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Farmer Knowledge and Risk Analysis: Postrelease Evaluation of Herbicide-Tolerant Canola in Western Canada

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The global controversy regarding the use of genetically modified (GM) crops has proved to be a challenge for "science-based" risk assessments. Although risk analysis incorporates societal perspectives in decision making over these crops, it is largely predicated on contrasts between "expert" and "lay" perspectives. The overall objective of this study is to explore the role for farmers' knowledge, and their decade-long experience with herbicide-tolerant (HT) canola, in the risk analysis of GM crops. From 2002 to 2003, data were collected using interviews ($n = 15$) and mail surveys ($n = 370$) with farmers from Manitoba and across Canada. The main benefits associated with HT canola were management oriented and included easier weed control, herbicide rotation, and better weed control, whereas the main risks were more diverse and included market harm, technology use agreements (TUAs), and increased seed costs. Benefits and risks were inversely related, and the salient factor influencing risk was farmer experiences with HT canola volunteers, followed by small farm size and duration using HT canola. These HT volunteers were reported by 38% of farmers, from both internal (e.g., seedbank, farm machinery, etc.) and external (e.g., wind, seed contamination, etc.) sources, and were found to persist over time. Farmer knowledge is a reliable and rich source of information regarding the efficacy of HT crops, demonstrating that individual experiences are important to risk perception. The socioeconomic nature of most risks combined with the continuing "farm income crisis" in North America demonstrates the need for a more holistic and inclusive approach to risk assessment associated with HT crops and, indeed, with all new agricultural technology.

KEY WORDS: Canola; farmer knowledge; genetically modified (GM); herbicide-tolerant (HT); risk analysis

1. INTRODUCTION[2]

Society is entrenched in a global "food fight" regarding the use of biotechnology in agriculture. Transgenic techniques, often referred to as genetic modification (GM) or genetic engineering (GE), are among the most contentious as they allow for the transfer of genes between species, resulting in genetically modified organisms (GMOs) that arguably have no biological antecedents.[(1)] The controversy over GM crops continues unabated, is comparable to that surrounding nuclear power,[(2)] and has the potential to profoundly alter the practice of risk assessment.[(3)]

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[2] See the Appendix for definitions of some terms used in this article.

Since their release in the mid 1990s, the planting of GM crops around the world has increased 60-fold, this from 1.7 million ha to 102 million ha.[(4)] The countries most committed to growing these crops are the United States (54.6 million ha), Argentina (18 million ha), Brazil (11.5 million ha), and Canada (6.1 million ha).[(4)] The main crops that have been transformed

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include soybeans, cotton, maize, and canola and, as a whole, approximately 70% of the planted GM crops are herbicide-tolerant (HT).[4] Regulators have approved these crops for environmental release, using a "science-based" risk assessment framework that deems them "substantially equivalent" to their non-GM counterparts.[5]

Risk assessment is regarded as an essential safety precaution prior to the release of GM crops. Its goal is to make a reasonable prerelease prediction of the behavior of a GM crop and to detect and avert potential problems.[6] While regulatory protocols vary somewhat around the world, GM risk assessment is generally conducted on a "case-by-case" basis that gauges the "possibility, probability, and consequences of harm."[5] This process is now becoming standardized, and scientific best practices and their ecological implications have been reviewed elsewhere.[7,8] However, GM crop risk assessment is still criticized as lacking an overarching conceptual framework, common informational requirements, regulatory harmonization,[9] and statistical rigor.[10] Moreover, the ostensible reliance of assessment on "substantial equivalence" has also been criticized for being "pseudoscientific,"[11] narrowing the scope of any considered risks,[12] and arguably favoring industry convenience at the expense of public safety.[13]

Some claim science-based risk assessments of these crops are expert-driven[14] and generally focus on "thin" harms (e.g., physical harms including mortality, morbidity, probability of deleterious genes escaping, etc.), whereas other potential "thick" harms (e.g., social disruption, economic losses, undermining of political and social institutions, etc.) are normally excluded.[15] The highly restrictive and science-based regulatory structure for GM crops effectively excludes nonexperts from any meaningful input.[16] That societal attitudes and concerns are deemed "irrational," "subjective," and "foolish"[17] and are therefore ignored, perpetuates the controversy.[18]

Risk analysis, in contrast, incorporates both "thick" and "thin" harms[19] within a broader social, cultural, economic, and political context, potentially mitigating the shortcomings of conventional risk assessment.[20] It has made a major contribution to the debate surrounding GM crops by evaluating and promoting the importance of perceptions and participation of stakeholders. A more inclusive approach to risk assessment is gaining acceptance,[21] although agreement on how this might be achieved remains a challenge.[22]

Importantly, much of the risk analysis literature is predicated on contrasts between "expert" and "lay" conceptions of risk,[23] and other forms of experience, indeed, expertise, are rarely considered.[24] Outcomes of risk analysis indicate that public perceptions of biotechnology are more complex than that of conventional experts.[25] One interpretation suggests that the public identifies closely with broad (i.e., "thick") views of risk, whereas experts are informed by data and statistics and, by comparison, have more conservative (i.e., "thin") risk conceptions.[17] Public views, however, demonstrate sophisticated capabilities in assessing risk,[26] and the "commonsense assumption" that experts have superior and more veridical risk judgment is increasingly questioned.[27] Studies focusing on public views of GM crops have generally focused on consumers.

Consumers in Europe, Japan, and North America often remain suspicious of GM technology, are concerned about negative environmental and health implications, and lack trust in food safety regulators and the risk assessment process as a whole.[17,28–30] A recent study suggests that consumers in Europe are relatively supportive of medical and industrial biotechnology, although they still ardently oppose GM foods.[31] In contrast, studies conducted in Mexico and the Philippines suggest consumers perceive greater agricultural and nutritional benefits from GM foods, but remain concerned about adverse effects on regional biodiversity.[32] These findings likely reflect the farmer-focus of the "first generation" of GM products, which, in turn, have few explicit benefits for consumers.[33]

Interestingly, these same farmers have yet to be meaningfully consulted regarding their attitudes toward and experiences with GM crops despite a decade of commercial use.[14] To date, most farmer-focused studies involving GM crops have primarily assessed economic benefits associated with canola in Canada,[34] soybeans and cotton in the United States,[35] cotton in Argentina,[36] and soybeans in Romania,[37] as well as both the economic benefits and risks of corn for growers and society in the United States.[38] This economic research, while important in its own right, does not fully characterize the diverse nature of farmer attitudes and experiences with GM crops.

Worldwide, only a handful of studies have explored farmer perceptions on the benefits and risks of biotechnology. Farmer attitudes regarding the potential introduction of GM crops in Australia[39] and New Zealand[40] indicated high levels of awareness and interest in the technology. Farmers in India indicated that economic benefits outweighed moral concern[41] while those from Central America were largely concerned about the contamination of traditional races of corn by transgenic maize.[42] Farmer experiences regarding this technology have yet to be fully studied for Canada, the United States, and Argentina as the first countries to commercialize GM crops, or are restricted to the benefits.[43] The role and potential contribution of farmer knowledge also has yet to be systematically evaluated for any GM crops and, indeed, risk research as a whole.

The overall objective of this study is to explore the role for farmers' knowledge in the risk analysis of GM crops. More specifically, we will:

- Evaluate risks represented by HT canola relative to other risks facing rural communities;
- Characterize the benefits and risks associated with HT canola;
- Identify what factors contribute to the risks and benefits associated with this technology; and
- Explore the role that this farmer knowledge might play in the risk analysis of HT crops and, more generally, agricultural technology.

2. MATERIALS AND METHODS

2.1. HT Crop Use

Canadian farmers rapidly adopted HT canola following its release in 1995. Three varieties of novel-trait HT canola have been introduced: Roundup Ready (RR), Liberty Link (LL), and Clearfield (CF), these tolerant to glyphosate, glufosinate, and imidazolinone herbicides, respectively.[44] At present, they represent 96% of the 5.25 million ha of canola grown in Canada; approximately 50% of this being RR, 32% being LL, and 14% being CF.[45] The great majority of these crops are grown in the western Canadian provinces of Manitoba, Saskatchewan, and Alberta.

2.2. Study Area

Interviews were conducted in the Canadian Prairies Ecozone, which includes the provinces of Alberta, Saskatchewan, and Manitoba (Fig. 1), and is characterized by a continental climate having short warm summers and long cold winters, with an annual mean temperature range from 1.5°C to 3.5°C.[46] Manitoba's annual mean temperature ranges from a mean maximum of 26.1°C in July to a mean minimum of −23.6°C in January.[46] Strong winds occur frequently in this province and summer precipitation occurs as heavy, localized storms. The mean annual precipitation is 504.4 mm; 404.4 mm falls as rain, which peaks in June, while 100 mm water equivalent of snow falls annually, peaking in January.[46] Over the last century, natural habitat has been largely cleared and replaced by agriculture, including the production of canola, wheat, barley, oats, and cattle.

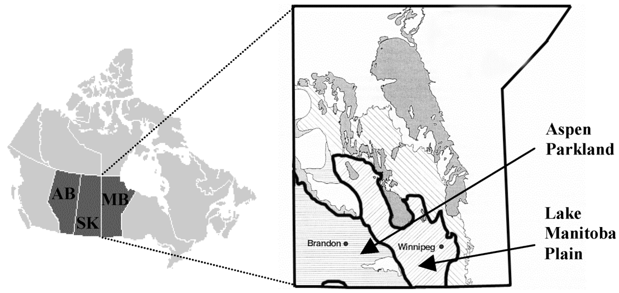

Fig. 1. Interviews were conducted across the Canadian prairies and questionnaires mailed to farms in Manitoba. Portrayed are the provinces of Alberta (AB), Saskatchewan (SK), and Manitoba (MB) (left) and the Aspen Parkland and Lake Manitoba Plain ecoregions in Manitoba (inset).

The survey portion of this study was situated in the two ecoregions, Lake Manitoba Plain (LMP) and Aspen Parkland (AP), which dominate southern Manitoba (Fig. 1). The average growing season for both ecoregions ranges from 173 to 187 days and both are dominated by Black Chernozemic soils. The LMP is generally recognized as having some of the most productive soils in Manitoba, largely due to fine-textured glaciolacustrine sediments that are especially suited to cereals, oilseeds, and pulses.[46] On average, canola is seeded on 1.0 million ha in the province.[47]

2.3. Data Collection

Our farmer-focused research on HT canola used a mixed methodology and was conducted in four iterative phases: (1) interviews with farmers across Canada; (2) development of a questionnaire that was mailed out and followed up with a nonresponse bias evaluation; (3) analysis and modeling of data using logistic regression and the information theoretic approach; and (4) incorporation of both qualitative responses and quantitative responses, thereby triangulating the results. The Joint-Faculty Human Subject Research Ethics Board Protocol at the University of Manitoba approved the study design (J2001:060).

Interviews with 15 farmers were conducted across western Canada between June and October 2002. We purposefully sampled these farmers to participate in an in-depth interview process and to explore attitudes and experiences with HT canola.[14] The qualitative data collected during these interviews also assisted in the development of a questionnaire, helping ensure that its content and wording were appropriate.

The 12-page questionnaire queried farmers on their experiences and attitudes regarding HT canola. In particular, we assessed concern regarding HT canola relative to other stressors that confront rural communities, specific benefits and risks associated with this technology, and factors that contribute to risk perception among farmers, especially those that had experience growing HT canola. The questionnaire used a seven-point "rank-ordered" Likert scale, ranging from "strongly disagree" to "strongly agree," and open-ended questions. Researchers associated with universities and industry as well as farmers reviewed the survey for comprehensiveness, technical accuracy, and impartiality.

Within each of the two ecoregions, rural municipalities (RMs) were equally divided into two classes (low or high abundance of volunteer canola), based on the 2001 Manitoba weed survey.[48] Farms were identified for each using mailing lists collected from Canada Post. In total, 5,762 farms were identified and questionnaires were sent as unaddressed "ad mail." This less-than-ideal use of ad mail was necessary as there is no comprehensive mailing list available for farmers in Manitoba. A modified version of the "tailored design method"[49] was used when mailing out the questionnaire. All recipients were mailed an introductory letter and questionnaire on March 17, 2003. Two follow-up reminders (including a postcard and subsequent letter) were sent, at two-week intervals, on March 31, 2003 and April 14, 2003, after the questionnaire was mailed in order to ensure the highest participation possible. Questionnaires were sent with self-addressed business reply envelopes, allowing it to be returned at no cost to the recipient.

In total, 425 farmers responded to the survey, representing an adjusted response rate of 25%. This was calculated by dividing completed questionnaires from eligible farmers ($n = 370$) by the total number of surveys sent to verified as farms growing oilseed crops ($n = 1{,}452$). Response rates for natural resource management surveys have been declining over time,[50] and are particularly low for rural research, as few farmers generally fill out surveys.[51] The large number of received surveys allowed for meaningful analysis and statistical inference.

We conducted a nonresponse bias telephone survey, using 12 questions that were selected from the original questionnaire. The RMs were randomly selected from those used in the mailout and in these, residents were randomly selected using rural telephone directories. Of 455 rural residents who were telephoned, 259 agreed to participate, of which 74 were eligible farmers. The main reasons for not filling out the survey, in order of importance, included ineligibility, getting ready for seeding, and simple refusal to fill out surveys of any kind. However, no differences in attitudes were identified between respondents and nonrespondents.

The great majority (97%) of respondents to our questionnaire were male; most (67%) were full-time farmers with an average of 28 years of farming experience. A large majority (85%) considered themselves knowledgeable about farming. The education background of respondents varied, although many (48%) had postsecondary training, this slightly higher than the Manitoba average (34%).[52] Average farm size was 575 ha, again somewhat higher than the average for a Manitoba canola grower (409 ha).[53] Minimum tillage was practiced by 51% of respondents, this similar to the provincial average (45.5%).[54] The large majority (78%) of farmers grew HT canola, including RR (47%), LL (22%), CF (13%), and various combinations of these (15%), which are also reflected by national data.[45]

2.4. Data Analyses

The perceptions of all farmers ($n = 370$) toward overall risks facing rural communities were summarized using mean, standard error (SE), and Cronbach's alpha.[55] HT farmers' attitudes toward 10 benefit and 10 risk items were assessed using the same approach and the internal consistency of both benefit and risk scales was assessed. Cronbach's alpha values were high, ranging from 0.88 to 0.91, and well above the 0.70 standard for multivariate variable reduction.[55] Correspondence analysis (CA),[56] a multivariate ordination technique for analyzing complex data sets, was used to determine how HT canola growers ($n = 298$) viewed these benefits and risks. This ordination technique uses a chi-squared distance measure to standardize the relationship between rows (i.e., farmers) and columns (i.e., responses) and summarizes the relationship in a biplot. This variable reduction allowed us to characterize the risk perception of individual farmers as a single CA score along a benefit/risk gradient.

Akaike's information criterion (AIC)[57] was used to model the independent variables that contributed to individual farmer perceptions regarding

HT canola risks and benefits. The 298 HT canola surveys were sorted into high-, medium-, and low-risk perception based on CA scores. The CA scores for high ($n = 100$) and low ($n = 100$) categories were then used as a binary response variable in logistic regression[58] to determine the contributing factors that put farmers at risk.

A set of candidate models of risk was generated using explanatory (i.e., independent) variables arising from farm and demographic data from the survey, these generated using the literature and *a priori* hypotheses. Multicollinearity among the eight independent variables was evaluated using Spearman rank correlations and all variables were found to be independent. All possible combinations of explanatory variables were explored for a total of $2^8 = 256$ risk models. A global model was developed that included all eight variables and a set of alternate models that included subsets of these variables and their interaction terms. The use of the information theoretic approach allows for modeling complex data on HT crops and, unlike null hypothesis testing, allows one to rigorously evaluate multiple predictors in combination.[59]

Models were evaluated and the most parsimonious were selected using AIC difference with small sample bias adjustment (ΔAIC_c) and Akaike weights (w).[60] Support exists for candidate models with $\Delta AIC_c < 4$, although the best model equals zero. We then calculated the cumulative AIC_c weights for each explanatory variable by summing the AIC_c weights of every model containing that variable.[57] Variables with the highest AIC_c weights contributed most to high-risk perception. This AIC-based approach allows models to be ranked, weighted, and compared using an empirical assessment of relative support for each competing hypothesis.[59] All statistical analyses were performed using SAS.[61]

Emerging themes were identified from the qualitative interview and survey data using content analysis.[62] Qualitative data were independently categorized and later reconciled by both researchers until we had a detailed impression of the emerging narratives. Memos were used to document important comments, assisting in the development of codes, and ultimately produced analytical benefit and risk categories that emerged from the farmer statements.[62] These data were robust and emerging themes matched the quantitative findings. Reflecting our mixed methodological approach, the outcomes of the quantitative and qualitative analyses were combined to triangulate and further verify interpretation of these results.

Table I. Farmer Perceptions Toward General Risks Facing Rural Communities in Order of Importance ($n = 370$)

Rank	Item	Mean	*SE*	Cronbach's Alpha
1	Input costs	6.72	0.04	0.65
2	Cost of machinery	6.67	0.04	0.65
3	Commodity prices	6.60	0.05	0.67
4	Lack of urban understanding	6.13	0.06	0.68
5	Excessive moisture	5.54	0.07	0.68
6	Drought	5.29	0.08	0.67
7	Natural disasters	5.29	0.07	0.65
8	Toxic chemicals	5.15	0.08	0.67
9	HT crops	5.08	0.09	0.70
10	Farm accidents	4.65	0.08	0.67

3. RESULTS

3.1. Overall Risks Facing Rural Communities

Farmers ($n = 370$) generally perceived the threat of HT crops to be low relative to other economic and environmental risks facing rural communities (Table I). The main economic risks included input costs (e.g., fertilizer, herbicides, etc.), machinery costs, and commodity prices. The main environmental risks included excessive moisture, drought, and natural disasters (Table I). Although respondents ranked HT crops 9th out of the 10 risks, they still "moderately agreed" that HT crops were risky (mean = 5.1, $SE = 0.09$).

3.2. Benefits Associated with HT Crops

Benefits associated with HT crops were assessed for users of the technology ($n = 298$). The main benefits were operational and when ranked in descending order of importance according to mean included easier weed control, herbicide rotation, better weed control, and reduced dockage (i.e., chaff and other foreign material) (Table II).

One interviewee indicated the relative ease of using the technology:

> *You get a much more even growth in the crops because of the effect of the herbicide plus it's also a better killer of weeds, it's a lower cost, it's much easier for farmers to handle, when you think about the dockage . . .* (Alberta farmer, interview)

The majority (77%) of farmers were pleased with the overall performance of their HT canola and, when compared to a conventional non-HT equivalent, almost half (47%) believed that it was more profitable. Yet only some (21%) thought the HT canola yielded better.

Table II. Herbicide-Tolerant (HT) Canola Farmer Perceptions and Experiences Regarding the Benefits and Risks of this Technology in Order of Importance ($n = 298$)

Rank	Item	Mean	*SE*[a]	Alpha[b]
Benefits				
B1	Easier weed control	5.47	0.08	0.88
B2	Herbicide rotation	5.37	0.08	0.88
B3	Better weed control	5.28	0.08	0.88
B4	Reduced dockage[c]	4.97	0.09	0.88
B5	Reduced need for tillage	4.66	0.09	0.89
B6	Higher yields	4.49	0.10	0.89
B7	Simpler pest management	4.39	0.09	0.89
B8	Less time required	4.36	0.10	0.88
B9	Environment	4.23	0.10	0.88
B10	Increased revenue	4.17	0.09	0.88
Risks				
R1	Loss of markets	5.87	0.08	0.91
R2	TUA[d] restricting rights	5.56	0.10	0.91
R3	Increased seed cost	5.36	0.08	0.91
R4	Lawsuits	5.20	0.10	0.91
R5	HT[e] volunteers	5.08	0.09	0.91
R6	Gene spread	5.07	0.09	0.91
R7	Herbicide resistant weeds	5.02	0.09	0.91
R8	RR[f] crops & tillage	4.98	0.10	0.91
R9	Seed saving	4.88	0.10	0.91
R10	Damage to nontarget species	3.67	0.09	0.91

[a]SE = standard error;
[b]Alpha = Cronbach's coefficient alpha;
[c]Dockage = chaff and other foreign materials;
[d]TUA = technology use agreement;
[e]HT = herbicide tolerant;
[f]RR = Roundup Ready.

One survey respondent commented on a number of other benefits:

> *there are many more positive aspects to GM crops ... 1) ability to remove weeds earlier than with conventional herbicide programs; 2) far greater crop safety with GM crops vs. conventional herbicides; and 3) farm more acres with GM crops—less time per acre spent cultivating, incorporating herbicides, less time scouting and choosing tank mixes, more consistent yields with less risk of weed problems*. (Survey 196)

Farmers disagreed with some other purported benefits. The majority (67%) disagreed that HT crops were protecting "small farm heritage," and most (58%) disagreed that HT crops were "the answer to feeding the world's hungry." Many (39%) farmers also rejected the notion that HT crops made "Canadian agriculture more competitive."

3.3. Risks Associated with HT Crops

Risk associated with HT crops was also assessed for technology users ($n = 298$) (Table II). The most pressing risks were economic and political in nature and, in descending order of importance according to mean, included loss of market, (TUA) restricting rights, increased seed cost, and lawsuits. All farmers expressed their concern regarding the loss of markets.

> *The loss of [European] markets due to GM's had a huge financial impact. This was likely larger than cost of controlling volunteers or benefit of easy weed control*. (Manitoba farmer, interview)

Operational risks also ranked high and, in descending order of importance, included HT volunteers, gene spread, herbicide resistant weeds, and RR crops causing problems in zero-tillage systems. One farmer indicated how he was sued over patented HT canola that contaminated his land, creating biological and legal risks that had implications for all farmers.

> *What it means to farmers all around the world is the loss and right to use your own seed ... My rights as a farmer have been taken away because now I can no longer grow canola under fear of a lawsuit*. (Saskatchewan farmer, interview)

Farmers generally believed that it was not possible to control HT traits from spreading in the environment. Thus, most felt that "Terminator Technology" (75% of respondents), "segregation techniques" (67%), and "good farming practices" (51%) would not solve HT trait contamination problems.

3.4. Factors Contributing to Risk Perception

Correspondence analysis (CA) separated respondents along a primary risk/benefit gradient, with farmers experiencing high benefit and low risk on the right side of the ordination, and farmers experiencing high risk and low benefit on the left (Fig. 2). The CA accounted for 45.52% of the contingency information in the data. These differing views were based on a farmer's specific experiences with HT technology, and suggested that HT users were not a homogeneous group and that benefits and risks unevenly affected farmers.

We categorized farmers along this primary gradient of variation: those for which (1) benefits were greater than risks; (2) benefits were equivalent to risks; and (3) risks were greater than benefits. The perceptions of individual farmers were summarized in a composite CA score along this gradient and ranged from 3.55 (highest benefit) to −3.02 (highest risk).

Eight independent variables (Table III) were used to construct 256 possible models and the most

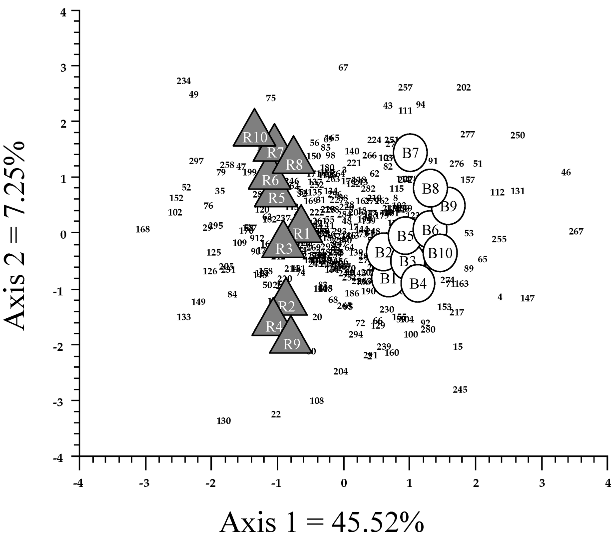

Fig. 2. Two-dimensional ordination biplot arising from the correspondence analysis of farmer attitudes ($n = 298$) regarding risks and benefits associated with herbicide-tolerant (HT) canola in Manitoba. Indicated are the risks (R1–R10) and the benefits (B1–B10) that correspond with rankings in Table II. The first two eigenvalues as percent $\lambda_1 = 45.52\%$ and $\lambda_2 = 7.25\%$ together summarize 52.77% of the contingency information for the data.

parsimonious model had a Δ $AIC_C = 0$, and consisted of variables for farm size (Farm size), years using HT canola (YrsHT), and volunteers (Vol) (Table IV).

The beta coefficients for the variables in the most parsimonious model (Table V) suggested that farmers perceived greater risk if they operated a smaller farm ($\beta = -1.81$, $SE = 0.60$). Linking the demise of these small family farms with HT technology, one farmer stated:

> *GM technology will most certainly hasten the demise of family farms if it is allowed to progress unchecked. When we started farming ... seed could be saved from year to year... now, each year, a tremendous monetary outlay for seed must be made in order to grow canola because of the new GMO systems ... more and more family*

Table III. Description of Independent Variables Used to Explain Farmer Perceptions and Experiences Regarding the Benefits and Risks of HT Canola

Abbreviation	Variable Description
Education	Ranking of education of respondent (grade/high school, college/university)
Farm size	Total acres of farm, including owned and rented land
Finances	Qualitative description of farm family's finances
Min till	Total acres of land in minimum and/or zero-tillage production
Organic	Total acres of land in organic production (certified and noncertified)
Vol	Experience of HT volunteer canola on farmer's land (yes, no)
Yrs farm	Total number of years that farmer had been actively farming
Yrs HT	Total number of years that farmer had used HT canola

Table IV. Selected Set of Candidate Models in Order of Importance (Based on AICc[a] $\Delta < 4$, with Best Model = 0) with Their Associated AICc Weights (w) and Number of Model Parameters (k) for Independent Variables that Best Predict Farmers Being at Risk from HT Canola

Model[b]	$-2\text{Log}(L)$	k	$AIC_c\Delta$[c]	$AIC_c w$[d]
Vol + HT yrs + farm size	253.39	4	0.0	0.23
Vol + farm size + HT yrs + Min till	252.28	5	0.9	0.14
Vol + farm size + HT yrs + organic	252.26	5	0.9	0.14
Vol + farm size + HT yrs + finances	252.3	5	0.9	0.14
Vol + farm size + HT yrs + yrs farm	252.7	5	1.3	0.11
Vol + HT yrs + Min till	255.68	4	2.3	0.07
Vol + farm size	259.20	3	3.8	0.03

[a]AICc = Akaike's information criterion with small sample bias adjustment (Burnham & Anderson, 1998).
[b]Variables in models described in Table III.
[c]$AIC_c\Delta$ = A measure of each model relative to the best model.
[d]AIC_c w = Another measure of the strength of evidence for each model, and is the ratio of $AIC_c\Delta$ values for each model relative to the entire set of candidate models.

Table V. Cumulative AICc[a](w) Weights, Beta Coefficients (β), and Standard Error (SE) for All Eight Independent Variables Hypothesized to Influence Farmer Benefit and Risk Perception and Experience with HT Canola

Variable[b]	Cumulative AICc Weight[c]	Beta-Coefficient	*SE*
Vol	0.99	1.02	0.05
Yrs HT	0.86	1.37	0.38
Farm size	0.84	−1.81	0.60
Min till	0.43	−0.56	0.64
Organic	0.38	1.27	1.58
Finances	0.35	0.24	0.32
Yrs farm	0.32	0.21	0.28
Education	0.26	−0.01	0.02

[a]AICc = Akaike's information criterion with small sample bias adjustment (Burnham & Anderson, 1998).
[b]Variables described in Table III.
[c]These "model averaged" weights were computed by summing the AICc weights of every model containing that particular variable.

farms will disappear—simply because they are unable to shoulder these costs which will happen annually without relief. (Survey 101)

Higher risk perception was expressed by those growing HT canola over multiple years ($\beta = 1.37$, $SE = 0.38$). A number of interviewed farmers similarly expressed concern that these risks increased over time.

All of this is escalating and we really need a period of time to take a serious look at what the long-term effects are going to be. (Manitoba farmer, interview)

Risks were also greatest for those who experienced volunteer canola on their land ($\beta = 1.02$, $SE = 0.05$). Indeed, many interviewees indicated having problems with HT volunteers.

These volunteers are showing up in fields that have never been planted to these crops. Farmers that have never seeded genetically modified crops are finding volunteers on their farm and that the volunteer picture is much broader than we had expected to see. (Manitoba farmer, interview)

The percent weight that independent variables contributed to each model was determined by summing their cumulative Akaike weights (Table V). The three variables that contributed most to risk were, in order of importance, HT volunteers (Vol: $w = 0.99$), years growing HT crops (YrsHT: $w = 0.86$), and farm size (Farm size: $w = 0.84$). By comparison, the other five variables (minimum tillage, organic, finances, years farming, and education) were of minimal importance.

3.5. Primary Risk: HT Volunteer Canola

In total, 38% of HT farmers ($n = 298$) had experienced HT volunteer canola on their land. Of these, 51% believed the source of HT volunteers came from "within" their operations, 20% believed they came from "outside," and 29% believed that it was from "both" sources. Many respondents were concerned about the promiscuous and persistent nature of these volunteers, and that this would eventually compromise benefits currently associated with the technology.

I had volunteer Roundup resistant canola in a sunflower field before I had ever used it, and, I could not remove it with Roundup [herbicide] or other means. We are finding resistant canola everywhere, even if it has never been seeded on that field. I like using Roundup as pre-emergent burn-off and its not working great anymore. (Survey 140)

Farmers who grew HT canola and had experienced HT volunteers believed that, on average, they were emerging in their fields 2.5 years after initially planting these crops. Moreover, HT volunteers were primarily Roundup Ready (72%) and emerged up to six years after having been planted (Fig. 3). Multiple resistant volunteers were also prevalent (20%), followed by CF (6%) and LL (2%) varieties. Many commented that HT volunteers continue to emerge in later years.

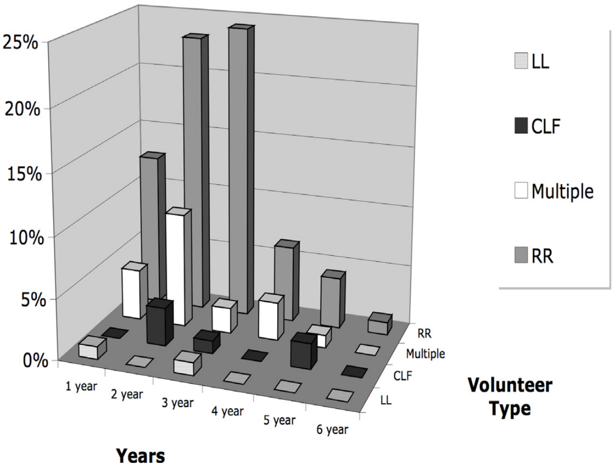

Fig. 3. Farmer ($n = 95$) experiences with HT canola volunteers, specifically the number of years till emergence represented as percentage. The different types of HT canola volunteers included Liberty Link (LL), Clearfield (CF), and Roundup Ready (RR), as well as a combination of these varieties (Multiple).

I don't think enough attention has been paid to the fact that we have these crops growing volunteer, not just the year after we grow them. In fact, I've found with my own experience with a zero-till system that my volunteers are two years after I produce a crop. (Manitoba farmer, interview)

Farmers affected by HT volunteer canola relied on a diversity of control methods, including, in ascending order of importance, hand pulling (1%), glyphosate (5%), others such as chemicals or letting the volunteers grow (7%), sweeps on the air seeder (9%), glyphosate and additional herbicide (17.5%), tilling (17.5%), and a combination of these techniques (43%). When examined in greater detail, many (9%) of the zero-till farmers in this study actually reverted to tillage to control RR volunteers.

A large majority (76%) of survey respondents who used HT canola anticipated that HT volunteers would become "more of a problem in the future." And an even greater proportion (85%) believed that industry had shifted the burden of responsibility for HT volunteers onto farmers. Concerned about the issue of corporate responsibility, one respondent stated:

> *Our biggest concern is Roundup Ready canola polluting our fields by being blown off neighbors fields and infesting our fields with voluntary plants. Is Monsanto going to compensate farmers in this situation?* (Survey 206)

4. DISCUSSION

Our study was designed to examine postrelease benefits and risks associated with growing of HT canola, and underlying factors that contribute to overall risk with the technology. Asking farmers to assess the "real-world" efficacy of and risks associated with HT canola arguably makes this publicly funded research the first of its kind in North America.

Overall, farmers in this study found that HT crops were less risky than other stressors confronting rural communities. Farm economics, these including inputs and machinery costs, as well as commodity prices, were of paramount concern. This reflects the decline of net income of Canadian farmers over the last 20 years[63] and that farmers are now amidst the worst farm-income crisis in history.[64] Environmental concerns that affected crop production, and in turn income, were also ranked high, these including excessive moisture, drought, and natural disasters. Although HT crops were ostensibly of less concern and reflected many benefits, ranking 9th out of 10, they were still perceived as "moderately risky."

The main benefits of HT canola in our study were operational, supporting results of an unpublished study conducted by industry roughly at the same time.[43] Respondents to our questionnaire identified that advantages included an improved ability to remove weeds earlier, increased safety associated with Roundup (the most popular herbicide used with HT crops), and an ability to farm more land. Unlike the industry-sponsored study,[43] however, those responding to our survey indicated little increase in yields associated with the technology. In general, the benefits identified in our and other studies are largely consistent with those promoted by technology developers themselves, and are thus already widely disseminated and well appreciated.[65]

In contrast, market harm was the highest ranked risk for HT canola, as two of the three available HT varieties are considered to be GM (i.e., RR and LL), a transformation technique entrenched with international trade-related problems. Until recently, the EU has had a moratorium against new GM crop approvals and was establishing stricter labeling and traceability requirements for products containing GM ingredients, this reflecting a "precautionary approach" to risk that was ultimately challenged and recently overturned at the WTO by the United States, Canada, and Argentina.[66] Domestically, neither organic canola farmers nor conventional honey producers can guarantee their products as GM-free, due to potential outcrossing and contamination, and this has adversely affected sales to the EU.[67] The threat of market harm was also highlighted by the controversy surrounding Monsanto's GM wheat at the time that our survey was distributed,[68] with over 80% of world grain buyers indicating that they would not purchase this technology if it were grown and marketed in North America.[69]

Corporate control of agriculture was also of concern to farmers, as reflected in the high ranking of risks associated with TUAs, increased seed costs, and lawsuits associated with HT crops. Although Monsanto is the only company that charges a $15/acre fee for HT canola, in large part because its technology is true reproducing and not a hybrid, there is now a wider trend toward contract production that may increase seed costs and erode farmer rights to save, reuse, and exchange seeds.[70,71] Many of these contracts allow companies to investigate farmers, their land, and community for evidence of appropriation of proprietary seed technologies, which may compromise "social cohesion"[72] and may undermine the "rural social fabric" of rural communities.[14,68] This issue was recently addressed by the landmark Supreme Court of Canada decision, *Monsanto v. Schmeiser*,[73] which essentially upheld industry's intellectual property claims over GM seeds and plants, making farmers liable for patent infringement, despite the likelihood that the seed they plant may have been contaminated by GM traits.[74,75]

Risks of environmental contamination and cleanup costs, specifically relating to HT volunteers and gene spread, were also considered important. Although HT canola was commercially released in Canada in 1995, it was not until much later that three-way HT trait stacking in volunteers occurring in fields[76] and roadside ditches,[77] large-scale pollen-mediated gene flow,[78] and contamination of pedigreed non-HT canola seed stocks across the Canadian prairies[79] were identified. Our study shows that farmers were knowledgeable and understandably concerned about canola outcrossing and believed bioconfinement of HT traits would be nearly impossible. They rejected genetic use restriction technologies (GURTs), specifically "Terminator Technology," as a feasible containment strategy. These GURTs remain controversial and have been discussed widely,[80] especially in light of recent attempts to weaken the U.N. *de facto* moratorium on their use.[81]

Farmers were further concerned about the impacts of HT volunteers on their operations and believed they would become more of a problem in the future. Indeed, Manitoba weed surveys indicate that volunteers have increased in relative abundance from 19th in 1997 to 10th in 2002.[48] This increase is only partially due to increased plantings, and some experts[82] and farmers alike are concerned that persistent HT volunteers may contaminate future canola crops. Our results indicate that volunteers emerged 2.5 years, on average, and upward of 6 years after initial planting of HT canola, this corroborated by ecological studies.[83] While HT volunteers can be controlled[83] they may cause problems associated with crop competition and loss of quality, harvesting difficulties, and pest and disease spread.[84] Importantly, 20% of farmers who reported volunteers indicated that these weeds were multiple resistant, suggesting that these trait stacked weeds may be more widespread than previously reported. These volunteers may lead to persistent metapopulations of feral HT canola[77] and more research is needed to better understand the spatiotemporal dynamics of these volunteers and how they affect both natural and managed environments.

It was also recognized that RR volunteers pose specific challenges for zero-tillage farmers, a widespread cropping practice that has substantially reduced soil erosion and increased water conservation, carbon sequestration, and wildlife habitat across the North American midwest. Zero-till farmers have an additional challenge when controlling HT volunteers, in that they seed directly through stubble, instead of tilling, thus requiring glyphosate (e.g., Roundup) for preseeding weed control, which will not kill Roundup-tolerant volunteers. In Manitoba, these volunteers are in greater densities on land managed using zero till,[85] and additional, more expensive and persistent herbicides (e.g., 2, 4-D) are now required, costing another CAN $1.50–2.00 per acre.[67] This threat to zero-till agriculture is one of the most substantial in a decade of HT crop use[86] and, indeed, might contribute to a decline in the use of direct seeding systems and their widely recognized benefits.[87]

Personal experience with HT volunteer canola was the salient factor that led farmers to identify with risks associated with this technology. Ironically, farmers generally have little control over "volunteers" or factors that give rise to them, whether these be gene flow, environmental conditions, seed contamination, or neighboring management decisions. This lack of control may, in part, underlie the heightened risk perception associated with these "involunteers," since it has long been recognized that risks are perceived as greater when viewed as involuntary and uncontrollable.[88–90] Although volunteer experience was the most important risk variable, farm size and duration of HT crop use also influenced risk perception.

Farmers who operated smaller farms were more likely to perceive themselves at risk. Generally, small farms are considered risk averse, as they have less capital for investment, and are therefore less likely to adopt new and potentially risky technologies.[91] Larger farms, on the other hand, have been better able to buffer potential risks associated with HT canola, and to better capture benefits,[72] and arguably have been the focus of this technology development. Thus, HT crops may select for increased profits for and control by agribusiness,[68] this often occurring at the expense of small family farms, rural communities, and the environment.[92] These changes are further compounded by cumulative stressors—such as low commodity prices, high input costs, poor government policies focused on deregulation, and free trade—that act to further marginalize small-scale and family farms.[63]

Risks associated with HT canola also increased with the time that the technology was used. Diffusion models suggest that early adopters of a technology that works and that is initially superior and that has broad support will benefit quickly.[93] These criteria were in place for the introduction of HT canola and presumably led to its rapid adoption and use. However, as the technology gains wider acceptance and use, benefits often plateau and the incentives for early adoption decline.[93] This phenomenon may help explain why farmers with the most experience using these crops devalued the benefits and favored the risks.

Our best candidate risk model comprised volunteers, small-scale farm, and duration of HT canola use and clearly demonstrates that overall farmer experience contributed most to their attitudinal rankings of benefits and risks. That personal experience was central when evaluating HT crops indicates that the geography of place and culture is important to risk perception,[94] and that the local farmer knowledge derived from working the land and interacting with communities plays an important role in risk conception.[95] We suggest that experience-based knowledge might play a central role in risk analysis, and that it offers a meaningful perspective beyond the dichotomy of "expert" versus "lay" knowledge regarding GM crops and risk. Resource-dependent communities often have much insight into the risks associated with managing their environments,[96] and this is especially clear with respect to rural communities and HT crops.

A decade of intimate experience with this technology yields farmer insights that are rich and at once place-specific and generalizable to HT crops as a whole. Yet these experiences largely remain unheard by policymakers and managers, who continue to discount farmer perspectives regarding agricultural technology on the grounds that it is nonscientific, subjective, and unreliable. When acknowledged at all, farmers are often viewed as passive research subjects or passive adopters of expert-developed technology. Although some question these assumptions and call for greater and more meaningful farmer involvement in agricultural research and policy making,[97] regulation of biotechnology in North America continues to rely on "science-based" and expert risk assessment.[13]

In Canada, the agency charged with assessing risks associated with HT crops (i.e., Canadian Food Inspection Agency) cannot explicitly incorporate social or economic data in its decision making, to say nothing of local farmer knowledge. Unsurprising, some leading experts on HT crops in Canada now recognize that risk assessment has failed to properly evaluate potential market harm, seed lot contamination, and impact of volunteers on agronomy and environment.[98] Further, the Royal Society of Canada severely criticized the Canadian government and its role in regulating human health and environmental risks associated with biotechnology, particularly the use of "substantial equivalence," and called for a more rigorous, independent, publicly accountable, and precautionary approach to risk assessment.[99]

This seeming failure on the part of industry and regulators to anticipate the diversity of risks associated with HT canola, as presented in this study, demonstrates the limitations of conventional risk assessment and suggests that a new, more inclusive, experience-based, and farmer-centered approach to risk assessment would benefit farmers and society alike. Indeed, like any seed, risk analysis should grow from the ground up, and we believe that this means starting with farmers and their local knowledge in the GM debate.

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APPENDIX: TERMINOLOGY

Canola: Canola was developed in Canada in the early 1970s through conventional plant breeding of rapeseed and is now a popular edible oil. It is part of the mustard family, and herbicide tolerance has been predominately introduced into *Brassica napus,* although other species include *B. rapa* and *B. juncea*. Two of the three available HT canola varieties, Roundup Ready and Liberty Link, are transformed using recombinant DNA, and are therefore considered GM products. The third, Clearfield, has a novel HT trait introduced using mutagenesis, and is therefore not considered a true GM product.

Volunteer: A volunteer is essentially a crop growing in another crop, which competes for nutrients and other resources, making it a weed that some farmers choose to control. Volunteers may arise from harvest losses in a previous year or seed movement from wind, transportation, etc. HT canola volunteers are resistant to specific chemicals and, depending on the agronomic context, may require additional management (e.g., herbicides, tilling, etc.).

Technology use agreements: Technology use agreements (TUAs) are contracts that farmers sign with certain seed companies to buy seed, particularly those that contain proprietary HT or other genetically modified traits. Companies that use these agreements, most notably Monsanto, often restrict farmers from saving seed annually and reserve the right to inspect a farmer's land for compliance. In the event of noncompliance, these TUAs are used to levy stiff penalties and may become the basis for lawsuits against farmers.

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