AgBioForum, 17(1): 1-12. ©2014 AgBioForum.

Evaluation of the Agronomic, Environmental, Economic, and Coexistence Impacts Following the Introduction of GM Canola to Australia (2008-2010)

David Hudson
SGA Solutions Pty. Ltd., Australia

Rosemary Richards
Bowman, Richards, and Associates, Australia

Despite genetically modified (GM) canola receiving Australian regulatory approval in 2003, commercial production did not occur until 2008 due to concerns relating to coexistence. Following commercial release, a three-year study was initiated to assess adoption patterns; agronomic, economic, environmental, and coexistence impacts; and attitudinal changes of farmers growing GM and/or non-GM canola. The study's findings demonstrate substantial benefits from GM canola including more effective weed control, reduced pesticide use, reduced use of cultivation, improvement in yields, reduced risk of herbicide resistance, and a reduction in the environmental 'footprint.' The economic impacts have been variable due to the initial lack of access to GM canola varieties, the cost of access to the GM technology, and grain marketing/logistic issues. Concerns relating to coexistence failed to materialize with GM canola respondents and the issue of coexistence has not influenced farmers' choice in opting to grow GM canola or to increase the area of GM canola grown. The study demonstrates that the major barrier to adoption is the perceived lack of economic value derived from GM canola compared to the alternate non-GM weed-control management system options.

Key words: canola, coexistence, economic, environment, herbicide, resistance, weed control, environment impact quotient.

Introduction

Australia has experienced almost two decades of genetically-modified (GM) cotton production since the introduction of the first single Bt gene INGARD® varieties in 1995, with GM cotton now accounting for more than 95% of all cotton grown. The rapid adoption of GM cotton has been due to the farmer benefits, including improved productivity, economic return, and a greatly reduced environmental 'footprint' for the cotton industry.

Australian grain growers were the first to broadly adopt the use of an herbicide-tolerant weed-control system in canola following the release of canola varieties with tolerance to the triazine herbicides in 1993. By 2010 it was estimated that approximately 80-85% of Australia's canola crop was triazine-tolerant canola.

The rapid adoption of triazine-tolerant canola was in response to the agronomic and economic benefits derived from the reduced need for cultivation, more effective control of a broad range of grass and broadleaf weeds, and increased management flexibility. This continued despite a number of management challenges—including lower yield and oil content potential associated with triazine-tolerant canola—and the use of triazine herbicides that are a soil-residual herbicide, which have a higher risk of soil and groundwater contamination.

In 2003, an alternate herbicide-tolerant weed-control management system with conventionally bred tolerance to the imidazolinone group of herbicides (Clearfield® canola) was released. The imidazolinone-tolerant weed-control system and hybrid technology delivered both an alternate weed-control system and improvements in yield and oil content; however, its adoption was restricted due to the presence of Group B herbicide resistance in a range of weeds within the canola-growing regions of Australia.

These examples of Australian farmers demonstrating a strong propensity to adopt new technology contrasts with the situation for GM canola in Australia; despite the GM herbicide-tolerant Roundup Ready® and InVigor® varieties gaining approval in 2004 on human health, safety, and environmental grounds from the federal regulator, the Office of Gene Technology Regulator (OGTR), the first commercial plantings of canola did not occur until 2008. The delay in commercial release of GM canola was a result of moratoriums on growing GM canola that were imposed by state governments on the grounds of perceived uncertainties over the coexistence and management of GM and non-GM crops through the

Table 1. Distribution of survey participants 2008, 2009, and 2010.

	2008 survey participants				2009 survey participants (n)				2010 survey participants (n)			
	NSW	Victoria	Total	(%)	NSW	Victoria	Total	(%)	NSW	Victoria	Total	(%)
Non-GM canola farmers	198	103	301	78.5	175	102	277	61.5	211	179	390	76.2
GM canola farmers	40	42	82	21.5	50	124	174	38.5	33	89	122	23.8
Total canola farmers	238	145	383	100.0	225	226	451	100.0	244	268	512	100.0

Table 2. Area of canola planted by survey participants.

Area (ha) of canola planted by survey participants	2008 (ha)	2009 (ha)	2010 (ha)	Change in area planted (2008 vs. 2010) (ha)	(%)
Conventional canola	10,545	15,305	24,984	+ 14,439	+ 136.9
Triazine-tolerant canola	56,327	49,017	62,529	+ 6,202	+ 11.0
Imidazolinone-tolerant canola	16,854	27,449	44,012	+ 27,158	+ 161.1
GM canola	6,908	22,162	23,890	+ 16,982	+ 245.8
Total area of canola	**90,634**	**113,933**	**155,415**	**+ 64,781**	**+71.5**

supply chain and the potential economic impact through loss of market access and/or premiums for non-GM canola. In 2008, these moratoriums were lifted in New South Wales (NSW) and Victoria, followed by Western Australia in 2010. Moratoriums still exist in the canola-growing states of South Australia and Tasmania.

A study was commissioned in 2008 by the Birchip Cropping Group (BCG) and Grains Research and Development Corporation (GRDC) to assess the impacts of the first GM canola available to farmers in NSW and Victoria.

The purpose of this study was to assess at farm level i) the coexistence of GM and non-GM canola weed-control programs and farming systems and ii) the impact of GM canola within and between different farming operations that may or may not include non-GM canola.

The study tracked, over a three-year period (2008-2010), adoption patterns; agronomic, economic, and environmental impacts; and attitudinal changes in relation to the concerns relating to the coexistence of GM and non-GM canola production systems.

Methodology

An annual telephone survey of canola growers in NSW and Victoria comprised the use of open, closed, and partially closed questions to elicit both quantitative and qualitative information from survey participants.

The quantitative component of the study focused on the tangible on-farm impacts and differences between GM canola and non-GM canola weed-control programs. The qualitative component of the study focused on the attitudes, perceptions, and behavior of both GM and non-GM canola growers to utilizing GM canola in their crop rotations. The study also tracked attitudes toward adoption and issues relating to the coexistence of GM and non-GM production systems.

The survey tracked a series of attitudinal benchmark questions over the three canola-growing seasons. Where a quantification of farmer attitudes was required, a sliding scale (0 to 10) was applied to record respondent opinions. Where appropriate, survey participants' additional comments were recorded and collated.

Survey participants were randomly selected annually from farmers growing canola across the major grain-growing regions of NSW and Victoria (Table 1).

Results

Agronomic Impacts: Farmer Adoption

> ***Finding***: *GM canola increased its share of the area planted to canola over the study period, primarily at the expense of non-GM triazine-tolerant canola.*

The area of canola grown by survey participants increased during 2009 and 2010 relative to the area grown by respondents in 2008. Of the weed-control programs available, the area planted to triazine-tolerant canola maintained market-share dominance throughout the survey. Despite the overall increase in area planted, the relative increase in the area planted to each canola type varied significantly. While remaining the dominant canola type through the survey, the change in area planted between 2008 and 2010 for triazine-tolerant canola increased by only 11.0%, whereas all other canola types demonstrated significant increases in the

Table 3. Average area of canola planted to GM and non-GM canola.

Weed-control program[1]	2008 (ha)	2009 (ha)	2010 (ha)
Non-GM canola farmers (ha/year)			
Conventional canola	99.8	112.6	161.5
Triazine-tolerant canola	195.3	169.1	208.5
Imidazolinone-tolerant canola	185.4	161.6	188.1
GM canola farmers (ha/year)			
Conventional canola	169.1	134.3	336.8
Triazine-tolerant canola	289.6	196.1	470.5
Imidazolinone-tolerant canola	158.7	160.5	276.2
GM canola	93.4	156.1	199.5

[1] Farmers may have grown multiple canola types and provided multiple responses.

area planted and market share relative to that of triazine-tolerant canola (Table 2).

> ***Finding**: GM canola growers were more likely to increase their overall plantings of canola.*

The average area of each type of canola planted by individual respondents increased across the survey period, however respondents growing GM canola were more likely to increase the overall area planted to canola than those growing non-GM canola (Table 3).

Agronomic Impacts: Weed Control

> ***Finding**: Fewer weed-control programs were adopted in GM canola than in non-GM canola.*

The extensive range of herbicides available for weed control in GM and non-GM canola led to respondents nominating a diverse range of herbicide permutations and combinations within and between weed-control programs as well as within and between years.

Of the weed-control programs nominated, respondents growing GM canola nominated the least number of weed-control programs adopted within and between years. By contrast, respondents growing non-GM triazine-tolerant canola and imidazolinone-tolerant canola nominated a significantly greater range of weed-control programs (Table 4).

Table 4. Weed-control management programs nominated by respondents (2008-2010).

	Number of weed-control programs nominated		
Weed-control program	**2008**	**2009**	**2010**
Conventional canola	11	28	28
Triazine-tolerant canola	69	65	64
Imidazolinone-tolerant canola	28	57	56
GM canola	10	12	15

Table 5. Priority weeds for pre- and/or post-emergent control in canola.

	Non-GM canola respondents (%)			GM canola respondents (%)		
Target weeds	**2008**	**2008**	**2010**	**2008**	**2009**	**2010**
Annual ryegrass (*Lolium rigidum*)	74.6	82.1	94.5	82.2	92.7	98.8
Wild radish (*Raphanus raphanistrum*)	27.5	42.2	59.6	34.7	41.1	66.7
Wild oats/ Black oats (*Avena sp.*)	46.7	39.5	8.4	20.8	29.8	34.9
Capeweed (*Arcotheca calendula*)	24.3	33.6	23.8	28.7	23.2	17.3

> ***Finding:** Effective weed control was the most common reason why farmers planted GM canola.*

Effective weed control and control of priority weeds, such as herbicide-tolerant annual ryegrass and wild radish, were primary reasons why growers planted GM canola (Table 5).

During the survey, the majority of respondents (>85%) reported that the weed-control efficacy achieved within GM canola was either ‘better than’ or ‘about the same’ when compared side by side to that achieved in non-GM canola.

Agronomic Impacts: Crop Yield

> ***Finding**: GM canola yields were no different to that of non-GM canola.*

Across each of the three years, the average yield recorded by respondents increased for all canola types. Within and between years there was no significant difference in canola yields reported between GM and non-GM canola (Table 6).

Table 6. Average crop yields reported for GM and non-GM canola (2008-2010).

Canola type	Average crop yield (mt/ha) 2008	2009	2010	Average (mt/ha)
Conventional canola	0.94	1.52	2.06	1.51
Triazine-tolerant canola	0.95	1.21	1.92	1.36
Imidazolinone-tolerant canola	1.00	1.47	2.10	1.52
GM canola	0.99	1.61	1.90	1.50

In addition to the actual yield data reported, GM canola growers were asked—by way of observation—their assessment of the comparative yield of GM canola to that of non-GM canola where they were grown simultaneously within the year of observation. In 2010, the majority (76%) of respondents rated the yield from GM canola cultivars as being either 'better than' or 'the same as' the comparative non-GM canola when grown simultaneously within the year of observation. This compared to 66% in 2009 and 80% in 2008 of respondents rating the yield from GM canola cultivars as being either 'better than' or 'the same as' the comparative non-GM canola when grown simultaneously within the year of observation.

Agronomic Impacts: Crop Performance

> ***Finding**: Farmers were satisfied with their experience growing GM canola.*

Respondents were asked to comment on the impact of growing GM canola on their management practices. Respondents observed

- better weed control, in particular control of herbicide-resistant annual ryegrass;
- greater flexibility with
  - a management option to plant early rather than waiting to control weed germinations prior to planting; and
  - a management option to 'dry sow,' allowing more timely planting of other crops;
- early crop vigor following emergence, allowing
  - the crop to establish an early leaf canopy, which competes out weeds and reduces the potential need for multiple post-emergent herbicide applications, and
  - improvement of crop performance in drought conditions (i.e., 2008) due to early vigor in establishing root systems and leaves.

Overall, across the three years of the study the majority of respondents growing GM canola (>95%) were satisfied with their experience; however, the number of respondents not satisfied with GM canola ranged from 1.5% in 2008, to 3.9% in 2009 and 4.9% in 2010.

Respondents nominated a number of reasons as to why they would not be growing GM canola in the following year, including

- lack of access to marketing/delivery points,
- cost of access to the GM canola technology,
- poor experience in the previous year,
- lack of value delivered,
- lack of fit in rotation, and
- lack of suitable paddocks for the GM canola technology (i.e., either paddocks with heavy weed burden or the presence of herbicide-resistant annual ryegrass)

Agronomic Impacts: Herbicide Resistance

> ***Finding**: GM canola led to the reduction in the use of "high-risk" herbicides for the development of herbicide resistance in weeds.*

When compared to non-GM canola weed-control programs, respondents growing GM canola within and between years were significantly less likely to apply herbicide groups with high and medium risk of developing resistance in weeds, in particular high-risk Group A and Group B herbicides (Table 7).

Respondents were benchmarked across the three years of the study in relation to their attitude as to whether they believed GM canola would cause herbicide-resistance problems. Respondents growing GM canola were less supportive (i.e., disagree/neutral) of the statement than those who were growing non-GM canola (Table 8).

Environmental Impacts: Cultivation

> ***Finding**: GM canola growers were more likely to undertake conservation tillage practices.*

Overall, GM canola growers were more likely to use conservation tillage practices than non-GM canola growers, with GM canola growers demonstrating

Table 7. Average area of canola treated by herbicide groups (2008-2010).

Herbicide resistance risk category[1]	High risk				Moderate risk					
Herbicide group	**A**	**B**	**C**	**D**	**G**	**I**	**K**	**L**	**M[2]**	**M[3]**
i) Pre-emergent herbicides										
Conventional canola	5%	0%	0%	75%	3%	0%	9%	0%	0%	0%
Triazine-tolerant canola	1%	0%	51%	49%	2%	0%	2%	0%	0%	0%
Imidazolinone-tolerant canola	1%	3%	0%	60%	2%	0%	9%	0%	0%	0%
GM canola	0%	0%	0%	44%	1%	0%	4%	0%	0%	0%
ii) Post-emergent herbicides										
Conventional canola	70%	0%	0%	0%	0%	26%	0%	0%	0%	0%
Triazine-tolerant canola	37%	0%	59%	0%	0%	8%	0%	0%	0%	0%
Imidazolinone-tolerant canola	45%	62%	0%	0%	0%	14%	0%	0%	0%	0%
GM canola	5%	0%	0%	0%	0%	1%	0%	0%	56%	42%

[1] Source: GRDC & CropLife Australia (2008)
[2] One post-emergent, in-crop application of glyphosate
[3] Two post-emergent, in-crop applications of glyphosate

Table 8. Farmers' attitudes towards the development of herbicide resistance.

I believe GM canola will cause herbicide-resistance problems. (%)			
	2008	**2009**	**2010**
GM canola grower respondents			
Agree	12.3	30.6	49.2
Neutral	50.7	18.4	15.3
Disagree	37.0	51.0	35.5
Non-GM canola grower respondents			
Agree	39.4	69.0	68.7
Neutral	41.6	11.9	10.2
Disagree	19.0	19.1	21.1

Table 9. Survey respondents undertaking cultivation prior to planting.

Weed-control program	2008 (%)	2009 (%)	2010 (%)	Average (%)
Conventional canola	27.3	18.2	32.0	25.8
Triazine-tolerant canola	15.9	12.7	38.0	22.2
Imidazolinone-tolerant canola	15.7	13.9	36.0	21.9
GM canola	7.9	10.0	13.0	10.3

- a reduction (-29%) in the use of cultivation for weed control;
- an increase (+39%) in the use of low soil impact cultivation equipment for weed control;
- an increased (+5%) use of direct drilling equipment for crop establishment; and
- a reduction in the consumption of diesel fuel (-16%) and emissions of compounds such as carbon dioxide, carbon monoxide, and oxides of nitrogen.

During the study, the number of respondents undertaking cultivation increased due to the presence of early season rainfall events, which stimulated early weed germinations in 2009 and 2010. This led to an increased frequency in the use of cultivation for weed control prior to planting. Respondents growing non-GM canola were more likely to undertake cultivation prior to planting the crop than respondents growing GM canola (Table 9).

Of the respondents undertaking cultivation in 2009 and 2010, those growing GM canola were more likely to undertake fewer cultivations with 'low impact/low horsepower requirement' equipment such as cultivators, harrows, and seeding equipment, as compared to respondents growing non-GM canola, who were more likely to undertake multiple cultivations with 'high impact/high horsepower requirement' cultivation equipment such as chisel plows and scarifiers (Table 10).

Environmental Impacts: Herbicide Use

> ***Finding**: GM canola increased the use of environmentally benign herbicides and reduced the use of soil residual herbicides.*

Respondents growing either triazine-tolerant canola and/or imidazolinone-tolerant canola were more reliant on the use and application of both pre-emergent and

Table 10. Frequency in use of various cultivation implements for weed control (%).

Cultivation implement	Deep ripper plow	Chisel plow	Scarifier	Cultivator	Harrows	Offset discs	Planter / seeder
2009							
Conventional canola	7	15	22	15	7	19	15
Triazine-tolerant canola	0	5	34	27	7	12	15
Imidazolinone-tolerant canola	7	17	21	28	3	21	3
GM canola	0	16	5	11	16	0	53
2010							
Conventional canola	3	8	28	30	10	20	3
Triazine-tolerant canola	0	6	38	19	10	23	4
Imidazolinone-tolerant canola	2	6	26	34	10	16	6
GM canola	0	5	5	26	26	32	5

Table 11. Area treated with all herbicides and the area treated with soil residual herbicides only (average 2008-2010).

	All herbicides		Soil residual herbicide only	
Weed-control system	Pre-emergent herbicides (%)	Post-emergent herbicides (%)	Pre-emergent herbicides (%)	Post-emergent herbicides (%)
Conventional canola	82.4	75.6	76.9	25.9
Triazine-tolerant canola	84.7	81.3	80.2	62.4
Imidazolinone-tolerant canola	66.0	91.8	62.3	75.0
GM canola	45.3	98.7	44.5	1.3

Table 12. Farmer attitudes toward the use of herbicides in GM canola and non-GM canola.

I believe GM canola requires less herbicides. (%)			
	2008	2009	2010
GM canola respondents			
Agree	56.1	71.8	62.8
Neutral	40.2	12.8	14.9
Disagree	3.7	15.4	22.3
Non-GM canola respondents			
Agree	79.0	47.5	43.7
Neutral	19.8	16.3	18.3
Disagree	1.2	36.2	38.0

Table 13. Canola grower attitudes toward the adoption of GM canola and the use of environmentally safer herbicides.

GM canola allows me to use herbicides that are safer for the environment. (%)			
	2008	2009	2010
GM canola grower respondents			
Agree	79.0	71.6	76.0
Neutral	9.8	12.8	13.2
Disagree	11.2	15.5	10.7
Non-GM canola grower respondents			
Agree	44.0	47.8	56.0
Neutral	41.6	16.3	16.8
Disagree	14.1	29.2	27.2

post-emergent soil residual herbicides for weed control than respondents growing GM canola. Respondents growing conventional canola were more reliant on the use and application of pre-emergent soil residual herbicides than soil residual post-emergent herbicides (Table 11).

During the three years of the study, the majority of respondents growing GM canola and those growing non-GM canola were in agreement that GM canola required less herbicide use. Respondents growing GM canola were more supportive of the statement than those who were not growing it. However, there was a decline in support for this statement by both groups in 2009 and 2010, which reflects the increase in use of multiple glyphosate applications and the use of trifluralin in GM canola during these years (Table 12).

Across the study period, respondents participating were benchmarked in relation to their attitude as to whether they believed GM canola would allow them to use herbicides that are safer for the environment. The majority of respondents in each year of the survey growing GM canola (>71.6%) and those growing non-GM canola (>44.0%) were in agreement that it would allow them to use herbicides that are safer for the environment (Table 13).

There was an increasing trend to support this statement by respondents growing GM canola (+7.4%) and

Table 14. Savings in fuel use from the adoption of GM canola.

GM canola vs. non-GM canola		Fuel consumption (KLs) savings (-) / increase (+) 2008	2009	2010	Total
Spray applications	Conventional canola	+ 3.37	+ 0.33	+ 20.03	+ 23.73
	Triazine-tolerant canola	- 19.64	+ 4.61	- 14.61	- 29.64
	Clearfield® canola	+ 5.39	+ 6.14	+ 17.73	+ 29.25
	Subtotal	- 10.88	+ 11.07	+ 23.16	+23.34
Cultivations	Conventional canola	- 14.51	- 8.77	- 51.32	- 74.61
	Triazine-tolerant canola	- 12.42	- 5.13	- 34.82	- 52.38
	Clearfield® canola	- 8.33	- 14.72	- 67.94	- 90.99
	Subtotal	- 35.26	- 28.62	- 154.09	- 217.98
Total savings in fuel use (KLs)		- 46.13	- 17.55	- 130.92	- 194.64
Area of GM canola (ha)		6,908	22,163	24,983	54,054
Average savings in fuel use (lt/ha)		- 6.68	- 0.79	- 5.24	- 4.24

non-GM canola (+12%) across the period of the study. Overall, respondents growing GM canola were more supportive of the statement than non-GM canola growers.

Environmental Impacts: Fuel Consumption

> ***Finding***: *On average, GM canola growers demonstrated lower fuel consumption.*

Respondents adopting a GM canola weed-management system as a replacement for alternate non-GM weed-control programs generated savings in fuel consumption. The fuel consumption savings were a result of i) the lower number of total cultivations, ii) the use of lower soil impact cultivation equipment, and iii) reduction in the application of pre-emergent herbicides requiring lower horsepower to pull the equipment through the soil.

Although there were savings in fuel consumption as a result of adopting GM canola relative to the alternate weed-control programs, the savings accrued were tempered by the increased fuel consumed when growing GM canola as a result of i) the increased average number of post-emergent applications of glyphosate, ii) the increased use of cultivation, and iii) the increased application of trifluralin for per-emergent weed control (Table 14).

Environmental Impacts: Environmental Impact Quotient (EIQ)

Brookes and Barfoot (2010), in a review of the global environmental impact of biotech crops (1996-2008), utilized the Environmental Impact Quotient (EIQ)[1] as an additional indicator of the environmental 'footprint' of pesticides.

The EIQ indicator, developed by Kovach, Petzoldt, Degni, and Tette (1992) and updated annually by Cornell University, effectively integrates the various environmental impacts of individual pesticides into a single 'field value per hectare.'

Respondents applying atrazine, simazine, and trifluralin for pre-emergent weed control in triazine-tolerant canola consistently generated significantly higher field EIQ/ha values throughout the survey. Across the three years of the survey, the average field EIQ value generated by respondents growing triazine-tolerant canola was 35.94 EIQ/ha compared to 15.67 EIQ/ha in the alternate weed-control programs.

A similar trend was observed in the use of post-emergent herbicides, where respondents growing triazine-tolerant canola continued to generate significantly higher field EIQ values (average 37.01 EIQ/ha) as a result of their continued reliance on the use of atrazine and simazine as the primary herbicides for weed control when applied following the establishment of the canola crop. Despite this, respondents growing triazine-tolerant canola decreased across the three years of the survey, resulting in the lowering of the field EIQ values generated (-5.31 EIQ/ha).

As a result of the relatively high field EIQ values generated from the use and reliance on the triazine herbicides for pre- and post-emergent weed control, the overall average field EIQ value for the triazine-tolerant

1. *Readers should note that the EIQ is an indicator only and does not take into account all environmental issues and impacts; it is therefore not a comprehensive indicator.*

Table 15. Environmental "footprint" of weed-control programs (2008-2010).

	EIQ value/ha		
Weed-control programs	**2008**	**2009**	**2010**
Conventional canola	11.8	12.1	17.1
Triazine-tolerant canola	46.4	62.7	58.6
Imidazolinone-tolerant canola	10.0	12.7	12.2
GM canola	23.2	22.6	21.9

canola weed-control system (avg. 55.90 EIQ/ha) was significantly higher than that of conventional canola (avg. 13.67 EIQ/ ha), imidazolinone-tolerant canola (avg. 11.59 EIQ/ha), and GM canola (avg. 22.58 EIQ/ ha; Table 15).

The analysis demonstrates that there are similar EIQ values for conventional canola and imidazolinone-tolerant canola throughout the three years of the study. Further contributing to this similarity is the significant area of imidazolinone-tolerant canola, which receives a conventional canola herbicide-based weed-control management program in preference to the use of imidazolinone herbicides, which are recommended for use in the imidazolinone-tolerant canola weed-control programs.

The major difference between the EIQ values for GM canola and the non-GM imidazolinone-tolerant canola is the use of high per-gram-unit activity and low volume application of Group A, Group B, and Group I herbicides in imidazolinone-tolerant canola versus the lower gram-unit activity and higher volume application of glyphosate (Group M) and trifluralin (Group D) required for weed control in GM canola, particularly in 2009 and 2010.

Economic Impacts: Cost of Weed Control

> ***Finding***: *GM canola demonstrated higher average variable costs for weed control, due in part to the technology access cost.*

The variable cost of the GM and non-GM weed-control programs varied significantly across the three years of the survey due to a number of interacting factors including, but not limited to, the

- variance in opening season rainfall events,
- canola cultivar selected (i.e., +/- herbicide-tolerance trait),
- 'weediness' of the paddock being selected for the growing of canola,
- timing of the canola crop within the paddock crop rotation,
- rate and cost of herbicides to be applied, and
- cost for access to the GM canola technology.

Table 16. Average variable weed-control program costs (2008-2010).

Canola type	**Average variable cost (a)[1] (AUD$/ha) of weed-control programs**	**Range (AUD$/ha)**
GM canola	58.08	37.70 - 75.76
Imidazolinone-tolerant canola	46.16	9.81 - 93.06
Triazine-tolerant canola	38.70	9.25 - 93.06
Conventional canola	25.12	7.62 - 44.45

(a)[1]: Includes the cost of herbicides applied, the cost of herbicide application, and for GM canola the GM canola Technology Access Fee.

During the study period, the average variable cost of weed control in GM canola was consistently higher than that of the non-GM canola weed-control management programs (Table 16).

During the study period, the cost of the GM canola technology was a combination of i) a fee applied to the planting seed containing the GM canola technology and ii) an end-point royalty (EPR) on the volume of grain produced per hectare from the GM canola technology.

When compared to the alternate non-GM canola weed-control programs, the difference in the variable cost of weed control in GM canola was due in part to the

- imposition by of a technology access fee for the GM canola herbicide-tolerant technology, which is not applicable to alternate non-GM weed-control programs;
- increased use of the pre-emergent herbicide trifluralin for complimentary control of herbicide-resistant annual ryegrass; and
- greater use of multiple applications of glyphosate for in-crop post-emergent weed control, increasing from 16.1% in 2008 to 50.0% in 2010.

The relatively high comparative cost of the GM canola weed-control system led to the adoption of the technology being below the expectations of industry stakeholders and that which occurred in Canada. The negative impact of the cost of technology access on adoption of GM canola can be demonstrated in 2010, where, based on the variable cost of weed control for

GM canola (range: AUD$47.25/ha to $75.73/ha), the available market (i.e., area planted to canola) for the technology based on the variable cost alone was limited to approximately 40% of the total available canola weed-control market (range: AUD$9.72/ha to $75.73/ha).

Within this scenario, for those respondents who were considering adopting GM canola, the incentive to change from a current non-GM weed-control management system was primarily limited to the opportunity cost of effectively controlling herbicide-resistant annual ryegrass (*Lolium rigidum*) and wild radish (*Raphanus raphanistrum*) in GM canola relative to the cost effectiveness of controlling these weeds both within an alternate non-GM canola weed-control management system, or in alternate cereal and/or legume phases of the crop rotation.

This was exemplified in the higher priority that GM canola growers placed on controlling these herbicide-tolerant weeds relative to the priority placed on them for control in alternate non-GM weed-control programs.

Conversely, where weed-control programs are being considered solely on the cost of weed control, the GM canola weed-management system may be excluded in situations where there are either ‘easy to control’ weeds and/or weeds that are still to evolve herbicide resistance.

Across the survey period, all respondents were benchmarked in relation to their attitude as to whether they believed GM canola was a ‘value for money,’ where the definition for ‘value for money’ encompassed a range of tangible and intangible benefits/costs, rather than just the direct tangible economic measures such as yield, farm gate price, or cost of weed control.

Following the first year of introduction (2008), the majority of respondents growing GM canola were neutral as to whether it was a ‘value for money,’ while in 2009 the majority changed their attitude and agreed that it was a ‘value for money.’ This fell in 2010 but remained above the level of 2008.

For respondents who were growing non-GM canola, the majority in 2009 (56.8%) and 2010 (59.4%) were of the opinion that GM canola was not a value for money (Table 17).

Coexistence

> ***Finding***: *Coexistence concerns were not evident for GM canola growers also growing non-GM canola or with their neighbors and surrounding farming community.*

Table 17. Farmer attitudes as to whether GM canola provides “value for money.”

I believe GM canola technology is ‘value for money.’ (%)			
	2008	**2009**	**2010**
GM canola grower respondents			
Agree	30.5	50.9	41.0
Neutral	62.2	19.9	22.1
Disagree	7.3	29.2	36.9
Non-GM canola grower respondents			
Agree	22.9	22.4	20.2
Neutral	49.6	20.8	20.4
Disagree	27.5	56.8	59.4

The rapid global adoption of GM crops alongside organic, specialty, and conventional crop-production systems has resulted in much attention being given to the concept of coexistence. This increase in attention is due to the growing consumer and producer awareness of providing choice, alongside increased demand for traceability in the food supply, irrespective of the production system utilized.

The introduction of GM canola in Australia was based on a ‘Market Choice’ protocol (Australian Oilseeds Federation, 2007) developed by the industry. This protocol was instrumental in state governments removing their moratoriums. The aim of the protocol was to provide a platform on which the introduction of approved GM crops can be undertaken in such a manner that the consumers, farmers, and supply-chain stakeholders desire for maintaining choice and product integrity is delivered, and that GM and non-GM supply chains can efficiently and economically coexist.

Respondents growing GM canola and those growing non-GM canola were asked a series of attitudinal questions relating to different facets of the coexistence of GM canola and non-GM canola. In each year of the survey, the majority (70%-95%) of respondents growing GM canola reported that they were also growing non-GM canola. As a result, these respondents were also in a position to assess the potential impact of GM canola on the growing and marketing of their non-GM canola crops.

The research confirmed that government, industry, and grower concerns relating to the coexistence of GM and non-GM canola crops prior to its introduction have failed to materialize, with the majority (88%) of GM canola respondents indicating that they had not received any complaints related to their growing of GM canola. Of the complaints received, these primarily related to

Table 18. Non-GM farmer awareness of GM canola crops and impact on their farming operations.

Non-GM canola farmer question	Response	2008 (%)	2009 (%)	2010 (%)
Awareness of a GM canola crop in close proximity	Yes	44.5	47.7	32.1
	No	51.3	44.7	58.7
	Unsure	4.2	7.6	9.2
Proximity of a GM canola crop	Paddock next to your boundary fence	8.2	9.2	18.5
	Neighbor's farm other than boundary fence	20.1	21.0	28.0
	In the district	71.6	69.8	53.5
Impact on your farming operation because of a GM canola crop being grown in your area?	Concerned	5.1	5.7	7.6
	No impact	94.9	94.3	92.6

- people's predisposing beliefs (i.e., they did not support the growing of GM canola);
- concern about the impact on non-GM products (e.g., canola, honey, dairy); and
- the development of weed resistance to glyphosate.

Further in relation to the coexistence of GM canola and non-GM canola, respondents growing non-GM canola types were asked about their awareness of GM crops grown in proximity to their farming operations and the perceived and/or actual impacts.

Of the non-GM canola respondents who were aware of a GM canola crop being grown in close proximity, the majority indicated that it was in the district. Alongside the increasing adoption of GM canola during the study period, there was an increase in the number of non-GM canola growers being aware of a GM canola crop being grown by neighbors (Table 18).

Despite the increase in the area and proximity of GM canola being grown, consistently the overwhelming majority of non-GM canola respondents who were aware of a GM canola crop being either grown by a neighbor or by other farmers in the district indicated that the GM canola crops being grown did not have an impact on their farming/business operation.

As one indicator of potential coexistence issues between GM and non-GM farmers throughout the survey period, respondents were benchmarked on their attitude towards pollen flow. Respondents were asked about whether they believed GM canola has pollen flow problems (i.e., will cause cross contamination with neighboring crops; Table 19).

The majority (approximately 70%) of respondents growing GM canola did not believe there was a problem with pollen flow. By contrast, respondents growing non-GM canola were more divided in their attitude as to whether they believed pollen flow was a potential problem.

Table 19. Farmer attitudes as to whether Roundup Ready® canola has pollen-flow problems.

I believe GM canola has pollen flow problems. (%)			
	2008	**2009**	**2010**
GM canola grower respondents			
Agree	1.4	13.2	10.3
Neutral	26.0	14.1	18.1
Disagree	72.6	72.7	71.6
Non-GM canola grower respondents			
Agree	30.9	40.7	39.0
Neutral	43.8	21.7	29.6
Disagree	25.3	37.6	31.4

The issue of coexistence does not appear to be a major factor influencing grower behavior in terms of farmers living amicably with their neighbors or within the broader farming community. Nor has the issue of coexistence influenced farmers' choice in opting to grow, or not to grow, GM canola or whether to increase the area of GM canola grown, which is forecast to increase by current adopters and non-adopters. For example, the majority of respondents currently growing GM canola (83.7%) and almost half of non-GM canola growers (40.6%) indicated that they are 'somewhat likely or very likely' to grow it in the future.

Barriers to the Adoption of GM Canola and Future Planting Intentions

Despite the increase in the number of respondents growing GM canola and the average area planted to GM canola increasing, a number of barriers limiting the adoption of GM canola were identified during the survey period. The barriers identified and farmer attitudes toward the relative importance of these barriers during the survey included the following.

- Limited range of cultivars available with the glyphosate tolerance trait, together with the relatively narrow range of maturity types, significantly limited the grain-growing regions in which GM canola could be adopted (decreased from 36% in 2008 to 18% in 2010).
- Potential risks associated with the development of herbicide resistance in weeds (i.e., glyphosate) could result in its loss for pre-plant knockdown weed-control across the crop rotation (remained static at 15% between 2008 and 2010).
- Farmers prefer to observe the experience of other growers before adopting (decreased from 26% in 2008 to 5% in 2010).
- There was a lack of access to retail outlets that were approved to license and sell GM technology to farmers (decreased from 25% in 2008 to 4% in 2010).
- The glyphosate-tolerant technology in GM canola has a relatively 'high' cost of access (increased from 13% in 2008 to 20% in 2010 as a proportion of the variable weed-control cost).
- Improvements are needed in marketing options for grain produced from GM canola (increase from 30.5% in 2008, to 67.2% in 2010), including the need for
  - 'better access' to delivery sites (i.e., more delivery sites, shorter distance, and lower freight cost); and
  - a more competitive 'farm gate' pricing structure for GM grain relative to that offered for non-GM canola grain (i.e., AUD$10-$15/t higher price for non-GM grain during the study period).
- The philosophical views of some respondents, i.e., opposed to the use of GM crops decreased from 35% in 2008 to 4% in 2010.
- There is a lack of education and provision of information regarding GM crops to the community/consumer.

A number of these barriers either diminished in importance or disappeared over the period of the survey. For example, respondents sought increased access to a range of both open-pollinated and hybrid GM canola varieties with a range of maturity types. In response to this initial barrier, the number of GM canola varieties had increased from four varieties in 2008 to 10 varieties in 2010, thus opening market access in canola-growing areas within Victoria and NSW.

The majority of respondents growing GM canola (83.7%), together with almost half of the non-GM canola-grower respondents (40.6%) indicated that they are 'somewhat likely' or 'very likely' to grow GM canola in the future.

By contrast, the majority of respondents who were not growing GM canola in 2010 (57.0%) were 'not very likely' or 'not at all likely' to grow GM canola in the future. Of the respondents currently growing GM canola, a minority (14.8%) indicated that they would be 'not very or not at all likely' to grow it in the future.

The majority of 2010 GM canola growers (64%) with experience in growing GM canola for multiple years indicated that they would grow GM canola again in 2011. These same growers indicated that they would also increase the average area planted to GM canola in the future.

Summary

In summary, this study provided the opportunity to document the quantitative (agronomic, economic, and environmental) and qualitative impacts of GM technology for canola growers and related on-farm coexistence implications across the first three years of farmers growing GM canola in Australia. The analysis shows that there have been substantial agronomic and environmental benefits at the farm level, while economic outcomes have been variable due to i) the lack of access to GM canola varieties with a range of maturity types, ii) the cost of GM canola technology access, and iii) marketing/logistic issues associated with GM grain.

Over the three-year period, when compared to non-GM triazine-tolerant canola, which dominates the area planted to canola in Victoria and NSW, the introduction of GM herbicide-tolerant canola technology has resulted in more effective weed control, reduced pesticide use, reduced use of cultivation, improvement in yields, reduced risk of herbicide resistance development, and a reduction in the environmental 'footprint' associated with pesticide use.

The level of adoption of GM canola has been below stakeholder expectations when compared to the adoption after 10 years' release of GM canola (95% market share) in Canada and GM cotton (98% market share) in Australia. The study suggests that the agronomic and environmental benefits of GM canola, together with the absence of coexistence issues at the farm gate were the major factors which led to the adoption of GM canola.

In contrast, the study suggests that the major barrier to broad adoption is the perceived lack of economic value derived from the GM canola technology package (i.e., the cost of access + the cost of weed control + yield + farm gate grain price + logistic costs) when compared to the established economic value of the alternate non-GM weed-control management system options.

Despite this, the overall sentiment expressed by GM and non-GM growers participating in the study was positive and indicated that they would increase adoption of GM canola. The positive sentiment expressed possibly reflects respondents' recognition of the benefits of GM canola, including i) effective weed control, especially the increasingly prevalent weeds that have developed herbicide tolerance; ii) the positive environmental and agronomic impacts; and iii) the increased flexibility in management at critical times of the year. In addition, it may reflect the respondents' expectations that as adoption, and consequently production, of GM canola increases, current barriers such as the cost of access to the technology and marketing/logistical issues will be addressed.

References

Brookes, G., & Barfoot, P. (2010). Global impact of biotech crops: Environmental effects, 1996-2008. *AgBioForum*, *13*(1), 76-94. Available on the World Wide Web: http://www.agbioforum.org.

Grains Research and Development Corporation (GRDC) & CropLife Australia. (2008, November). *Herbicide resistance mode of action groups*. Barton, Australia: Author. Available on the World Wide Web: http://www.grdc.com.au/uploads/documents/GRDC_HerbicideCard.pdf.

Kovach, J., Petzoldt, C., Degni, J., & Tette, J. (1992). A method to measure the environmental impact of pesticides. New York's Food and Life Sciences Bulletin. Geneva, NY: NYS Agricultural Experiment Station, Cornell University.

Acknowledgements

This project has been assisted by the generous contributions of time from many individuals and funding from key organizations. In particular, we would like to thank the canola growers across New South Wales and Victoria who gave generously of their time to participate in the survey from 2008 to 2010. To Mr. Graham Brookes, we would like to express our gratitude for his review of the final report and robust commentary and advice on its content and direction. Finally, we would like to acknowledge the funding provided by the Grains Research and Development Corporation (GRDC) and the in-kind support and funding from the Birchip Cropping Group (BCG).