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Plant Gene Technology: Improving the Productivity of Australian Agriculture

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Science for Decision Makers is a series published by the Bureau of Rural Sciences. It describes the latest developments in scientific advice, assessments or tools relating to agricultural, fisheries and forestry industries, including their supporting communities.

Its purpose is to make rural science more accessible to those needing to understand the benefits and implications of the most recent research as a basis for decision-making.

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Key Points

1 Maintaining and improving crop and pasture production depends on the development of improved varieties through plant breeding that:

- improves yields
- resists pests and diseases
- requires fewer inputs such as fertilisers
- tolerates environmental stresses.

The success of plant breeding in recent decades and its contribution to increased world food production can be attributed in large part to the adoption of new technologies, including plant gene technology.

2 Plant gene technology is applied in many ways in plant breeding. It is used to:

- identify the genetic basis of desired plant characteristics
- track the inheritance of desired traits in breeding programs
- understand how genes control plant growth and development
- move genes within and between species.

3 Gene technology allows plant breeders to modify plants in ways not possible using conventional techniques. It enables plant breeders to directly incorporate, delete or modify genes of interest. Genes can be incorporated from species unrelated to the crop or pasture plant in question, giving breeders access to a range of genetic diversity much broader than before.

4 Experience with genetically modified (GM) crops in different countries has demonstrated their economic, agronomic and environmental benefits. Australia's adoption of GM insect-resistant and herbicide-tolerant cotton has given farmers extra tools for pest and weed control and reduced insecticide use by up to 85 per cent. Other benefits include lower pesticide residues in soils and waterways, reduced fuel use by farmers, and greater storage of organic carbon in soils.

5 The adoption of GM herbicide-tolerant canola varieties in Australia is expected to improve weed control and increase yields compared with many non-GM canola varieties currently grown. Plant gene technology also has potential to produce novel products from plants, improve food quality, increase the productivity of current crops and adapt crops to environmental stresses such as drought.

6 As with all new technology, plant gene technology raises a range of issues including safety, consumer and market acceptance, and cultural issues. A rigorous regulatory framework, together with industry management measures, can address safety concerns and issues such as GM/non-GM coexistence and adventitious presence, while allowing the benefits of plant gene technology to be realised.

Introduction: from conventional breeding to plant gene technology

For thousands of years, farmers have selected and saved seed from crop plants with desirable features, such as high yield and disease resistance. Early farmers engaged in what plant breeders now call *selective breeding*. Over many generations, they produced varieties that bore little resemblance to the wild forms from which the crops originated.

Over time, plant breeding became more sophisticated, involving the deliberate crossing of different varieties or even species, including crossing with close wild relatives. In recent decades, more sophisticated plant breeding techniques have been developed, to select desired characteristics, keep valued characteristics together in a variety, and bring new genetic variation into crops.

Hybridisation is the principal technique used in conventional plant breeding. It involves crossing two genetically distinct parent plants to produce offspring with the desired combination of parental characteristics. Hybridisation can be between individuals of the same species or between individuals of closely related species.

Wheat breeding — hybrid plants resulting from crossing Durum wheat with a wild species relative.

Did you know?

A notable example of hybridisation is *Triticale*, a grain crop grown for stockfeed. *Triticale* was produced by crossing wheat and rye to combine the high yield potential and good grain quality of wheat with the disease and environmental stress tolerance of rye.

Other conventional techniques used include:

- *artificial pollination*
- *embryo rescue*—saving fertilised plant embryos that would otherwise die
- *male sterility*—using natural sterility factors to ensure a cross from one parent to the other, but not vice versa
- *tissue culture*—growing plant tissue in artificial culture conditions to generate whole plants
- *cytogenetic techniques*—manipulating the gross, supra-molecular structures of deoxyribonucleic acid (DNA), known as chromosomes.

Plant breeders have also induced mutation experimentally, using physical or chemical treatments such as gamma irradiation and azide treatments, to produce populations of plants with many random mutations. Mutation occurs in nature, but induced mutation (a process known as mutagenesis) allows plant breeders to speed up natural mutation rates or generate novel mutations to increase genetic variations to screen and use.

Did you know?

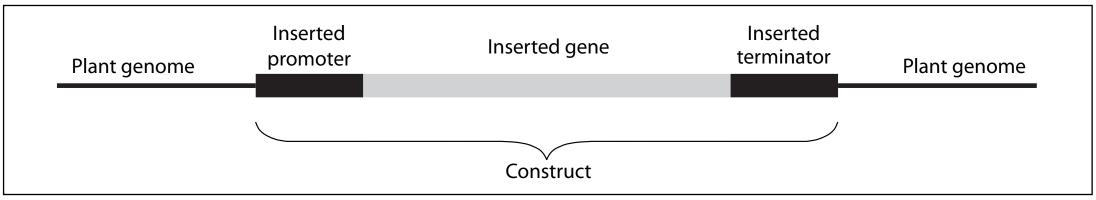
Important new commercial varieties have been developed using mutagenesis, including many cereal varieties, for example semi-dwarf rice varieties and a canola variety tolerant to the herbicide imidazolinone.

Plant varieties developed using all or any of the above conventional techniques are not referred to as GM. The term genetically modified is reserved for plants developed using molecular genetic techniques (see pages 3–4).

The genetic variation that can be exploited by plant breeders using conventional techniques is limited to the gene pools of the crop or pasture species in question and, in many cases, their close relations. This is because, in conventional breeding, gene transfer depends on plants' natural reproductive processes.

However, the advent of plant gene technology has made it possible to transfer genes from almost any kind of organism into plants.

Figure 1: A DNA construct inserted into a plant's genome by gene technology. When a foreign gene is inserted into a genome, it must contain a promoter and a terminator to perform the regulatory functions that lead to the production of a protein. The DNA sequence between the promoter and terminator determines the type of protein that is produced. The entire DNA segment inserted into a genome is called a construct. Source: Mewett et al. 2008.



Plant gene technology: what is it?

Gene technology is based on a range of techniques. These are variously used to extract DNA from cells, make multiple copies of DNA sequences, identify genes, make gene products, and engineer novel DNA molecules with segments derived from more than one 'parent' DNA molecule. The latter DNA is referred to as recombinant DNA and, if transplanted into a target tissue or cell, is known as a DNA construct.

Being able to make recombinant DNA molecules has opened up completely new areas of enquiry and is expanding the scientific understanding of plants. It has provided the ability to define and characterise the complete genetic make-up (the genome) of an organism, and how this make-up determines a plant's characteristics, its development and how it interacts with the environment. Genes can now be identified and their functions defined and characterised.

In modern plant breeding, gene technology is mostly applied to make breeding programs more focussed, better designed and faster, with greater scope for plant improvement. It does not necessarily result in producing GM plants (see below). For example, molecular markers are routinely used to increase the efficiency of conventional plant breeding and develop new (non-GM) varieties of crop plants with desirable characteristics.

Molecular markers are short segments of DNA that are associated with a particular gene or characteristic. They result from the natural variation in the basic constituents (nucleotides) of the DNA segment in question. This variation can be used in marker-assisted selection at the single nucleotide level ('single nucleotide polymorphisms'—SNPs) or higher DNA structural levels (for example, 'amplified fragment length polymorphisms'—AFLPs).

Plant breeders use these markers to screen for plants with one or more desired characteristics, select those plants, and track inheritance. Molecular markers speed up breeding programs. For example, they enable the rapid genetic screening of plants resistant to a particular disease, as an alternative to screening by exposing successive generations of plants to the disease to select for resistance.

Molecular markers also allow the accurate and rapid screening of whole genomes of large plant populations in a breeding program. All desired characteristics can be targeted allowing only those plants with multiple desired characteristics for a new variety to be retained. This can avoid or reduce the need for laborious crossing of those plants with new desired characteristics, back to parent lines or varieties in a breeding program.

Did you know?

In Australia, molecular markers have been used to develop the wheat varieties 'MacKellar' (virus-tolerant) and 'Young' (rust-resistant). Both have provided farmers with higher yields compared with earlier varieties.

When gene technology is used to develop new plant varieties through the direct incorporation of a DNA construct (Figure 1) or the deletion or modification of specific genes, the resulting plants are known as genetically modified (GM), genetically engineered (GE) or transgenic plants. These terms are commonly used to distinguish

Transgenic wheat plant in tissue culture — after genetically modifying plant cells, conventional techniques such as tissue culture and hybridisation have to be used to produce GM crops.

these plants from plants developed using conventional plant breeding only.

Developing GM crop varieties also involves the use of conventional techniques, such as tissue culture and the hybridisation of GM individuals with individuals of various elite breeding lines. Indeed, plant gene technology techniques enhance and complement conventional breeding techniques and do not replace them.

Did you know?

The first GM plant was a tobacco plant, reported in 1983, but no GM plants were commercially grown until the FlavrSavr™ tomato was commercialised in the USA in 1994. The plants were genetically modified to silence a fruit ripening enzyme, which resulted in tomatoes with a longer shelf life.

Gene technology remains a rapidly developing technology. Two relatively recent advances in gene technology are:

Targeted Induced Local Lesions in Genomes (TILLING), a technique that combines traditional techniques for chemical mutagenesis with high-throughput screening using molecular markers to identify the induced mutations in genes that are known only by their nucleotide sequence. The aim of TILLING is to rapidly generate new variants with novel and desirable characteristics, without introducing foreign DNA.

Gene silencing, a technique that is used to reduce or prevent the expression of a gene. One form of gene silencing, known as RNA interference, involves degrading the ribonucleic acid (RNA) molecules that are produced from DNA when a gene is switched on in a cell. Degradation prevents synthesis of protein from the RNA and therefore prevents expression of the characteristic conferred by the gene. This enables discovery of the gene's function and subsequently its targeted use in plant breeding.

Plant gene technology has led to a better understanding of gene function, enabled greater precision in genetically altering plants, and given plant breeders access to vast genetic diversity. All genetic diversity in all organisms is now potentially accessible.

Plant gene technology, together with increased conservation and improved management of natural and stored plant genetic diversity, will help farmers meet future agronomic and environmental challenges—including drought and climate change—and contribute to sustainable food production.

What is happening overseas?

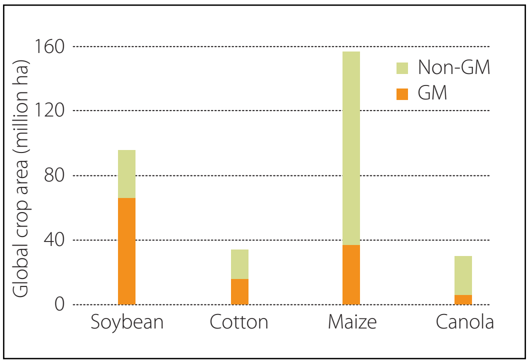
Globally, 125 million hectares (ha) of GM crops were grown commercially in 2008. The four major GM crops are GM soybean, maize, cotton and canola (Figure 2). The GM varieties of these crops have been modified for herbicide tolerance and/or insect resistance traits, which improve weed and insect control, respectively.

Did you know?

13.3 million farmers in 25 different countries grew GM crops in 2008. Ninety percent of these were resource-poor farmers in developing countries.

Other GM crops that have been commercialised overseas include alfalfa (lucerne), squash, sweet pepper, tomato, sugarbeet and papaya. Other GM characteristics approved for planting overseas include virus resistance, delayed ripening/altered shelf life, modified oil content and enhanced amino acid content.

Figure 2: Global areas of principal GM crops—2008
Source: James 2008.



What is happening in Australia?

Only three species have GM lines approved for commercial production in Australia: cotton, modified for herbicide tolerance, insect resistance or a combination of the two; canola, modified for herbicide resistance; and carnations, modified for flower colour. These characteristics are described in more detail in Box 1.

In 1995, GM carnations with novel flower colour—blue, violet or purple—were the first GM plants approved for commercial release in Australia. These colours could not be bred in carnations using conventional breeding techniques. Tens of millions of GM carnation flowers are now sold across the world each year.

Did you know?

The company that developed GM carnations has developed GM roses with blue flowers, which are now available in Japan.

GM cotton has been grown since 1996 in both New South Wales and Queensland, the only states currently growing cotton commercially in Australia. Until recently, GM cotton was the only GM broadacre crop grown commercially in Australia. More than 90 per cent of Australia's cotton is now GM, either insect-resistant, herbicide-tolerant or both.

In 2003, GM herbicide-tolerant canola was also approved for commercial release in Australia. However, in the same year, canola-growing states brought in moratorium legislation that prevented commercial plantings. Following a review of their moratoria, Victoria and NSW have allowed GM canola to be grown commercially since 2008.

South Australia and Tasmania continue their moratoria on GM canola. Western Australia lifted its moratorium on the commercial production of GM cotton in the Ord River Irrigation Area in the north-west of the state in 2008, and allowed commercial-scale GM canola trials in 2009. Queensland and the Northern Territory have no GM moratoria in place.

How are GM crops regulated in Australia?

Live and viable GM organisms (GMOs) are regulated in Australia by the Gene Technology Regulator under the *Gene Technology Act 2000* (Cwlth) and corresponding state and territory legislation. The Regulator is supported by the Office of the Gene Technology Regulator (OGTR). The regulatory system centres on a rigorous process of identifying and assessing risks to human health and the environment based on scientific evidence.

Australia's gene technology regulatory system operates as an integrated framework involving other agencies that have responsibility for regulating GMOs or GM products as part of a broader or different mandate.

Food Standards Australia New Zealand (FSANZ) is responsible for examining the safety of GM foods under Standard 1.5.2 (*Food Produced Using Gene Technology*) of the Australia New Zealand *Food Standards Code*. Approval of GM foods or ingredients is given if FSANZ concludes the GM food is as safe as its conventional equivalent.

BOX 1

GM plants approved for commercial production in Australia

Insect-resistant plants

GM insect-resistant plants contain one or more genes that encode proteins that are toxic to targeted insect pests. Effectively, the crop plant is protected by an insecticide produced by the plant itself, reducing the need to apply synthetic insecticides to the crop. Continuous protection by insecticides produced by the plant provides more effective control of insect pests and environmental and economic benefits compared with previous control based on sprayed insecticides.

The most common GM insect-resistant plants have one or more genes from the bacterium *Bacillus thuringiensis* ('Bt'), and are often referred to as Bt crops. *Bacillus thuringiensis* is the same bacterium present in conventional Bt pest control products, long approved by the Australian Pesticides and Veterinary Medicines Authority, and permitted to be used for plant pest control by the organic industry in the Australian National Standard for Organic and Bio-dynamic Produce.

Herbicide-tolerant plants

GM herbicide-tolerant plants have been modified to survive being sprayed by specific herbicides. A herbicide can therefore be applied to kill weeds in-field without damaging the crop. The most common GM herbicide-tolerant crops are tolerant to the herbicides glyphosate or glufosinate ammonium. These herbicides are broad spectrum herbicides and are relatively environmentally benign.

Not all herbicide-tolerant crops are GM. Some have been bred using mutagenesis and other conventional breeding techniques.

Flowers with novel colour

Ornamental plant species have been modified to produce flowers with colours that do not occur naturally in that species. For example, carnation plants have been genetically modified to express genes from petunias involved in producing delphinidin pigments in flowers—pigments that give flowers their blue, violet and purple colours. Other species modified for flower colour include roses, petunias and chrysanthemums.

Photo: Florigene

An approved GM food or ingredient must be labelled with the words 'genetically modified' if novel DNA and/or novel protein is present in the final food, or if it has altered characteristics compared with its conventional counterpart. The terms 'foods' and 'food ingredients' include food additives and processing aids.

Exemptions to the labelling requirement include:

- highly refined foods where the effect of the refining process is to remove novel DNA and protein (e.g. refined sugars and vegetable oils)
- processing aids or food additives where novel DNA or protein is not present
- flavourings that are present in the food at a concentration of no more than 1 gram per kilogram (0.1 per cent) in the final food
- foods, ingredients or processing aids in which the GM food is unintentionally present in a quantity of no more than 10 grams per kilogram (1 per cent) per ingredient
- foods prepared for immediate consumption, such as restaurant and take-away food, and catered meals.

Did you know?

FSANZ has approved 38 GM foods (from soybean, canola, maize, rice, potato, sugar beet, cotton and alfalfa [lucerne]) for sale in Australia and New Zealand (as at May 2009).

The Australian Pesticides and Veterinary Medicines Authority (APVMA) is responsible for assessing and registering GM products used as pesticides or veterinary medicines, including live GMOs used for these purposes. The APVMA also regulates chemical use associated with GMOs, for example the use of chemical herbicides on GM herbicide-tolerant crops. The APVMA evaluates risks to human safety, the environment and Australia's trade with other countries, and whether or not the product will be effective.

The Therapeutic Goods Administration (TGA) safeguards public health and safety in Australia by regulating medicines, medical devices, blood and tissues. This includes any GM products or products derived from GMOs.

The National Industrial Chemicals Notification and Assessment Scheme provides a national notification and assessment regime to protect the health of the public, workers and the environment from the harmful effects of industrial chemicals, including chemicals derived using gene technology.

Further information on the regulation of GMOs and GM products in Australia is available from www.bioregs.gov.au

What is in the pipeline?

A wide range of GM crop, pasture and other plants is being developed and trialled internationally and in Australia (Table 1), including plants with:

- improved tolerance of environmental stresses such as salinity and water stress
- improved pest and disease control
- enhanced nutrition and flavour
- improved oil quality
- longer post-harvest life
- improved feed and pasture quality
- improved ease of processing
- the ability to produce pharmaceutical and industrial products, for example insulin, antibodies, edible vaccines and bioplastics.

Current field trials of GM crops in Australia include:

- cotton and sugarcane with improved water-use efficiency
- cotton tolerant to water-logging
- sugarcane with improved nitrogen-use efficiency
- wheat with improved drought tolerance
- forage grasses with improved forage qualities
- bananas with enhanced nutrition and disease resistance.

Will plant gene technology provide benefits?

Agronomic benefits of GM crops in Australia

In Australia, GM insect-resistant cottons are regarded as the most significant step forward in cotton pest management in the industry. The number of applications of insecticide needed to control cotton bollworm has been reduced by up to 75 per cent compared with non-GM cotton, and insect control can be more targeted, allowing survival of beneficial insects such as insect predators. GM herbicide-tolerant cotton varieties have increased weed control options and improved weed control.

There has been an overall increase in cotton yield in Australia from the 1960–61 growing season to the present day (Figure 3). In the past 10 years, yield has increased at a rate 3.6 times faster than the decade before (Holtzapffel et al. 2008).

Figure 3: Australian cotton yield since 1960–61. Graphed from data reported by USDA-FAS (2006). Data points indicate yields for individual years. The line represents the five-year average yield for each of the previous five years commencing from the 1965–66 data point. Source: Holtzapffel et al. 2008.

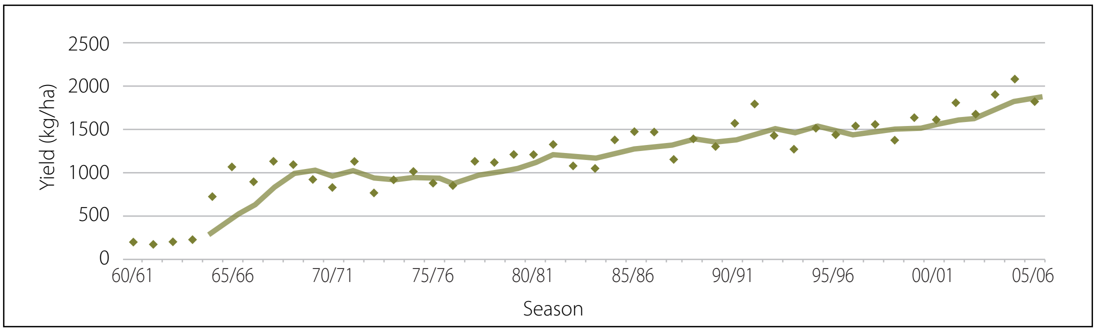


Table 1: A selection of current Australian research on GM plants.

CHARACTERISTIC	RESEARCH
Healthier oils	CSIRO is developing oilseed crops that produce healthier, more stable cooking oils. Successful field trials have been conducted with GM cotton varieties that produce cottonseed oil with reduced saturated fats and increased unsaturated fats. Unlike saturated fats, unsaturated fats help reduce 'bad' cholesterol and increase 'good' cholesterol. CSIRO is also undertaking research to produce oilseed crops with beneficial omega-3 and omega-6 oils, which are currently mostly derived from fish sources.
Allergy free ryegrass	The majority of hay fever-causing pollen in Australia is from ryegrass. Researchers at the Molecular Plant Breeding Cooperative Research Centre (CRC) are working to produce ryegrass with pollen lacking the protein that causes hay fever. The GM allergy free ryegrass is currently undergoing field trials in the USA.
Biofuels from sugarcane	Farmacule BioIndustries, Syngenta and the Queensland University of Technology have established a Sugarcane Development Centre. The centre aims to develop and commercialise cellulosic ethanol and biofuels produced from sugarcane biomass using a range of biotechnologies, including Farmacule's 'INPACT' technology. INPACT involves the insertion into the plant of a molecular switch that initiates the breakdown of plant celluloses into components that are precursors of ethanol.
Bioplastics from sugarcane	The CRC for Sugar Industry Innovation through Biotechnology is investigating the production of polyhydroxyalkanoates (PHAs) in sugarcane. PHAs are used to make biodegradable plastics. The group has successfully produced PHAs in both the leaves and stems of sugarcane.
Frost tolerant wheat	Scientists from the Victorian Department of Primary Industries have discovered a gene from a grass species (Antarctic Hairgrass) responsible for inhibiting ice crystal growth in tissues, enabling the plant to tolerate freezing. This gene may be used to develop wheat with enhanced frost tolerance.
Water use efficient crops	Scientists from a number of organisations are researching and developing crops with improved water use efficiency or drought tolerance. Crops include sugarcane (being developed by the Bureau of Sugar Experiment Stations Limited), cotton (Monsanto) and wheat (Victorian Department of Primary Industries).
Ornamental plants	GM lines of roses and *Torenia X hybrida* ('wishbone flowers') have been trialed in Australia. *Torenia* flowers are usually blue/purple but plants have been modified with geranium and snapdragon genes to produce a range of flower colours, including white, blue with white sectors, pale pink, dark pink and pale yellow. Rose plants have been modified with genes from plants such as pansy, *Torenia* and iris, to produce flowers that are light purple or violet.

This rate of yield increase can be attributed to the adoption of GM cotton varieties, the development of improved breeding programs and the adoption of best management practices by the Australia cotton industry.

The canola type most commonly grown in Australia is triazine-tolerant (TT) canola, a non-GM canola that is tolerant to triazine herbicides. Herbicide tolerance in this canola is conferred by a natural mutation, first found in a wild population of canola. The mutation also reduces photosynthetic efficiency and therefore growth rates, leading to decreased yield and oil content of TT canola compared with non-TT canola.

Two types of GM herbicide-tolerant canola have been approved for commercial release in Australia: glyphosate-tolerant canola (Roundup Ready® canola) and glufosinate ammonium-tolerant canola (InVigor® hybrid canola). These canolas are expected to increase yields and productivity for farmers by avoiding the yield and oil content penalties of TT canola.

The yield and performance of Roundup Ready® canola was compared with current common non-GM canola varieties, including TT canola, in trials over a typical five-year crop rotation system (Stanton 2004). Roundup Ready® canola delivered superior weed control and generally higher yields. GM canola seed that was unavoidably shed during harvest and germinated in a subsequent crop, was easily controlled. InVigor® hybrid canola is also expected to produce higher yields, in particular because it contains a genetic system that makes hybrid breeding easier, resulting in so-called 'hybrid vigour' of the plants.

Environmental benefits of GM crops in Australia

Growing GM cotton varieties in Australia has environmental benefits resulting from decreased insecticide use (Figure 4) and changes in the kinds of herbicides used.

Growing GM insect-resistant cotton varieties (the current variety being Bollgard II®) as part of integrated pest management programs has enabled reductions in the amount of insecticide used by up to 85 per cent compared with conventional cotton, and good yields. This has decreased the potential for chemical contamination of rivers in cotton growing regions (Figure 5).

Furthermore, because the insecticidal toxins are produced within plants and, unlike synthetic insecticides, are targeted to only one group of insects, there is less exposure of the environment to the insecticide, and effects on non-target organisms are reduced. Fuel use is also reduced because fewer insecticide applications are needed.

GM herbicide-tolerant cotton varieties (Roundup Ready®, Roundup Ready Flex® and Liberty Link®) have enabled greater adoption of minimum tillage practices and some replacement of residual herbicides with herbicides that are more environmentally benign (glyphosate and glufosinate ammonium).

The benefits of minimum tillage include less soil erosion, increased retention of soil moisture and increased soil biomass (and hence more carbon stored in the soil). Residual herbicides persist and remain active in soils for a long time (sometimes years) compared with glyphosate and glufosinate ammonium. Reducing the use of residual herbicides in cotton farming therefore has advantages for the environment, including decreasing the risk of herbicide contamination of waterways.

Similarly, the environmental benefits of growing GM herbicide-tolerant canola varieties in Australia are likely to include replacing use of residual herbicides such as triazines, imidazolinones, bipyridiliums and sulfonylurea herbicides. The environmental effects of herbicide use on these GM herbicide-tolerant varieties have been estimated to be less than the effects of herbicide use on current non-GM canola varieties including TT canola (Holtzapffel et al. 2008).

Figure 4: Trend in average quantities of insecticides used per hectare in Australian cotton crops over the decade 1995–2005. The early GM Ingard® cotton variety was genetically modified to contain a single type of insecticidal protein. Later GM Bollgard II® cotton varieties are modified to contain two types of insecticidal protein. Source: Browne et al. 2006.

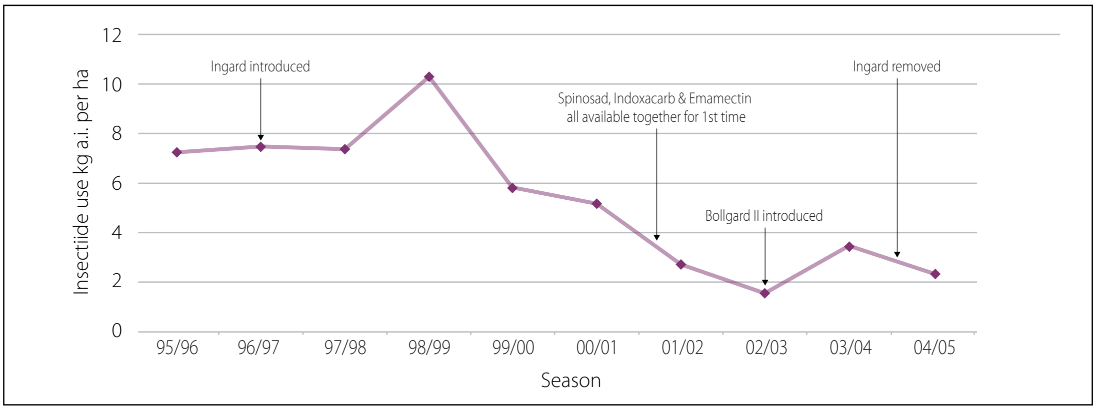
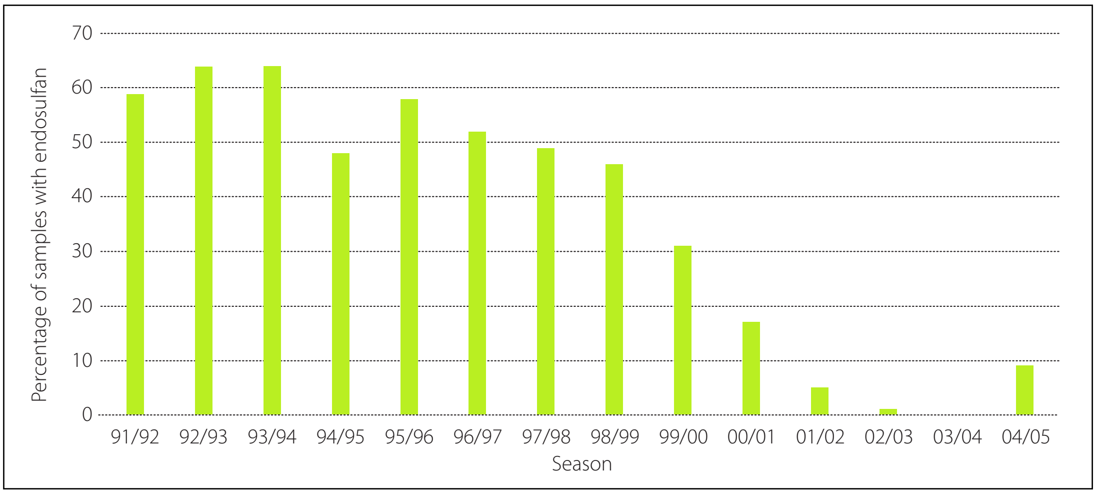


Figure 5: Percentage of river water samples containing the insecticide endosulfan. Graphed from aggregate data reported by the New South Wales Department of Natural Resources for four north-western New South Wales rivers. Source: Browne et al. 2006.



Economic benefits of GM crops in Australia

The introduction of GM cotton varieties in Australia has also had economic benefits. Spending on insecticides, herbicides and their application has decreased. These benefits are partly offset by higher seed costs, but most Australian farmers find GM cotton to be more profitable than conventional cotton (Brookes and Barfoot 2008).

The primary economic benefit of the introduction of GM herbicide-tolerant canola varieties into the Australian cropping system is likely to be increased productivity, because these varieties will largely replace non-GM TT canola varieties that have yield and oil content penalties. Other economic benefits include savings in material and labour costs—for example because insecticide spraying is reduced.

The Australian Bureau of Agricultural and Resource Economics (ABARE) has analysed the economic effects of GM crop adoption in Australia. Adoption of GM canola was estimated to increase both state and regional gross income, with the benefits from early adoption significantly higher than from a delayed adoption (Acworth et al. 2008).

In a separate study, ABARE concluded that Australia's export competitiveness would be adversely affected and Australia would forego significant economic gains, by delaying the uptake of GM oilseeds and wheat if emerging economies (Argentina, Brazil, India and China) increased their adoption of these GM crops (Nossal et al. 2008).

Issues for decision-makers

Consumer attitudes to plant gene technology and GM crops

Human health and safety of GMOs and GM products in Australia is addressed through comprehensive regulatory systems.

Differences in perception of risks, confidence in regulatory authorities, attitudes to globalisation, and cultural differences are among the many factors that contribute to diverse consumer attitudes to GM crops both within and between countries. While uptake of GM crops has been rapid in some countries—including the United States, Canada, India, Brazil and China—GM crops and foods have been less readily accepted in the European Union.

Consumer attitudes towards GM food products have been regularly surveyed. An Australian survey prepared for Biotechnology Australia (Eureka Strategic Research, 2007) found that public acceptability of GM food crops rose to 73 per cent in 2007, up from 48 per cent in 2005. The survey showed GM technologies that hold benefits for consumers or the environment, such as helping to address health problems or climate change effects, were more likely to be supported. Decisions about adoption of GM crops and GM foods by farmers and industry are often affected by perceptions of public attitudes rather than good information about public attitudes.

Trade and market access issues, which producers and exporters of GM products take into account, include consumer acceptance of GM crops in Australia's export markets and the regulatory systems of importing countries. Products derived from GM crops or livestock produced using animal

feed derived from GM crops may need to be labelled, to comply with the regulations of some importing countries.

Many countries that import grain require labelling of food products that contain GM ingredients. To ensure product integrity for non-GM export markets, the production and supply chain would need to segregate GM and non-GM varieties.

Coexistence, product integrity and segregation of GM and non-GM crops

Segregation and maintenance of product integrity may be required where GM and non-GM varieties of a given crop co-exist in a farming system. Markets may require information on the GM status of a commodity or there may be a price premium for either the non-GM or the GM commodity.

When required, maintenance of product integrity is monitored through a process known as identity preservation. In this process, a crop variety is developed, bred, grown, handled, stored, delivered and processed under controlled, documented conditions to assure the customer that the unique identity has been maintained from seed producer through to end user. Where product must be segregated, effective arrangements include seed and grain certification systems, crop management systems, appropriate grain handling systems, and seed and grain testing.

Industry and growers are familiar with implementing such systems and practices, as there is a long and successful history in Australia of segregation and identity preservation systems for grains, such as hard versus soft wheat and feed versus malting barley. Existing segregation systems already include cases where there are no simple physical or visual methods to distinguish between varieties or grain quality.

Similar systems can be applied to ensure the product integrity of GM and non-GM grains, but new measures may be required such as industry-developed crop management practices and testing to verify non-GM or GM identity.

Adventitious presence issues

In Australia, there are industry-approved thresholds for the adventitious (unintended) presence of GM canola (that has been approved for commercial release by the Gene Technology Regulator) in non-GM canola. Thresholds are 0.5 per cent for seed-for-sowing and 0.9 per cent for harvested grain. Segregation systems to maintain product integrity are either in place (including a robust seed certification system) or could be implemented as the scale of commercial GM canola production increases.

The Australian Oilseeds Federation introduced new Trading Standards for canola in August 2008, following Victorian and New South Wales government decisions to allow GM canola to be grown commercially. The two standards for canola are: CSO1 Canola, which may or may not contain GM canola approved by the Gene Technology Regulator; and CSO1-a Non-GM Canola, where an adventitious presence of 0.9 per cent of GM canola approved by the Gene Technology Regulator is permitted. The thresholds do not apply to unapproved GMOs, which are illegal in Australia. Operators within the canola supply chain, including growers, will supply canola according to the trading standard applicable to their operation.

Implementing segregation and identity preservation systems (where required by markets) so that mixing (for example, from cross-pollination with other crops in the field or through co-mingling in the grain handling system) is negligible, gives operators in the supply chain confidence that a product's integrity has been maintained. Implementing such systems can help avoid possible market risks arising from the presence of GM material in non-GM agricultural products.

Conclusions

Maintaining and improving crop productivity and the competitiveness and sustainability of Australian agriculture depends on the continual development of improved varieties through plant breeding. Innovation is crucial.

Plant gene technology techniques, including genetic modification, have been widely applied to plant improvement in Australia. Their agronomic, environmental and economic worth has already been demonstrated. Future applications will provide further benefits and help farmers adapt to change and remain competitive.

Gene technology holds significant potential for producing novel products from plants, improving food quality, increasing the productivity of current crops, and adapting crops to environmental stresses such as drought.

As with all new technology, there are challenges. These are being met through appropriate regulation and management. Benefits need to be fully realised through further research and development and improved understanding, demonstration and communication of benefits and management measures.

Selected references and further reading

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Tractors harvesting rows of ripened cotton