From gene discovery to paddock reality

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Abstract
Australia's cereal breeding industry has contributed to large improvements to cropping yields for over 100 years and this has enabled Australia to maintain its world competitive cereal production systems. As the rate of yield improvement has declined, and new technologies have become available, emphasis has shifted to the development and application of molecular biology research capabilities. The cereal industry in Australia focuses on wheat and barley production and these crops have become the focus for such new technology development. This paper looks at the various issues surrounding the translation of genetic modification into commercial cereal crops. To be successful a GM crop must offer significant benefits to the grower and end-user. The novel crop must also suit the target environment and cropping system and may well be offered to growers as part of a broad agronomic and management package. The cost of introducing a new GM trait into a crop is enormous and it is unlikely that Australia will be able to maintain its competitive position in cereals without significant commercial interaction with overseas researchers and commercial firms.

Keywords
Biotechnology, delivery, genetic engineering, regulation

Introduction
Over the past 100 years, conventional cereal plant breeding in Australia has contributed to a doubling of yield (Figure 1). These increases have come through improvements in breeding methodologies, closely linked to adoption of new technologies and practices.

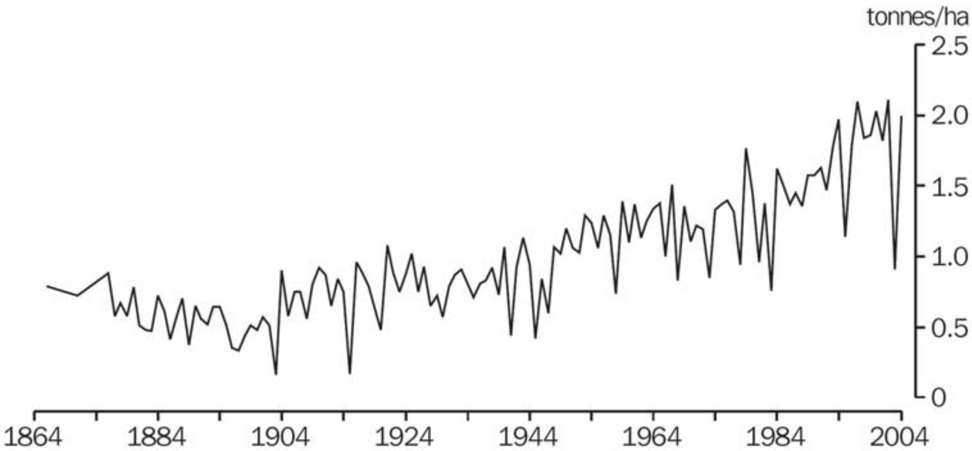

Figure 1. Australian wheat yields (Trewin 2006)

A survey of global yields of wheat suggest that yields have "tapered off" toward the end of the twentieth century (FAOSTAT; Feuillet et al 2008). Consequently, the plant breeding community has investigated the potential of genetic technologies to effect further improvements in plant yield and quality. This is especially so in crop plants such as wheat and barley where Australia still holds a competitive advantage in the world marketplace. Since the first biotechnology patent was granted in 1980 (www.abc.net.au), the Australian research community has made a considerable effort to identify applications for agricultural biotechnology. The investment for this effort has come from various sources, including the Australian Federal and State Governments, the farming community and many research organisations.

Recently, Australia has built an extensive national biotechnology infrastructure and has assembled a number of centres of excellence in this area. There has also been a long term commitment to education and training of scientists. The new generation of plant breeders has been trained not only in genetics but also in a range of molecular and associated technologies that have become crucial to our crop improvement capabilities.

The biotechnology resources and skills available in Australia have already contributed to Australia's position as a leader in application of molecular markers to wheat and barley breeding. The combination of the use of marker technology and double haploid systems has been central to Australia's recent competitiveness in cereal improvement (Langridge and Chalmers 2005). The strength of the Australian position came through large National Molecular Marker Programs. The use of molecular technologies promises to have greatest impact in crop quality and yield when plants are genetically modified (GM) for specialized characteristics.

Nature of GM traits

The first GM organism to be released in Australia was in 1987 at the Waite Campus of the University of Adelaide. Since then, Australia has established a rigorous approval system for GM organisms and the Office of Gene Technology Regulator now licenses dealings in GMOs and in approving a number of GMOs for release.

The current generation of GM traits has focused on traits that help reduce production costs. The international scene is dominated by tolerance to Monsanto's herbicide "Roundup", and insect tolerance; based on a series of *Bacillus thuringiensis* (Bt) genes. Herbicide tolerance has been particularly important in soybean, cotton and canola. The insect tolerance genes are widely used in maize and cotton with Bt rice recently approved for commercial production in Iran and likely to be released soon in China. Other transgenes that have proved important for specific crops are genes for virus resistance in papaya and cucurbits.

Although production traits have dominated crop releases so far, there have also been several releases of GM crops with altered quality characteristics such as the high laurate canola and the modified flower colour in carnations. The first GM food crop also had altered quality characteristics; this was Calgene's "FlavrSavr" tomato with enhanced storage life. It is also important to note that the engineering of a male sterility system in canola has been important in the development of several high yielding hybrid varieties.

The list of species for which GM food crops are being grown commercially at present includes rice, canola, maize, soybean, squash, papaya, sugarbeet, cotton (cotton seed oil is approved for human consumption) potato and tomato. A large array of new transgenic lines is in advanced stages of evaluation. One of the most exciting is new drought tolerant maize lines from Monsanto and the enhanced nitrogen use efficiency from Arcadia Biosciences Inc.

Field evaluation of GM crops in Australia has been underway for many years with the first release occurring in the mid 1980s. In Australia there are currently three research groups trialing GM wheat. These include drought tolerant wheat based on genes from BASF at DPI Victoria, wheat with altered quality characteristics to improve starch composition at CSIRO, and drought tolerant lines through ACPFG based in Adelaide. GM barley is also in field trials in South Australia (ACPFG). These barley lines are being tested for modified cell wall composition (improved nutritional and processing quality), boron tolerance and drought tolerance.

Other technologies being trialed are multiple insect tolerance genes in cotton, herbicide tolerant Indian mustard and canola, sugarcane modified for enhanced drought tolerance and increased nitrogen use efficiency and Torrenia with altered flower colour. In the past, field trials have covered a wide range of plant species for a variety of genes; the species trialed include peas, clover, lupins, wheat, barley, canola, Indian mustard, cotton, papaya, pineapples, potatoes, tobacco, sugarcane, grapevine, roses, carnations and poppy (http://www.ogtr.gov.au/).

An idea of the scale of GM research in Australia can be seen by looking at the number of licenses issued by the Office of the Gene Technology Regulator (OGTR). There have been 71 licenses issued for release of GMOs and the previous regulatory body (GMAC) issued over 150 licenses. However, GM technology underpins most aspects of modern biological research. There are over 1,500 approved facilities for work on GMOs in Australia in over 400 research organisations and there are several thousand research projects that have been registered (http://www.ogtr.gov.au/). Therefore, this is clearly an area of enormous activity.

Impact of GM crops

The adoption of GM crops world-wide has continued to increase at around 12% each year. In 2005 there were over 100 million ha of GM crops grown worldwide or over double the area sown in 2000 (James 2007) (Table 1). GM crops are now used by over 10 million farmers in 22 countries around the world. In North America the proportion of the soybean crop that is GM has risen to over 90%, the proportion of the maize crop is 75% GM and the proportion of the canola crop is 70% GM. GM technology has also been widely adopted in developing countries in Asia and Africa, where pest tolerant crops are greatly improving the security of food supply and income and hence political security. The most rapid increase in area under GM crops over the past few years has been in India and China. Even in Europe, where the main opposition to GM crops originated, GM crops are now grown in Germany, France, Spain, Portugal, Czech Republic and Slovakia.

Table 1. Global Area of Biotech Crops in 2007-top 8 countries (James 2007)

Rank	Country	Area (mHa)	Biotech Crops
1	USA	57.7	Soybean, maize, cotton, canola, squash, papaya, alfalfa
2	Argentina	19.1	Soybean, maize, cotton
3	Brazil	15.0	Soybean, cotton
4	Canada	7.0	Canola, maize, soybean
5	India	6.2	Cotton
6	China	3.8	Cotton, tomato, poplar, petunia, papaya, sweet pepper
7	Paraguay	2.6	Soybean
8	South Africa	1.8	Maize, soybean, cotton

Worldwide consumer sentiment has resulted in slow development of GM food crops in many countries, particularly in Europe. Indirect use of GM crops to make human food products has been accepted; for example in the use of soybeans, canola, maize and cottonseed for food and in animal food. It is expected that human food use of GM grains will increase, and the large multi-national companies have ongoing commitments to GM crops that can be used in food production. However, there are currently no commercially available GM wheat or barley varieties anywhere in the world.

In Australia, the only broad acre GM crop has been cotton although GM canola has entered commercial production in NSW and Victoria this year. The impact of GM cotton has been significant. An assessment of the reduction in insecticide use in Australia through the release of Bt cotton found that where 135 kg of active ingredient per hectare (kg a.i./ha) was used on conventional cotton only 28 kg a.i./ha was required for the Bt lines. This represents a reduction of almost 80% (Knox et al 2006).

Significant benefits are also expected from the use of GM herbicide tolerant canola in Australia. The introduction of Roundup Ready crops in the US and Canada has not increased levels of herbicide applications but has led to a dramatic expansion in “zero-till” agriculture with a resultant large reduction is erosion and soil degradation. GM canola has also proved important in the cleanup of weedy fields (Beckie et al 2006). An analysis of the potential economic impact of Roundup tolerant canola in Western Australia concluded that the value of GM Canola "is positive in 70% of all scenarios investigated" with a benefit to growers of over $10 per ha per year in 40% of the scenarios examined (Monjardino et al 2005).

With respect to market implications of GM canola a recent ABARE report noted that "*GM canola is generally accepted as readily as conventional canola and is priced at very similar levels"* (Foster and French 2007).

Delivery mechanisms

In considering the delivery mechanisms and processes from gene discovery activities it is necessary to divide the potential outputs into several classes and also to consider the different potential end-users. While all products are seen as important, the most tangible are those that will lead to new varieties and offer direct benefits to growers. A crucial subdivision for these outputs is based on the origin of the technology; it is important to determine if it is available in the public domain, was the product of a collaborative project with a commercial or public sector partner or was sourced from a commercial partner and where there may be restricted access through a license.

In general terms, the process of moving from gene discovery to providing germplasm suitable for integration into a breeding program occurs in several phases as outlined in Figure 2. Once a gene of potential value has been identified, its function must be demonstrated (Proof of Function). This usually involves generation of transgenic plants and glasshouse evaluation to describe the phenotype of the transgenics. In most cases the transgenics will be produced in the lines that are easiest to transform and these are unlikely to be well adapted commercial lines.

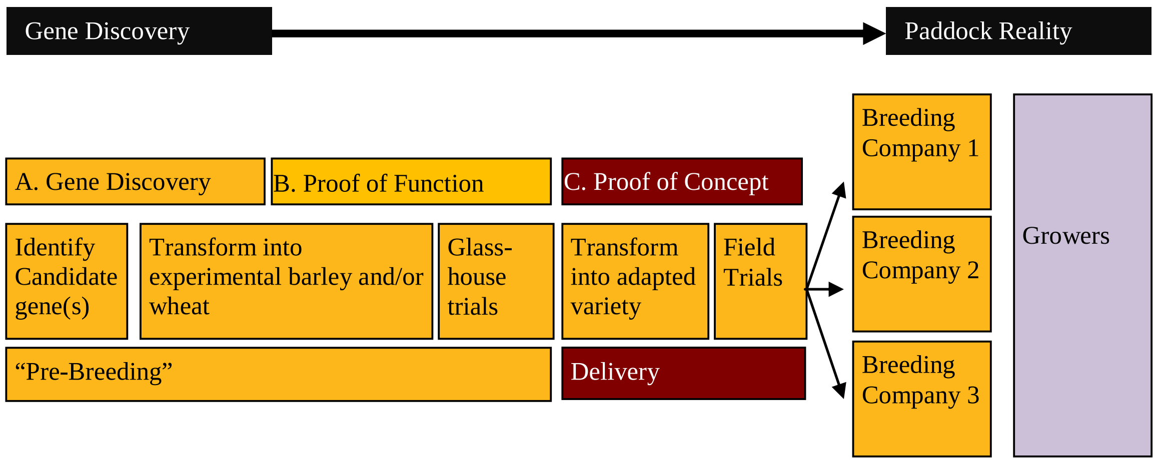

Figure 2. Delivery path for a GM technology

The next phase, "Proof of Concept" requires field validation of the modified phenotype. This stage should indicate if the modification can perform under field conditions and in well adapted germplasm; ideally in elite backgrounds. However, it is probable that this material will not be suitable for commercial release and further modifications will be needed.

The new DNA sequences can be integrated into almost any site in the genome although there is a strong preference for insertion into transcribed regions depending on the transformation method. In most cases multiple copies or even rearranged copies of the new sequence can be inserted. Activity of the transgenes, and the stability of their expression, can vary depending on the integration site and copy number of insertions. Consequently many independent transgenic lines must be generated and tested to select the line or lines that show the most suitable characteristics. For regulatory approval it may also be important to remove the selectable marker that was used to select the transformation event. This is usually an antibiotic resistance or herbicide resistance gene. Clearly the new lines will also need to undergo field evaluation before transfer to the breeding programs.

The conditions related to delivery will clearly vary greatly for the different types and antecedents of the output. However, in all cases, effective delivery depends upon the clear definition of the likely conditions associated with its use and effective communication strategy to ensure that the most appropriate users are aware of the output and conditions. The product development pipeline used by Monsanto is shown in Table 2. In this case the plant breeding or "trait integration" process occurs within the organisation.

Table 2. Monsanto product pipeline (Monsanto 2008)

	Proof of Concept	Early Product Development	Advanced Development	Pre-Launch
Key Activities	Gene optimization Crop transformation Field testing	Large-scale transformation Trait development Pre-regulatory data Field testing	Trait integration Expanded field testing Regulatory data generation	Regulatory submission Seed bulk-up Pre-marketing
Average duration	12 to 24 months	12 to 24 months	12 to 24 months	12 to 36 months
Average Probability of Success	25%	50%	75%	90%

Commercial GM crops

In developing GM technologies for commercial products, the risks are large, the timelines long and the costs huge. The GM cotton and canola lines being grown in Australia are based on overseas technologies.

Whilst there are many GM technologies which are being developed within the Australian pre-breeding industry, there are none that have become commercial crops aside from GM carnations. The development of commercial GM crops for the Australian Grains Industry is difficult because of the resources required to translate technologies from the "lab" to the "land". In general terms, for GM technologies, there are not significant opportunities for generating commercial revenue from within Australia alone. Therefore an important component of the delivery plan for Australia involves rapid and broad take-up of the technologies locally and focuses on overseas linkages to develop financial returns from the technology.

Time

The timeline provided above under the Monsanto model (Table 2) proposes a period of four to nine years from Proof of Concept through to launch of a GM product. One of the major factors expanding the delivery timeline has been the increasing regulatory burden associated with full deregulation of GM product. Since the first non-vegetable biotechnology crop was deregulated in the US in 1995, the time to obtain regulatory approval there has increased markedly. No new crop species obtained approval in the US between 2000 and 2005 (Jaffe 2005). The deregulation process in the USA requires a period of public consultation. The US experience has been that, whilst fewer biotechnology crops are being deregulated, the time for consultation has doubled (Table 3) in recent years. Therefore the costs are increasing and the difficulty of introducing new technologies is becoming greater.

Table 3. Consultation time under the USA regulatory approval scheme for GM crops (Jaffe 2005)

Period	Average Number of Months for Consultation
1995-1999	6.4
2000-2004	13.9
Average 1995-2004	8.2

Costs

Companies that have successfully commercialised GM crops have rarely provided estimates of the costs to deregulate a biotechnology crop. Anecdotal costs of up to $40-$50 million have been cited but it is more likely that the costs are between $6 – 15 million for a herbicide tolerant maize (Kalaitzandonakes et al 2007). This is after a gene has been discovered and experimentally proven; which in itself may take tens of millions of dollars.

Benefits

The benefits to Australia through adoption of new technologies for its major crops have been the subject of much speculation. ABARE Economics have recently published a report entitled "Economic Impacts of GM in Australia" (Acworth et al 2008). In this report it is estimated that a five year delay in introducing overseas GM canola varieties to South Australia would lead to $66 million in foregone income and $97million for Western Australia despite canola being a relatively small crop in Australia. For the more significant crops the foregone income is much higher (Figure 3). For example in NSW, it is estimated that foregone benefits may be around $3 billion for a wider range of crops.

The most significant financial benefit from adopting new technologies is achieved if those new technologies also have application in hybrid crops and can be introgressed into commercial varieties overseas. It is much more straightforward to capture value in hybrid crops than in non-hybrids from the sale of new seed.

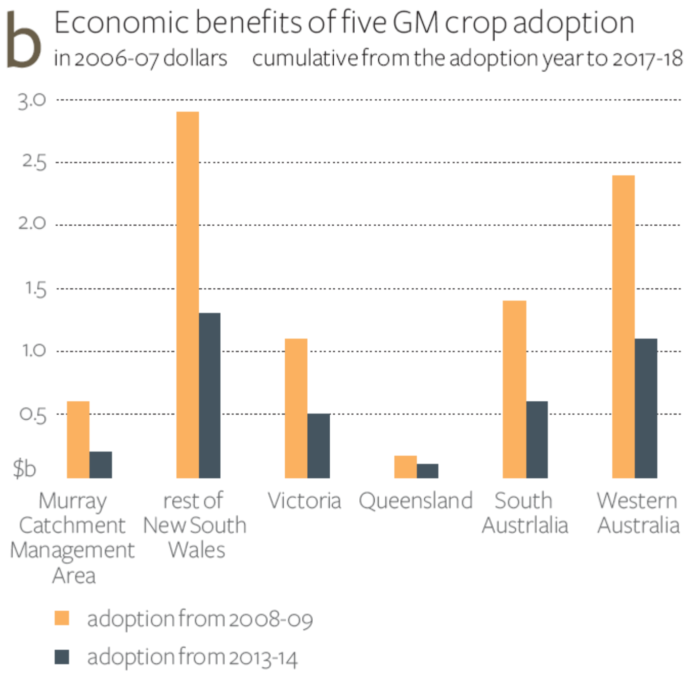

Figure 3. Potential benefits of GM adoption in Australia for canola, soy bean, maize, wheat and rice (from ABARE Report "Economic Impacts of GM in Australia", Acworth et al 2008)

Commercial licenses

Whilst there is a great deal of research activity in Australia, most of the agricultural research is occurring elsewhere in the world, both in the private and public sector (Pardey and Beintema 2001). Some of this international research is focused on solving local issues but much of the research is occurring in areas relevant to most of the world (such as water use efficiency). Much of that research is occurring within large multi-national companies. For example, it is estimated that Monsanto alone spends around $500m per year in this area with Syngenta spending an estimated $250m per year (Pray et al 2005). These companies have their own proprietary germplasm adapted for local conditions. Also most of this commercial research is occurring in hybrid crops for which farmers buy seed annually. Therefore in Australia, there are three main issues in translating research into outcomes.

The first is the issue of competitiveness. Whilst Australia has excellent research capabilities, it cannot expect to compete widely with the massive international private sector investments in research. Similar to the way in which Australia manufactures motor vehicles, we must have the expectation, that to produce new Australian varieties, we will utilize the best technologies from an international toolbox rather than creating it all ourselves. This means that we have to collaborate with international industry rather than compete with it. Whilst Australia is a large exporter of cereal grains, it is still a relatively small producer. It also has a relatively small population and as such, does not have the resources to act alone in developing GM technologies. Australia does not have the economies of scale to ensure sufficient financial returns from new technologies to justify the costs of their development. This means that, whilst there are excellent research capabilities it should be expected that technologies will be accessed from overseas to augment those developed in Australia.

Secondly, even though there are many technologies available from overseas, quite often they are not housed within the most appropriate crop species or indeed even in a variety adapted to Australia's harsh conditions. Australia must expect to spend a considerable proportion of its research effort in adapting overseas technologies to its own adapted germplasm.

Thirdly, Australia's main crops are wheat and barley; self fertilizing crops which allow farmers to save seed for following years (unlike the largest volume GM crops produced overseas). This means that different value-capture models are needed in Australia to those found overseas. The current End Point Royalty system is a different means of capturing value to most models used overseas and in Australia is reported as having a high level of compliance.

Regulatory requirements
The regulatory requirements constitute a major cost and time factor associated with commercialising a GM crop. These requirements apply at all stages of development and delivery of GM technology, through the initial gene discovery phases, field evaluation, approval for commercial release, approval for human consumption and for export. Although we have seen a consistent growth in the area sown to GM crops since there first large scale release in 1996, the time and costs associated with meeting the regulatory requirements have increased (for example the consultancy period shown in Table 3).

Field Trials
As mentioned, glasshouse performance of a cereal is not necessarily an indication of the way that the plant will perform in actual field conditions. There have been many examples of technologies that have performed superbly under optimal watering and nutrient conditions only to fail miserably in the field. In particular, variable stresses that occur routinely in Australian agriculture are difficult to predict and replicate in glasshouse conditions. An example is water availability. In some seasons there is plentiful water at the start of a season, yet little at the end. In other seasons the reverse may apply. To compound the problems, there are also a wide range of average climatic profiles across Australia.

There are several research groups around Australia that have technologies which have now reached the stage of development where experimental field trials are required. In particular, CSIRO Plant Industry, the Molecular Plant Breeding CRC and ACPFG currently have experimental field trials for GM wheat and/or barley. In Australia, experimental field trials may occur if approval is obtained from the Federal Government's Office of the Gene Technology Regulator (OGTR) and if such field trials comply with relevant State Government legislation.

The OGTR is governed by the *Gene Technology Act 2000* (21 June 2001) (www.ogtr.gov.au) and its role is to *"is to protect the health and safety of people, and the environment, by identifying risks posed by or as a result of gene technology, and by managing those risks through regulating certain dealings with genetically modified organisms (GMOs).*

In the case of South Australia, Tasmania and Western Australia, an exemption must be sought from the Minister for Agriculture since a blanket GM moratorium which is in place (Genetically Modified Crops Management Act 2004). Recently the NSW and Victorian Governments have lifted their moratorium on the growth of GM Canola.

Role of management plans
The commercial release of a GM crop plant is subject to a tight regulatory process. The OGTR considers the potential impact of the GM plant on human health and safety and on the environment. Approval will only be given when no risks are believed to exist or because processes can be implemented to manage any perceived risks. Extensive field data under semi-contained conditions is a prerequisite for commercial release. An example of management strategy can be seen in the early varieties of GM cotton that were released in Australia. The insect resistant or Bt cotton had already been grown extensively overseas with no recorded problems. Therefore the assessment focused on risks in the Australian environment and ecosystems. Four such risks were identified that required evaluation:

- The impact of the Bt toxins on non-target insects
- The weediness of cotton and the risk of enhancing weediness
- Outcrossing to native Gossipium species and impact of the transgene on distribution and survival of the native species
- Development of resistance to the Bt toxin in pest species

The first two risks were deemed negligible and not requiring management; the second two were seen as requiring a management plan to minimize the risks.

The management plan restricted the permitted area of cultivation of the GM cotton to areas away from the major centres of diversity for Gossipium; cultivation was not permitted north of the 22nd parallel or in the Kimberly region of Western Australia. The dangers of breakdown of resistance was to be managed by requiring growers to maintain at least 20% of the cultivated area to non-GM varieties or other potential hosts to insect pests such as sorghum. These areas were to act as refuges for insects to prevent heavy selection for resistance. Models of population dynamics suggested that the 20% refuges would delay development of resistant insect pests. Additional pest management strategies, such as "pupae busting", cultivation to break pupal emergence tubes, were to be used to minimise pest population sizes.

Approval for commercial release by the OGTR and its predecessor the Genetic Manipulation Advisory Committee was only part of the regulatory process. The Bt cotton was regarded as a pesticide in its own right since the plant itself contained an insecticide. Therefore formal approval was also required from the Australian Pesticides and Veterinary Medicines Authority (APVMA). Since the cottonseed oil was used for human consumption, approval was also required from Food Standards Australia New Zealand (FSANZ).

De-regulation

Approval for commercial release does not necessarily mean that a GM line can be grown in the same way as a non-GM variety. As noted above, the Bt cotton was released for commercial production under a tight set of conditions and the lines could only be grown in certain areas. Full de-regulation of a GM line will only occur if the regulatory authorize believe there are no remaining risks that require management.

Significance of the event

Different countries vary in their perceptions of the hazards and risks associated with GM crops. Under the regime in the USA, if the GM plant and products can be shown to be essentially identical to the parent or wild type variants, with the exemption of the modified characteristic, then no special regulation, or indeed labeling, is required. Under the Canadian system all novel foods are regulated whether they are produced by GM technologies or some other means. Both these systems focus on the end product of genetic engineering.

In contrast the European Union believes the technology itself must be regulated. Consequently each GM event is separately regulated. For example, during the transformation process many independent transgenic lines are produced. If more than one line is to be commercialised then each must undergo a separate regulatory analysis. This means that the organisation producing the GM lines must be very careful not to mix different events because presence of seed from a non-approved event within the seed pool of an approved GM line will render the whole seed batch unmarketable. The organisation responsible for the GM lines must also ensure that they have an assay that allows discrimination of different events. This means the site of insertion of the transgene must be mapped and sequenced.

Removal of selectable markers

As noted above when genes are "transformed" into the required variety a selectable marker, usually an antibiotic or herbicide resistance is incorporated into the "gene construct". This allows selection of transformed cells or plantlets. The most widely used markers were the neomycin phosphoryl transferase (NPTII) and the Bar gene for resistance to phosphinotricine (Basta or Liberty). These genes and their products have been extensively analysed and there is no known risk or problem associated with their use. Although many existing GM products contain these genes the regulatory framework has now changed and it would be difficult, and in some jurisdiction impossible, to commercialise lines that carried these genes. Removal of the selectable marker can be achieved using co-transformation and segregation of the target transgene and selectable marker, by using a range of recombination systems to recombine out the marker or simply by not using the selectable marker in the first place and simply screening large numbers of regenerants to identify those derived from transformed cells.

These strategies are feasible and are now widely used but they add time and complexity to the development of transgenic lines.

Food safety

The food regulatory system in Australia involves 10 governments and around 20 departments (Australian Food and Grocery Council 2008) developing policy. Many additional agencies are also responsible for enforcement. The main agency is Food Standards Australia New Zealand (FSANZ) which is an independent statutory agency established under the Food Standards Australia New Zealand Act 1991. The role of FSANZ is to ensure safe food for consumers by providing suitable regulation. Similar to the US FDA in this area, it is the authority which ensures that new GM technologies comply with standards for safe food.

Approval for a GM foodstuff requires extensive analytical data and usually animal feeding trials to demonstrate that the GM product does not have any negative consequences. Issues of particular concern for the regulator are potential allergencity, toxicity or anti-nutritional characteristics. The analysis must consider both the raw food and any products produced after processing. For example, GM wheat must be tested for the wide range of end-uses.

International requirements

Since a large proportion of our agricultural produce is exported, the international regulatory requirements must be considered. Indeed, the basis for State moratoria blocking GM production of canola was based around perceived impacts on marketing. All states have accepted the rigour of the OGTR assessment to ensure that human and environmental safety issues are adequately dealt with. However, in exporting overseas we must be aware of the international requirements and those of the destination country.

Cartagena protocol

The Cartagena Protocol is an international agreement regarding bio-safety. It sets out agreed rules regarding the safe handling of living organisms across international boundaries and is focused on ensuring that such handling does not compromise human health or natural biodiversity. The BioSafety Clearing-House (http://bch.cbd.int/) was established under the Cartagena Protocol. It is a web-based system for exchanging information relevant to the transfer of living organisms.

For export of a GM product the exporter must provide detailed information to the importing country under the Advanced Informed Agreement procedure. The importing country must have a competent national authority that acknowledges receipt of the information and authorises shipment or gives reasons for rejection. This exchange of information applies only to the first movement of the GM and is not required if the GM product is in transit, for contained use only or will be directly used for food and rendered unviable.

Conclusion

The translation of new GM technologies into Australian cereal and other crops is a complex task but promises substantial benefits to growers and the Australian economy. Unlike previous cereal crop improvement through conventional breeding, it is likely that Australia will need to interact internationally to ensure the best outcomes for growers. Through international interaction, Australia will augment its own research capabilities with technologies and know-how developed overseas. The difficult task will be to combine locally developed technologies with those from overseas and incorporate them into the locally adapted germplasm.

The costs to introduce a new biotechnology into a commercial, adapted variety is large and it is likely that any such product will need to have international application. It also seems probable that we will need to work with overseas groups or organisations that have the experience and resources to undertake the extensive and expensive regulatory process.

For many GM crops we will also need to consider the broader agronomic system where these plants are to be grown. Our experience with Bt cotton has demonstrated the benefits of a clear strategy for deployment of the GM lines. For the herbicide tolerant canola now being grown in Eastern Australia the role of this new tool alongside the many other options for weed management must be considered. Enhanced drought tolerance and nitrogen sue efficiency are also in the pipeline but it is not yet clear how these new traits will express themselves in the field and fit into our farming systems.

References

ABC http://www.abc.net.au/science/features/biotech/1980.htm. Website accessed on 30 July 2008

Acworth, W, Yainshet, A and Curtotti, R 2008, Economic impacts of GM crops in Australia. ABARE Research report 08.04 may 2008.

Australian Food and Grocery Council submission to the Federal Government Export Policy Review http://www.dfat.gov.au/trade/export_review/submissions_received/AustralianFoodandGroceryCouncil.pdf accessed on 30 July 2008

Beckie HJ, Harker KN, Hall LM, Warwick SI, Legere A, Sikema PH, Clayton GW, Thomas AG, Leeson JY, Seguin-Swartz G and Simard M-J (2006) A decade of herbicide-resistant crops in Canada. Canadian J Plant Sci **86**, 1243-1264

Biosafety Clearing House. http://bch.cbd.int/ accessed 30 July 2008FAOSTAT http://faostat.fao.org/site/291/default.aspx accessed 2 September 2008

Feuillet C, Langridge P, Waugh R. (2008) Cereal breeding takes a walk on the wild side. Trends Genet. **24**, 24-32

Foster M, French S. (2007) ABARE Research Report 07.5

Genetically Modified Crops Management Act 2004 available at http://www.legislation.sa.gov.au/LZ/C/A/GENETICALLY%20MODIFIED%20CROPS%20MANAGEMENT%20ACT%202004.aspx

Jaffe G, (2005) Withering on the Vine: Will Agricultural Biotech's Promises bear Fruit? www.cspinet.org accessed on July 29 2008

James C, ISAAA Brief 37-2007: Executive Summary Global Status of Commercialized Biotech/GM Crops: 2007 http://www.isaaa.org/resources/publications/briefs/37/executivesummary/default.html accessed on 30 July 2008

Kalaitzandonakes N, Alston JM & Bradford KJ , (2007) Compliance costs for regulatory approval of new biotech crops, Nature Biotech. **25**, 509 - 511

Knox, OGG, Constable GA, Pyke B, Gupta VVSR (2006) Environmental impact of conventional and Bt insecticidal cotton expressing one and two Cry genes in Australia. Aust J Agric Res, **57**, 501–509

Langridge, P., Chalmers, K. (2005) The principle: Identification and application of molecular markers. In "Molecular marker systems in plant breeding and crop improvement: Biotechnology in Agriculture and Forestry" 55; pp 3-22

Monjardino M, Pannell DJ, Powles SB (2005). The economic value of glyphosate-resistantcanola in the management of two widespread crop weeds in a Western Australian farming system. Agric. Systems **84**, 297–315

Monsanto (2008). *http://www.monsanto.com/pdf/products/2008_monsanto_pipeline.pdf*

OGTR http://www.ogtr.gov.au. Website accessed on 3rd August 2008

Pardey, P.G. and N.M. Beintema. *Slow Magic: Agricultural R&D a Century after Mendel*. Washington, D.C.: IFPRI Food Policy Report, 2001

Pray C, Oehmke JF, Naseem A. (2005) Innovation and Dynamic Efficiency in Plant Biotechnology: An Introduction to the Researchable Issues. The AgBio Forum, **8**, 52-63

Trewin D, Australian Bureau of Statistics. 2006 Yearbook Number 88, (ABS Catalogue Number 1301.0)