Genomic Age Series

Part 4: GM Canola – benefits, risks & challenges

Abstract

The potential benefits, risks and challenges associated with introducing GM canola into Australian agricultural systems are reviewed. The benefits offered by herbicide tolerant cultivars of canola have been attractive to canola growers overseas. The range of herbicides to which canola cultivars are tolerant has been expanded in North America by the development of transgenic lines which now dominate. Similar cultivars are licensed for use in Australia but are blocked by state legislation.

Experience from North America indicates that considerable on-farm benefits may accrue in Australia by growing GM canola. On-farm risks of gene flow and co-existence appear to be relatively minor, but marketing (including segregating and identity detection of GM and non-GM canola) and trade implications need to be resolved. The canola industry is facing challenges from other vegetable oils, including from varieties producing oils with modified fatty acid profiles that meet market needs for lower saturated fats and trans fatty acid levels. The industry also faces increasing isolation from overseas innovation in canola breeding.

Peter Carr
Consultant

Carr Consulting & Services,
Camden Park SA 5038

Dr Chris Preston
Discipline Head Plant & Food Science

The University of Adelaide,
Glen Osmond SA 5064

Dr Max Foster
Principal Economist

ABARE, Canberra NSW 2601

Introduction

Canola is a term applied to *Brassica napus* varieties that have been bred for low levels of two toxicants, erucic acid and glucosinolates. In the 1960s and 1970s, breeding programs in several countries including Australia produced high quality varieties with oil low in erucic acid (below 2 %) and meal low in glucosinolates (total glucosinolates of <30 µmoles/g toasted oil free meal). The removal of these compounds from oilseed rape enabled both the use of canola oil for human consumption and canola meal in livestock rations. The development of canola in Australia has been reviewed by Cowling (2006).

More recently, Indian mustard (*B. juncea*) cultivars that produce canola grade oil have been developed, permitting the possible expansion of edible oil crops into dryland cropping areas of Australia.

Genetic engineering may enhance the agronomic performance of commodity crops and produce speciality products for a range of food/feed and non-food/feed markets. Genetically modified (GM) herbicide tolerant canola varieties were sown in Canada for the first time in 1996. Today transgenic varieties account for more than 80% of North American canola production, and provide an intriguing insight into what benefit, or otherwise, that such traits might provide to the Australian canola industry.

Australia's canola industry

Canola is now well established as the third major crop in Australia's dryland cropping systems. Australian canola is a winter sown crop grown primarily for its oil (40-45%). The resulting seed meal is used as a valuable source of protein (30-36%) in formulated livestock feeds. Canola also provides benefits to cereal production as a 'break crop' in rotations (Kirkegaard *et al*. 1997). Although Australia is a relatively small producer of canola by global standards, it is a significant exporter (Table 1).

	Production (Kt)	Production (as % of world canola production)	Export (Kt)	Export (as % of world canola trade)
2000/01	1,775	4.7%	1,429	19.9%
2001/02	1,756	4.9%	1,388	27.6%
2002/03	871	2.7%	502	12.1%
2003/04	1,703	4.3%	1,206	22.0%
2004/05	1,496	3.6%	1,080	21.3%
2005/06	1,400	2.9%	950	15.2%

Table 1: Annual production and export of canola in Australia
Source: USDA Foreign Agriculture Service (http://www.fas.usda.gov/psd)

The production of canola has more inherent risks than wheat or barley. Canola has lower and more variable yield than cereals, coupled with more volatile returns that reflect changes in international market prices for oilseeds and the effect of variable exchange rates. Canola also has higher N, P and S requirements than cereals. It requires a larger up-front investment in fertiliser and weed control, and there is greater risk of unprofitable yield as a consequence of poor seasonal finishes and from the impact of fungal diseases, particularly Blackleg (*Leptosphaeria maculans*) and Sclerotinia Stem Rot (*Sclerotinia sclerotiorum*).

While breeders have been able to continually maintain genetic-based resistance to Blackleg in Australian canola, Sclerotinia has proved to be more intractable - neither genetic resistance nor chemical application has proved to be effective.

Canola yield decline is an emerging issue in some of the traditionally productive canola areas of southern NSW, with canola yields failing to meet seasonal expectations. Both Blackleg and Sclerotina Stem Rot have been implicated (Kirkegaard *et al*. 2006).

The issue of weed control

The presence of weeds in canola crops is a significant management issue with implications for yield, oil and meal quality. Weeds compete with the crop during critical early stages of growth, and the presence of mature brassicaceous weeds at harvest contaminate the harvested canola grain and lead to unacceptable levels of glucosinolate and erucic acid in processed oil and seed meal.

A strong negative relationship exists between sowing date and grain and oil yield, especially in medium rainfall areas (Zhang *et al*. 2006) and consequently delayed sowing impacts negatively on crop profitability. Traditional weed control practices may result in delayed sowing of canola because of the need to cultivate or spray weeds germinating after the seasonal break. Weed control strategies that are effective and which do not delay sowing are therefore central to profitable canola growing.

Herbicide tolerant canola cultivars provide new options for weed control, and non-GM herbicide tolerant varieties currently make up 80% of the canola sown in Australia (OGTR 2003). These varieties are tolerant to either the triazine herbicides (TT canola), or to the imidazolinone herbicides (IT canola, also known elsewhere as Clearfield® types).

Characteristics of TT canola types

While triazine chemicals provide timely, effective and cost-competitive weed control, the TT mutant allele impairs photosynthetic efficiency, causing TT cultivars to suffer yield penalties of ~10% (Robertson *et al*. 2002). Despite their lower yield, the popularity of TT cultivars, (which make up about 60% of the area sown to canola), is due to the easy, effective and rapid weed control they offer. This in turn allows canola to be sown soon after the seasonal break; providing a longer growing period with reduced risk of yield reduction should dry seasonal conditions occur late in the season. Earlier sowing also allows crops to partially escape ascospore showers of Blackleg from nearby canola stubbles (Khanguru *et al*. 2005).

A recent review of atrazine has supported its continued use in cereal production in Australia (Australian Pesticides and Veterinary Medicines Authority 2004). However, it is persistent in soils and may cause carryover problems with subsequent wheat crops (Bowmer 1991; Holford *et al*. 1989). Furthermore, the long-term future for triazine chemicals is somewhat uncertain, as they have recently been removed from use in Europe (European Union 2004). Its ongoing use in Australia may eventually be curtailed through market chain controls imposed by overseas customers as part of their environmental stewardship responsibilities.

Characteristics of IT canola types

IT varieties comprise approximately 15% of canola sowings in Australia, and provide an effective weed control solution without suffering any associated yield penalty. However, IT resistant weed populations, in particular wild radish (*Raphanus raphanistrum*) and wild mustard (*Sisymbrium orientale*), are emerging and will limit the future use of this herbicide group. Imidazolinone herbicides can have residual effects on subsequent crop germination.

The remaining 25% of the canola area in Australia is sown to non-herbicide tolerant varieties. The use of these cultivars is limited by intractable weed problems and need for pre-sowing weed control.

Genetically Modified Canola in Australia

Since 2003, two types of transgenic herbicide tolerant canola have been licensed in Australia, although neither has yet progressed to commercial use.

The Gene Technology Regulator granted a licence to Bayer CropScience for the commercial cultivation of InVigor® canola in Australia. This licence was for a hybrid canola tolerant to glufosinate ammonium, (a non-residual, broad-spectrum contact herbicide not previously used in Australia for grain production). In addition to the introduction of this herbicide tolerance gene from a soil-borne *Streptomyces* species, InVigor® canola also contains a hybridisation mechanism based on a transgenic male sterility gene (*barnase*) and a transgenic fertility restorer gene (*barstar*). These genes provide a new hybridisation system for the production of cultivars that enhance performance from hybrid vigour. There are several InVigor® cultivars sown commercially in North America, and these are amongst the highest yielding canola varieties in Canada (Beckie *et al*. 2006; Blackshaw 2006).

The Gene Technology Regulator also granted a licence to Monsanto for the commercial cultivation of Roundup Ready® canola in Australia. This licence was for an open pollinated canola tolerant to glyphosate, (a non-residual, broad-spectrum systemic herbicide already being widely used in Australian cropping systems). This tolerance was obtained from the insertion of two genes derived from *Agrobacterium* and from *Ochrobactrum* species.

The genetic transformations in each of these GM canolas were also assessed and approved by Food Standards Australia New Zealand (FSANZ) and the Australian Pesticides and Veterinary Medicines Authority (APVMA). However, all the canola-growing states introduced legislation prohibiting cultivation of GM crops. These moratoria remain in force today, but are scheduled for review in SA, Victoria and NSW in 2008.

Limited GM canola seed breeding and development work continues to be undertaken in the field in Victoria and SA, under specific legislative exemptions, by Bayer CropScience (InVigor®), and by Nufarm, Pacific Seeds and Pioneer Hi-Bred Australia (Roundup Ready®). These are closed sites operating under controlled conditions, and no material from the sites enters the supply chain.

Conventionally bred herbicide tolerant canolas have already achieved high levels of adoption in Australia, despite some productivity disadvantages, because they provide timely and effective solutions to weed control. Thus, is there a compelling case for introducing GM canolas, given that the cultivars available also provide herbicide tolerance?

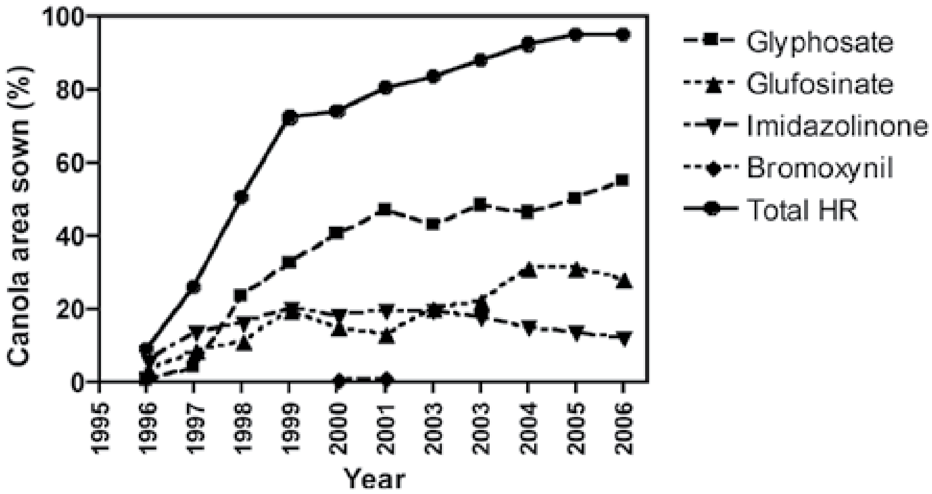

Figure 1. Percentage of canola area sown to herbicide resistant (HR) canola cultivars in Canada from 1996 to 2006 (adapted from Beckie et al. 2006 and Blackshaw 2006).

The Case for GM Canola

Limited Australian evaluations

Due to the State moratoria, only limited performance information is available for GM canola grown under Australian field conditions. The small number of Australian yield trials, mostly small plots, indicate that GM canola has generally performed well when compared to conventional or TT canola varieties of similar maturity (Pike and Clarke 2004; Ralph and Kruithoff 2004). These are summarised in Table 2. Currently only very limited gross margin analysis of cereal/GM canola cropping systems has been undertaken, and these are not yet able to be based on firm measures of agronomic performance and system efficiencies at farm scale, or include firm estimates of the "technology fee" that will be associated with use of this new technology.

Type	Yield as % of check variety	Oil %
InVigor canola, aggregated results for 2003 & 2005 (Bayer CropScience, pers. comm.)		
InVigor ARHY4112	121	45
InVigor ARHY0323	117	44
InVigor 60	113	45
Conventional canola (check)	100	42
Commercial Hybrid	100	43
Roundup Ready canola – 2003 A summary of the yield results from six trial sites throughout Australia in 2003 (one in WA, one in SA, one in NSW, and three in Victoria). (adapted from Ralph & Kruithoff 2004)		
TT canola	95	n/a
Conventional canola (check)	100	n/a
Roundup Ready canola	107	n/a

NB: The InVigor and Roundup Ready results above are not comparable, having been drawn from different locations and with differing cultural practices.

Table 2: Small plot performance of GM canola in Australia

Evaluations from Canada

In Canada, herbicide tolerant GM forms of canola dominate production. The main factors driving adoption were: earlier sowing opportunities, better weed control, ability to adopt no-till crop sowing systems, ability to grow canola in more marginal areas, greater cropping flexibility and increased profits (Sercon Management Consulting and Koch Paul Associates 2001).

Initial adoption of Roundup Ready® canola in Canada was rapid, reaching almost 50% of the canola area within 5 years (Figure 1). Since then the area of Roundup Ready® canola has grown more slowly (Beckie *et al*. 2006) but in recent years there has been a rapid expansion in the area sown to Liberty Link® or InVigor® canola which now represents 30% of the sown area (Blackshaw 2006). Adoption of Roundup Ready® and InVigor® canola in the USA has also been substantial, and together they now account for more than 84% of the canola area (Brooks and Barfoot 2005).

A significant advantage of GM herbicide tolerant canola varieties in Canada and the USA has been the ability to sow crops earlier since effective weed control can be achieved by post-emergent herbicides (Beckie *et al*. 2006). This has also resulted in a significant expansion of canola acreage into cropping areas with shorter growing seasons (Blackshaw 2006). It has also assisted weed control by allowing the crop to establish in the absence of weed competition and provide rapid canopy closure. Canadian canola growers can now also control herbicide resistant weeds with new herbicides (Blackshaw 2006). Frequently, GM canola is used in Canada to clean up weedy fields within rotations (Beckie *et al*. 2006).

GM canola, by providing effective options for post-emergent herbicide control, has also facilitated the wider adoption of no-till agriculture on the Canadian Prairies. The adoption of no-till cropping provides significant environmental benefits including reduced erosion, reduced dust, improved water quality and increased soil organic matter levels. Economic benefits from adopting no-till systems included reduced fuel use, increased yields through better timeliness of sowing and reduced labour requirements. A major driver of adoption of GM canola in Canada has been better profitability. Canadian farmers reported increased profitability of C$14.33 per hectare with GM canola, primarily as a result of higher yields (Sercon Management Consulting and Koch Paul Associates 2001).

Can Canada's success be repeated in Australia?

The benefits of GM canola experienced in Canada will not be automatically mirrored in Australia due to differences in climates, cost structures and farming systems. For example, there is already widespread adoption of no-till crop sowing in Australia (D'Emden and Llewellyn 2006). However, the availability of additional post-emergent herbicides in GM canola would provide benefits where resistance to grass herbicides is common. The ability to control all weeds post-emergent may also be a benefit in drier regions and in years with late breaks by allowing dry sowing of canola.

An additional benefit for Australian growers will be the ability to replace TT canola with higher yielding herbicide tolerant GM varieties that in turn will reduce reliance on triazine herbicides in Australian cropping systems. Furthermore, glyphosate and glufosinate have the advantage of having limited soil activity and mobility, thereby posing negligible risk to the environment or impacts on subsequent rotations (Norton 2003).

The use of InVigor® canola would also enable introduction of a new herbicide type into Australian grain cropping systems. To date, there are no known examples of resistance to glufosinate evolving, providing a lower risk option for weed control. However, glufosinate may have a lowered efficacy in controlling some key weeds under cool southern Australian winter conditions (Kumaratilake *et al*. 2002; Kumaratilake and Preston 2005).

Co-existence of GM and non-GM canola production

Canola is principally a self-pollinating species with a varying degree of outcrossing. The amount of interplant outcrossing varies with cultivar and environment and may be up to 55% (Becker *et al*. 1992). However, when distance and pollen competition are considered, actual outcrossing rates between canola crops will be much lower. An Australian study demonstrated less than 0.1% outcrossing between canola crops (Rieger *et al*. 2002). Even when multiple source fields are considered, it is unlikely that pollen movement will account for more than 0.15% outcrossing between crops under Australian conditions (Baker and Preston 2003).

In addition to pollen movement, gene flow could occur through seed movement. The most likely sources of seed movement would be via seeding, harvesting and windrowing equipment, from sowing contaminated seed, or from seed lost during transport. Under current regulations, canola seed certified after 2007 in Australia will be required to contain less than 0.1% of GM if it is to comply with moratorium legislation, (i.e. to be deemed to be "non-GM").

GM canola could also appear in conventional crops via canola volunteers in fields. Seed may be lost before or during harvest and may produce volunteers in subsequent seasons. Herbicide tolerant canola volunteers have occasionally proved problematic in Canada (Legere *et al*. 2001). Good management of volunteers will reduce these risks. Canola seed generally has no dormancy, but secondary dormancy can be induced by deep burial (Gulden *et al*. 2003).

Research in South Australia has demonstrated that most grain growers manage canola volunteers well and canola seed banks are largely depleted 2 years after harvest (Baker and Preston, unpublished data). This work suggests that GM canola volunteers are unlikely to be problematic unless canola rotations of less than 3 years are employed.

A major risk with the adoption of herbicide tolerant crops is the development of over-reliance on a narrow range of herbicides, leading to the evolution of herbicide resistance. Herbicide resistance evolves as a consequence of the persistent use of a single herbicide or herbicide mode of action. While GM herbicide-tolerant canola will provide new in-crop herbicide options for canola, over-reliance on herbicides alone needs to be avoided, and used as just one of several strategies for controlling weeds.

The potential for the overuse of glyphosate is a major concern, since it is already used widely for pre-sowing weed control in Australian grain cropping systems. The intensive use of glyphosate has resulted in the evolution of more than 50 glyphosate-resistant *Lolium rigidum* populations (Preston 2006). These populations have evolved where glyphosate has been used intensively, where few or no other herbicides have been used, and where no tillage has been employed (Powles and Preston 2006). It will be important for glyphosate use to be managed carefully in rotations with Roundup Ready® canola so this problem is not exacerbated.

An additional means of resistance developing in weeds is through pollen mediated outcrossing, where the resistance gene from crop plants can be incorporated into closely related weed species. Canola is known to cross with a number of related species, however, only

2(a) Proposed Glyphosate Resistance Management Strategy for Roundup Ready® Canola

- Growers and their advisors will be required to conduct a resistance risk assessment before planting Roundup Ready® canola. This risk assessment will include consideration of how often glyphosate has been used in that field and the amount of weed resistance in that field. Where the risk assessment indicates a high risk of glyphosate resistance, growers will be advised that Roundup Ready® canola should not be planted in that field. Where a moderate risk of resistance is identified, growers will be advised that they can grow Roundup Ready® canola, but will be expected to take additional measures to reduce the risk of glyphosate resistance evolving.
- Farmers will be expected to take action to reduce the risks of glyphosate resistance evolving by leaving glyphosate out of their rotation in the year after growing Roundup Ready® canola or by taking other action, such as the use of paraquat and diquat or full cut disturbance at seeding, that will control any glyphosate resistant weeds (Monsanto 2003).
- The plan also requires growers to identify and manage Roundup Ready® canola volunteers.

2(b) Possible Glufosinate Resistance Management Strategy for InVigor® Canola

The Liberty herbicide resistance management plan for use with InVigor® canola has not been released. However, given that glufosinate is not used anywhere else in the crop rotation, the risk of resistant weeds evolving is low (Preston and Rieger 2000). Therefore, it is expected the resistance management plan will focus on volunteer management, good farm hygiene and identifying and reporting adverse events.

Figure 2: Resistance Management Strategies for GM Canola

rarely do such crosses produce fertile plants and viable seeds under field conditions (Rieger *et al*. 1999; Salisbury 2002).

Of these weed species, *Raphanus raphanistrum* (wild radish) is of most concern in Australia. This weed is widespread across the Australian grain cropping zone and occurs within canola crops. Other compatible species (*Brassica rapa* and *Brassica juncea*) are rare weeds in Australian cropping systems. Research examining the potential for outcrossing to occur in the field between canola and *R. raphanistrum* demonstrated a very low frequency of fertile hybrids of 1 in 24 million seed tested (Rieger *et al*. 2001), indicating that fertile hybrids will occur rarely in fields. Moreover, the frequency of outcrossing is probably similar to the natural frequency of resistance occurring in normal weed populations (Preston and Powles 2002), again suggesting that outcrossing from canola to *R. raphanistrum* is unlikely to greatly increase the rate of evolution of herbicide resistant weeds.

Market acceptance of GM Canola

In Canada, canola is not segregated according to GM status. In the decade since GM canola sowings commenced in Canada, annual production and exports of canola grain, oil and meal have increased significantly. This has occurred despite a range of market access barriers to GM crops and products that other countries had erected in response to perceptions of consumer concerns and environmental issues. These barriers included import restrictions on unapproved events, mandatory food labelling requirements, and in the European Union, fodder labelling requirements as well.

The presence of these barriers has led to varying responses by canola importing countries. Japan has remained a major importer of Canadian canola, while the EU ceased imports of commodity canola grain. That in turn saw Canadian canola redirected to new markets such as China, and to the increasing export of canola oil from Canada to the EU.

Labelling regimes in most countries do not require food to be labelled if novel DNA that has been granted approval in that country is not detectable. This is particularly relevant to canola oil, as this generally is highly refined and contains no novel DNA or novel protein. In addition, no country requires labelling of products from animals fed GM feedstuffs, although the EU and China do require labelling of feedstuffs that contain GM materials.

ABARE has recently reviewed the evidence for market acceptance of GM canola (Foster and French 2007). Comparing import prices in the key canola importing countries – (Japan, Mexico, Pakistan and China), ABARE found no convincing evidence that non-GM canola was earning higher prices than GM canola. While there is anecdotal evidence of price premiums in EU market for non-GM canola, this is difficult to confirm. Recent large imports of Canadian canola oil have effectively capped any price premium that may have emerged. In March 2007, the EU Council of Agriculture Ministers (European Union 2007) approved the importation of GM canola grain for all uses with the exception of cultivation and uses in food. This will enable GM canola grain to be imported for crushing for biodiesel and animal feed uses.

The concern has also been expressed in Australia by key marketers that *unintended presence* of GM canola in other key grains exports, particularly wheat and barley, may jeopardise these markets if the admixture rises above threshold levels set by importers. However, Foster and French (2007) concluded that there was no evidence of unintended traces of GM canola causing market acceptance problems for Canadian wheat and barley exports.

Segregation and identity preservation

Where sufficient market premium exists for non-GM canola, it may be necessary to implement a segregated supply chain, and establish identity preservation arrangements within the non-GM supply chain to guarantee its status and purity. Two recent studies have examined the cost associated with segregation or identity preservation of GM crops in Australia.

- Crowe and Pluske (2006) examined additional costs associated with operating a system of receival sites in which some sites were dedicated to handling GM canola in the Great Southern region of Western Australia, centred on the port of Albany. They concluded there was an increase in post farm gate costs of transportation, handling and storage for segregating GM and non-GM canola, equivalent to 5–9 per cent of the farm gate price.
- Foster (2006) reported a framework that enables additional costs to be estimated and to establish who bears the additional costs. If GM canola was introduced, this framework suggests that additional costs to producers for identity preserved non-GM canola at 'representative' receival sites in four different regions of Western Australia would average 4 to 6 per cent of their farm gate canola prices in a typical year.

As GM are developed crops with characteristics that earn price premiums, such as improved oils, the emphasis on segregation and identity preservation is likely to shift to the GM varieties. This can be seen overseas with the development of identity preserved supply chains for products such as high oleic canola in Canada.

Future Challenges for Australian Canola

Several challenges face both conventional and GM canola. Firstly, if existing licensed transgenic canola cultivars in Australia are to become available for use by Australian farmers, then the current legislative prohibitions will need to be relaxed to permit their cultivation. This will depend on the ability of the grain supply chain, from seed breeders to domestic end users and exporters, to collectively implement the standards, and supply chain management systems necessary to give governments and industry sufficient comfort that segregation can be implemented to the degree necessary without reducing industry's competitiveness. The principles of co-existence have been adequately described by AgriFood Awareness (2006), Queensland Govt (2005), SCIMAC (2005).

Secondly, any discussion of Australian canola's future at this time, whether involving GM product or not, needs to be set in the context of global trends in vegetable oil production and use. There are new drivers and technologies reshaping the vegetable oil market, in which canola will be faced with both threats and opportunities. These drivers are:

- The diversion of increasing amounts of vegetable oils to the production of biodiesel. The USA has embarked on a biodiesel program based on the conversion of soy oil, while the EU has mandated canola/rapeseed as its biodiesel fuel stock. However the EU's renewable fuel goals cannot be met from its existing rapeseed production base. These initiatives will greatly increase the demand for renewable oils in general, and imports of GM canola grain and oil in particular.
- Consumer and health authority pressure to adopt diets with less saturated fat and minimal trans fats, which has resulted in considerable effort towards modifying vegetable oils genetically instead of relying on post-harvest industrial processing such as hydrogenation. The hydrogenation process partially re-saturates unsaturated oils to suit various market needs for stability, texture and "mouth feel". This process also creates some trans fats in the hydrogenated oil. There is now a convergence by soy, canola, sunflower and cotton breeders towards the "ideal" oil for the trans-fat replacement market, where levels of saturated fatty acids are reduced for reasons of cardio-vascular health, and the levels of linolenic acid are reduced to provide improved oxidative stability for extended re-use frying, thereby avoiding trans fats by removing the need for hydrogenation. Already cultivars of soybeans, canola and sunflower have been bred with modified oil profiles and commercialised in Canada and USA in direct-supply, identity-preserved supply chains.

Conventional canola oil has one of the highest levels of the poly-unsaturated oil linolenic acid (~10%), but new canola varieties with higher levels of oleic acid and lower linolenic acid provide a 50% longer frying life (White 2004). These are promoted as "high stability" oils. The development of novel oil profiles in canola can be achieved through conventional breeding methods, and some high oleic cultivars are becoming available to Australian growers. However, these varieties have lower oil yield than normal canolas, but the yield differential is being reduced through breeding and selection.

Soy, (which by volume is by far the predominant vegetable oil and is canola's main competitor), has a greater ongoing investment in soy oil modification than canola. This will make soy oil more competitive with canola oil for food markets. Crops with GM-based novel oil composition (such as soybeans) can be rapidly adopted under the regulatory environment in major grain producing and exporting areas such as North and South America thus positioning these countries to quickly gain market share in the premium price markets for modified oils. This leaves traditional canola to be increasingly sold on the commodity/biofuel market that appears to offer no significant or enduring premium for non-GM canola.

The question is - can Australia continue to be a price-competitive supplier of canola into the world market without pursuing the growing markets for new oil types coupled with the productivity benefits offered by herbicide tolerance and other traits that may flow from genomic and phenomic studies both here and overseas.

Finally, Crowley (2006) states that "major challenges exist for the Australian canola industry to access global genetic resources and increase effective population size while improving local adaptation...". Australian canola has been developed from a relatively closed and limited gene pool. While some recent introductions of new germplasm have occurred, these need to be cross-bred with local cultivars to introgress valuable new alleles into germplasm adapted to Australian conditions. Virtually all high performing Canadian canola germplasm now has herbicide tolerance traits, which currently makes its use as a source of genetic diversity to Australian breeders problematical.

New genetic diversity will be required to enable future genetic progress in traits such as polygenic blackleg resistance and broader adaptation to lower rainfall parts of the Australian cropping zone. Access to genetic diversity also extends to traits only available through genetic modification, such as the new gene systems for nitrogen use efficiency developed in the USA (Arcadia biosciences 2007) and reported to have demonstrated proof of concept in canola and other crop species.

References

AFAA 2006. AgriFood Awareness Australia, Towards Coexistence: Management Practices for Agricultural Production Systems, accessed at http://www.afaa.com.au/booklet/AFAA_Coexistence_Bklet_FINAL_Jan06.pdf

Australian Chicken Meat Federation (2006). Industry Position Statement on Genetically Modified Feed, Sydney, February. www.chicken.org.au/files/ACMF_Statement_on_GM_Feed.pdf

Australian Pesticides and Veterinary Medicines Authority (2004). Media Release 0407, 8 December, http://www.apvma.gov.au/media/mr0407.shtml

Baker, J. and Preston, C. (2003). Predicting the spread of herbicide resistance in Australian canola fields. Transgenic Research 12: 731-737.

Beckie, H.J., Harker, K.N., Hall, L.M., Warwick, S.I., Légère, A., Sikema, P.H., Clayton, G.W., Thomas, A.G., Leeson, J.Y., Séguin-Swartz, G. and Simard, M-J. (2006). A decade of herbicide-resistant crops in Canada. Canadian Journal of Plant Science 86: 1243-1264.

Becker, H.C., Karle, R. and Han, S.S. (1992). Environmental variation for outcrossing rates in rapeseed (*Brassica napus*). Theoretical and Applied Genetics 84: 303-306.

Blackshaw, R.E. (2006). Evolving on-farm weed management systems: the Canadian experience. In: Proceedings of the 15th Australian Weeds Conference. (C. Preston, J.H. Watts and N.D. Crossman, eds). Weed Management Society of South Australia, Inc. pp. 17-21.

Bowmer, K.H. (1991). Atrazine persistence and toxicity in two irrigated soils of Australia. Australian Journal of Soil Research **29**: 339-350.

Brookes, G. and Barfoot, P. (2005). GM Crops: The Global Economic and Environmental Impact - The First Nine Years 1996–2004. AgBioForum 8: 187-196.

Brookes, G., Craddock, N. and Kniel, B. (2005). Global GM Market: Implications for the European Union Food Chain, PG Economics Ltd, Frampton, United Kingdom (www.pgeconomics.co.uk/pdf/Global_GM_Market.pdf).

Cowling, AW, (2006). Genetic diversity in Australian canola and implications for future breeding. In: Proceedings of 13th Agronomy Conference 2006, Perth, Western Australia.

Crowe, B. and Pluske, J. (2006), 'Is it cost effective to segregate canola in WA?', Australian Agribusiness Review, vol. 14, paper no. 8, (www.agrifood.info/review/2006/Crowe_2.html).

D'Emden F.H. and Llewellyn R.S. (2006). No-tillage adoption decisions in southern Australian cropping and the role of weed management. Australian Journal of Experimental Agriculture 46: 563-569.

European Union, (2004). Commission decision of 10 March 2004 concerning the non-inclusion of atrazine in Annex I to Council Directive 91/414/EEC and the withdrawal of authorisations for plant protection products containing this active substance. Official Journal of the European Union, Legislation 78: 53 -55.

European Union, (2007). Council of Agriculture and Fisheries, Press Release, Brussels 18 Sept 2006. http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/format=HTML&aged=0&language=EN&guiLanguage=en

Fernandez-Cornejo, J. and Caswell, M. (2006). The First Decade of Genetically Engineered Crops in the United States, Economic Information Bulletin Number 11, (US Dept. of Agriculture, Washington DC, April) www.ers.usda.gov/publications/eib11/eib11.pdf.

Foster, M. (2006). GM Grains in Australia: Identity Preservation, ABARE Research Report 06.25 (Prepared for the Australian Government Department of Agriculture, Fisheries and Forestry and the Grains Research and Development Corporation, Canberra, December 2006).

Foster, M. and French, S. (2007). Market Acceptance of GM Canola, ABARE (Research Report 07.5 prepared for the Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, March 2007).

Gulden, R.H., Shirtliffe, S.J. and Thomas, A.G. (2003). Secondary seed dormancy prolongs persistence of volunteer canola in western Canada. Weed Science 51: 904-913.

Holford, I.C.R., Haigh, B.M. and Ferris, I.G. (1989). Atrazine persistence and phytotoxicity on wheat as affected by nitrogen and rotation-induced changes in soil properties. Australian Journal of Agricultural Research 40: 1143-1153.

Khangura, RK and Barbetti MJ (2004). Time of sowing and fungicides affect blackleg (Leptosphaeria maculans) severity and yield in canola. Australian Journal of Experimental Agriculture 44: 1205 - 1213

Kirkegaard et al. (1997). Comparison of canola, Indian mustard and Linola in two contrasting environments II. Break-crop and nitrogen effects on subsequent wheat crops. Field Crops Research 52: 179 - 191

Kirkegaard JA, Robertson MJ, Hamblin P, and Sprague SJ (2006). Effect of blackleg and sclerotinia stem rot on canola yield in the high rainfall zone of southern New South Wales, Australia. Australian Journal of Agricultural Research 57: 201 - 212

Kumaratilake, A.R. and Preston, C. (2005). Low temperature reduces glufosinate activity and glufosinate translocation in wild radish (*Raphanus raphanistrum* L.). Weed Science 53: 10-16.

Kumaratilake, A.R., Lorraine-Colwill, D.F. and Preston, C. (2002). A comparative study of glufosinate efficacy in rigid ryegrass (*Lolium rigidum*) and sterile oats (*Avena sterilis*). Weed Science 50: 560-566.

Legere, A., Simard, M.J., Thomas, A.G., Pageau, D., Lajeunesse, J., Warwick, S.I. and Derksen, D.A. (2001). Presence and persistence of volunteer canola in Canadian cropping systems. The BCPC Conference: Weeds, 2001 pp. 143-148.

Monsanto (2003). Roundup Ready® Resistance Management Plan. Monsanto Australia Limited, Melbourne. 9pp.

Norton, R. (2003). Conservation farming systems and canola. (University of Melbourne, Melbourne) 29 pp.

OGTR (2003). General Release of Roundup Ready oilseed rape Brassica napus. in Australia. Risk Assessment and Risk Management Plan. Office of the Gene Technology Regulator, Canberra Australia. 210 pp. Available from: http,//www.ogtr.gov.au/pdf/ir/dir020finalrarmp.pdf.

Pike, D. and Clarke, M. (2004). InVigor® hybrid canola. In: WA Agribusiness Crop Updates, 2004: Oilseeds. (WA Department of Agriculture, Perth. pp. 5-7).

Powles, S.B. and Preston, C. (2006). Evolved glyphosate resistance in plants: Biochemical and genetic basis of resistance. Weed Technology 20: 282-289.

Preston, C. and Powles, S.B. (2002). Evolution of herbicide resistance in weeds: initial frequency of target site-based resistance to acetolactate synthase-inhibiting herbicides in *Lolium rigidum*. Heredity 88: 8-13.

Preston, C. and Rieger, M.A. (2000). Risks of herbicide resistant weeds from use of herbicide tolerant crops. Plant Protection Quarterly 15: 77-79.

Queensland Govt. (2005). Developing a Framework for GM and non-GM Crops In Queensland: A Framework for Coexistence. (Dept of Primary Industries and Fisheries, October 2005).

Ralph, A. and Kruithoff, D. (2004). The benefits of Roundup Ready® canola for Western Australian farming systems. In: WA Agribusiness Crop Updates, 2004: Oilseeds. (WA Department of Agriculture, Perth. pp. 8-10).

Reiger, M.A., Potter, T., Preston, C. and Powles, S.B. (2001). Hybridisation between Brassica napus L. and Raphanus raphanistrum L. under agronomic field conditions. Theoretical and Applied Genetics 103: 555-560.

Rieger, M.A., Lamond, M., Preston, C., Powles, S.B. and Roush, R.T. (2002). Pollen-mediated movement of herbicide resistance between commercial canola fields. Science 296: 2386-2388.

Rieger, M.A., Preston, C. and Powles, S.B. (1999). Risks of gene flow from transgenic herbicide-resistant canola (Brassica napus) to weedy relatives in southern Australian cropping systems. Australian Journal of Agricultural Research 50: 115-128.

Robertson, M.J., Holland, J.F., Cawley, S., Potter, T.D., Burton, W., Walton, G.H. and Thomas, G. (2002). Growth and yield differences between triazine-tolerant and non-tolerant cultivars of canola. Australian Journal of Agricultural Research 53: 643-651.

Salisbury, P.A. (2002). Genetically modified canola in Australia: Agronomic and Environmental Considerations. (Australian Oilseeds Federation, Sydney. 69pp).

SCIMAC. Supply Chain Initiative on Modified Agricultural Crops, GM Crop Coexistence – 10 Key Principles. www.scimac.org.uk

Sercon Management Consulting, Inc. and Koch Paul Associates (2001). An agronomic and economic assessment of transgenic canola. (Canola Council of Canada, Winnipeg. 55pp).

US Department of Agriculture (2006). PSD Online, Washington, DC (www.fas.usda.gov/psd)

White, K. (2004). Monola cultivars and oil - innovations and issues. (GRDC Research Update - Southern Region) www.grdc.com.au/growers/res_upd/irrigation/i04/white.htm

Zhang H, Turner NC, Poole ML, Simpson N (2006). Crop production in the high rainfall zones of southern Australia - potential, constraints and opportunities. Australian Journal of Experimental Agriculture 46: 1035 - 1049.

Continued from page 32

Taylor, I.N., Charles, G.W. and Inchbold B. (2003). Reducing residual pre-emergent or pre-plant herbicide use in cotton through the development of weed thresholds. Proceedings of World Cotton Research Conference-3. Cape Town, South Africa, March 2003.

Stotzky, G. (2002). Release, persistence and biological activity in soil of insecticidal proteins from Bacillus thuringiensis. In: Letourneau, D., Burrows, B. (Eds.), Genetically Engineered Organisms: Assessing Environmental and Human Health Effects, CRC Press, Boca Raton, pp. 187–222.

Whitehouse, M.E.A., Wilson, L.J. and Fitt, G.P. (2005). A comparison of Arthropod communities in transgenic Bt and conventional cotton in Australia. Environmental Entomology. 34: 1224-1241.

Wilson, A.G.L. (1974). Resistance of Heliothis armiger to insecticides in the Ord River irrigation area, north western Australia. *J Econ Entomol*. **67**, 256-258.

Walker, S.R.; Taylor, I.N.; Milne, G.; Osten, V.A.; Hoque, Z.; Farquharson, R.J. (2005). A survey of management and economic impact of weeds in dryland cotton cropping systems of subtropical Australia. *Aust J Exp Agric* **45**, 79-91.

Werth, J.A., Preston, C., Roberts, G.N. and Taylor, I.N. (2006). Weed management practices in glyphosate-tolerant and conventional cotton fields in Australia. *Aust J Exp Agric* **46**, 1177-1183.