GM – Non-GM Crops Coexistence in Western Canada: Can it Work?

Rene C. Van Acker[1], Rene_Van_Acker@umanitoba.ca, Anita L. Brûlé-Babel[1], Lyle F. Friesen[1], Lyle_Friesen@umanitoba.ca, Martin H. Entz[1]
[1]Department of Plant Science, Faculty of Agricultural and Food Sciences, University of Manitoba, Winnipeg, MB, Canada, R3T 2N2.

Abstract
The pending approval of the unconfined release of Roundup Ready wheat in North America has brought to the attention of regulators and scientists in North America the issue of coexistence of genetically engineered (GM) and non-GM crops. In Canada, there has been great adoption by farmers of Roundup Ready and other GM canola varieties. At the time of commercial release of GM canola in Canada no specific GM, non-GM coexistence plans were considered or implemented. GM traits (transgenes) have since become ubiquitous in canola crops in Canada and this has led to some problems. For example, although Roundup Ready canola provides direct operational value to adopting farmers, controlling volunteer Roundup Ready canola in low disturbance direct seeding systems adds cost for farmers. The spread of the Roundup Ready trait in canola means that this added cost is borne by both adopters and non-adopters of the technology. The factors and conditions which led to the spread of the Roundup Ready transgene in canola in Canada appear to be similar for wheat if Roundup Ready wheat were to be released in Canada in the same way that Roundup Ready canola has been. To minimize potential negative impacts from movement of the gene conferring glyphosate (Roundup) tolerance among volunteer wheat populations after the release of Roundup Ready wheat, a coexistence plan must be created and implemented. The plan must be species and trait specific and based on knowledge of biology, ecology and agronomy. The plan must be made functional by legislation and regulation and must provide formal routes of recourse for non-adopters affected by transgene movement. Coexistence plans are progressive and will facilitate the introduction of new traits into crops both by GM and non-GM means.

Introduction

In Canada and the United States, approvals for the unconfined release of Roundup Ready spring wheat (*Triticum aestivum* L.) are pending. Roundup Ready wheat is modified through recombinant DNA technology to be herbicide-tolerant and is considered genetically engineered wheat (GM wheat). There has been some debate and controversy in North America surrounding the pending approval of Roundup Ready wheat. Proponents of this product suggest that it will simplify weed control in spring wheat, reduce herbicide injury to wheat, improve control of current herbicide-resistant weed biotypes, eliminate off-type wheat within a given wheat crop, and increase in-crop opportunities for the control or suppression of perennial weeds (Harker et al. 2003; Van Acker and Entz 2002). Those concerned about the unconfined release of Roundup Ready wheat suggest a number of risks associated with its release including difficulty and cost of controlling volunteer Roundup Ready wheat in low-disturbance direct seeding (no tillage prior to seeding) cropping systems, the evolution of glyphosate resistant weeds in glyphosate dependent cropping systems, the loss of farm saved seed for wheat (Ogg and Jackson 2001; Van Acker et al. 2003), and the adventitious presence of GM-wheat in non-GM wheat segregated for sale to satisfy domestic and export customers of North American wheat who are unwilling to purchase GM wheat (Rosher 2003). At the core of most of the concerns are questions about movement of the transgene conferring Roundup tolerance from GM to non-GM wheat crops and whether coexistence of Roundup Ready and non-Roundup Ready wheat is possible. In western Canada, Roundup Ready canola (*Brassica napus* L.) has been grown commercially for 8 years on large acreages. Experiences with Roundup Ready canola can be used as a valuable reference for consideration of possible intraspecific transgene movement in wheat and the creation of a functional coexistence plan for Roundup Ready and non-Roundup Ready wheat.

Intraspecific transgene movement in canola in western Canada

GM canola is very popular with western Canadian farmers. In 2003, 48% of the canola grown in western Canada (2.25 of approximately 4.7 million ha in 2003) was Roundup Ready, and since it's commercial release in 1996, more than 8 million ha of Roundup Ready canola have been grown by western Canadian farmers (M. Lawton, Monsanto Canada Inc, pers. comm.). Farmers value the operational benefits of this product citing simplicity and effective weed control as key values they capture by growing Roundup Ready canola.

At the time of unconfined commercial release of Roundup Ready canola in Canada, it was known that there was significant potential for out-crossing within the canola (*Brassica napus* L.) genome and that transgene movement from canola crop to canola crop would occur (Canadian Food Inspection Agency 1995). Work after the release and massive adoption of GM-canola in western Canada has shown that pollen mediated gene flow in canola can be an effective cause of transgene movement. Beckie et al. (2001) and Rieger et al. (2002) found that out-crossing in canola (*B. napus*) occurred to a distance of 800 and 2500 m, respectively. These studies helped in part to explain why Friesen et al. (2003) and Downey and Beckie (2002) found that a majority of the western Canadian grown pedigreed non-GM canola (*B. napus*) seedlots they tested contained genetically engineered herbicide tolerance traits. This adventitious presence of transgenes was not caused by pollen flow alone. Thirty-three percent of the seedlots (9 of 27) tested by Friesen et al. (2003), and 18% of the seedlots tested by Downey and Beckie (2002) (13 of 70) had the Roundup Ready transgene present at levels above 0.25%. Given current knowledge of pollen mediated gene flow in *B. napus*, it is unlikely that pollen flow would cause greater than 0.1% presence in a single generation of pedigreed seed production given strict seed production protocols. Adventitious presence levels above 0.25% were likely the result of inadvertent mechanical mixing of certified seedlots during harvest or handling, or contamination occurring in earlier generations of pedigreed seed production (i.e. Breeder or Foundation seed).

The general spread of transgenes among canola crops within a region such as western Canada is a function of canola biology and ecology and the environmental and agronomic conditions under which it is grown. The species' characteristics and agronomic conditions interact to create opportunities for genes to move from crop to crop. The characteristics and conditions which have combined to create effective transgene movement for the Roundup Ready trait in canola in western Canada include:

- A very large number of acres of Roundup Ready (2.25 million ha in 2003) and non-Roundup Ready canola (2.45 million ha in 2003) grown in fields across western Canada in a temporal and spatial randomly stratified fashion.
- The relatively high frequency of canola in crop rotations in western Canada (e.g. on average 1 in 4 years on any given field in Manitoba) (Thomas et al. 1999).
- The large volunteer canola population in fields in western Canada (Leeson et al. 2002 a,b; Thomas et al. 1996; Thomas et al. 1998 a,b; Gulden et al. 2003).
- Volunteer canola commonly survives to flowering at significant occurrence densities in a significant proportion of fields in western Canada (Leeson et al. 2002a,b; Thomas et al. 1996).
- In western Canada, glyphosate use is extensive and farmers who practice low-disturbance direct seeding use glyphosate every spring for pre-seeding weed control. Low-disturbance direct seeding is currently practiced on 25-30% of the annually cropped acres in western Canada, and that percentage is rising (Statistics Canada 2002). A tremendous selection pressure is created for the Roundup Ready trait in volunteer canola populations. In this situation Roundup Ready volunteer canola has a very large positive fitness advantage over non-Roundup Ready volunteer canola and, according to population genetics theory and experience with herbicide resistant weed populations, the frequency of the Roundup Ready trait will rise rapidly in the volunteer canola populations (Brûlé-Babel et al. 2003; Gealy et al. 2003; Jaseniuk et al. 1996).
- Volunteer canola can persist until, emerge in, and flower in subsequent canola crops (Simard et al. 2002; Légère et al. 2001; Leeson et al. 2002 a,b).

- Plant to plant out-crossing rates in canola are relatively high (Cuthbert and McVetty 2001).
- The current canola pedigreed seed production system was designed to maintain varietal purity standards related to performance and end-use function. The system was not designed to prevent gene flow at the level required to prevent problematic appearance of the Roundup Ready trait in non-Roundup Ready canola varieties.

Sometimes gene movement matters

The result of Roundup Ready transgene movement in western Canada is that essentially all volunteer canola populations in western Canada contain some proportion of Roundup Ready volunteers. This is true even if Roundup Ready canola cultivars have never been intentionally planted in a given field. Farmers now cannot be certain of the herbicide tolerance status of their volunteer canola population. When Roundup Ready volunteer canola is present in a field, pre-seeding weed control in low-disturbance direct seeding systems requires the addition of another herbicide as well as glyphosate, adding cost and complication in the crop rotation because of the pre-seeding residue left by some herbicides (Van Acker et al. 2003). Farmers who choose to grow Roundup Ready canola balance the added costs and complications against the measurable benefits they receive from this technology. However, because of the ubiquitous presence of the Roundup Ready trait in volunteer canola populations, the added costs and complications in rotation are also borne by farmers who choose not to grow Roundup Ready canola (non-adopters).

The impact of gene movement depends upon the crop. For example, controlling Roundup Ready wheat volunteers in a low-disturbance direct seeding system would cost more than controlling Roundup Ready canola volunteers (Harker et al. 2003; Van Acker et al. 2003). If the transgene conferring glyphosate tolerance became ubiquitous in volunteer wheat populations in a manner similar to what we have witnessed in canola, then the cost associated with low-disturbance direct seeding systems in western Canada would rise significantly. This would threaten the economic viability of these systems and in turn threaten Canadian farmers' ability to capture the environmental, resource conservation and economic value of low-disturbance direct seeding (McRae et al 2000). In this manner, a production economics issue related to the movement of one trait within a crop species can become an environmental issue.

The potential for damage resulting from gene movement also depends upon the gene (trait) that is moving (Gealy et al. 2003). Other novel herbicide tolerance traits in canola (glufosinate tolerance and imidazolinone tolerance in the Liberty Link and Clearfield canola systems, respectively) also move into conventional non-herbicide resistant canola varieties in western Canada (Hall et al. 2000). The movement of these traits does not create problems for non-adopting farmers in western Canada because they do not currently depend on glufosinate or imidazolinone herbicides for pre-seeding weed control to replace pre-seeding tillage in low-disturbance direct seeding systems. However, if there were a segregated market for GM and non-GM canola for Canadian farmers, then the movement of transgenes conferring either glufosinate or glyphosate tolerance would matter because these are both GM traits. It should be noted as well, that gene (trait) movement can be a problem whether or not the trait is considered GM. For example, if the Roundup Ready trait had been incorporated into wheat using conventional breeding means, the movement of this trait among volunteer wheat populations would still pose a threat to the economics of low-disturbance direct-seeding systems in western Canada because of the dependence of these systems on Roundup herbicide for inexpensive, non-selective, non-residual, pre-seeding weed control.

The potential for intraspecific transgene movement in wheat

Pollen movement in wheat is facilitated by wind and gravity. In wheat, anthers normally open within the floret, followed by filament elongation and extrusion of the anthers outside of the floret. A small amount of pollen is shed on the stigma within the floret, while 80% of the pollen is shed outside of the floret. Florets that have not been successfully self-pollinated will remain open and be receptive to pollen from other sources for up to 13 days after flowering (de Vries 1971). Estimates of out-crossing rates in wheat are dependent on synchrony of flowering between pollen donors (males) and pollen receptors (females), the presence of receptive females, and the availability of single dominant nuclear marker genes to facilitate detection of out-crossing. Waines and Hegde (2003) stated that "...there is enough evidence to show that cross-pollination [in wheat] regularly occurs and the reproductive biology of wheat is favourable to facilitate varying degrees of gene flow in a variety of situations."

The factors and conditions that facilitated movement of the Roundup Ready transgene in canola in western Canada appear to be similar for wheat. These include:

- A large number of acres of wheat grown in all agricultural regions of western Canada (up to 10 million ha annually).
- The relatively high frequency of wheat in crop rotations in western Canada (e.g. on average, 2 in 5 years in any given field in Manitoba) (Thomas et al. 1999).
- The high population levels of volunteer wheat in average fields in western Canada (Leeson et al. 2002 a,b; Thomas et al 1996).
- -Volunteer wheat commonly survives to flowering at significant occurrence densities in a significant proportion of fields in western Canada (Leeson et al. 2002a,b; Thomas et al. 1996).
- In low disturbance direct-seeding systems, Roundup Ready volunteer wheat would be selected for within the volunteer wheat population and, according to population genetics theory and experience with herbicide resistant weed populations (Jaseniuk et al. 1996), this would cause the glyphosate tolerance gene frequency to rapidly rise in the volunteer wheat population.
- Empirical evidence shows that in practice wheat is as persistent as canola both in terms of quantity (density) and frequency (% of fields) and it can persist to a measurable level for up to five years (Beckie et al. 2001).
- Volunteer wheat can persist until, emerge in, and flower in subsequent wheat crops (Beckie et al. 2001).
- Out-crossing rates in wheat are relatively high from plant to plant within a commercial crop (Brûlé-Babel et al. 2003; Hucl and Matus-Cádiz 2001; Waines and Hegde 2003).
- The current wheat pedigreed seed production system was designed to maintain varietal purity standards related to performance and end-use function. The system was not designed to prevent gene flow at levels required to prevent problematic appearance of the Roundup Ready trait in non-Roundup Ready varieties.

Coexistence planning for Roundup Ready wheat and non-Roundup Ready wheat

The appearance of the Roundup Ready trait in non-Roundup Ready pedigreed canola seedlots in Canada was arguably predictable (Warwick et al. 1999). In Canada, the experience with canola can be used as the basis for planning for Roundup Ready and non-Roundup Ready wheat coexistence. Currently, industry led stewardship plans are being proposed to prevent potential negative impacts resulting from transgene movement after the release of Roundup Ready wheat in western Canada. These plans are functionally problematic because industry has limited ability to demand, monitor, or enforce adherence to such plans. In the case of non-adopters, industry may have no ability to demand adherence to these plans. This is especially problematic for the containment of the Roundup Ready trait because prevention of transgene movement via pollen flow in wheat relies critically on management of receptor wheat crops (Waines and Hegde 2003), and in many (and perhaps most) cases receptor wheat crops will be grown by non-adopters of the Roundup Ready technology. To be effective, coexistence plans for Roundup Ready and non-Roundup Ready wheat need to have certain characteristics. The coexistence plan must:

- Be based on realistic, science-based, robust, tested models of transgene movement in wheat in western Canada.
- Specifically recognize that the Roundup Ready trait is particularly difficult to contain because glyphosate is used extensively for pre-seeding weed (and volunteer wheat) control in western

Canada and this gives Roundup Ready volunteers a selective advantage within volunteer wheat populations in western Canada.
- Represent the reality of the biology of pollen mediated gene flow in wheat with specific recognition of the fact that in the absence of genetic technology preventing pollen mediated gene flow, transgene flow has to be controlled at the receptor wheat crop. This poses a particular challenge for transgene containment when receptor crops are grown by non-adopters of the technology.
- Represent a realistic expectation of commitment from farmers to implement the plan given the reality of the vast acreages, the short cropping season in western Canada, and the almost total reliance of current cropping systems on herbicides for weed control.
- Incorporate a mechanism for dealing with non-compliance, and recognition of the jurisdiction and responsibilities of the various stakeholders. Issues of liability and compensation will also need to be addressed.
- Incorporate a mechanism for recourse for those affected by gene movement. With Roundup Ready canola in western Canada mitigation of gene movement impacts were *ad hoc* and left to the technology developer even though the technology developer was not bound by law or regulation to provide such mitigation.
- Be made functional and enforceable via regulation arising from legislation.
- Be regional and systemic. The experience with movement of the Roundup Ready trait in canola showed that in western Canada volunteer canola existed as a metapopulation with respect to the Roundup Ready transgene. Therefore, containment will require coexistence plan application and adherence throughout the entire cropping system and across the entire region of western Canada. Management for containment within a given field and for a given crop alone will be insufficient to achieve coexistence.

Conclusion

The need for coexistence plans and the stringency of a given plan is a function of the crop and the genes (trait). In some cases gene (trait) movement matters. Whether the movement matters is not necessarily a function of whether the trait is considered GM or not. For those traits for which movement matters, coexistence plans must be created which are based on biology, ecology, agronomy, and competitive advantage of the trait (selection pressure). These plans must be made functional and enforceable through regulation arising from legislation and they must include a formal route of recourse for those affected by gene movement. Effective and functional coexistence plans will protect choice for farmers and consumers. For GM and non-GM crops, or more generally, for crops which contain traits that must be contained, coexistence planning is progressive. It will facilitate the introduction of new traits in crops using either recombinant DNA (GM) or non-GM means.

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Views on GM differ across the world. Almost half of all crops grown in the US are GM , whereas widespread opposition in Europe means virtually no GM crops are grown there. In Canada, regulation is focused on the characteristics of the crop produced, while in the EU the focus is on how it has been modified . GM crops do not damage the environment by nature of their modification; GM is merely a technology, and it is the resulting product that we should be concerned about and regulate, just as we would any new product. There are outstanding plant scientists who work on GM in the UK, but the Scottish, Welsh and Northern Irish governments have declared their opposition to GM plants. Why is there such strong opposition in a country with great trust in scientists? Stewart Wells: Promoters of GM crops are continually saying that farmers can use fewer pesticides. But does it matter whether itÂ's the farmer who is applying pesticide and herbicide to the land, or whether it is the actual crop applying the pesticide to the land? In the first generation of Bt corn the entire corn plant is manufacturing the toxin and the residues are staying in the soil.Â It has been fairly widely adopted in Western Canada since it was introduced in 1996. Farmers saw it as a way to simplify production of canola, which had previously required herbicide and pesticide to be incorporated into the soil by tilling prior to planting. But having grown Roundup Ready canola I, like a lot of other people, am now having second thoughts about the long-term economics. Therefore, suitable coexistence measures can be put in place during cultivation, harvest, transport, storage and processing to ensure coexistence of GMOs with conventional and organic crops. Unintended presence of GMOs in conventional and organic crops - The objective of coexistence measures is to avoid unintended presence of GMOs in other products, preventing the potential economic loss and impact of the admixture of GM and non-GM crops. Consumer's choice - The choice of the consumers between genetically modified and non-genetically modified food is possible with a functioning traceability and labelling system, and an agricultural sector producing the different types of products.