GM Canola: The Canadian Experience

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This article examines the agronomic, economic and environmental impacts of genetically modified (GM) herbicide-resistant (HR) canola (*Brassica napus*) after 15 years of cultivation in Canada. The rapid adoption of GM canola is due to improved weed control, greater yields and higher economic returns. GM canola has reduced the environmental impact of herbicides compared with their non-HR crop counterparts. There are no marked changes in volunteer weed problems associated with GM canola, except in no-till systems when glyphosate was used alone to control volunteers. GM canola has not reduced weed species diversity. Moreover, GM canola has provided new in-crop herbicide modes of action and has been an important management tool for slowing weed resistance to high-risk herbicides. Reliance on GM crops in rotations using the same mode-of-action herbicide and/or multiple in-crop herbicide applications over time can result in intense selection pressure for weed resistance. With current favourable economic returns from growing canola, many farmers are shortening their GM canola rotations. To date, evolved glyphosate- or glufosinate-resistant weeds in GM canola in Canada has not yet occurred.

Genetically-modified herbicide-resistant (GM-HR) canola was introduced commercially in Canada in 1995. In 2009, Canada was among the top five countries producing GM crops (James 2009). Spring-planted canola occupies over 80% of the area cultivated to GM-HR crops. Most canola (99%) is grown in the Northern Great Plains (Prairie) region of western Canada. GM canola comprised nearly 90% of the 6.6 million ha grown in 2009 (Canola Council of Canada, personal communication; Statistics Canada 2009). In 2009, glyphosate (GLY)- and glufosinate (GLU)-resistant canola occupied 48 and 41% of land planted to canola, respectively (Figure 1). Non-GM imidazolinone (IMI)-resistant canola was planted on 10% of canola acreage, with only 1% planted to non-HR cultivars.

Adoption of GM-HR canola was driven primarily by easier and improved weed control and higher net returns (Devine & Buth 2001). Convenience in herbicide application to manage increasing farm size and concomitant time pressures is an important driver of HR canola adoption. Herbicides used in HR canola can be applied over a wide range of crop growth stages with little potential injury. HR canola has facilitated the adoption of conservation-tillage systems (and vice versa) by use of post-emergence-applied herbicides (eg GLY, GLU, IMI), rather than pre-emergence soil-incorporated herbicides commonly used in non-HR canola.

Improved Weed Control, Yields and Economic Returns

Before the introduction of HR canola cultivars, herbicide options were limited. Soil-applied herbicides, such as trifluralin or ethalfluralin, had activity on a restricted number of weed species. Efficacy was strongly influenced by soil and

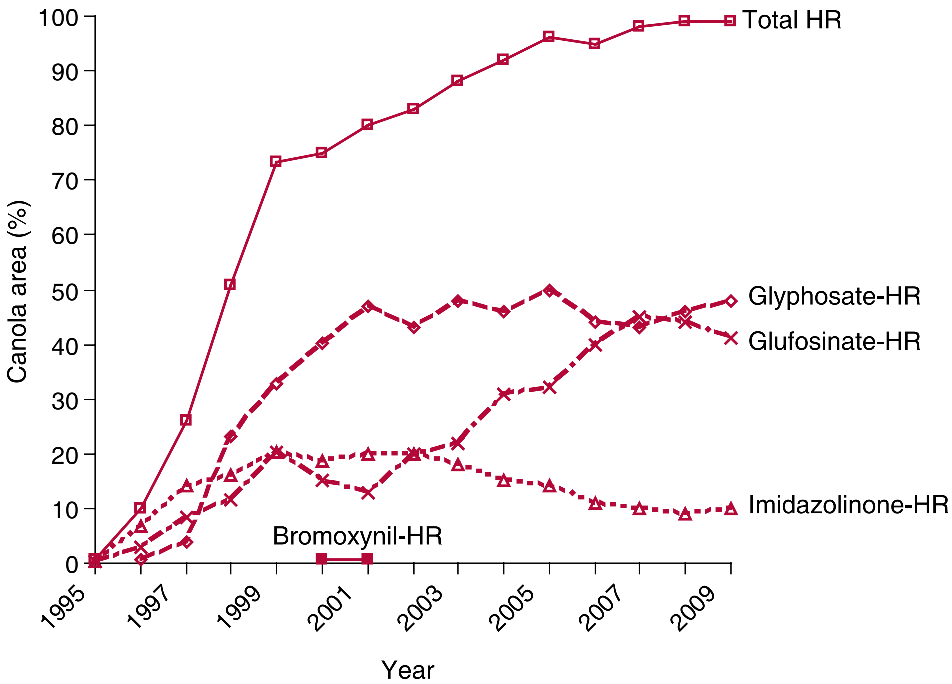

Figure 1: Adoption of GM herbicide-resistant (HR) canola (glyphosate, glufosinate, bromoxynil) and non-GM canola (imidazolinone) in Canada: 1995 to 2009.

Source: HJ Beckie.

environmental conditions, and was relatively low. Furthermore, soil residual activity resulted in some rotational restrictions on subsequent crops. These pre-emergence herbicides required soil incorporation, thus limiting adoption of no-till practices. Available post-emergence herbicides had activity on few broadleaf weed species. Overall, weed competition resulted in extensive yield loss in canola and farmers were careful to grow canola only in fields with low weed pressure. HR canola is often grown in weedy fields, as part of a strategy to reduce weed seed banks in subsequent years. HR canola allows farmers to manage many of their most difficult weeds (Devine & Buth 2001; Harker et al. 2000). Yields of GM canola are greater when treated with GLY or GLU than with herbicides typically used in non-HR canola, particularly where difficult-to-control weed populations were competing with the crop (Harker et al. 2000). The improved weed management associated with HR canola provides an opportunity to reduce herbicide use in succeeding crops (Harker & Clayton 2003).

GM canola has allowed farmers to plant earlier compared with a non-HR canola system using soil-incorporated herbicides. Greater yields of canola planted in early spring compared with mid-May are a result of better utilisation of moisture from snow melt and reduced temperature stress during the flowering period. Planting earlier than usual also disrupts normal patterns of weed emergence, thus aiding integrated weed management (Harker & Clayton 2003). Hybrid HR cultivars are becoming increasingly popular with farmers because of their yield performance. In 2010, HR hybrids constituted most of the canola market. Hybrid cultivars are often taller, more vigorous, establish a denser canopy, and are more weed-competitive than open-pollinated cultivars (Harker et al. 2003; Zand & Beckie 2002).

Net economic returns for farmers were higher for GM-HR than non-HR canola production (Koch Paul Associates 2000; Serecon Consulting Inc. & Koch Paul Associates 2001). Greater yields, less dockage (ie weed seeds by weight), improved

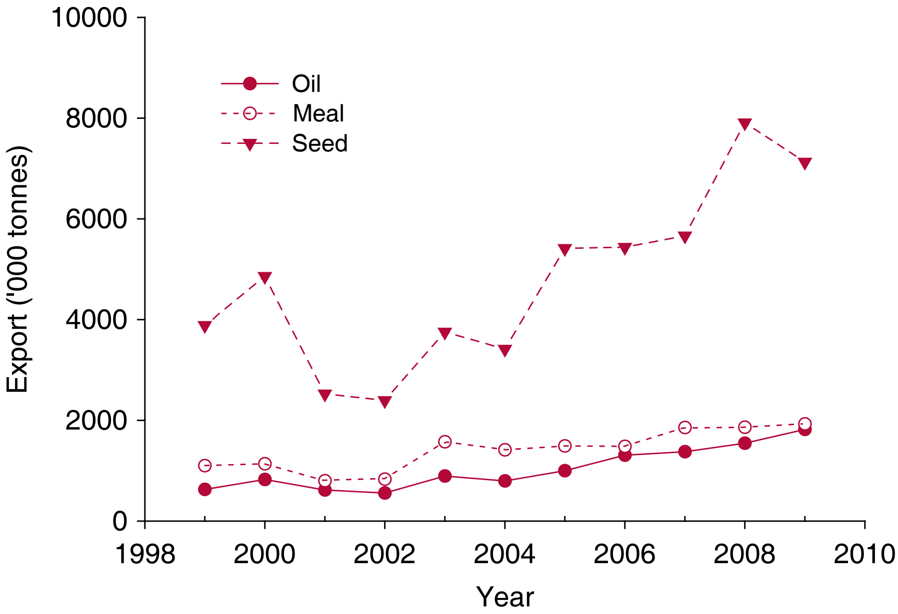

Figure 2: Canadian canola export from 1999 to 2009 for oil, meal and seed.

Source: Statistics Canada (2010).

seed quality, and reduced herbicide and tillage costs contributed to the improved net returns. O'Donovan et al. (2006) reported higher net returns for herbicide regimes in GLY-HR canola than those traditionally used in non-HR canola. The farm income benefit of GM-HR canola relative to non-HR canola from 1996 to 2004 in Canada has been estimated at US$617 million[1] (Brookes & Barfoot 2005).

Cultivation of GM canola has not restricted market access. Canadian canola exports of oil, meal and seed have not decreased as the percentage of GM-HR cultivars have increased (Figure 2; Statistics Canada 2010). Therefore, traditional markets for export have remained open.

Reduced Energy and Herbicide Use

GM-HR canola cultivation reduced fuel consumption by 31 million L (12.6 L ha^{-1}) in 2000, mainly because of fewer tillage and spraying operations, etc (Serecon Management Consulting Inc & Koch Paul Associates 2001). Reduced fuel usage in GM-HR vs. non-HR canola in Canada resulted in a reduction in carbon dioxide emissions of 94 million kg from 1996 to 2004 (Brookes & Barfoot 2005). In addition, a reduction in carbon dioxide emissions of 906 million kg during this period was attributed to soil carbon sequestration as a result of less tillage in GM-HR than non-HR canola in Canada. In 2000, herbicide use in GM-HR canola in Canada was reduced by 6000 t of product (ca. 40% reduction in total herbicide costs) compared with non-HR canola (Serecon Management Consulting Inc & Koch Paul Associates 2001). From 1996 to 2004, Brookes & Barfoot (2005) estimated that GM-HR canola resulted in a 20% reduction in environmental impact (EI) of herbicide use per hectare relative to non-HR canola. Leeson et al. (2006) found a similar reduction in EI of herbicide use per hectare from the 1990s to 2005 in HR compared with non-HR canola production systems in the Prairies. O'Donovan et al. (2006) confirmed that GLY-HR canola generally requires less herbicide active ingredient being applied to the environment compared with herbicide regimes traditionally used in non-HR canola.

1 Based on data from Serecon Management Consulting Inc. and Koch Paul Associates (2001), which determined a yield benefit of 10.7% and variable input cost savings of Cdn$39 ha^{-1} for HR vs. non-HR canola in all nine years.

Improved Management of Herbicide-Resistant Weeds

Non-selective herbicides used in GM canola in Canada have been a powerful tool to proactively and reactively manage HR weeds, such as those resistant to group A or B herbicides. As a result, the economic impact of these HR weeds has been diminished. However, frequent use of HR crops in cropping systems, resulting in recurrent application of herbicides with the same mode of action, may select for new HR weed biotypes or augment the selection that has occurred previously. The inexpensive cost of GLY relative to total variable costs of canola production and its lack of soil residual activity are disincentives for a reduction in herbicide-use intensity. With current favourable economic returns from growing canola, and as a means to combat weed resistance, many farmers are shortening their GM canola rotations (Beckie 2010). In western Canada, GLU is used primarily in GLU-HR canola and marginally as a desiccant in seed alfalfa (lucerne), lentil, and potato. The absence to date of reported cases of weed resistance to GLY or GLU in GM canola in Canada is attributed to diversification in HR traits in cultivated canola and rotational frequency of the crop (typically once every three to four years in rotation).

Gene Flow and Biodiversity

In canola, pollen-mediated gene flow can result in multiple-HR (ie gene-stacked) volunteers where cultivars with various HR traits are grown in proximity (Beckie et al. 2003; Hall et al. 2000). Two Canadian studies have documented GM adventitious presence (AP) levels in certified seed (Downey & Beckie 2002; Friesen et al. 2003). Breeders and seed companies are now monitoring seedlots for AP of GM-HR traits using commercially available test strips. Together, AP in pedigreed canola seedlots planted and pollen-mediated gene flow can result in large, unexpected populations of single- or multiple-HR canola, and canola volunteers in subsequent years. All volunteers, whether non-HR, single-HR, or multiple-HR, can be controlled equally well by herbicides with alternative modes of action, such as metribuzin, 2, 4-D, or MCPA (Beckie et al. 2004). Harker et al. (2006) showed that the vast majority of canola volunteers occur in the year immediately following canola; preventing volunteer canola seed production in that first year reduces volunteer densities in subsequent years below economic thresholds. There are over 30 registered herbicide treatments for control of single- or multiple-HR canola volunteers in cereals, the most frequent crop type to follow canola in a typical three- to four-year rotation. Herbicide use to control volunteer canola is similar across canola and tillage systems (Serecon Management Consulting Inc. 2005).

Three-quarters of farmers who grew GM-HR canola in 2000 indicated that management of canola volunteers was no more of a problem with GM-HR cultivars than with non-HR cultivars (Serecon Management Consulting Inc. & Koch Paul Associates 2001). Most canola farmers are now aware that volunteers may contain unexpected or multiple HR genes.

Studies conducted to investigate gene flow between GM canola and related crucifers found no evidence of gene flow into dog mustard (*Erucastrum gallicum*), wild radish (*Raphanus raphanistrum*), and wild mustard (*Sinapis arvensis* L.) (Warwick et al. 2003); however, herbicide resistance was transmitted to wild bird's rape (*Brassica rapa* L.), a closely-related species (Simard et al. 2006).

An important question surrounding GM crops, particularly in Europe, is the impact of such crops on weed diversity. Weed species diversity was assessed from field surveys conducted in western Canada in the 1990s (pre-GM-HR canola) and 2000s (post-GM-HR canola) (Beckie et al. 2006). Weed species diversity in non-HR wheat (not grown on canola stubble) in these two periods was used as a basis for comparison. Differences in weed communities before and after the adoption of HR canola were found to be similar to those observed in wheat, indicating that GM-HR canola has not reduced weed diversity. Harker et al. (2005) confirmed these observations; although three years of glyphosate-resistant wheat did cause weed population shifts at some sites, no differences in weed diversity were detected. In western Canada, very few agricultural weed species are native and none are rare or threatened, thus the impact of GM crops on weed diversity is not as important an issue as in the centers of origin of these species. The abundance of native weed species relative to that of all species has not changed between GM-HR and non-HR canola (Beckie et al. 2006).

Conclusions

While experience with HR canola in Canada provides ample evidence that widespread gene flow occurs, there have been few negative consequences relative to the increased economic benefit and decreased herbicide and energy use measured over the past decade. There have been no reductions in weed species diversity measures, no invasions of natural areas reported, and no increase in herbicide costs associated with management of volunteers. Moreover, glyphosate- and glufosinate-HR canola have provided new in-crop herbicide modes of action and have been an important management tool for slowing weed resistance to high-risk herbicides.

However, frequent use of HR crops in rotation combined with lack of herbicide mode-of-action diversity can increase selection of herbicide resistance, leading to increased herbicide use to control HR weed biotypes. Sound stewardship of these crops is based on their judicious use in cropping systems. History has repeatedly shown that simplified cropping systems with reliance on the same type of crop or same herbicide mode of action will favour a few dominant weed species and eventually weed resistance.

The future introduction of biotic and abiotic stress-tolerant crops (eg resistance to disease, drought, cold temperature, soil salinity, nitrogen deficiency in soils, and the stacking of these traits) will pose a much greater challenge for industry in meeting the regulatory requirements and regulators in ensuring environmental safety. Stress-tolerant crops, and any plant species that incorporate their novel traits, will potentially have a selective advantage in non-cropped areas whether or not herbicides are applied. Ensuring their non-invasiveness into natural areas will be a key requirement for regulators.

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