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Comparative environmental impact assessment of herbicides used on genetically modified and non-genetically modified herbicide-tolerant canola crops using two risk indicators

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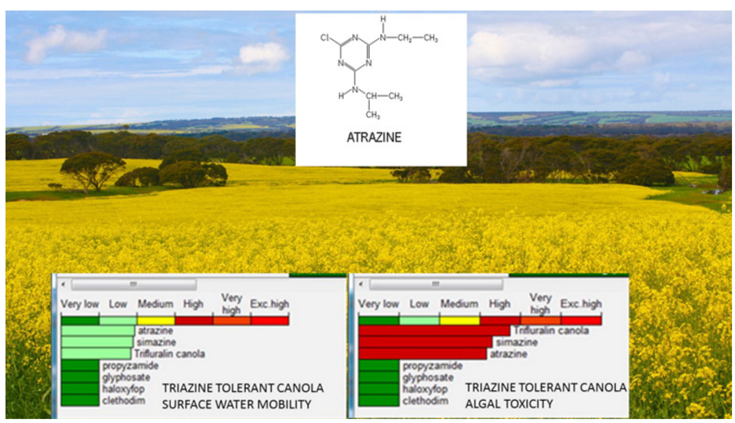
HIGHLIGHTS

- An assessment was made of herbicides used in non-GM and GM canola in Australia.
- Herbicides used in TT canola showed high relative mobility and ecotoxicity risk.
- EIQ field use rating for TT canola was 3x greater than that for other varieties.
- Based on mobility and toxicity GM and non-GM canola varieties had similar risk.
- The EIQ assessment tool does not consider toxicity to aquatic organisms.

GRAPHICAL ABSTRACT



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ABSTRACT

Canola (*Brassica napus* L.) is the third largest field crop in Australia by area sown. Genetically modified (GM) and non-GM canola varieties released or being developed in Australia include Clearfield® (imidazolinone tolerant), TT (triazine tolerant), InVigor® (glufosinate-ammonium tolerant), Roundup Ready® - RR® (glyphosate tolerant) and Hyola® RT® (tolerant to both glyphosate and triazine). We used two risk assessment approaches – the Environmental Impact Quotient (EIQ) and the Pesticide Impact Rating Index (PIRI) – to compare the environmental risks associated with herbicides used in the canola varieties (GM and non-GM) that are currently grown or may be grown in the future. Risk assessments found that from an environmental impact viewpoint a number of herbicides used in the production of TT canola showed high relative risk in terms of mobility and ecotoxicity of herbicides. The EIQ field use rating values for atrazine and simazine in particular were high compared with those for glyphosate and trifluralin. Imazapic and imazapyr, which are only used in Clearfield® canola, had extremely low EIQ field use rating values, likely reflecting the very low application rates used for these chemicals (0.02 to 0.04 kg/ha) compared with those used for atrazine and simazine (1.2 to 1.5 kg/ha). The PIRI assessment showed that irrespective of the canola variety grown, trifluralin posed a high toxicity risk to fish (Rainbow trout, *Oncorhynchus mykiss*), algae and *Daphnia* sp. While the replacement of trifluralin with propyzamide had little effect on the mobility score, it greatly decreased the ecotoxicity score to fish, algae and *Daphnia* sp. due to the

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lower LC50 values for propyzamide compared with trifluralin. This study has shown that based on likelihood of off-site transport of herbicides in surface water and potential toxicity to non-target organisms, the GM canola varieties have no advantage over non-herbicide tolerant (non HT) or Clearfield® canola.

1. Introduction

Canola (*Brassica napus* L.) comprises a significant portion of total annual economic yield from Australian agricultural commodities and is Australia's third largest field crop by area sown, behind wheat and barley. The area of canola harvested in Australia increased rapidly from approximately 400,000 ha in the mid-1990s to approximately 2,700,000 ha in the 2013–2014 year (ABARES, 2014). Most of the Australian crop is produced in Western Australia (WA) and New South Wales (NSW), with major plantings also in Victoria (Vic) and South Australia (SA). Canola is grown in all agricultural districts in southern Australia as an oil seed crop, providing diversification on farms. It is also used in agricultural rotations as a break crop in cereal and grain legume production to reduce the incidence and severity of both weeds and plant diseases. Also, isothiocyanates released from canola roots have been shown to suppress soil-borne pathogenic fungi such as *Gaeumannomyces graminis* var. *tritici* that causes Take-All disease in cereal crops. According to Fisher and Tozer (2009), the benefits of including canola in a farming system are to provide flexibility in controlling broadleaf weeds and cereal root diseases, combating the emergence of herbicide tolerant weeds, and increasing the yields of a following cereal crop.

Weed control is a significant concern for canola growers. Australian farmers grow two conventionally-bred herbicide tolerant (HT) varieties of canola: triazine tolerant (TT) canola (Beversdorf and Kott, 1987) and Clearfield® (imidazolinone tolerant) (Tan et al., 2005). The development of triazine tolerant (TT) canola has provided growers with a low cost and effective control of broadleaf weeds (Norton et al., 1999). Its introduction to Australia in 1993 allowed the rapid expansion of production areas, particularly in WA (Holtzapffel et al., 2008). Currently TT canola accounts for 50–60% of Australian production, although in some states, such as WA, this figure can exceed 80% (DAFWA, 2015; Pacific Seeds, 2015). However, the more frequent use of particular herbicides has increased the risk of emergence of resistant weeds (Holtzapffel et al., 2008). While Clearfield® has had a role in crop rotations, the increased resistance of weeds to particular classes of herbicides, including the imidazolinone herbicides, is a concern. Further, the over-reliance on these herbicides in other popular crops in winter cropping rotations, is expected to result in a decline in the production of Clearfield® canola (C. Preston, University of Adelaide, pers. comm.).

In recent years, genetically modified (GM) HT varieties of canola have been developed to provide farmers with other weed control options. Worldwide GM-HT crops have been rapidly adopted, the benefits and issues associated with their cultivation being reviewed elsewhere (Cerdeora and Duke, 2006; Duke, 2015; Green, 2012; James, 2014). InVigor® canola and Roundup Ready® (RR®) canola have been engineered to be tolerant to the herbicides glufosinate-ammonium and glyphosate, respectively. GM hybrids tolerant to both these herbicides have also been bred. In Australia RR® varieties are the only GM canola currently grown (ABCA, 2015; Weekly Times, 2014); InVigor® canola, although approved for cultivation in Australia, is not grown. Pioneer also propose the release in 2016 of another GM canola variety, Optimum™ GLY canola, that is glyphosate tolerant (OGTR, 2015). These GM canola varieties offer different options for weed control, allow earlier sowing and avoid inherent yield and oil penalties associated with TT canola. However, recently new dual HT canola hybrids, Hyola® RT®, which are tolerant to both triazine and glyphosate herbicides, have been developed by the conventional breeding of existing TT and GM RR® canola varieties. These hybrids are expected to offer growers the advantage of the broad spectrum knockdown control of glyphosate with the residual activity of the triazine herbicides (Pacific Seeds, 2015).

In Canada, the GM canola varieties LibertyLink® (equivalent to InVigor®) and RR® made up >90% of plantings in 2014 (Syan et al., 2014). In 2013, 220,401 ha of GM canola was planted in Australia, which was approximately 9% of the estimated 2.4 million ha total crop. However, in WA there has been greater uptake, with RR® varieties accounting for 19% of the total area sown to canola in 2014 (DAFWA, 2015). Hudson and Richards (2014) found GM HT canola offered the greatest economic advantage relative to TT canola, particularly where farmers are faced with weeds (e.g. annual ryegrass and wild radish) that are resistant to a number of non-glyphosate herbicides. However, at least in some circumstances, such as in years that are very wet, the resulting weed pressure is such that TT canola appears to be better suited to those conditions (Hudson and Richards, 2014). Hudson and Richards (2014) reported that, compared with Clearfield® and non HT canola, GM HT canola offered little yield gain and the cost savings associated with reduced herbicide costs have tended to be offset by the cost of the technology.

While the introduction of GM crops worldwide may offer numerous potential advantages for growers (Barfoot and Brookes, 2014; Beckie et al., 2006; Smyth et al., 2011), there have been concerns about various impacts of growing GM crops. With particular reference to GM HT crops, these concerns include the effects of the use of the associated herbicide on non-target organisms and the selection and spread (by over-use of the herbicide) of herbicide tolerant weeds.

The Environmental Impact Quotient (EIQ) is a commonly used risk indicator that has been previously used for an environment impact assessment of GM canola in Canada (Barfoot and Brookes, 2014; Levitan et al., 1995). In Australia an environmental risk assessment has been done using EIQ for various canola systems in NSW and WA (Holtzapffel et al., 2008) and in NSW and Vic (BCG and GRDC, 2014). The EIQ assessment however is limited by structural pitfalls, with one of the main criticisms being that a high dose of a less toxic chemical can receive a comparable EIQ to a highly toxic chemical used at a lower dose (Levitan et al., 1995). In this study we used two risk assessment approaches, namely the EIQ and the Pesticide Impact Rating Index (PIRI), to assess the impact on the environment, especially on water quality, of herbicide usage in canola varieties currently grown (non-GM and GM) and anticipated changes in herbicide usage that may arise from the introduction of GM HT canola (InVigor® and Hyola®-RT®) in Australia. This assessment was aimed solely at determining the potential environmental impact associated with off-site transport of selected herbicides likely to be used in the canola varieties studied.

2. Method of assessment

The estimation of off-site risks from a herbicide needs to integrate a range of parameters of the chemical, including water solubility or affinity to soil particles (organic matter, clay particles) and therefore mode of transport (either in soil solid or water phases), persistence in the environment and toxicity to a selected non-target organism. In this study two indices for assessing risk assessment, namely EIQ (Eshenaur et al., 2015; Kovach et al., 1992) and PIRI (Kookana et al., 2005) were compared.

2.1. Indices used in assessment

2.1.1. Environmental Impact Quotient (EIQ)

The EIQ scores the potential risk for a pesticide based on measures of toxicity and measures of potential exposure such as half-life, runoff or