In 2002, the Jewish Orthodox Union concluded that genetically modified (GM) foods, including those with pig genes, may be consumed by Jews. The Islamic Jurisprudence Council followed suit. After similar debate, it decided foods produced from genetically manipulated crops are halal and suitable for Muslims, although there may be issues with crops that contain DNA from forbidden foods.

Today’s concerns about the influence of genes on the nature and characteristics of food crops would no doubt surprise ancient farmers. Not so much by the act of manipulating plants but by the speed of the technology. After all, since the birth of agriculture around 10,000 years ago farmers, and more recently breeders and scientists, have sought to increase the efficiency, reliability and safety of food production.

Early farmers selected varieties, or lines, that allowed them to improve production systems and support harvesting and storage. This led to major changes in characteristics of plants compared to their wild relatives. Importantly, farmers selected plants that performed well when grown as
a community, a crop. Farmers in different regions continued to select plants for their environment and over time diverse landraces were generated. Farmers also exchanged lines with neighbours and along trading routes, creating a flow of genetic material over regions and continents. In each area, farmers continued selection for the best-performing lines. For instance, when Europeans arrived in Australia they brought their crops with them. Many performed badly, so selection for lines adapted to our environment became a priority.

**FROM FIELDS TO LABORATORIES**

Selection by farmers underpinned modern agriculture but much higher rates of genetic improvement could be achieved by systematic breeding. The discovery of the principles of genetics laid the foundations for rapid improvements in crops over the past century. As knowledge of genetics and genes has expanded the rate of crop improvement has accelerated.

**Selecting the best**

Systematic breeding uses variation to create new gene combinations. For example, a wheat variety may show high yields but be susceptible to a harmful disease. The breeder can correct this defect by crossing to a plant that has resistance to the disease but may be low-yielding. Offspring of the cross have different combinations of genes from parents and are screened to identify the individuals that have inherited both the good yield and the disease resistance. Breeders select the best-performing plants to continually improve yield and quality of their crops. The more diverse the variation available, and the more plants the breeders can screen, the greater the opportunity for advances.

Selective breeding is essentially a numbers game since many important crop characteristics, such as yield, drought tolerance and fruit size, are complex and controlled by a very large number of genes. This means that finding the best combination of genes can be difficult. However, mechanised sowing and harvesting now enables breeders to grow and assess thousands of genetic combinations. Additionally, the advent of computing and powerful statistical methods supports the accurate evaluation of performance of the new plant lines.

More recently, DNA markers have allowed breeders to follow individual genes as they are passed to the offspring. DNA markers are like DNA-fingerprinting used in forensic science and allow breeders to track desirable genes, such as for disease resistance or larger fruit, in the many thousands of plants in their programs. Based on the DNA fingerprint, the breeders can predict many of the key characteristics of the plants when grown as a crop, such as disease resistance, quality and even yield.

**Generating new genetic variation**

Breeders continually search for new methods for expanding the number of useful genes available for cross-breeding and selecting in the next generations of plants. The search for new variation has taken breeders well beyond the traditional view of breeding as crosses between sexually compatible plants. In the 1950s chemicals or ionising radiation were widely used to produce mutations and induce novel changes. Many modern varieties of crops and fruits, such as several seedless mandarin varieties and many new disease resistances include these mutations.

**Return to the wild side**

Breeders have also made extensive use of the wild relatives of our domesticated plants by methods known as wide-crossing. Genetic information from the wild relatives is integrated into the genetic make-up of the crop plant by a process called chromosome engineering.
This form of engineering has provided a key technique for improving a range of characteristics, particularly disease resistance.

These methods involve large-scale changes in the genetic make-up of crop plants and bring hundreds or thousands of new genes into the crop. In both chromosome engineering and mutation breeding, thousands of genes are altered and most of the changes will actually reduce the performance of the plants. Scientists and breeders clean up the genetic material by slowly removing unwanted, often deleterious genes or mutations, while retaining the desirable genes.

These techniques have been used for half a century and have been critical to the success of current crops such as wheat, corn, rice, barley, and many fruits and vegetables. Importantly, the new plants produced by chromosome engineering or mutation breeding are not subject to regulation and can be generated, screened and commercialised without the need for special scrutiny by government and international regulatory agencies.

**Genetic engineering**

From a scientific perspective, genetic engineering is a logical development and refinement of earlier techniques. Most plants and animals contain around 30,000 genes. A major advantage of genetic engineering is that single genes are modified, not hundreds or thousands, and modifications are specific for the desired feature, such as disease or pest resistance.

A genetically engineered plant contains one or more genes that have been inserted into the genetic make-up of the plant using recombinant DNA technology. This technology involves isolating or synthesising a gene in a laboratory and then transferring it to the new host plant. Once inserted into the genetic make-up of the host plant, the gene will be passed on to its descendants in the same way as all the other genes that make up the organism. The genes can be from any source but they may need to be modified to work properly in their new host. The most widely used genes in genetically engineered crops currently being grown provide tolerance to herbicides or resistance to insect pests or viral diseases.
Genetic engineering has developed into a major scientific tool also supporting many aspects of biological and medical research. Virtually every university and biological research laboratory routinely engineers bacteria, plants or animals in the course of research. The result: over the past few decades knowledge and understanding of genes, their function and regulation has exploded.

**THE UPSIDE**

As understanding has grown, scientists are increasingly confident in the viability and safety of genetic engineering. However, regulatory complexity limits development and delivery of practical outcomes for this technology.

For years, genetic engineering has been seen as the future direction for crop improvement. Where available it’s rapidly adopted by growers. Over the past few years the area sown with genetic-engineered crops – GM crops – in developing countries has outstripped production in advanced economies. The traits so far have improved production and provided benefits for farmers. However, GM plants with improved nutritional characteristics such as high vitamin A, high iron and resistant starch have been developed and are close to release.

Many public and private sector groups are evaluating GM crops for improved drought and salinity tolerance. Importantly, GM technologies could offer greater flexibility in addressing challenges resulting from increasingly variable climatic conditions and the need to reduce the use of pesticides, fungicides and fertilisers.

The United Nations Food and Agriculture Organisation estimated in 2012 that wheat yields must be increased by 70 per cent by 2050 to meet expected demand. All technologies, including GM, will be needed to meet the target.

**THE DOWNSIDE**

Many concerns about GM technology relate to ethical and political issues. Some of the first GM plants contained not only the genes for the new trait but also genes for resistance to antibiotics, as can happen when genes are transferred from a bacterium that possesses antibiotic resistance. This helped scientists select for plants that had been engineered but raised concerns that the antibiotic genes could exacerbate the problems of antibiotic-resistant bacteria. However, several studies showed that the genes were not transferred from the plants to bacteria and scientists soon developed methods to remove the antibiotic genes from the GM plants.

Opponents of GM technologies also raised questions about the safety of foods produced from GM crops. The European Union spent more than half a billion dollars on studies of GM safety to support the political anti-GM stand, only to conclude that GM-derived foods are as safe as conventional crops. Unfortunately,
these safety studies are dismissed by anti-GM groups.

Still, there are concerns about corporate control of the technology. The GM crops currently grown were all released by large multinational seed companies. Ironically, high regulatory costs strengthen the corporatisation of food production and weaken public sector engagement by making it virtually impossible for public-sector organisations to take a GM technology through to farmers’ fields.

**A POLITICAL BOTTLENECK?**

Almost three decades of plant biological research was based on the assumption that GM technology would be routinely applied. But delivery of these outcomes is slow and costly. Consequently, major investment is flowing into finding alternative techniques that won’t be classified as GM. In my opinion this risks further polarising the European/American divide as North America will likely classify new techniques as non-GM while the Europeans will continue GM-style regulation.

GM technology is espoused as a critical tool for ensuring global food security. However, it’s also a source of dispute in agricultural aid programs with several European countries tying aid to non-GM approaches. Pressure is also on developing counties to take on the regulatory regimes of developed countries that are either strongly pro- or anti-GM, rather than considering local needs and capabilities.

Humanity enjoys the safest and cheapest food in history – and prehistory – through the industrialisation of food production. Simultaneously, our population is increasingly urbanised and poorly informed about modern agriculture. Little wonder many people reject industrialised production systems in favour of more traditional methods, while still demanding cheap, safe food.

I argue this cannot be done without using new scientifically validated technologies. Scientists must work to gain community support through open discussion. We can be sensitive to the concerns of consumers and conscious that not all concerns are related to the science; we can help the Rabbinical and Islamic Jurisprudence Councils by avoiding pig genes in our crops. It’s a tough task, an ongoing task, but for me it’s a critically important task.

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FURTHER READING


Climate change is disrupting the ebb and flow of the continent’s water supplies, writes Åsa Wahlquist.
Although Australia is the driest inhabited continent; under the ground and out of sight it possesses vast reserves of water. Groundwater supplies about 17 per cent of the water the nation uses. Many areas depend on it.

On Melbourne Cup Day, 2006, Prime Minister John Howard called a meeting to discuss the unprecedented drought in the Murray-Darling Basin. Afterwards, he commissioned the biggest single project the CSIRO has ever undertaken: the Murray-Darling Basin Sustainable Yields Project.

It has since been extended to other areas including northern Australia and the Great Artesian Basin. The resulting world-leading expertise is about to be exported, to assist nations from the USA to India to understand and manage their water better.

Dr Bill Young, director of CSIRO’s Water for a Healthy Country Flagship, says Australia now has “a much more robust picture of how much water we have, its variability in space and time, and the likely impacts of a changing climate on both of those things”.

Australia truly is a land of droughts and flooding rains. Not only does it have an extraordinarily variable rainfall – the long dry in the Murray-Darling Basin ended in 2010 with two record-setting years for high rainfall – but climate change is now affecting the rain as well as inflows into rivers and dams.

But while the east coast flooded, the south-west became even drier. That dryness is directly attributed to worsening climate change, and Perth’s water managers are planning for a future with no dam water.

One of the great ironies is that although Australia is the driest inhabited continent, under the ground and out of sight it possesses vast reserves of water. Groundwater supplies about 17 per cent of the water the nation uses. Many areas, particularly in inland Australia, depend on it.

Groundwater is a finite resource, replenished only when surface water seeps into the aquifer. There are fears that some aquifers have reached ‘peak water’, as it is being used faster than it’s recharging.

Recharge can be a slow process. Some of the 64,000 million litres of water held in the Great Artesian Basin (GAB), which lies under one-fifth of Australia, is 2 million years old (see: Figure 1). Young, a natural resources engineer, admits the GAB “is a lot more complex...
than it was thought”. The CSIRO and Geoscience Australia have produced stunning 3D images to help communicate the new understandings. One thing they didn’t expect is that the GAB has different levels of connection with nearby basins.

CSIRO research scientist, hydrogeologist Dr Brian Smerdon, says while the eastern side is predicted to have increased groundwater levels, the western side is likely to have lower levels, due to a very long-term natural decline.

“It is very difficult to know the precise rates of inflow and outflow for such a complex groundwater basin,” Smerdon says. “It appears that outflows are greater than inflows for most of the Basin. Continued extraction of groundwater from the Basin requires continued measurement of the groundwater levels.”

Groundwater is frequently linked to surface water. As hydrologist Richard Evans points out, this makes it possible to “allocate the same resource twice, to surface-water users and to groundwater users”. In a number of catchments in the Murray-Darling, groundwater extractions exceeded recharge.

CSIRO scientist Dr Wenju Cai says this decline in rainfall is one of the most compelling examples of human-induced climate change in the world. He explains the system that brings rain to WA during winter has moved towards the South Pole. The poles are warming faster than other latitudes, reducing the temperature gradient between the poles and the equator. This has led to a major change in global atmospheric circulation and a decrease in the subtropical jet stream and a decline in winter storm tracks over the south-west.

According to McFarlane, Perth lies over several major aquifers. The city is currently pumping from a very deep aquifer which is replenished slowly. “The amount of water they are taking out is far in excess of the recharge,” he says. Pumping has at least reduced water pressure, “by making room in the aquifer they are sucking water in. It is still not enough,” McFarlane says.

Perth does have a water future, but it is one that will be increasingly reliant on cutting-edge science, on desalination and recycling and a better understanding of its underground water.
DREAMING OF NORTHERN WATER

Australians have frequently looked north and fantasised about using the heavy monsoonal rains that fall there.

But the CSIRO Northern Australia Sustainable Yields Project found the region is in fact seasonally water limited because of the potential water loss from vegetation and from evaporation far exceeds rainfall. Rainfall is highly seasonal: 94 per cent falls in the wet season and the remaining three to six months of the year are dry and the climate is extreme and changing.

Most of the rain falls on the flat coast, where there are limited opportunities for dam-building. The best dam-building sites are in the upper reaches of the catchments where rainfall is sporadic and evaporation highest.

The Northern Australia Taskforce found groundwater development provided the best prospect. It noted the only large northern irrigation development, the Ord River Scheme, opened in 1972. Unfortunately, the wet and humid conditions have proved perfect for pests and diseases, while distance and lack of infrastructure has hindered exports. More than $500 million has been invested in the scheme by the WA and federal governments so far, yet it currently produces just $140 million in agricultural products, including rockmelons, pumpkins, mangoes, chickpeas and chia. The main crop is sandalwood.

According to Dr Bill Young, the CSIRO is undertaking a major project in the north “where we are testing soils, looking at the terrain and working out where you could put dams that would offer a good water yield”.

He argues Australia should develop its northern water resources, but it must be done “in a careful, reasoned and evidence-based way, and not repeat the mistakes of the Murray-Darling. We have the wherewithal to do the science and do it in a smart way and then it will be a sustainable development in the nation’s interest.”

In 1972, drought hit eastern Australia. Monash University climatologist Professor Neville Nicholls, then with the Bureau of Meteorology, says: “We really didn’t know it was an El Niño until 1973, after it had gone. By 1982 we had some real-time monitoring capability and by 1997 it was terrific.” Identifying the El Niño-Southern Oscillation (ENSO) has been a significant step in understanding, and managing, Australia’s waters.

Just how much rain falls on Australia depends on how much evaporates from the sea surface and where the weather systems deliver that moisture-filled air. In El Niño events, the warm water and clouds move away from Australia, often, but not always, bringing drought to eastern Australia. In La Niña years, the warm water and clouds move to the western Pacific, and trade winds blow the clouds over eastern Australia where they yield rain, as they did so spectacularly in 2010 and 2011.

In 1999, climate scientists identified a similar pattern in the Indian Ocean, called the Indian Ocean Dipole (IOD). CSIRO Marine and Atmospheric Research scientist Dr Wenju Cai says the frequency and intensity of the north-west cloud band events that bring rain are suppressed during a positive IOD. They are often, but not always, correlated with an El Niño.
“South-eastern Australia, the Murray-Darling Basin, is more controlled by the positive IOD,” Cai explains. “The Indian Ocean Dipole we now come to understand is perhaps even more important than ENSO.” (See: See-saws and boys and girls, in Marine Life In A Changing Climate, p21, for more detail.)

This improved understanding should lead to more accurate seasonal forecasts. “The science is going to fill the gap,” Cai says. “We know the ocean variability, sea-surface temperature is very important. Predicting sea-surface temperature, we get a good handle on that, but from sea-surface temperature to rainfall is the hardest bit, because it requires a climate model to simulate convection properly.”

Young would like to see more work done on city water supplies, looking at climate change, supply and demand “in the context of a growing and urbanising population, and work out what that means for the right investments in water infrastructure in terms of centralised and decentralised systems”. He points out our cities are growing and urbanising, and wants good science to inform both large- and small-scale investments in urban water infrastructure.

Urban Australians proved their water awareness during the dry of the 2000s, adopting water-saving technologies, obeying water restrictions, and in Melbourne and Brisbane in particular, seriously reducing their household water use.

Young says the science that has developed out of the crisis in the Murray-Darling has resulted in Australia becoming a world leader. With the world’s demand for food rising, access to water will be critical. Young says Australian scientists will be at the forefront “exporting our expertise both in a science and technology sense and in a business sense to help address some of the global emerging problems”.

Åsa Wahquist is a rural writer.

FURTHER READING

CSIRO Sustainable Yields Projects – a comprehensive scientific assessment of current and future water availability in major water systems across Australia to provide a consistent framework for future water policy decisions.

Groundwater Essentials, National Water Commission – The National Water Commission is responsible for driving progress towards the sustainable management and use of Australia’s water resources under our blueprint for water reform – the National Water Initiative.

Great Artesian Basin – This CSIRO-led project examined the water resources of the Great Artesian Basin and assessed potential impacts of climate change and resource development.