9th ICABR International Conference
on

Agricultural Biotechnology: Ten Years Later

Ravello (Italy), July 6 to July 10, 2005

Economic Impacts of Two GM Crops in Australia

David Tribe[1] and Roger Kalla[2].

[1] Department of Microbiology and Immunology, University of Melbourne, Victoria 3010, Australia (detribe@unimelb.edu.au)

[2] Korn Technologies, Ivanhoe East, Victoria 3079, Australia (srkalla@bigpond.net.au)

Abstract

Australian commercial cotton growers have employed Genetic Modification (GM) technology since 1996, exploiting two insect protection Bt traits and one herbicide tolerance trait. About 90% of the cotton crop is now GM. This has helped economic sustainability, cost reduction, and environmental stewardship. Complex new regulations affecting GM crop commercialization were introduced into Australian parliaments in 2000-2004. Under this legislation, the Australian canola industry's innovation with GM methods has been severely penalized. Australian vegetable oil exports now face world markets where nutritionally enhanced cottonseed and soybean oils, and cost advantaged Canadian canola oil will all compete with advantages over Australian canola.

Key words: canola, oilseed, cotton, trade, biotechnology, genetic, commodity, regulation, political.

Introduction.

Australia is an efficient competitive producer of agricultural commodities, with significant public sector research investment. In 2000/01, Batterham (2000) the fraction of research investment in the agricultural sector was 18% of total public funded research. This level of investment reflects the importance of agriculture as a generator of export income, as a provider of high quality raw materials for manufacturing industries, and the substantial economic benefits from such public research in the past and the present. The economic history in Australia provides good examples of the attractive economic returns from such investment particularly in the cotton and oilseeds industries that are the subject of this paper.

Australia has been a consistent and active advocate for trade liberalization particularly for agricultural commodities and is a founding member of the Cairns group, a coalition of 17 agricultural exporting countries that has been an influential voice in the agricultural reform debate since its formation in 1986 and has continued to play a key role in pressing the WTO membership to meet in full the far-reaching mandate set in Doha (www.cairnsgroup.org).

There are a number of internationally well regarded agricultural research institutes and centres in Australia, including federally funded public agencies such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and a number of Cooperative Research Centres (CRCs) which incorporates public research agencies as well as companies. The local State Departments of Agriculture have historically taken a very proactive role as research providers and in the breeding of new crops and animals that thrive in the varying climatic zones of Australia.

In Australia, cotton is a summer crop produced mostly using irrigation in semi-tropical Northern New South Wales, and also extensively grown in Queensland. Oilseed rape (canola) is a winter crop predominately grown in the dry-land farming belt of Southern Australia, often in rotation with wheat. The economics of both crops in Australia are dominated by export opportunities and challenges as there is no cotton spinning industry and local commodity markets are relatively small. Australia is a major cotton exporting country, ranking after the USA and Uzbekistan, and a major canola exporter, ranking just behind Canada in the international oilseed rape trade.

Comprehensive understanding of world commodity markets is thus an integral part of Australian strategic decision-making with both crops. Such decisions need to take account of dynamic international markets for both crops, exemplified by (i) the dramatic restructuring in recent years of textile manufacturing from the industrialized countries to expanding Asian cotton textile industries, and (ii) significantly expanded recent crop areas for the major oilseed commodity (soybeans) in Brazil and Argentina. Sound strategic decisions on cotton and canola also recognize the volatile forces affecting placement investment of risk capital for agricultural commodities and their effects. These include high regulatory costs, extended time lags, sensitivity to political influence and other intangible barriers for investment returns. Dramatic declines in agricultural biotechnology research in the EU, Lheureux et.al. (2003), and flight of capital investment to attractive markets such as the USA, India and Brazil are examples of investor responses to these influences.

Restructuring of global textile industries has meant that developing countries, particularly China, are globally now the major cotton fiber consumers, taking 52% of world consumption in 2003, up from 49% in 1998. China, Pakistan, India, and Turkey, themselves cotton producers, are also now the major cotton importers, taking an estimated 42% of world cotton imports in 2003/4, up from 15% in 2000/1 (ICAC (2004), Macdonald & Vollrath (2005)).

There is differentiation in the markets for different grades of cotton based on lint quality attributes such as fiber length, fiber strength, and characteristics such as color. For example, FiberMax ® varieties constitute 24% of the US cotton seed market and are branded as specially bred seed varieties that give superior lint quality.

International oil and oilseeds markets include both soybeans, canola and several other oil commodities. These different oils and oilseeds are substitutable commodities and competition between them is likely to intensify with increasing exploitation of crop varieties that mimic the favorable attributes of the other commodities. The overall oilseed sector that has undergone considerable expansion in recent years driven by demand for soy-based animal feeds and substantial expansion of soy cropped area in Brazil and Argentina. The share of global oilseed crop area planted to soybeans rose from 30% in 1996 to 37% in 2004 (FAO statistics).Taken together though, Australia and Canada typically export the majority of international commodity trade in oilseed rape. The EU is self sufficient in oilseed rape and in oilseeds generally, while India is a major global oil/oilseed importer.

Influence of Research Investment on Global Markets for Cotton Fiber.

For many decades population growth has continued to sustain steady increases in global demand for cotton fiber (which showed growth at 1.8% per annum in the period 1961-2003), although in the decades following World War II, competing technological innovation in synthetic fibers progressively diminished cotton's share of the global fiber market.

In more recent years cotton has progressively regained a competitive advantage, and for the five-years up to 2003 there has been a boom in demand for cotton, with 2003 being the fifth straight year with record global cotton consumption. This trend is expected to continue into 2005. As shown in Figure 1, for at least twenty years cotton has become increasingly price competitive with alternative synthetic fibers, ICAC (2004). The boom in cotton consumption has been aided by population growth, increases in GDP, and integration of textile trade within WTO rules. But the sustained consumption boom was made possible by continued investment in technological innovation and subsequent technology diffusion from leading regions to late adopting regions.

Australia has a long history on ongoing investment in the cotton industry, including public sector investment, is one of the world leaders in innovative cotton production technology, arguably more efficient that any other country in the world, and has very competitive production costs for cotton.

World cotton trade grew at 2.5 % per year for the period 1998-2003, was a record of 7.3 million tons in 2003/4, and is forecast to reach a record 7.9 million tons (or 36% of production) in 2005/6. Recent record cotton consumption by textile millers, ICAC (2004) has been led by the major consumers China and India. There is also increasing dependence of China, India, Pakistan and Turkey on imports for milling, with a surge in imports by China in 2003/4, ICAC (2004).

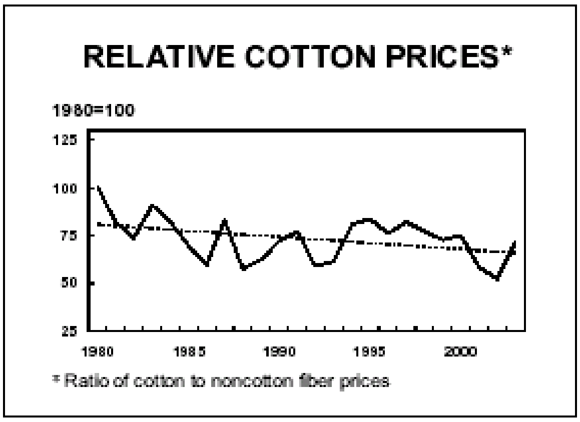

Figure 1.Trends in relative cotton prices, ICAC (2004).

These major shifts in trade are linked are linked to the global restructuring of cotton textile milling from the industrial counties (i.e. Europe and the USA) to developing countries, mainly China, in recent years. This trend has been accelerating and in 2003, industrial country cotton consumption fell by 11%, the single largest drop since 1937. This trend is expected to continue, ICAC (2004). GM modified cotton is entering world trade in increasing volumes and there is no-price differential between GM and non-GM cottons. GM-cotton fibers accounted for 36% of exports in 2003/4, ICAC (2004).

The role of investment in agricultural innovation in influencing global markets is highlighted by recent reports from India. In that country, new seed varieties, including both GM Bt insect damage protected cotton varieties, and higher yielding hybrid varieties has been associated with a remarkable record-breaking jump in average Indian cotton yields in the 2003/4 season, followed by forecasts of national average yields improvements for the 2004/5 season to a record 39% above the 10 year average Foreign Agricultural Service USDA (April 2005). In the leading high technology cotton producers there has been a steady ongoing improvement in cotton yields over an extended period since at least 1960, amounting to yield gains of 1.5-3% per year from improvements in crop breeding and agronomy. In China there have been dramatic yield gains post-1961 resulting from an acceptance of the value of free market economics in that country's agricultural sector and an increasing awareness of the cost to public and environmental health connected with the excessive use of pesticides.

Besides driving the shift in textile industry activity to developing countries, technological innovation in the cotton industry is providing major environmental benefits. Despite a demand boom for cotton fiber, this has not lead to an increase in cropland sown to cotton. World cotton production increases continue to be achieved primarily by technology improvement rather than expansion of total crop of area: statistics show a static trend for global cotton crop area at a fixed level of 33 million hectares from 1980/1 through to 2004/5, with a progressive rise in average world cotton yield per hectare from near 410 kg/hectare in 1980/1 to approaching 660 kg/hectare in

2004/5 (see Figure 2). Additionally, there have been globally substantial decreases in overall spraying of persistent synthetic pesticides by growers in the USA, Australia, China, India, and South Africa (e.g. see Shelton et al. 2002; Huang et al. 2002; Roush 2004) because of widespread adoption of GM cotton varieties that are genetically protected against insect attack by the Bt-trait.

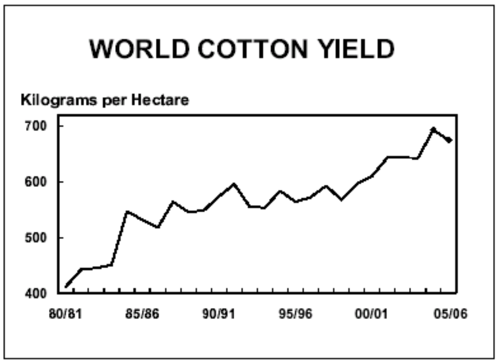

Figure 2.Global trends in average cotton yield 1980-2004/5 from ICAC (2004).

Global markets for Food Oils.

Although oilseeds are readily substitutable commodities, different sources of oil are distinguished by differences in biochemical profile, and perhaps the most important components in this profile are the fatty acids, which affect both suitability for particular applications such as commercial frying and the nutritional value of the oil, although other components such as flavor components and anti-oxidant levels can be relevant.

The relative sizes of the main sectors in the global food oil and oilseeds market corresponding to oils from different plants are detailed in Table 1. Smaller volume, higher price oils such as olive oil and fish oils, not included in the table, are also relevant to understanding of these markets. The table does document how global oilseed output has continued to expand in recent years and shows that globally soybeans are the major oilseed crop. Oilseed rape (Brassica crops, including canola) oilseeds are relatively heavily traded though, and Australia supplies about 27% of international trade in oilseed rape.

In the last fifty years there have been considerable shifts in market demand among the various types of oil commodities. Some major driving forces have been suitability of oils for commercial frying, the popularity of fried fast-food, and public perceptions about health benefits of particular oils and of fat intake in general. Crop breeders have responded to these forces by specially breeding new crop varieties with changed and improved biochemical profiles. Canola provides a good illustration of these changes. *Brassica napus* (rapeseed) had been used for 4000 years as a source of lighting oil, Norton (2003) citing Bunting (1986), but it was only in the early 1950s, when Canadian Brassica oilseed breeders developed new varieties of oilseed rape with reduced levels of toxic erucic fatty acid and glucosinolate anti-nutrients, now known worldwide under the brand name canola, that globally significant cropping of oilseed rape (canola) for use as food commenced.

Table 1. Global production and trade for major oilseed commodities (USDA, www.fas.usda.gov, Australian Oilseeds Federation, www.australianoilseeds.com).

Commodity	***Season 2004/2005***	***Season 2001/2002***	***Season 2001/2002***
	Production Million tonne	Production Million tonne	Exports Million tonne
World, Rapeseed	45.55	36.03	4.93
World, Cottonseed	45.12	36.71	0.98
World, Soybeans	219.23	185.12	53.5
World, Peanuts	33.44	33.81	1.93
World, Sunflower	25.23	21.37	1.29
World, Copra	5.49	5.21	0.14
World, Palm kernal	8.74	7.2	0.08
World, Total Oilseeds	**382.79**	**325.36**	**62.83**
Australia, Canola	1.521	1.608	1.351
Australia, Cottonseed	0.850	0.875	0.098
Australia, Soybeans	0.071	0.072	0
Australia, Sunflower	0.073	0.070	0
Australia, other Oilseed	0.010	0.015	**0**
Australia, Total Oilseeds	**2.535**	**2.91**	**1.45**

This breeding innovation led the current significant international trade in oilseed rape (canola) and derived food oils from a source that was previously dangerous to eat but is now valued for its nutritional advantages. Canola now exists as a defined brand of oilseed rape in terms of an oil with low erucic acid content (<2%) and low glucosinolate levels and it possesses a particular fatty acid profile which is perceived as being healthier than animal and palm oils, and well suited to commercial frying. However, there is still a market for technical grade rapeseed oils for industrial use in Europe. High erucic acid rapeseed varieties (HEAR) successfully coexist in Germany and other countries side-by-side with canola cultivars through simple and low cost measures to segregate these non-food oilseeds from canola cultivars.

Oils chemically consist of a variety fatty acids esterified to glycerol from which they are easily released as the free acid components. The nutritional value of food oils is primarily determined by their fatty acid biochemical profile - that is the types of distinct fatty acid components present in the oil and their relative quantities. This composition is genetically determined, and different varieties of oilseed plant can contain different profiles of fatty acids and this profile can be changed by selective breeding or by direct genetic manipulation.

It is necessary to review specific details of fatty acid biochemistry to fully understand current and prospective oilseed markets. The constituent fatty acids of oils can differ chemically from one another in three pertinent aspects. First, there is the degree of saturation. The major portion of the fatty acid molecule is a hydrocarbon-like side chain which is generally about 16-18 CH_2 residues in size. This side chain can completely lack carbon-carbon double bonds, and be thus described chemically as being completely *saturated.* Alternatively, the hydrocarbon side chain may contain one or more carbon double bonds, and be *unsaturated* or even *polyunsaturated* if it has multiple double bonds per molecule. This feature directly affects the key biological function of fatty acids – namely fluidity of natural membranes containing fatty acids. Polyunsaturated fatty acids alpha-linolenic acid (an omega-3 acid, see below), and linoleic acid are essential dietary components.

Second, the molecular position of the double bond in the side chain may be nutritionally significant as in the so-called omega-3 fatty acids just mentioned. Third, chemical treatment with hydrogen used to convert oils to more practically useful profiles can convert fatty acid double bonds from their natural *cis*-configuration to an unnatural *trans*-configuration, which behave biologically more like saturated fats.

A number of distinct health issues connected with oil biochemical profiles have been raised and debated within the scientific literature, and these medical and nutritional issues have strongly influenced oilseed markets, and will continue to influence them in the future. Briefly, these main health and nutrition issues are (see e.g. McDonald (1999), Institute of Medicine (2002), Sayanova & Napier (2004), German & Dillard (2004)):

1. Medical recommendations to keep saturated fats to low levels (10% or less of total calorie intake).
2. Recognition of the favorable dietary value of oils (such as canola oil or olive oil) which promise reduction of undesirable human blood cholesterol levels and better management of heart disease risks because they offer an oil with a high content monounsaturated fatty acids such as oleic acid or nutritionally essential polyunsaturated fatty acids such as linoleic acid.
3. The opinion that trans-fatty acids in a diet act like saturated fats in promoting high blood cholesterol levels, and that health issues are raised by diets with relatively high trans-fatty acid content that comes from chemical hydrogenation treatment of oils with high

polyunsaturated fatty acid content. Chemical hydrogenation has practical advantages, and when used on oils that have a relatively low content of polyunsaturated fatty acids tends to yield products that have a favorably low *trans*-double bond content. There is extensive nutritional research focusing on the health consequences of diets containing trans-fatty acids.

4. Increased medical recognition that oils popularly known as omega-3 dietary acids have important roles in human health and are implicated in prevention of cardiovascular and inflammatory disease, mitigation of senile dementia and enhancement of intelligence (Institute of Medicine (2002), Sayanova & Napier (2004), Suzuki et al. (2001), Calon et al. (2004). These nutritionally important oils include essential polyunsaturated fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are dietary fatty acids currently obtainable in fish products.

Representative data describing the major relevant components of commodity oils are presented in Figure 3.

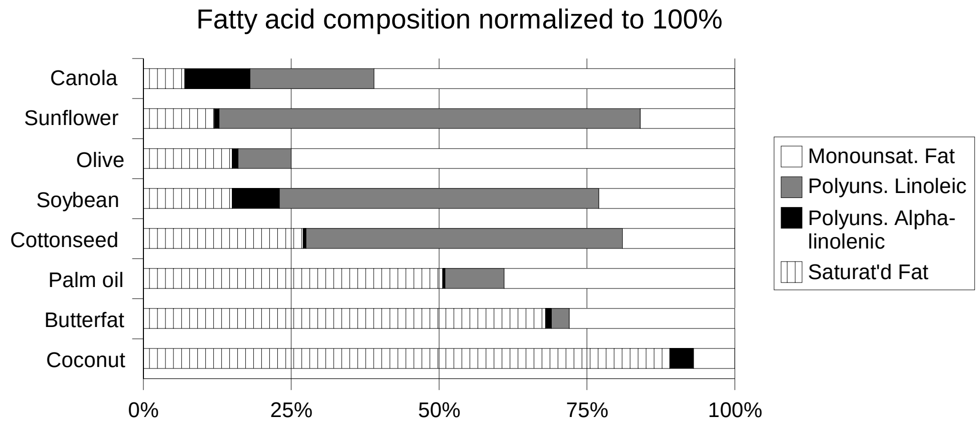

Figure 3. Representative fatty acid composition analysis for oil commodities, McDonald (1999).

It can be seen in Figure 3 that canola oil has low levels of saturated fatty acids and moderate levels of polyunsaturated fatty acids. This means that it combines the nutritional advantages of a low-saturated fat oil with ability to yield products containing low trans-fatty acids after hydrogenation treatment. The figure illustrates that a high a high content of monounsaturated fatty acid (usually oleic acid) is generally needed for an oil to have a moderate polyunsaturated fatty acid content combined with nutritionally desirable minimal saturated fat content. Olive oil is such a product, but this is a high priced commodity. Moderate polyunsaturated fatty acid content, and particularly lower linolenic acid in an oil help to minimize various difficulties such as instability to heat and propensity to yield high trans-fatty acid content on hydrogenation. It is interesting to note that the CSIRO is using its proprietary gene silencing technology to develop cottonseed with significantly increased levels of monounsaturated fatty acid oleic acid. GM cotton with high oleic oil profile is presently being evaluated in small scale field trials in the cotton growing areas of Australia. If this approach proves successful, the profile of cottonseed oil would approach the canola oil profile.

Similarly, it is now possible to mimic the canola fatty acid profile with soybean oil, as evidenced the commercial growing of several varieties low (1-3%) linolenic acid cultivars of conventional (non-GM) soybeans in the US 2005 season (www.qualisoy.com). Many other oils such as butterfat and palm oils have very high contents of saturated fatty acids, or have higher content of polyunsaturated fatty acids. However, there are presently no information on programs in increasing the oleic oil content in these crops. In many markets with a major shift from fats of animal origin with a high content of saturated fatty acids to vegetable oils with low content of saturated fats over the last thirty years, associated with medical advice that this reduces health risks of associated with high serum cholesterol levels and circulatory disease.

Potential of health promoting oils. Docosahexaenoic Acid, or DHA, as mentioned, is one long-chain omega-3 fatty acid that is particularly favoured for its health benefits. Nutritional authorities recommend a daily intake of at least 500mg of long-chain omega-3 including DHA, yet dietary surveys show that most Australians consume only a tenth of this amount. DHA and other long-chain omega-3 fatty acids are made by lower plant forms, including marine plants like microalgae that are consumed by fish which acquire DHA when they eat the microalgae. As a result fish accumulate favourably high levels of DHA which in turn can be consumed by humans as a source of DHA. Some land plants can make other types of omega-3, namely short-chain omega-3 fatty acids, but these are not as useful in the human diet as the long-chain fatty omega-3 fatty acids like DHA. Many foods are now enriched with omega-3 oils derived from fish, but with declining natural fish stocks, and aquaculture's current reliance on fish-based feeds, additional sources of long-chain omega-3 oils are urgently needed.

Researchers from the CSIRO Food Futures Flagship have shown that land based plants can make their own DHA when they are equipped with the necessary genes from microalgae. This has the potential to revolutionise the oil seed market by further substitution of essential oils from an animal origin (e.g. fish for DHA) with plant derived oils. It is entirely plausible that the high oleic oil cottonseed under development could also be engineered to contain a certain level of DHAs which would greatly increase the health benefits of these novel products to the consumer (see www.csiro.au, Food Futures Flagship page; also Abbadi et al. (2001), Sayanova & Napier (2004).

Expansion of Australian Cotton and Oilseed Sectors-Cotton expansion

There has been rapid expansion of the Australian cotton industry since 1970, with 700% growth in output over the last 20 years. In Australia the production of cotton is almost entirely for export, and Australia has steadily expanded its share of global cotton exports to achieve a share in the range 12-18% of total world exports in recent years. From the data in Figure 4, it can be seen that this has involved a significant increase in harvested area since 1980. Yields per hectare have trended upwards during this expansion. The recent drought (2002-2003) has depressed total output, and forced a heavier reliance on irrigation which is used for the bulk of production. Historically, cotton production in Australia goes back far further than canola farming (which only commenced in the early 1970s.) The Australian Cotton Growing Association dates back to 1921, and a cotton marketing board was formed in 1926.

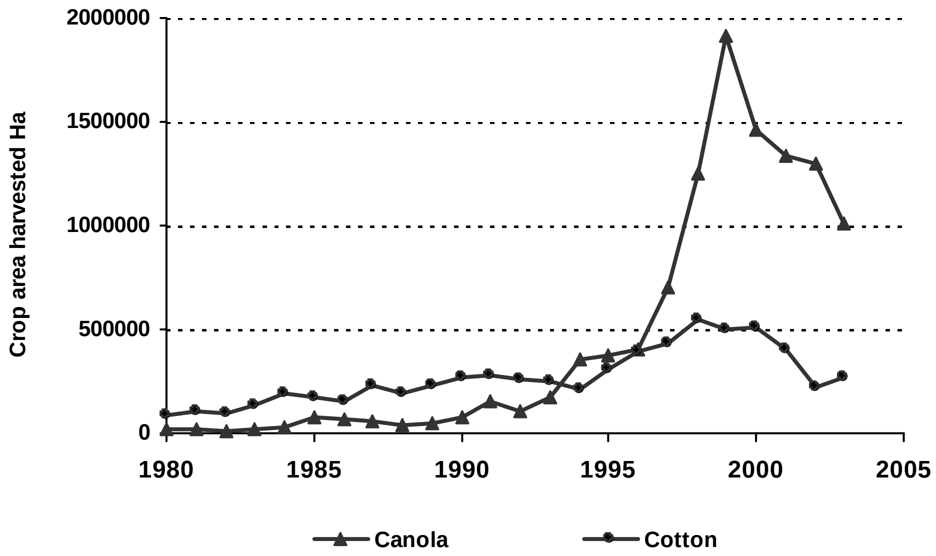

Figure 4. Expansion of cotton and canola cropping in Australia.(FAO, ICAC, ABARE).

This spectacular expansion was fostered by early public capital investment in irrigation, the development of a cotton seed breeding cooperative (Cotton Seed Distributors, CSD, 1967), followed by the establishment of the Australian Cotton Research Foundation (1972), and the involvement of the publicly funded research agency CSIRO in breeding research. In the 1960s, industry establishment was stimulated by a Raw Cotton Bounty subsidy. By 1991 cotton had became Australia's fourth largest agricultural export.

The competitive advantages enabling this expansion are the arguably best agricultural environment in the world for cotton production, including a favorable warm climate and deep soils in the main cotton areas of Northern New South Wales, good irrigation capacity, well developed scientific breeding and agronomic research capacity, and an orientation of the whole industry to export markets, underpinned by a commitment to delivering high quality fibre. CSIRO has continued to provide innovative solutions for the cotton industry and is one of the partners in creation of the FiberMax ® brand mentioned earlier. Breeding and irrigation are significant factors in Australia's ability to deliver quality cotton, which is mainly exported to South East Asian (1998/9: 42% crop) and East Asian markets (1998/9: 39% crop). Southern hemisphere crops from Australia become available at a time that is seasonally out of phase with the major producers in the

Northern hemisphere.

The Australian cotton industry is currently very cost competitive on world markets and unsubsidized. Cotton industry support by the Australian Government was discontinued in 1971, and currently industry very high yield per hectare (1888 kg/ha in 2003/4, compared with world average of 638 kg/ha, ICAC (2004). Years of drought (e.g. 2002-2003) can impact of this capacity. From an environmentalist perspective, every hectare of cotton farmed in Australia saves four or more hectares of more marginal land overseas from the plough.

Canola Industry Expansion.

As can be seen from Figure 4, the expansion of the canola industry in Australia is more recent and even more spectacular than with cotton. A comprehensive account of this development of is available, Salisbury et al. (1999). The excellent industry review by Norton (2003) is also an authoritative source. These two reports describe the numerous technical challenges that were surmounted in the creation of a canola export industry in Australia.

The first Australian commercial varieties of oilseed rape were imported from Canada in 1967, and were poor in quality by today's standard with 20-40% toxic erucic acids in the oil, and a high glucosinolate content. It soon became obvious that oilseed rape breeding programs were needed to improve yields, and to manage blackleg disease which emerged as a major problem in commercial farming the 1970s. This fungal disease is a far more severe agronomic problem in Australia, and particularly in Western Australia, than in Canada. An important source of resistance to this disease are genes from *Brassica sylvestris* that can be transferred by artificial genetic techniques, that are excluded from restrictive regulation, into *Brassica napus* Norton (2003).

Several different canola breeding innovations were crucially important in allowing spectacular expansion of the Australian industry in the 1990s. Varieties (Maluka and Shiralee) yielding high quality oil, with high blackleg tolerance, and giving high yield were first released in 1987 and Pacific Seeds released high yielding hybrid varieties Hyola 30 and Hyola 42 in 1988 and 1991 respectively. A triazine herbicide tolerant canola was first commercialized 1993. Triazine tolerant (TT) varieties were widely adopted even though having low yield and oil content, because they can to be grown where weeds such as wild radish are serious cropping issues, and in Western Australia triazine tolerant varieties are used in about 90% of canola growing regions. Imidiazolinone (Imi) tolerant Clearfield ® canola varieties that do not suffer the inherent yield penalty of TT varieties, developed using conventional mutagenesis, were introduced commercially in 2000, both TT and Imi herbicide tolerant varieties facilitate minimum tillage farming, with savings in tillage costs and other benefits such as increased soil carbon and reduced erosion Norton 2003). Benefits of minimum tillage are also seen with herbicide tolerant GM cotton (see later).

The area sown to canola expanded from 190,000 hectare in 1991 to 1.6 million hectares in

1999 and agronomic advances were important in this expansion. They include liming of acidic soils and use of sulfur fertilizers, but in winter cropping areas of southern Australia the major factor for this rapid expansion of canola acreage is the advantages of canola as a rotation crop with wheat, Norton (2003). Australian research has shown that wheat sown after canola has a 20% boost in yield compared to wheat following wheat possibly due to allelophatic effects by residues from the canola deposited in the soil that inhibits growth of weeds in the following cereal crop. Factors responsible the recent contraction in canola area (see Figure 4) include the 2002-3 drought and improvements in wheat prices.

Australian experience with GM Cotton varieties.

The first commercial introductions of GM-cotton varieties occurred both in Australia and the USA in 1996 and was well prior to formal Australian parliamentary legislation (namely the Gene Technology Act 2000, and various subsequent Australian state (regional government) acts), that were introduced in the period 2003-2005 to regulate commercial dealings with GM crops.

The GM varieties planted in the 1996 Australian season were insect resistant cultivars containing a single bacterial insecticidal protein from *Bacillus thuringiensis* (namely Bt protein Cry1Ac) and the crop variety was marketed as Ingard ® by Monsanto Australia. At the time of Ingard ® introduction there was widespread concern in Australia, both within and outside the cotton industry, about the industry's heavy reliance on spraying with synthetic pesticides, and the environmental and health issues raised by recurrent emergence of insect pests such as *Helicoverpa armigera* or heliothis moth larvae displaying resistance to many of the synthetic pesticides then used in cotton cropping. At that time, the economic demise of the Australian cotton industry seemed entirely plausible, and the specter of damage to human health from synthetic pesticide spray drift and pesticide residuals in the environment loomed menacingly over the industry. In short the economic and political driving force for investigation of better production technologies was high.

The industry response to that challenge was the commercial introduction of Ingard ® cotton varieties by an approach that integrated pest management with scientific plant breeding. Moreover, research into the cellular and biochemical processes of insect adaptation to dietary toxins and in particular the larval midgut function has been performed by CSIRO to complement its molecular plant breeding approaches to combat emergence of resistance in the insects to the bacterial insecticidal protein (www.ento.csiro.au/research/gpg/heliothis.html). These complementary research approaches linked several organizations including CSIRO and the Cotton Cooperative Research Centre, and State Government departments, but a critical component was the commercial partnership between Monsanto Australia and the seed cooperative CSD to use time consuming conventional plant crossbreeding for introduction of the Cry1Ac Bt trait into commercially competitive, elite cotton varieties suited to Australian conditions. During the first season or two following introduction of the Ingard ® cotton varieties there was some overt grower criticism of that variety's apparent shortcomings in performance and value, but this ebullient learning period was fruitful because it was followed by later seasons where there was strong uptake of Ingard ® varieties as grower appreciation of their advantages became widespread.

The controversial nature of the genetically modified Bt trait within the scientific community was also beneficial. An intense scientific debate about the importance of good stewardship of Bt trait to prevent emergence of widespread insect resistance to Bt action preceded introduction of Ingard ®, Shelton et. al. (2002). This debate provided the stimulus whereby growers entered into agreements with the seed provider to limit the area planted on farms with Bt-cotton to less than 30% of their cotton crop area. The origin of this crop stewardship policy was from theoretical genetics concepts. The conceptual models of insect breeding behavior, Roush (1998) suggested that providing a non-Bt plant refuge for insect foraging without insecticidal selection pressure, would ensure an abundance of Bt sensitive mating partners (genotype SS) to mate any Bt resistant insects (which can be assumed to be RR-homozygotes in genotype) emerging from the Bt-trait crop. The progeny of these matings would be genotypically RS heterozygotes, and as resistance should be recessive to sensitivity, the progeny are predicted to have the phenotype of being sensitive to Bt toxin. Modeling studies indicate that such a "refuge"strategy should significantly slow emergence of cotton grower difficulties with insect pest resistance to Bt, Shelton et al. (2002), Roush (1998).

A second GM cotton trait was introduced in the 2000 season, namely glyphosate tolerant cotton (Round Up Ready ®). This crop was very rapidly accepted by growers, and within two seasons constituted more than 40% of all cotton sown in Australia, Crossan & Kennedy (2004). Agronomic studies confirmed, Crossan & Kennedy (2004) a significant benefit to growers from this variety of AUS$395 /hectare, net of technology fees. Additionally, glyphosate tolerant cotton has significant environmental benefits - it allows a shift from precautionary and possibly unnecessary usage of persistent pre-emergent herbicides, to judicious usage of post-emergent herbicides, and only if or when they are needed. Glyphosate is relatively non-toxic, has no herbicidal action once in the soil, is non-persistent, and unlike other herbicides, is bound to soil particles and does not leach into rivers and streams. Importantly, it helps promote the conservation benefits of minimum tillage farming, with greater buildup of soil carbon and nitrogen and reduction of soil erosion, Norton (2003), Crossan & Kennedy (2004).

The environmental benefits of Ingard ® Bt-cotton have also been significant. Sprayings of synthetic pesticides are reduced by about 50% and levels of endosulfan runoff in streams, for instance in the Namoi river, are lower by about 50% after introduction of Ingard, Roush (2004). Most recently, during the 2003/4 cotton season a doubly protected Bt-cotton variety, Bollgard II ® , has been introduced that contains both Cry1Ac and Cry2Ab proteins and has higher levels of protective protein in leaves and cotton squares. Because of the predicted environmental superiority of this variety, the older Ingard ® GM-variety was retired from the seed market.

Bollgard II passed successfully through a different regulatory procedure than the first GM cotton varieties, as new Australian Federal Government legislation enacted in 2000 come into force on 21st June 2001 to create a new legally formalized regulatory authority for GM organisms called *The Office of the Gene Technology Regulator* (OGTR, see www.ogtr.gov.au). It was OGTR that formally approved the Bollgard II varieties in September 2002, including the food use of cottonseed oil from Bollgard II. The OGTR process involves extensive consultation with different organizations such as the Environment Minister, the food regulatory authority Food Safety Australia New Zealand (FSANZ), and authorities regulating agricultural chemicals (see regulatory process outlined at www.ogtr.gov.au). Bollgard II was determined as being as safe for human health and the environment as existing crop varieties. After being approved by OGTR the Bollgard II varieties were enthusiastically adopted by growers, and there is little evidence of general public concerns about GM cotton or cotton products in Australia. In fact Australia's reputation as a Mega Biotech Crop Country (ISAAA Brief No 32-2004) is entirely due to the rapid uptake of GM-cotton.

The two stacked traits with different insect targets (Cry1Ac plus Cry2Ab) in Bollgard II ® provide extra assurance against the emergence of insect resistance to Bt insecticidal proteins, and a cap on GM-crop plantings (previously set at 30% for Ingard) is not imposed with Bollgard II. Non-cotton crops and plants are regarded as providing satisfactory refuges to generate abundant numbers of homozygous (SS) sensitive mating partners for any emerging resistant phenotypes. This new GM variety is giving additional reductions in total synthetic pesticide use beyond that obtained with Ingard ® varieties, firstly because less spraying is needed (reduced by 90% per hectare from conventional non-GM crop), and second, because greater areas of GM-insect protected crop can now be sown as sowing of Bt-cotton are no-longer capped at 30%. About 90% of the 1500 Australian cotton growers now plant GM-cotton seeds of one type or another, and there is no evidence of market resistance to GM cottons on global markets, ICAC (2004), and there currently exists in Australia strong commercial and investment confidence in the future of GM-cotton. Regulated field trials for elite varieties with improved versions of the glyphosate tolerant trait (Roundup Ready Flex ®, Roundup Ready /Bollgard II ® combined trait varieties) have recently been approved by the OGTR (April 2005, http://www.ogtr.gov.au/ir/dir055.htm).

Australian Experience with GM-canola.

The Australian canola seed industry's experience with new GM-crop varieties has taken a very different trajectory to the cotton seed sector. Two major companies have been involved in Australian GM-canola breeding, namely Bayer CropSciences and Monsanto Australia. Bayer has developed canola hybrids branded as Liberty-link ® , which are also glufosinate herbicide tolerant, and Monsanto Australia has developed Australian cultivars carrying the glyphosate tolerance trait (Roundup Ready ® canola).

The entry of both Liberty-link ® and RoundUp Ready ® canola varieties into the Australian grower markets occurred in the period 2001-2004 through a formalized safety review process under the management of the OGTR. This included a full review of environmental safety, weed management strategy, and food safety implications, together with public consultations to engage community opinion and get feedback on the regulatory judgments. These processes included systematic review of food safety data supplied to the OGTR by the seed companies, which was reviewed by FSANZ, together with intensive review of issues such as the potential for cross pollination with Brassica related weed species.

The OGTR also provided oversight of extensive field trails carried out by the companies to validate agronomic characteristics of the varieties. During these trials it emerged that significant unintended dispersal and flowering of GM canola plants took place at some of the sites for field trials used by the companies, including sites retired from use. These events were publicized extensively in newspapers and financial costs of the subsequent remedial measures were an unexpectedly large expense for the seed companies.

Banning of GM crops by regional Australian governments. By 2003-2004 both the Bayer hybrid and the Monsanto herbicide tolerant GM canola varieties were formally approved by the Federal Government regulator, OGTR, as being as safe for human health and the environment as existing commercial non-GM canola varieties. Surprisingly, this approval did not result in either of the seed varieties being commercialized, as shortly after they received Federal Government approval they were also made subject to other new legislation introduced by 6 State Governments (that is, the by regional participants in the Australian Federation) which all had concertedly introduced laws controlling commercial cropping of genetically modified crops by the end of 2004. These laws effectively ban commercial operations with GM canola (and other new GM crops) in Australia for an extended period, with some limited exceptions for research purpose only where seed does not enter Australian commodity markets. However, the new laws exempt the existing thriving GM cotton industry which development predated the State legislation. These bans were not introduced by Australian regional governments because of any stated concerns about safety of the GM canola, which had been settled by the OGTR review. They were introduced , it seems, out of concern for possible impact of GM canola on marketability of other agricultural products - namely dairy and wheat - that relies on Australia's “Green and Clean” image which, it was asserted, would be tarnished by GM-canola cropping.

In each Australian state the economically dominant sectors of agriculture are substantially different. The new commercial GM crop laws overtly reflect these differences. Tropical

Queensland, with a substantial cotton industry has no laws banning GM crops; partly tropical New South Wales with a very strong cotton industry and a countervailing politically powerful inner city environmentalist constituency has the shortest GM crop ban (moratorium), that is subject to review relatively soon in March 2006. New South Wales' politicians recognized the political power of cotton sector by excluding GM cotton from being subject to the GM-crop ban by the erroneous categorization of cotton as a non-food crop. Tasmania has a strong poppyseed industry that stands to gain from future introduction of GM poppies so also has ensured that this industry remains competitive giving special exemption to the poppy industry in it's GM ban which extends to 2009. The Victorian State Government positions its GM crop legislation as a precautionary measure to support to the strong dairy product export industry in that state. This has presumably been done to forestall any potential damage to cheese exports to Japan should anti-GM activists in Japan stage a food scare campaign to publicize conjectural hazards of GM canola drift into Australian dairy pastures, O'Neill (2004). However, the Victorian State Government has posed no restrictions on cattle feed derived from Australian GM cotton seed or imported GM soy and the animal feed industry is essentially self regulating

In short, the marketing perceptions of the currently regionally powerful agricultural export sectors have played a dominant role in regionally adapted policy decisions, and the economic competitiveness of Australian canola growers who face international competition that have access to the cost advantages of GM oilseeds, Norton (2003), Brooks & Aniol (2005), seems to have been heavily discounted. Another political factor at play is the strong dependence of regional Australian State Government’s on electoral support in inner-city electorates and the current lack of understanding of many urban voters of the essential requirement for agricultural innovations and their application in modern farming to ensure the future competitiveness of Australian agriculture.

Future opportunities and threats for Australian food oil commodities markets.

A number of studies on the impact of GM technologies in Australian agriculture have shown, Norton (2003) that failure to adopt GM canola technologies would cause decline in Australian economic competitiveness. With the complex raft of additional Australian GM crop legislation 2003-2005 and continuing announcements of technology changes enhancing the potential for competition for canola, especially from cottonseed and soybean oils, Australian canola seems to receive an even greater penalty. Thus it is now most likely, due to the timing of regional GM bans that ensure market obsolescence of existing elite GM canola cultivars before their possible commercial release, that Australian canola growers will be denied access to the GM crop cost advantages for the foreseeable future or till at least 2015. These cost advantages are currently available to Canadian canola growers in form of better yielding elite hybrid canolas, and GM canola has been grown commercially in Canada since 1995.

Another predictable market challenge to canola is entry in 2005 of vegetable oils derived from low linolenic acid soybeans, offering low trans-fatty acid content (www.qualisoy.com). These oils will be especially strong competitors once retail labeling of trans fatty acid content is made to be obligatory in the US in 2006. The increasing global market share dominance of soybean oils, in itself a magnet for further risk capital investment in further seed varieties, suggests that this is a threat that Australian oilseed industry cannot ignore. Australian canola also faces new oil commodity competition within Australia. New GM cottonseed oils having high oleic acid content, including those developed by Australia's CSIRO, will also eventually compete in trans-fatty acid sensitive markets. On the whole GM cottonseed oils is better armed to meet the challenge from low-linolenic soybean oils through investments flowing into technological innovation in cotton and lack of economic penalties posed by excessive regulations which block commercialization of GM canola in Australia at present.

In the longer term another predictable market shift that will erode Australian canola market share and future development will be expanded retailing of novel 'nutriceutical' vegetable oils – that is foods that make claims of improved health or medicinal benefits to the consumer. These form the third generation GM traits being engineered into crop plants such as canola and could include cottonseed oils that contain omega-3-related DHA. The wide scope in wealthy, environmentally conscious, aging industrialized societies for marketing campaigns based on promises of prevention of Alzheimer's disease and rheumatoid arthritis as well as promotion of cardiovascular health and intelligence coupled to the environmentally positive cachet of the rescuing of dwindling ocean fish stocks (currently the source of omega-3 dietary fats), is likely to justify attractive price premiums and create strong demand. The Australian canola industry is now effectively prevented from entering these markets, but not so the Canadian canola industry. The Australian cottonseed oil sector is, however, very well placed to enter this market.

Australian canola now suffers from very real risks to future investments that would, if no political blocks existed, fuel further expansion of the canola industry. Concurrently to the damage caused by apparent lost investment on GM canola in Australia, the barriers to successful biotechnology investment in competing oilseed commodities have been dropping. Obvious alternatives for any investor entering the Australian or international markets are the Australian cotton and cottonseed oil markets and Indian cotton seed market, both of which are currently attractive targets for investment in seed variety development. Soybeans are also an attractive target for investment in seed varieties that produce new oils because of their dominant global oilseeds market position and large markets for proprietary seed varieties. The soybean industry in Australia is comparatively small (see Table 1) and has focused on filling a niche domestic market as a source of non-GM soy attracting a premium price. Neither the soybean nor cottonseed industries have been penalized to the same extent as canola and this has already had the effect of shifting investments away from canola, to cotton within Australia for instance, and has the real possibly of shifting investments in oilseed breeding from canola to GM and non-GM soybeans. Overseas soybeans and soybean oils can be imported into Australia while avoiding economic penalties imposed on the local canola industry by the ban on further technological improvements using GM technologies.

2005: A Tipping Point for Australian and Global GM crop Markets?

There have been recent events that could reposition GM crop technologies in the environmental and health perceptions of Australian urban voters and radically change global commodity markets by extensive flow on effects. Penetration of biotechnology innovation into developing Asian economies is currently causing both substantial economic benefits, and tangible demonstration of particular advantages of GM crop technology to developing countries. Even putting aside the considerable beneficial human welfare results of such events, they are pertinent to the Australian farm sector because of their implications for future export markets. The economic findings from three (2001-2003) years of commercial experience with GM cotton in India are now becoming available, Qaim & Ziberman (2003), Foreign Agricultural Service USDA (2005), and they fully support the surprising conclusion that productivity improvements from Bt-cotton in India are significantly greater than in the other countries where Bt-cottons are used, but understandably so because of greater insect pest pressure in India. The most compelling statistic to emerge is a dramatic jump in average national cotton crop yields for the 2003 season to an estimated 39% above the ten-year average, which would seem to confirm somewhat controversial early suggestions made by Qaim and Zilberman about the 2001 season. This welcome economic success of GM cotton in India is now spurring a wave of further crop innovation in that country to introduce the Bt trait into numerous higher-yielding Indian cotton varieties - in fact attracting risk capital that might in different circumstances have gone to Australian canola. Increased availability of local GM cottonseed on the Indian markets alone will mean the extent of any market resistance to GM oilseed products by the major oil importing nation will be reduced.

We have also outlined previously the major export market penetration of GM cotton varieties and absence of market premiums for GM derived cottons in international trade, and can nominate cottonseed oil as at least one major global food commodity with minimal market entry barriers for future GM innovations that will create health enhancing oils to strongly compete in wealthier, health conscious world markets – i.e. the markets in which canola currently trades.

There are two other recent events that are also likely to have substantial flow-on effects that would affect the reception to GM food crops in Asian markets towards which Australian exporters are oriented. These may well represent the tipping point in global GM commodity trade, as they may substantially change the urban resistance in Westernized countries. In China, small-hold rice farmers in poorer households have been allowed to participate in trials of two new varieties of rice that are genetically modified to protect the crop against insect pests. Well designed studies published in the peer-reviewed literature, Huang et al. (2005), describe health outcomes, synthetic pesticide usage, and crop yields from these poorer farmer households, and compare them with a control group of farmers who used conventional rice varieties. The Chinese households who adopted GM rice benefited decisively from reduced use of pesticides, higher rice yields and improved health.

Another important report describes continuing progress in the creation of GM rice varieties (called Golden Rice 2) with a high content of pro-vitamin A that could benefit many millions of poor people in developing countries suffering from vitamin A deficiency, a tragically prevalent cause of blindness and immune dysfunction, Paine et al. (2005). As these scientific milestones add significantly to the prospect of expanded markets for GM food components such as cottonseed oils, soybean oils and GM canola, hopefully rice will join maize, Gressel et al. (2004), Minorsky (2000) , as the second major cereal grain staple in which GM technology has provided tangible health and welfare benefits to poorer communities. This would have decisive effects on the main markets to which Australia exports.

(Dr David Tribe is experienced in biochemistry, molecular biology, public health, management of GM crops, and commercialization of biotechnology. Dr Roger Kalla is a plant breeder, molecular biologist and agricultural scientist with experience in public policy. D.T. thanks Dr Luigi Tarenzi for facilities that enabled this manuscript's completion.)

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