Plant Biotechnology: Current and Potential Impact For Improving Pest Management In U.S. Agriculture An Analysis of 40 Case Studies

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Herbicide Tolerant Canola

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24. CANOLA

Herbicide Tolerant

Production

Canola is an edible type of rapeseed that was developed in the 1970's [17]. Rapeseed grown prior to that time had moderate levels of erucic acid, which was recognized to be harmful in laboratory rat tests (cholesterol elevation and reduced weight). Breeders in Canada developed rapeseed varieties with low erucic acid content [25]. In 1978, Varieties with less than 2 percent erucic acid were trademarked as "Canola." Canola varieties must also have less than 30 micromoles of glucosinolates per gram of oil-free meal. Glucosinolates will negatively affect the consumption of canola meal by animals, thus reducing its feeding value. Canola's amino acid distribution is very complementary to soybean meal and the two meals are often included in the same feed ration. Feeding studies have shown that animals perform better when fed a mixture of the two meals than when fed either alone [17]. Canola oil has been recognized as the healthiest oil available to consumers with low saturated and high monounsaturated fatty acids and a unique level of the omega3 fatty acid, alpha-linolenic acid. Canola oil is usually blended with other vegetable oils for the production of various solid and liquid cooking oils and salad dressings. Canola proteins are currently not being sold into the human food market.

Canola was grown on 1.3 million acres in North Dakota in 2000. Canola is ripe when plants turn a straw color and seeds become dark brown [17]. Canola is planted in early May in North Dakota and requires 80-95 days to reach maturity. North Dakota produced 1.6 billion pounds of canola seed in 2000 with a value of $108 million. North Dakota accounts for 81% of US canola production. Canola production in North Dakota grew rapidly following its introduction in the late 1980's from 16000 acres in 1992 to 1.3 million acres in 2000. Table 24.1 summarizes North Dakota canola production trends 1987-2000. Canola acreage increased by 49% in 2000 compared to 1999 (Table 24.1). The increase is partially attributable to the commercialization of herbicide tolerant transgenic canola in 1999 as well as the agronomic benefits of including canola in crop rotations.

Weed control

Since canola is a shallow-seeded crop, the use of a rotary hoe or harrow for weed control is discouraged. These tillage tools can injure or destroy canola seedlings [17]. Canola is a cool season crop that is most productive when seeded early in the spring from mid-April to mid-May. Broadleaf weeds and annual grasses that compete with canola germinate and emerge along with the canola seedlings. Although delayed seeding and/or tillage can reduce weed abundance; it is not a compatible practice in canola production because of canola's cool season growth requirements for optimum production. Canola is noncompetitive in the seedling stage but can later become very competitive. Therefore, early season weed control, until the crop canopy develops, is more important than in some other crops.

Weeds are the most limiting factor in canola production. Weeds affect canola in two ways. First, weeds reduce yield by competing for available resources. Uncontrolled weeds such as wild mustard have been reported to reduce canola yields ranging from 19 to 77% [2]. Second, weed seeds such as wild mustard reduce the quality by contaminating canola seed and pose problems in processing due to higher erucic acid and glucosinolate levels [3]. Weeds in the mustard family usually have high levels of erucic acid and glucosinolate.

Wild mustard is a serious contaminant in canola and can cause price discounts or rejection in the market. Wild mustard seeds are similar in shape to canola making them practically impossible to separate from canola seed using commercial cleaning processes [3]. Contamination of canola with wild mustard seed increases the level of erucic acid in the oils as well as the glucosinolate content of the remaining meal [2].

Common problem weeds in canola production in North Dakota include the broadleaf weeds wild mustard, Russian thistle, kochia, wild buckwheat, redroot pigweed, and lambsquarters while wild oat, quackgrass, and foxtail (green and yellow) species are the problem grasses [13]. Wild mustard and wild buckwheat predominate on at least 55 to 75% of canola acreage. Additionally, perennial weeds such as Canada thistle are a major

problem [9]. The number of acres infested with Canada thistle tripled from 1993 to 1997. This was due in part to above-normal rainfall received in four of the years 1993-1997 (Canada thistle is more competitive in years of higher growing season rainfall). Two Canada thistle plants per square foot reduce canola yields by 24%. Many fields in North Dakota have much higher Canada thistle populations than this. More than 60% of the canola acres in North Dakota are infested with Canada thistle [15].

100% of North Dakota's canola acreage is treated with herbicides annually [9]. Weed control in canola includes the use of the herbicides trifluralin, ethalfluralin, sethoxydim, and quizalofop [4]. While sethoxydim and quizalofop are strictly grass herbicides with no broadleaf activity, trifluralin controls annual grasses and some small seeded broadleaf species. However, trifluralin is not effective on wild mustard, wild buckwheat, wild oat, and smartweed. Ethalfluralin is similar to trifluralin, but more effective on certain weeds such as kochia and somewhat more expensive. The continuous use of trifluralin and sulfonylurea herbicides in cereals that precede canola in rotation have led to the development of resistant weed species. In North Dakota, dinitroaniline-resistant green foxtail and acetolactatesynthase-resistant kochia populations have increased in recent years [8].

Ethametsulfuron is the only herbicide that will selectively control weeds closely related to canola such as field pennycress, flixweed and wild mustard without significant crop injury [21]. Clopyralid is a broadleaf herbicide that has been granted emergency registration specifically to control perennial weeds such as Canada thistle and sowthistle. Of these herbicides, except for trifluralin and ethalfluralin, which are preplant incorporated, all the other herbicides are applied post-emergence. Table 24.2 shows weed control ratings for canola herbicides. Table 24.3 delineates canola herbicide usage in North Dakota in 2001.

Other challenges that threaten canola production include issues with herbicide carryover and herbicide-resistant weeds. Canola is sensitive to many herbicides used in the preceding rotational crops (cereals and soybean) such chlorsulfuron, imazethapyr and metribuzin [5] [6].

Herbicide Tolerant Canola

Two transgenic, herbicide tolerant canola systems were introduced in 1999, Roundup Ready and LibertyLink. Clearfield canola is resistant to the imidazolinone class of herbicides; however, it is not transgenic. Clearfield canola was developed through mutagenesis [7]. The advantage of Clearfield canola is that it facilitates the use of the broad-spectrum canola herbicide, imazamox, as well as permits the use of imidazolinone herbicides on other crops used in rotation without the fear of injuring canola. Thus, Clearfield varieties allow for expanded canola acreage in rotations including soybean, a crop in which imadazolinone herbicides are routinely used.

LibertyLink canola is resistant to the non-selective, non-residual, contact herbicide glufosinate. The gene that imparts resistance to the herbicide glufosinate was isolated from the bacteria *Streptomyces hygroscopicus*. This gene (*bar*) encodes for phosphinothricin acetyl transferase (PAT), an enzyme that catalyzes the metabolic inactivation of glufosinate by transferring acetyl groups. Glufosinate is effective against annual broadleaf and grass weeds and provides good suppression of perennial weeds.

Roundup Ready canola was launched in the US in 1999 while it was launched in Canada in 1996. Roundup Ready canola varieties were developed to be tolerant to the application of glyphosate (Roundup) [15].

The phytotoxic activity of glyphosate is due to its inhibitory effect on the enzyme, 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS), which is the key enzyme in the synthesis of aromatic amino acids. Roundup Ready canola carries a gene from a soil bacterium that codes for glyphosate-insensitive EPSPS as well as a GOX gene which metabolizes glyphosate. As a result, upon glyphosate treatment, Roundup Ready canola

plants remain unaffected as the enzyme continues to meet the plants' need for amino acids.

Glyphosate is a contact, non-selective (kills plants regardless of the species), non-residual (no soil activity after application) and systemic (translocated within the plant) herbicide. It is effective against both annual and perennial weeds. Glyphosate controls a broader spectrum of grass and broadleaf annual weeds than pre-emergent canola herbicides (see Table 24.2). Glyphosate provides excellent control of all weeds including wild oat and ALS-resistant kochia in canola [13]. In addition, Roundup Ready canola fits well in the Canada thistle management program as it provides a more economical option when multiple hard-to-control weeds are present in the field. Though clopyralid is an effective herbicide against Canada thistle, it is an expensive alternative. Roundup Ready technology facilitates the use of two applications of glyphosate on canola from emergence to 6-leaf-stage. The wide application window allows growers to use glyphosate on several flushes of weeds. However, canola growers in North Dakota routinely use only one well-timed glyphosate application for effective weed control, usually at two-to-four-leaf stage of canola [9] [11] [12]. A single application of glyphosate at .375 LbAI/A produced an average yield increase of 130 Lb/A (+6%) with an increased net return of $18/A (+12%) in comparison to a three-way treatment of trifluralin plus quizalofop and ethametsulfuron.

A study in North Dakota showed that Roundup Ready Canola varieties yielded more than conventional varieties at three out of four locations [16]. In addition, net returns were highest for the Roundup Ready system at three out of four locations in the same study. Research in North Dakota also suggested that transgenic varieties may offer yield advantage if there are high densities of weeds present that cannot be controlled by conventional herbicides such as trifluralin, ethalfluralin, or quizalofop, for example: Canada thistle, wild mustard, kochia, etc [9] [16]. Under these circumstances, yield increases up to 200-400 lb/A, compared to trifluralin/ethalfluralin have been noted [9].

An added benefit using glyphosate or glufosinate is the ability to preserve moisture at the soil surface and therefore promote a good seedbed for shallow seeding which is not possible with the weed control strategies using conventional preemergence herbicides. By eliminating pre-emergent herbicide use canola growers save time and soil moisture by eliminating tillage to incorporate the herbicide. Canola yields are higher because the crop is seeded earlier in the spring. With the Roundup Ready system there is no need to delay seeding for tillage or for activation of soil incorporated herbicides. The increasing popularity of transgenic canola in North Dakota is due to the "one pass" approach. Growers do not have to make multiple trips across fields for controlling weeds when they use transgenic canola.

Estimated Impacts

In 1999, the year of commercialization of transgenic varieties, Section 18 registrations for North Dakota were granted in March. As a result, farmers did not have enough time to buy the seed and thus only 25% of the canola acreage was planted to transgenic canola. There has been a tremendous increase in transgenic canola acreage in North Dakota since then to 50 and 70% of total acreage in 2000 and 2001, respectively [9][14]. Of the total transgenic canola acreage, it is estimated that 95% is planted with Roundup Ready and 5% with LibertyLink canola [14]. Less acreage planted to LibertyLink canola in North Dakota is attributed to the availability of few varieties, lack of varieties that have good harvestability, in addition to lack of growers' awareness of LibertyLink technology. Some LibertyLink varieties used in 2000 were susceptible to lodging and led to yield loss [9]. Currently, only four LibertyLink varieties are available in the market while twenty varieties are available for Roundup Ready [14]. It is projected that insertion of the *bar* gene in better canola varieties may increase the LibertyLink acreage in future years. Currently, only five percent of the total acreage is Clearfield. Clearfield canola is not as popular among growers as imazamox is not an effective herbicide for the control of ALS-resistant kochia [9] [14].

It is believed that the introduction of glyphosate tolerant canola was the major contributing factor to the significant increase in canola acreage in North Dakota

following its introduction in 1999 due to its efficacy in controlling troublesome weeds that had previously discouraged growers from expanding acreage. The major impact associated with the adoption of transgenic herbicide tolerant canola varieties in North Dakota has been a reduction in herbicide treatment costs. Table 24.4 delineates the per acre costs of a herbicide treatment program for conventional canola which includes the use of trifluralin and quizalofop and either clopyralid or ethametsulfuron. As can be seen, the average cost of the conventional program is $34.65/acre. In comparison, the per acre cost of the glyphosate program is estimated at $22/acre, including application cost, seed premium, and technology fee. Thus, it is estimated that North Dakota canola growers are saving $12.65/acre on the 871,000 acres planted with Roundup Ready canola producing total savings of $11.0 million per year. In addition, as can be seen in Table 24.4, the average application rate of herbicides in the conventional program is 1.11 LbAI/A while the Roundup Ready acreage is treated with an average of .50 LbAI/A (.38 LbAE/A) which represents a reduction of .61 LbAI/A or 531,000 pounds of herbicide active ingredients on Roundup Ready acreage. It is assumed that canola yields are similar in the two systems due to the efficacy ratings for the herbicides used in combination versus glyphosate (see Table 24.2).

A recent report analyzing the effects in Canada of widespread adoption of glyphosate tolerant canola reported that there was a yield increase of 10% with an increase in profit of $10.58/A (Canadian $) [18]. In Canada, the glyphosate tolerant varieties are planted on 55% of the nation's 12 million canola acres. The report estimated a reduction of 6,000 tons of herbicide use as a result of using the transgenic canola (1.8 Lb/A).

Table 24.1

Canola Production: North Dakota

Year	Acres (000)	Production (million Lbs.)	Value (000 $)
1987	0	0	---
1992	16	22	---
1997	376	427	---
1998	800	1147	117
1999	855	1085	81
2000	1270	1650	108

Source [1][10][23]

Table 24.2
Weed Control Ratings: Canola Herbicides: North Dakota

Weed Species	Triflur alin	Ethalf-luralin	Etha-metsu-lfuron	Clopy-ralid	Setho-xydim	Quiza-lofop	Glyp-hosate	Glufo-sinate	Imaz-amox
Wild Mustard	N	N	E	P	N	N	G-E	E	E
Russian Thistle	G	G-E	P	P-F	N	N	F-G	G-E	G-E
Kochia	F-G	G	P	N	N	N	F-E	E	E
Pigweed	E	E	P-F	P	N	N	G-E	E	E
Lambsquarters	G-E	E	P-F	P-F	N	N	G-E	F-G	F-G
Wild Oat	F	F	P	N	G-E	E	G-E	G-E	E
Quackgrass	N	N	N	N	F-G	G-E	E	P	G-E
Foxtail	E	E	N	N	E	E	E	E	E
Canada Thistle	N	N	N	G-E	N	N	G	P-F	N-P

N = None, P = Poor, F = Fair, G = Good, E = Excellent
Source [8]

Table 24.3 Herbicide usage in North Dakota for canola in 2001.

Trade name	Common name	% acres treated	lb ai/A
Treflan	Trifluralin	10	1.000
Sonalan	Ethalfluralin	15	1.000
Muster	Ethametsulfuron	8	0.014
Stinger	Clopyralid	10	0.090
Poast	Sethoxydim	10	0.190
Assure	Quizalofop	15	0.050
Roundup	Glyphosate	67	0.500
Liberty	Glufosinate	3	0.450
Raptor	Imazamox	5	0.031

Source: [9][22]

Table 24.4
Herbicide Cost Comparison: Canola, North Dakota

Conventional	**$/LbAI**		**LbAI/A**		**$/A**	
Trifluralin	8		1.0		8.00	
Quizalofop	148		.05		7.40	
Clopyralid or Ethametsulfuron	168[1]	533[2]	.09[1]	.014[2]	15.00[1]	7.50[2]
Totals			1.16	1.06	$30.40[1]	$22.90[2]
2 Applications @ $4.00/Application/A[3]					$8.00/A	
Total Conventional Cost					$38.40[1]	$30.90[2]
Avg. Total Conventional Cost					**$34.65**	
Glyphosate Tolerant						
Seed Premium					$3.00	
Technology Fee plus .50 Lb AI					$15.00	
Application Cost (1 application)					$4.00	
Total					**$22.00**	

Source [8][22][24]

[1] Clopyralid
[2] Ethametsulfuron
[3] One application of trifluralin followed by one application of postemergence herbicides.

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