Allergic responses may occur as a result of inserting material from a food that already causes allergic reactions in some people, such as peanuts, eggs, or wheat. Toxins are already present in many widely consumed foods, but the concern is that genetic modification used to create a particular characteristic, such as pest resistance, could increase the toxicity of a plant.

At present, genetic modification has not been shown to introduce any new or altered hazards into the food supply. The potential for long-term risks associated with GM foods is considered to be no different to that of conventional foods already in the food supply. To date, the European Commission has released two reports that span 25 years of research on potentially harmful effects of GM crops or food on human health or the environment. The reports concluded:

> *The use of more precise technology and the greater regulatory scrutiny probably makes GMOs even safer than conventional plants and foods …*
>
> *There is, as of today, no scientific evidence associating GMOs with higher risks for the environment or for food and feed safety than conventional plants and organisms.* (EuropaBio 2012)

Similarly, Food Standards Australia New Zealand (FSANZ) states that genetically modified foods are subject to rigorous safety assessments before they are permitted into the food supply chain. The assessment includes extensive analysis of the composition of food with full consideration of the safety on any new substances that have been introduced. FSANZ states:

> 'To date, gene technology has not been shown to introduce any new or altered hazards into the food supply, therefore the potential for long term risks associated with genetically modified foods is considered to be no different to that for conventional foods already in the food supply. As a consequence, FSANZ does not consider that long term studies are generally needed to ensure the safety of GM foods.' (FSANZ 2013)

Those opposed to GM products argue that it is impossible to verify the safety of genetically modified crops. A number of articles on the internet cast doubt on the veracity of studies that show GM foods are safe for human consumption. Research on the safety of genetically modified crops is available, but there are claims that only studies approved by agricultural biotechnology companies are made available (*Scientific American* 2009) (see *Section Market influence over science* below).

Some scientific studies have found negative health impacts of genetically modified food, but it is difficult to find studies accepted by the wider scientific community. A study by Gilles-Eric Séralini of the University of Caen, France, reported that genetically modified maize consumed by rats led to increased levels of cancer. The article was published in September 2012 by *Food and Chemical Toxicology*, but on 28 November the journal retracted the article. This followed criticism that the rats used in the experiment were prone to cancer anyway, and that the experimental protocol used was unable to distinguish between tumours which might have been caused by GM food and those that were spontaneous. Further criticisms of the study included that too few animals were used and that the researchers did not discover any mechanism by which genetically modified food could cause cancer (*The Economist* 2013).

Even though such studies may be discredited, it is difficult to reduce their impact once they are in the public domain. Opponents to GM technology quote such research as scientific evidence and can use the fact the study is discredited to feed into conspiracy theories. Similar cases can also be found on the topic of immunisation.

We sometimes expect that new or unfamiliar technology should be without risk before it is deemed safe enough for us to adopt, but it is mistaken to assume that either new or existing technology bears no risk. Innovation – including agricultural and food technologies – depends on trial and error to reduce harm. It is common for fear of the new to be exaggerated while we see older and familiar products as safe, but we consume low doses of natural and artificial toxins every day – celery produces mutagenic carcinogens, spinach contains oxalic acid that build kidney stones, lima beans contain cyanide (Kiple and Ornelas 2000). Most food hazards, however, come from bacteria such as *Escherichia coli* and *Salmonella enterica* (Prakash 2001). Genetically modified crops and products are subjected to more rigorous safety tests than their conventionally bred counterparts(FSANZ 2013).

3.2.1. Environmental concerns

There are concerns that the introduction of genetically modified crops to the food chain will harm the environment by reducing crop biodiversity or the creation of 'superweeds' (weeds which are particularly robust or resistant to herbicides or natural checks on growth).

Agriculture has been fundamental to the rise of human civilisation, and has produced an enormous diversity of crop plants. The preservation of crop biodiversity is a concern: the genetic sameness of current wheat, maize or rice crops could be of considerable concern if a newly mutated plant disease arises there is potential to inflict serious damage on a large proportion of the world's food supply (Kiple and Ornelas 2000).

Concern surrounding the creation of superweeds is often linked to GM crops, although the risk of crop gene flow to weeds is a problem for both conventional and biotech farming practices. The method used to introduce stress tolerance and pesticide resistance in plants has no bearing on the risk of gene transfer between crops and weeds. All farmers – organic, conventional and GM – need good crop management practices to ensure that weeds do not become noxious (Prakash 2001).

4. The biotech industry

In addition to the concern that genetically modified foods might pose health and environmental risks, those who oppose GM are passionate in their fight against large agricultural biotechnology companies. Companies like Monsanto are blamed for exploiting poor farmers and small farm owners who are forced to buy seeds each year, unable to legally save seeds from year to year. Supporters of GM are puzzled that the technology is blamed for the business practices of large companies selling the product (Finkel 2014).

> *Opposing GMOs because Monsanto uses the technology is kind of like opposing petrol because it's made and sold by BP or Exxon-Mobil*'. (Ropeik 2014)

Opposition to the technology has resulted in an increase to the safety threshold expected of genetically modified crops (in comparison to conventionally bred crops). Unexpectedly, this has led to greater cost for the assessment, registration and use of the technology which discourages smaller competitors, reinforcing the oligopoly opponents are fighting against (Klaus 2014).

4.1. GM seed patents

For thousands of years farmers have saved the seeds of plants with desirable characteristics. Seed saving has been an integral part of agriculture and is a continuing practice for most farmers. Until recently seeds were not viewed as a commodity, and crop plant genetics were considered common property. Because of this, there was little investment in seed development; farmers did not need to buy seeds from year to year and could share seeds with each other (Stein 2004).

The seed industry has undergone significant change since genetic information and resources – which were once treated as public assets – became subject to proprietary control. Although patent protection may promote innovation, it also means that proprietary control is mostly owned by a few large companies because they are in the best position to pay for expensive research and regulation costs. Patent holders may license the seed to others for set fees and they may specify license terms and conditions. Patent holders have the right to prevent others from producing or selling patented seeds for a period of 20 years (Rowe 2010).

The patenting of genetic information has been a controversial issue because genes are naturally occurring. The earliest genetic patents were issued in 1982 in the US, which opened the door to patenting biotechnology discoveries. Patents are issued to encourage innovation and provide protection to allow those investing in an innovation to secure the profit from their investment. Corporations claim they need product control while opponents claim that patenting gives corporations too much influence over a product that everyone needs. It is in the financial interest of large biotech companies to deny farmers the ability to save seeds from year to year, forcing them to buy the product new year after year. Many farmers are required to sign contracts that prevent them from legally saving GM seeds. The long and complex history of intellectual property rights and seed technology illustrates how political and business motives play an important role in deciding policy. Strong intellectual property protection for GM seeds has been partly responsible for the rapid growth and development in new seed varieties (Stein 2004).

The growth of seed patents has led to concern that they may be used for anti-competitive purposes by dominant companies, who could eliminate competition and obtain monopoly control over genetic resources that are critical to farmers and food production. However, existing anti-trust laws hold that companies may not deliberately abuse their patent rights to destroy competition, to monopolise, to engage in price-fixing arrangements or to stifle research and innovation. Monsanto, for example, licenses its patented traits to competitors, arguing that this make good business sense and is pro-competition (Matson, Tang et al. 2012).

GM crops, music and patents **(Swan 2013)**
There's a clear parallel with software, which we evolved from viewing as a digital product, to something that was licensed. Digital music isn't broken or evil because some record companies decided to sneak Digital Rights Management into it, and GM crops shouldn't be rejected because we allowed the same system to develop there. Restricting commercial farmers from reusing seed is not hugely different from demanding record stores don't burn their own copies of the CDs they buy wholesale.

Did Microsoft abuse its monopoly to push products and services at the detriment of users? Most probably. But we didn't solve that problem by demanding a moratorium on personal computers. And if you have a problem with Monsanto's business practices, it's most likely patent laws, not GM crops, that are your enemy.

Another controversial issue is the stacking of traits in GM seeds. Seed companies can stack a number of genetically engineered traits into seed varieties that they sell to farmers. In some cases farmers may pay more for traits they do not want or need. However, stacking is a commonly accepted marketing strategy in many industries such as pay TV and telecommunications.

4.2. Market influence over science

There are claims – usually by those opposed to GM – that scientists find it difficult to test the safety and effects of genetic modification on plants because of restricted access to the necessary patent material and data to conduct comprehensive experiments. In some cases the researcher must submit findings to the company for review before publication, in exchange for gaining permission to do research (Waltz 2012). This is common practice for research funded by industry (such as pharmaceuticals that provide all of our medicines).

Patent law allows patent holders to control and restrict independent research, which has led to inadequate testing of human and environmental health risks of GM products. These research restrictions can be interpreted as contrary to the public interest and inconsistent with the underlying principles of patent law. It is worth considering whether the balance of public interest in promoting independent research should outweigh the interests of patent holders. Courts could use patent overreach doctrine to reign in the level of protection afforded to patent owners in the area of GM crop technology. This would allow open and independent research of the effects of genetically modified foods (Rowe 2010).

Large biotech companies are not the only players in the GM crop industry. Many government agencies develop new GM crops. In Australia CSIRO is doing research on insect-resistant cotton, pest-resistant cowpeas (a food and fodder crop) and the addition of omega-3 oils in grains. Golden rice, which aims to address vitamin A deficiency (see *Section Golden rice: regulating the process not the product*), was developed by public institutions for a humanitarian project.

5. Attitudes to new food technologies

Attitudes to technology play a crucial role in acceptance by the public, uptake by industry, and the level of intervention by government. These attitudes have impacts on adoption, adaptation, use of technology, development and innovation.

Concerns about food supply arose with the movement of people from country to towns during the Industrial Revolution of the mid-18th to early 19th century. Agricultural technologies were needed to substantially increase crop yields, and technologies of food preservation and storage needed improvement. During this time a number of new technologies were adopted by the food production industry: introduction of artificial fertilisers, steam engines used for ploughing, and selection of seeds for improved crop yield. Early attempts to improve treatment and storage of food – such as canning – often resulted in poor results for human health, requiring trial and error before they became acceptable. Even the first refrigeration system which developed from the ice trade was subject to poor public reception, being seen as having a ‘deceptive freshness’ (Truninger 2013).

New food technologies such as animal cloning, nanotechnologies, food irradiation and GM are met with similar resistance today. Many factors affect consumer attitudes to new food technologies, and their acceptance of them. New technologies can be complex and difficult to comprehend. Providing information about work (such as safety laws and regulations) that is done to mitigate risks helps to reduce perception of the riskiness of new technologies, although we are likely to look for information that supports long-held beliefs, and providing more scientific information does not necessarily change attitudes (Rollin, Kennedy et al. 2011).

The technical challenges inherent in genetic engineering technology are great, but they are less challenging than the social, ethical and regulatory concerns it generates. There is scientific evidence that GM is a useful product that poses no known risk to humans, but there is considerable opposition to its use. Why does GM crop technology produce such divergent views? Both sides of the debate want access to safe, affordable and nutritious food grown in a sustainable way for all people. Those opposed to GM claim it is unsafe for human consumption and the environment. Those who support it argue that genetically modified food undergoes more rigorous safety testing than other food products and that genetically modified foods have been shown to decrease the need for pesticides and herbicides, whilst increasing crop yield.

5.1. Risk perception factors

Because of the intimate relationship people have with food, in areas like the GM food debate people are at our most risk-averse. Food is so important to our survival that the factors influencing our opinions on food technologies go beyond numbers and scientific information. Research has found that people do not base decisions on facts alone. Simply providing 'non-believers' with facts and scientific evidence will not be enough to change minds. Although scientific evidence indicates that GM products are safe, many people not only remain unconvinced of its safety but are passionate in their opposition. As far GM products go, people consider uncertainty about a new product, the appeal to nature, and the level of personal control and choice (Ropeik 2010).

The way we perceive risk is more about our feelings and perception of the unknown. In his book *How risky is it, really?*, David Ropeik explains the brain's foremost job is to first calculate whether something poses a risk, and to make quick protective judgements. The brain's second job is to think. When assessing risk, people can place more emotional significance on potential loss than on equivalent gain. That is, there is a preference to avoid a small unknown risk over a larger, known risk. This risk aversion overwhelms the objective consideration of evidence (Ropeik 2014).

Uncertainty in GM encompasses also fear of the new and unknown. Genetic modification is highly complex technology that is difficult to explain in a sound bite. Conflicting views from the scientific community and activists on the safety to human health and the environment contribute to the high degree of uncertainty by the public. This unease has led to the precautionary approach adopted by Australian and European governments. GM products are strictly regulated along the entire chain of production from development to sale.

The psychology of personal control and choice greatly influences risk perception. People are more comfortable selecting riskier options if there is some sense of control involved in the decision. People feel less threatened when they choose a risk for themselves rather than have a risk imposed on them. There are claims that labelling provides consumers with the information required to make an informed choice, but studies indicate that the effect of including GM labelling on food products is not yet well understood (Rollin, Kennedy et al. 2011), see *Section: The meaning behind GM food labels.*

The issue of fairness in risk assessment refers to the perception that the disadvantaged face greater risks. Social activists believe this to be true of farmers in developing countries and smallholder farmers who are burdened with the cost of genetically modified seeds and the licensing agreements that do not allow seed saving. Patent law around agricultural biotechnology is a highly controversial issue.

5.2. Cognitive bias

Cognitive bias can influence how technology is understood, how risk is perceived and consequently how technology is developed, supported and regulated. Cognitive biases can lead to systematic deviations from a standard of rationality or good judgment, and are often studied in psychology and behavioural economics. Biases are not necessarily all bad. Psychologists believe that many of these biases serve an adaptive purpose – they allow us to reach decisions quickly. Many of these biases affect belief formation, business and economic decisions, and human behaviour in general.

A person's first memory of a technology is their strongest memory, so any information received after that is weighted unevenly. It is difficult to change perceptions after people form their original opinion, even after additional information is provided (Kahneman 2011) (Sunstein 2013).

Some examples of common cognitive bias are belief bias, bandwagon effect, confirmation bias, gambler's fallacy, hindsight bias and zero risk fallacy. The fallacy that natural is better is also a popular misperception, and is used to the advantage of many industries. People rely heavily on synthetic and artificial materials in our everyday lives, and there are many natural products that are not good for us. The organic and non-GM markets are able to exploit consumer preferences for natural products.

5.2.1. The appeal to nature fallacy

The appeal to nature fallacy refers to the belief that natural things are good and unnatural things are bad. People refer to 'natural beauty', 'the natural order of things', 'you're a natural', 'natural remedy'. The word natural is loaded with positive connotations. But of course not all good things are natural, and not all natural things are good.

Some opponents of GM crops claim that genetic modification is a bad idea because it is unnatural, but classifying plant breeding techniques as natural or otherwise is complicated. All plant breeding techniques involve genetic modification in some form. Plants bred and selected by conventional techniques, including heat, chemical and radiation mutagenesis, are also used in organic farming. These practices induce variation of the species and can carry an equal mutational load to genetically engineered plants (Puchta and Fauser 2013).

The 'natural' versus 'human made' phenomena can be further illustrated by comparing how medicine and natural remedies are regulated. Medicinal development, testing, sale and advertisement is tightly controlled and this high level of regulation is well supported by the public. By contrast, naturopathic medicines and supplements have not been well regulated to date. (Ropeik 2010).

Over one million Australians regularly purchase organic food products, while 65% of consumers buy organic food on some occasion. While there is a core group purchasing organic products with regularity, there is a broadening base or 'mainstreaming' of organic consumers. One of the key barriers to increased sales of organic food has been the ease of access to this niche market. This barrier has been reduced considerably, most likely due to the greater availability of organic product on retail shelves. The organic industry is a growing industry and there is clearly market value in the organic brand (Swinburne University of Technology 2012).

Tasmania bans GM crops to maintain clean, green brand (ABC News 2014)

Tasmania is the only Australian state to have to a blanket ban on genetically modified organisms (GMOs).The state wants to protect the reputation of Tasmania's food and agricultural exports as clean and green. Those opposed to GM see the ban as a great point of difference.

The Government will keep exemptions for scientific trials of GM crops and has not ruled out lifting the ban in the future.

Studies have shown that consumers value taste, 'naturalness', convenience, healthiness (often associated with naturalness) and price when making food choices (Rollin, Kennedy et al. 2011). Four of the five leading benefit attributes for organic foods concern what it does *not* contain (e.g. chemicals, preservatives). Addressing these preferences could be the key to producing and marketing new food technologies like GM products to consumers, especially given that GM has the potential to provide food free of chemicals.

5.3. How social activism can influence public attitudes, and in turn regulation

The anti-GMO movement developed in tandem with the technology of genetic modification in the 1970s. The issues which concerned the early activists grew from the potential health risks posed to laboratory scientists and the environment from cross-contamination of the organisms. Another area of concern was the decision to extend intellectual property to genetic information, making it a marketable product.

In the mid-1990s, the movement against genetic engineering gathered strength, particularly in countries like France and Great Britain. In 1996 agricultural biotechnology company Monsanto introduced genetically manipulated soybeans to Europe. Against the advice of an executive from the UK company Zeneca, Monsanto introduced this GM product without labelling it as such. The activist community was outraged and jumped on this attempt to conceal the origin of the product, using Monsanto's lack of disclosure as further proof of the power and manipulation the company exerted (Schurman 2004).

Monsanto proved to be a useful industry target for the activist groups. The company was the global leader in the seed technology industry, its entire business was based around seed development, and it was known to be aggressive in pushing genetically manipulated products without full disclosure. The activist community created alternative frameworks through the language used to influence how consumers would interpret and understand these new biotechnologies, for example, the use of the word 'Frankenfoods' as a deliberate attempt to invoke fear. The effectiveness of the movement is clear when considering that although no genetically manipulated food health issues have yet been proven, the increasing support from the public and the anti-GM movement in Europe forced many governments to alter their regulatory approach to this technology (Schurman 2004).

Most genetically manipulated products are used to produce food for human consumption, in some cases indirectly through animal feed which is ultimately consumed by humans. As already discussed, food is a highly sensitive commodity. Potential changes to it cause alarm in many people. It is essential for our health and survival, we eat it, we feed it to our children. Food also has a powerful cultural significance, and is closely tied to our cultural identity. The power of suggestion that genetically manipulated food might not be healthy was enough to deter adoption by many European countries at the time. Social activism has been very influential in the decision-making processes involved in regulation of GM technology, particularly in Europe (Schurman 2004).

China, the sixth-largest GM crop-growing nation, also has anti-GM activists concerned about food safety and the influence on food supply in China through American owned biotech companies (EuropaBio 2012). In 2009, China granted safety certificates for two genetically manipulated varieties of rice and one variety of maize, potentially making it the first country to use genetically manipulated technology in the production of a main staple. But further approvals needed for commercial growing are yet to be granted. More recently in China, GM food supporters are becoming more vocal in an effort to combat the influence of the activists. In 2013, the Chinese Ministry of Agriculture was reported to be preparing a public education campaign on the merits of genetically manipulated (*The Economist* 2013).

5.4. Australian attitudes to GM products

The only genetically modified crops currently being grown in Australia are cotton and canola. Cotton seed and canola oil are used in spreads, tinned food and for deep frying but there are currently no GM fresh fruits and vegetables, grown in Australia. We do however allow manufacturers to use imported GM food ingredients in products such as soybeans, canola, corn, rice, sugarbeet, potatoes and cotton[3].

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[3] http://consumewithcare.org/the-low-down-on-genetically-modified-foods/ .

In 2013, a study by *Ipsos* of Australian community attitudes to GM food found that over half of the respondents were in favour of growing GM crops in their state. Factors that were most likely to change the mind of those who did not support GM crops included positive environmental and health outcomes, and if crops passed strict environmental and health regulations (IPSOS Social Research Unit 2013). Fifty-five per cent of the study's respondents said they were unaware that 'most of the cotton grown in Australia is genetically modified' and 36% said they did not know whether 'most of the fruit and vegetables grown in Australia were genetically modified'. Compared to an earlier survey in 2010, awareness of introducing the genes of a plant into a different species of plant had increased, while awareness of introducing the genes of an animal into a plant had decreased.

Sources of GM food sold in Australia (Better Heatlh Channel 2014)

- Soya imported from the United States – the soya has been genetically modified to be resistant to a herbicide. It can be found in a wide range of foods, such as chocolates, potato chips, margarine, mayonnaise, biscuits and bread.
- Cottonseed oil made from GM cotton – this oil, made from cotton resistant to a pesticide, is used in Australia for frying (by the food industry) and in mayonnaise and salad dressings
- Imported GM corn – this is mainly used as cattle feed at present and has not been approved for farming in Australia. However, GM corn may have entered the Australian market through imported foods like breakfast cereal, bread, corn chips and gravy mixes. If so, it must be labelled.
- GM ingredients in imported foods – including GM potatoes, canola oil, rice, sugar beet, yeast, cauliflower and coffee.

Respondents were significantly less willing to eat food that had some form of perceived scientific intervention, such as genetic modification, than to eat other foods. They were least willing to eat meat and other products that came from genetically modified animals. People with higher levels of support for biotechnology in general were more willing to eat all the food types covered in the survey (Ipsos 2013).

Currently Australia grows only genetically modified cotton and canola. There are existing licences for GM wheat field trails in NSW, SA, WA, VIC and ACT with the aim to commercialise genetically modified wheat in 2015. The *No Appetite for Australian GM whea*t report commissioned by a number of concerned networks, details results of an investigation into attitudes towards GM wheat of major wheat buying companies in Australia and key export markets. The results of the survey indicate that existing Australian wheat markets do not want genetically modified wheat now or in the near future because they believe consumers are not ready to accept genetically modified wheat in the foreseeable future (Safe Food Foundation 2013).

5.5. Attitudes in developing nations

Worldwide, the area under biotech crops has increased a hundredfold in the past 20 years, from 1.7 million hectares in 1996 to 170 million hectares in 2012. Of the 28 countries which planted biotech crops in 2012, 20 were developing countries and eight were industrial countries (ISAAA 2013). In many cases GM crops have the potential to benefit poorer communities. Higher crop yields are usually achieved where farming practices and pest management are not of the highest standard, which is more likely in developing nations.

The generally more favourable attitude toward GM crops in developing countries can be explained by the urgent need for food and for improved nutritional content. There is also some evidence that lower perceived risks in developing countries are due to greater trust in government, regulation and positive media influences (Rollin, Kennedy et al. 2011).

There are sizeable black markets for Bt cotton seeds around the world. The difficulty in accessing GM seeds and the high cost has led to illegal Bt cotton farming where farmers illegally save seeds. (Qaim and De Janvry 2003). The cases of illegal adoption indicate that promising technology will be adopted by communities in spite of regulation and law. The Nuffield Council on Bioethics recommends that genetically modified technology adopted in developing countries is done so within a legal framework of regulation which would include monitoring health and environmental effects. If there is a particular technology that has the potential to improve economic security and health then developed nations must not restrict the ability of the developing nation to pursue these options and adopt a useful technology (Nuffield Council on Bioethics 2003).

5.6. Can attitudes to technology be changed?

Even though genetically modified food is widely accepted by the scientific community as a safe option, there is still great opposition to genetic modification. Scientists are baffled when members of the public and activist groups so vehemently deny scientific evidence. But the ability of scientific evidence to contribute to public debate about societal risks depends on how the public assimilates information. This instinctive reaction is based on an individual's values and beliefs which inform their attitudes.

A study by Oklahoma State University researchers determined that assimilation of information is heavily dependent on prior beliefs. The study looked at cognitive bias in genetically modified foods and global warming. The researchers concluded that failure to change opinions after new evidence is presented is a result of several factors, including misinterpreting information, illusionary correlations, selectively scrutinising information, information-processing problems, knowledge, political affiliation and cognitive function (McFadden and Lusk 2014).

Generally speaking, consumers who perceive scientific progress as an improvement on social welfare tend to perceive more benefits and fewer risks. When there is little information on a new technology, and consumers cannot assess possible risks, then trust in institutions becomes highly influential (Rodriguez-Entrena and Salazar-Ordonez 2013). The scientific community and government can promote confidence and trust in scientific institutions to counter any opposing forces and opinions. Regulatory bodies also play a key role in ensuring that necessary guidelines are in place to manage health and safety concerns.

Because prior belief greatly influences how people interpret new information, it is important for the scientific community to understand how to communicate complex science to the general public. Any solution to food security will involve some level of environmental cost but the pursuit of 'zero-risk' should not discourage efforts that are scientifically feasible, practical and broadly accepted by an informed society.

6. Regulation of GM crops: understanding how GM crops are regulated and the impact regulation has on uptake

Public attitudes, risk perception, cognitive bias and social activism have all played a key role in the vast difference between regulation of conventional and genetically modified crops. Genetic manipulation of crops presents some technical challenges, but these challenges are less restrictive than the ethical, cultural and regulatory impediments to the adoption of this technology. The prolonged and precautionary approach of regulatory approval is a major block in the adoption of GM technology and its products.

6.1. Golden rice: regulating the process not the product

Increased crop yields of global food staples such as rice, maize and wheat have been responsible for addressing starvation across the developing world. Diets that are heavily dependent on such foods, however, do not provide the range of vitamins, minerals and whole protein vital to human health (Kiple and Ornelas 2000). For example, the most important food staple in the developing world, rice, has no vitamin A and little iron. Although the increased production of rice in the developing countries has alleviated food shortages it has resulted in problems such as vitamin A and iron deficiency. GM research attempted to address these deficiencies with the development of golden rice, a variety enriched in vitamin A.

Golden rice was initially developed by Ingo Potrykus from the Swiss Federal Institute of Technology and Peter Beyer from the University of Freiburg to contribute to reducing vitamin A deficiency in rice-dependent developing nations. The work on golden rice was first published in 2000 as a significant breakthrough, but though the team hoped that it would be available to farmers by 2002, its use was delayed for more than ten years by the GM regulatory process (Potrykus 2012).

In his paper *'Golden Rice': a GMO-product for public good, and the consequences of GE-regulation*, Ingo Potrykus called for the *traits* of plants to be regulated, instead of the *technology*. He argues this would make regulation cheaper and faster without compromising safety since genetic engineering technology has an unprecedented safety record. Golden rice was to be provided free of any charge to growers and consumers in poor developing countries to address the great public health problem of vitamin A deficiency. Within the public domain there was no funding available beyond the proof of concept stage, so the product's development needed private sector support (Potrykus 2012).

Potrykus concluded that the rules and regulations for the use of transgenic plants and the political attitude based on the precautionary approach led to the significant delay in making golden rice available. This level of scrutiny does not apply to traditional breeding techniques that are similarly unpredictable in the products they produce (Potrykus 2012). There is no evidence to support the claim that there is a difference between crops produced by conventional plant breeding or genetic modification techniques. Regulation based on process rather than crop traits has impeded the development of this technology and its potential benefits for food security issues. It is time for agnostic regulation (*Nature Biotechnology* 2012, Tautz 2013, Klaus 2014).

One of the consequences of this heavy regulation is the market dominance of a few financially powerful companies for GM products. One key barrier to new companies entering the market is the high cost of seed research and development (Matson, Tang et al. 2012). The lengthy and expensive testing and regulatory regime for GM crops and the danger that consumers will reject the products means that only a handful of large companies can afford the risk of developing them. The cost for the development of a GM variety is currently so great that it is difficult for a public institution to get any product to market.

6.2. The effect on early adopters of GM technology

Early adopters of the technology can face additional costs in terms of higher seed prices, technology fees and restrictive user agreements such as mandatory buffer zones. Seed cost is dependent on the patenting arrangements and contract agreements with biotechnology companies, within each country. Companies like Monsanto often specify that seeds can only be used for one season.

Mandatory buffer zones are implemented to ensure crops are separated by an appropriate distance to avoid cross-contamination. The distances can range from several metres to several kilometres for different crops, but the effectiveness of regulated distances is in dispute. In Australia, GM crops are regulated by the federal Office of the Gene Technology Regulator. Australian regulations require GM adopters to avoid cross-contamination of their approved GM crops with non-GM crops. In contrast, current regulations in the US do not require GM farmers to control approved GM crops – it is the responsibility of the non-adopters to take precautions to avoid contamination. GM technology is more widely accepted in the US and as a result, regulation is not based on the precautionary approach (Ludlow 2012).

Contamination between neighbouring farms may result from wind and insect-borne cross-pollination or inadequate harvesting and handling practices. The coexistence of GM farming with non-GM and organic farming is an ongoing problem that requires effective monitoring and management. In Australia, contamination of organic crops with crop containing GM material can be particularly devastating to the organic farmer, as the organic industry certification organisation has a zero tolerance for GM content and organic farmers risk losing their organic certification. This is not the case in countries like the US.

In a landmark Australian case, an organic farmer in Western Australia sued his neighbour for contaminating his non-GM crop (non canola) with GM canola. The farmer, Steve Marsh, claimed his organic farm was contaminated by GM canola in 2010. The contamination resulted in Marsh losing his organic certification from NASAA. GM farmer Michael Baxter argues that he complied with the set buffer zone and that it was unfair to impose unnecessary conditions on him (such as increased buffer zones) which limited how much land he could use to grow GM canola. He argued that Marsh should sue NASAA for imposing unrealistic standards (ABC News 2014). Justice Kenneth Martin reserved particular and sharp criticism for NASAA, saying that the retraction of organic certification was 'unjustifiable'. Marsh had never grown canola so there was no risk of a genetic transfer from Baxter's GM plants (Roush 2014).

In 2012, Karianne Ludlow of Monash University published a paper comparing the economic loss of non-GM adopters in Australia, Canada and the US. The claim non-adopters make is that they can no longer choose to be non-adopters because of the use of GM crops in their region and the risk of contamination. Ludlow proposes that GM adopters who comply with the law – by using legal seeds and abiding by set buffer zones – but who inadvertently cause contamination of other organic crops should not be liable because the standards of cross-contamination are self-imposed by the organic market (Ludlow 2012).

Under the current regime in Australia, those who choose to take advantage of new technologies – the early adopters (of the GM technology) – to bear the responsibility and cost of the restrictive rules. Current regulations in Australia restrict adopters of GM technology, potentially providing organic farmers with an unfair commercial advantage.

6.3. The meaning behind GM food labels

Since the industrialisation of food, food labelling has become more widespread. In the past, food was produced locally and consumed locally. Consumers had a direct relationship with their food producers and providers. Advances in production, storage and transport have led to the demise of the direct relationship between consumer and producer/seller. Food labelling was introduced to provide reliable information to consumers so they could make informed decisions when making purchases. There is a general trend toward more comprehensive labelling of all food products. Consumers want clear and informative labelling for a range of reasons: nutritional and calorific content, allergy and tolerance concerns, and information about the full lifecycle of the product, such as farming practices, or country of origin. One of the more recent food labelling issues is whether or not to label products containing genetically modified organisms.

In Australia and Europe, labelling is mandatory for products that contain more than the specified threshold of GM content (1.0% in Australia, 0.9% in Europe). That is, in Australia labelling is not required when there is 1% or less per ingredient of an approved GM food source (Food Standards Australia and New Zealand 2013). The acceptable level of 1% allows for accidental contamination of non-GM crops which would still permit the producer to label their product as non-GM. The level of GM content permitted is not related to any food safety concerns. In Australia, Food Standards Australia New Zealand (FSANZ) has regulated the labelling of GM food since 2001.

> *GM labelling is not about safety. It is about helping consumers make an informed choice about the food they buy.* (Food Standards Australia and New Zealand 2013)

Labelling does provide consumers with the information required to make an informed choice. However, studies indicate that the effect of including GM labelling on purchasing food products is not yet well understood (Rollin, Kennedy et al. 2011). As with much of the regulatory processes linked to GM technology, labelling of GM content in food products is not based on scientific evidence of any adverse effects, but is a response to public concern and opposition to the technology.

Summary

The history of agricultural practices shows that the ability to modify, create and select crop varieties is not new. Humans have intervened with the evolution of plants for more than 10 000 years. The revolutionary element of genetic modification technologies is not in the ability to genetically modify organisms, but in the ability to do it with a higher level of precision and speed. GM farming is increasing rapidly particularly among developing nations. In addition to improving agricultural practices, reducing waste and improving nutrition, GM crops have the potential address food security issues by increasing crop yield and improving food quality and nutrient composition. Research indicates that economic performance of GM crops is highly dependent on the crop variety, region and country.

The introduction of GM food has challenged the way we think of and regulate food technology. Public attitudes to GM technology play a crucial role in acceptance by the public, uptake by industry, and level of intervention by government. Public opinion is polarised, although research to date indicates no health and safety issues related to GM foods and there is wide scientific support for GM. Recent research has found that personal opinion and belief heavily influence decision making and that cognitive bias plays an important role in all decisions, including the acceptance of biotechnology.

Better scientific information and education do not necessarily change attitudes. The GM food debate is complex, based on transparency, the manipulation of nature and market power of corporations. Strong opposition to genetic engineering by activists and the general public has resulted in heavy regulation of the technology. Unfortunately, this resistance and burdensome regulation has led to a greater monopoly discouraging smaller biotech companies and publicly funded organisations from pursuing the technology.

To date, there is no scientific reason for technology-specific regulation of crops bred using genetic modification. There is no demonstrated difference between conventional and GM crops. The level of regulatory burden on GM crops is not supported by any proven harm or risk. It is important to continue long-term health and environmental assessments, but it is also important to take an evidence-based approach so that all nations are able to benefit from new technology.

Attachment 1: GM crop technology

Genetic modification (GM) refers to the mutation, insertion or deletion of genetic material. Plant biotechnology techniques can transfer genes from one organism to another to introduce a new trait into the plant. For example, insect-resistant GM cotton uses a gene from a naturally occurring soil bacterium to provide the cotton with built-in insect protection. GM does not necessarily mean that a gene from another organism has to be used to create the genetically modified organisms (GMO); it can also mean that the organism's own genes are changed.

Plant biotechnology has been around for over 30 years. The main tools initially used to introduce DNA into plants were the biolistic method (which injects DNA bound to tiny particles of gold or tungsten cells into plant tissue or cells under high pressure), or *Agrobacterium*, a genus of bacteria with the ability to transfer genes into a plant host. All transgenic crops that are currently commercially grown were produced using these methods. This has been effective with simple traits such as herbicide tolerance and insect resistance. However, the random nature of gene insertions can have undesirable effects, and these methods are not favourable for making combined trait changes.

Advances in GM crop technology

New biotechnology methods that offer precise **genome editing** by site-specific integration, deletion and mutation of genes are expected to have a great effect on plant biotechnology. The genome is modified using artificially engineered nucleases. A nuclease is an enzyme capable of breaking the phosphodiester bonds, which are strong bonds between the subunits of nucleic acid. The nuclease creates specific double-stranded breaks at desired locations in the genome, which previous methods were unable to do. Zinc finger nucleases (ZFNs) and transcription activator-like effector nucleases (TALENs) target unique sequences within complex genomes and are used to edit the genome *in situ*. The CRISPR/Cas system performs targeted, highly efficient alterations of genome sequences.

The role of ICT

Information technology has been crucial in advancing genetic modification technology. The rapid speed of sequencing attained with modern DNA sequencing technology has been instrumental in sequencing many different types of DNA. Sequencing provides the order of individual nucleotides in DNA or RNA which is isolated from organisms such as animals, plants and bacteria. An enormous amount of data is generated in sequencing any genome. Algorithms are used to evaluate the raw sequence data.

Next generation sequencing (NGS) refers to the development of high-throughput sequencing producing thousands or millions of sequences concurrently. The demand for sequencing has resulted in NGS technologies which have in turn lowered the cost of DNA sequencing (see Figure 2).

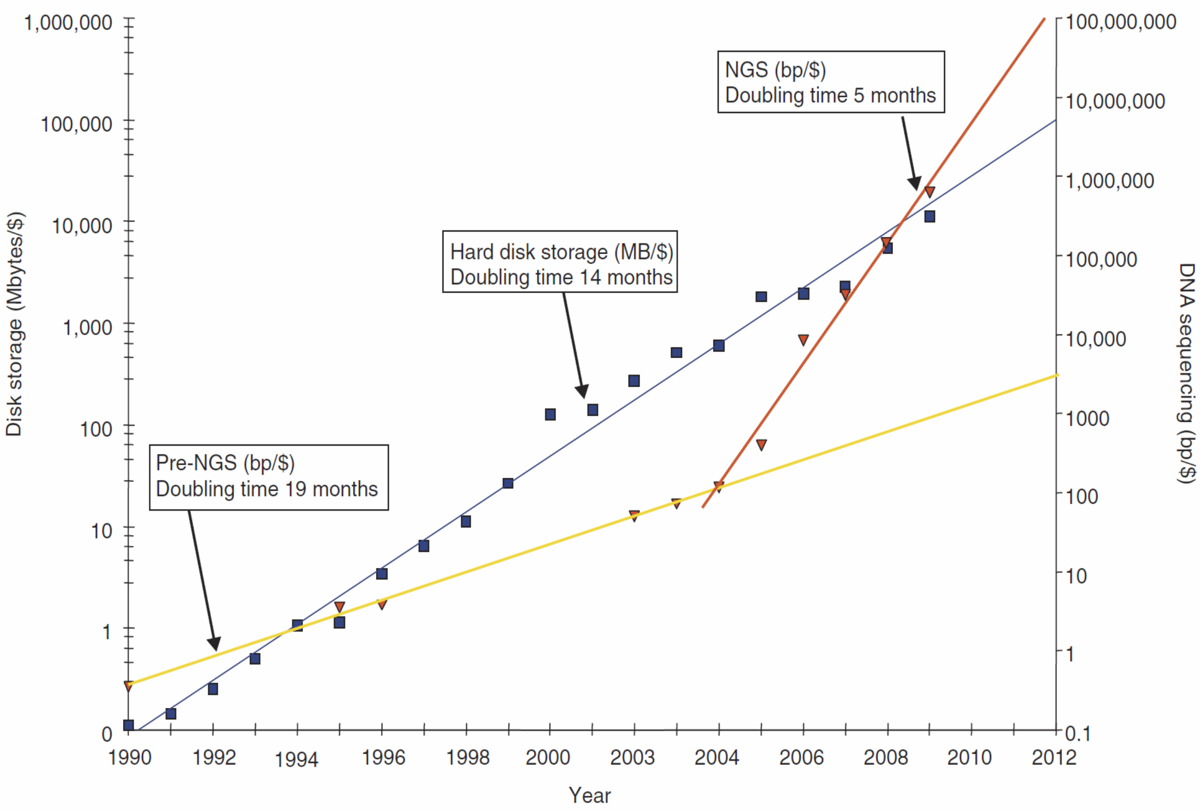

Figure 2 Next generation sequencing capability and cost over time (Stein 2010)

The increase in sequence throughput from different sequencing platforms in NGS is exponential. The current bottleneck is in the processing of data, which requires high performance computing infrastructure, memory, storage and skilled bioinformatics technicians (Thudi, Li et al. 2012). Storage and management of large datasets is very challenging. In addition to data storage and management, data analysis is necessary to make sense of the large volumes of sequence data. The ICT and bioinformatics disciplines will be required to develop tools for management, analysis and storage of different types of data and quality. Cloud computing is a potential solution to the question of massive data storage as well as analysis.

Attachment 2: Differential impacts

The issues that surround food security and the effects of GM crops are complex, multidimensional and of varying importance to different groups (Table 1). Consumers and farmers might have different cultural and economic reasons for choosing to produce or consume organic or genetically modified products.

system	key issues	consumer	farmer	biotech industry	government
security	food security (sustainability)				x
	environmental impact (pesticide use, soil and climate conditions)	x	x		x
	ecosystem (interaction of new genetic material)	x			x
society	organic vs GM vs non-GM (cross-contamination, labelling, choice)	x	x		x
	agricultural practices (required for both GM and non-GM crops)		x		
	health (introduction of new allergens, antibiotic resistance, long-term studies)	x			x
economy	cost of genomics (including data analysis)			x	
	ownership of seeds (IP)		x	x	
	cost of seeds		x	x	
	crop yield		x		

Table 1 Impact and areas of concern for different groups. Crosses indicate where the highest level of interest/concern most likely lies.

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