Environmental biosafety :
Consequences of the introduction of herbicide-resistant canola in Canada

Linda HALL (1)

[1]Research Scientist, Crop Diversification Division, Alberta Agriculture, Food and Rural Development/Agricultural, Food and Nutritional Science, University of Alberta, 410 Agriculture/Forestry, University of Alberta, Edmonton, T56G 2P5 (Linda Hall's CV)

Introduction

Canada has a unique and conservative regulatory system for plants with novel traits (PNTs). In Canada, plants are regulated on the basis of the traits expressed and not on the basis of the method used to introduce the traits. Therefore, PNTs may be produced by conventional breeding, mutagenesis or recombinant DNA techniques (Canadian Food Inspection Agency 2004). To evaluate the impact of PNTs, they are compared to current varieties on the basis of substantial equivalence of the following: potential of the PNT to become a weed of agriculture or be invasive of natural habitats; potential for gene-flow to wild relatives whose hybrid offspring may become more weedy or more invasive; potential for the PNT to become a plant pest; potential impact of the PNT or its gene products on non-target species, including humans; potential impact on biodiversity.

In 1995, herbicide-resistant (HR) PNT canola were released in Canada and today varieties resistant to glyphosate, imidazolinone and glufosinate herbicides occupy a 46, 25 and 20% the canola hectares, respectively. They have been widely adopted by growers and now constitute conventional agronomic practice. Seed from all types of canola seed are co-mingled and then marketed, primarily in the Canada, USA, and Japan.

Gene flow in HT canola

Gene flow, the movement of genetic information from one population to another, occurs via both pollen and seed in canola (reviewed in Légère 2005;Hall et al. 2005). While pollen movement occurs over relatively short distances and duration, seed may persist in the soil seed bank for many years and harvested seed is the medium for long distance transport. While gene flow is relatively easily measured, the consequences of gene flow are more difficult to assess.

Gene flow via pollen

Canola is partially self-fertile but outcrossing may occur to adjacent canola fields, to canola volunteers and possibly to weedy relatives. Gene flow between HR varieties allows gene stacking in the subsequent volunteers (Hall et al. 2000). In a careful conducted field scale study, Beckie et al. (2003) documented gene flow in 11 paired glyphosate/glufosinate resistant commercial fields. As expected, pollen mediated gene flow diminished with distance, from an average of 1.4% at the common border to 0.04% at 400 m. Volunteers with multiple herbicide-resistances were confirmed in following year at 800 m, the limit of the study area. While the presence of unexpected multiple HR volunteer canola have been widely reported, the economic and agronomic consequences of these volunteers has been minimal (discussed below).

A major concern prior to and following the release of HR canola was the potential hybridization with progenitors or weedy relatives and introgression of HR traits. If hybrids become resistant to herbicides, this may increasing weediness ("superweeds"). Successful introgression of traits is influenced by many factors, including the hybridization rate, fertility of the hybrids, proximity of plants, size of the pollen source and sink populations, location of the transgenes on the chromosome (positional effects) and many other factors. *B. rapa* is grown as a crop in Western Canada and weedy *B. rapa* occurs in Eastern Canada. In field trials and commercial fields hybridization to *B. rapa* average 7% to 14% (Warwick et al. 2003). Hybrids may have reduced fitness which may slow but is unlikely to prevent introgression of transgenes (reviewed in Légère 2005). In the same study, outcrossing of canola with *Raphanus raphanistrum*, *Erucastrum gallicum, Sinapis arvensis* was examined in commercial fields, and field and greenhouse experiments. When 32,821 potential *B. napus* x *R. raphanistrum* hybrids were screened, a single HR hybrid was produced. The hybrid had reduced pollen viability and did not set seed when self pollinated. No hybrids were detected in commercial fields when 22,114 seedlings were screened. No hybrids from *Erucastrum gallicum, Sinapis arvensis* were detected when 42,828 and 24,841 seedlings were screened, respectively. Under Canadian conditions, it seems probable a RH *B. rapa* will be reported, but hybrids with other species seem less likely. The consequences of HT *B. napus/B. rapa* hybrids are more difficult to assess. They may become a significant weed concern, or like HR canola, they may continue to be limited by alternative herbicides and management practices within cropping systems. In natural areas where non-selective herbicides are rarely used, they would have no selective advantage and other controls, such as competition, are expected to continue to limit populations.

Gene flow via seed

Seed is both the delivery system for transgenic technologies and conduit for gene flow that could influence agriculture on a world wide scale. Seed mediated gene flow can occur via seed co-mingling, as seed in the seed bank (see below) or by planting or re-planting of impure seed. More than 80% of Canadian producers use certified seed with established thresholds for adventitious presence, the unintended incidence of something other than the desired crop (Kershen and McHughen 2005). Seed purity has traditionally been assessed on visually traits and in Canada a maximum of 0.25% adventitious presence is permitted in certified canola seed. Friesen et al (2003) examined 27 purchased seed lots for the presence of inadvertent transgenes and 14 seed lots had >0.25% adventitious presence and 3 seed lots >2.0%. Inadvertent presence can occur though co-mingling, or via pollen mediated gene flow within seed production facilities. Presumably, farm saved seed that is not subject to restrictions on the distance between canola crops and the number of years between canola crops could contain higher levels of inadvertent transgenes. As genetic testing for seed purity becomes more common, commercially acceptable standards for seed purity are likely to change (Kershen and McHughen 2005).

Weediness of canola volunteers

Volunteer canola has been and continues to be an important agricultural weed in western Canada. Canola has significant dehiscence prior to and during harvest. (Gulden et al. 2003) Gulden *et al* 2003 examined harvest losses in 35 fields and seed losses averaged 107 kg ha^{-1} or 6% of crop yield (3,000 seeds m^{-2}). Seed losses varied widely, from 1,500 – 7,130 seeds m^{-2}. Canola seeds lack primary dormancy and inappropriate germination in fall can reduce the number of seeds in the seed bank (Gulden et al. 2004). However, secondary dormancy can be induced in canola, allowing seed to persist in the seed bank. Although only 1.5 – 2% seeds survive after one and two years, significant densities of canola volunteers are common. In Western Canadian researchers have conducted stratified random residual weed surveys over the prairies prior to and following the introduction of HR canola. In fields where they occur, canola densities average 4.5 - 5.3 plants m^{-2} averaged over several years in the western provinces (Leeson et al. 2005). While many volunteers are resistant to herbicides (glyphosate, imidazolinones or glufosinate), there is no evidence that volunteer density, frequency or relative abundance since the introduction of HR canola. Producers have modified herbicide prescriptions to control HR and conventional volunteers which are controlled equally by alterative herbicides (Beckie et al. 2004).

There is a concern that weed diversity may have been decreased following the introduction of HR canola. Weed diversity is difficult to associate with a single factor as it is influenced by tillage practices, herbicide usage, weather patterns and cropping patterns. To separate the influence HR canola and from confounding factors, Thomas *et al* 2004 used multivariate analysis to compare weed populations in HR and conventional canola (n = >550) and wheat n = >750) prior to and following the introduction of HR canola. Average weed densities and species richness were lower following the introduction of HR canola in both wheat and canola crops, with wheat showing the largest decline. Data indicates that weed communities were most effected by year, suggesting that abiotic factors and management practices effect diversity more than the introduction of HR canola.

Conclusion

HR canola has essentially replaced conventional canola in Western Canada for most growers. Although pollen and seed mediated gene flow have occurred, canola has not become more weedy in agricultural areas or invasive of nature areas. Wild relatives, especially *B. rapa*, have the potential to become herbicide resistant but it is not known if herbicide resistance will, in itself, increase weediness of hybrids. There are no data to indicate that weed biodiversity has been reduced by the introduction of HR canola.

There have been few negative environmental or agronomic consequences from the introduction of HR canola in Western Canada. These have been outweighed by the positive benefits to the environment, as discussed in other papers in this forum. The rapid and sustained adoption HR crops by producers suggests that they perceive significant net economic and agronomic benefit (Harker et al. 2000;Devine and Buth 2001).

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