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IMPLICATIONS OF GM-CROP CULTIVATION • SERIES • RESEARCH ARTICLE

Farmer knowledge and a priori risk analysis: pre-release evaluation of genetically modified Roundup Ready wheat across the Canadian prairies

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Abstract
Background, aim, and scope The controversy over the world's first genetically modified (GM) wheat, Roundup Ready wheat (RRW), challenged the efficacy of 'science-based' risk assessment, largely because it excluded the public, particularly farmers, from meaningful input. Risk analysis, in contrast, is broader in orientation as it incorporates scientific data as well as socioeconomic, ethical, and legal concerns, and considers expert and lay input in decision-making. Local knowledge (LK) of farmers is experience-based and represents a rich and reliable source of information regarding the impacts associated with agricultural technology, thereby complementing the scientific data normally used in risk assessment. The overall goal of this study was to explore the role of farmer LK in the a priori risk analysis of RRW.
Materials and methods In 2004, data were collected from farmers using mail surveys sent across the three prairie provinces (i.e., Manitoba, Saskatchewan, and Alberta) in western Canada. A stratified random sampling approach was used whereby four separate sampling districts were identified in regions where wheat was grown for each province. Rural post offices were randomly selected in each sampling district using Canada Post databases such that no one post office exceeded 80 farms and that each sampling district comprised 225–235 test farms (n=11,040). In total, 1,814 people responded, representing an adjusted response rate for farmers of 33%. A subsequent telephone survey showed there was no non-response bias.
Results The primary benefits associated with RRW were associated with weed control, whereas risks emphasized the importance of market harm, corporate control, agronomic problems, and the likelihood of contamination. Overall, risks were ranked much higher than benefits, and the great majority of farmers were highly critical of RRW commercialization. In total, 83.2% of respondents disagreed that RRW should have unconfined release into the environment. Risk was associated with distrust in government and corporations, previous experience with GM canola, and a strong belief in the importance of community and environment. Farmers were critical of expert-based risk assessment,

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particularly RRW field trials, and believed that their LK was valuable for assessing agbiotechnology as a whole.

Discussion Over 90% of canola production across the Canadian prairies makes use of herbicide-tolerant (HT) varieties. Yet, respondents were generally uniform in their criticism of RRW, regardless whether they were HT users, non-HT-users, conservation tillage or organic in approach. They had a sophisticated understanding of how GM trait confinement was intrinsically tied to grain system segregation and, ultimately, market accessibility, and were concerned that gene flow in RRW would not be contained. Organic farmers were particularly critical of RRW, in large part because certification standards prohibit the presence of GM traits. Farmers practicing conservation tillage were also at relatively great risk, in part because their dependence on glyphosate to control weeds increases the likelihood that RRW volunteer would become more difficult and costly to control.

Conclusions This research is the first of its kind to include farmer knowledge in the a priori risk analysis of GM crops and, arguably, given its prairie-wide scope, is the largest scale, independent-farmer-focused study on GM crops ever conducted. The surprising uniformity in attitudes between users and non-users of GM technology and among organic, conventional, conservation tillage and GM using farmers speaks to the ability of farmers to discriminate among HT varieties. Our results clearly show that prairie farmers recognize that the risks associated with RRW commercialization outweigh any benefits.

Recommendations and perspectives Farmer knowledge systems are holistic in nature, incorporating socioeconomic, cultural, political, and agroecological factors that all can contribute meaningfully to the pre-release evaluation of GM crops. The inclusion of farmers and other stakeholders in risk assessment will also help enhance and even restore public confidence in science-focused approaches to risk assessment. Although farmers are highly knowledgeable regarding RRW and arguably any agricultural technology, their expertise continues to be overlooked by decision-makers and regulators across North America.

Keywords A priori risk analysis · Farmer knowledge · Genetically modified crops · Public participation · Roundup Ready wheat

1 Background, aim, and scope

The development, field trials, and proposed introduction of the world's first genetically modified (GM) wheat crop in North America was highly controversial and, ultimately led many to question the legitimacy of 'science-based' regulation regarding agbiotechnology. The disputed crop was Monsanto's transgenic Roundup Ready wheat (RRW), which is designed to be herbicide-tolerant (HT), to glyphosate. Although voluntarily withdrawn from commercialization in May 2004 (Stokstad 2004), renewed interest in and advocacy for GM wheat, particularly RRW, is now being expressed as a way to increase innovation and grain supply in the face of a global food crisis (Dyck et al. 2007). Each year, wheat is grown across the Canadian prairies, and sold to more than 70 countries, with export sales worth between \$4 and \$6 billion USD (Huygen et al. 2004). It is marketed by the Canadian Wheat Board, a farmer-controlled organization that is the largest seller of wheat and barley in the world, representing over 20% of the global market (CWB 2008). Over 80% of Canada's wheat export markets have indicated they would not purchase GM wheat if it were grown in Canada (Huygen et al. 2003). Yet, the Canadian Food Inspection Agency, the agency responsible for approving environmental release of GM crops in Canada, is not authorized to incorporate socioeconomic considerations into its risk assessment process (Carter et al. 2005).

A priori risk assessment for GM crops is a strictly scientific process (NRC 2002), which attempts to predict and avert potential problems (Sharples 1991), and excludes socioeconomic considerations such as market impact (Yarrow 1999). The exclusion of these non-scientific issues by 'science-based' regulation in North America has been criticized (RSC 2001), particularly for acting as an institutional barrier to considering the important social, economic, and ethical implications of these products (Abergel and Barrett 2002). This highly restrictive approach to regulation arguably creates a value-laden 'risk window' that only makes visible scientific impacts, thereby restricting the scope of information it can provide (Jensen et al. 2003).

As a broader framework for assessing adverse impacts, risk analysis incorporates scientific data as well as socioeconomic, ethical, and legal concerns (Auberson-Huang 2002), potentially mitigating the shortcomings and complementing conventional, science-based risk assessment (NRC 2002). Public attitudes play an important role in risk analysis, particularly regarding controversial issues such as biotechnology (Aerni 2002), and the contribution that lay people can bring to bear on issues that affect society as a whole is increasingly recognized (Pidgeon et al. 2006).

Yet most data regarding RRW have been gathered by experts from outdoor field trials sponsored by Monsanto since 1994 and conducted across Canada and the US (MacRae et al. 2002). Benefits associated with RRW include simplified weed control, suppression of perennial weeds (Van Acker et al. 2003), increased yields (Blackshaw and Harker 2002), early seeding, reduced herbicide injury to wheat (Carter et al. 2005), and cleaner grain (Wilson et al. 2003). However, the technology might also have adverse implications for crop production and the environment as a whole, including difficulties in controlling volunteers, threats to conservation tillage systems, loss of seed saving, evolution of glyphosate resistant weeds (Van Acker et al. 2003), and gene flow between RRW and non-GM wheat (Brule-Babel et al. 2006).

Field trials for RRW were particularly contentious in Canada as they were grown in undisclosed locations across the prairies and managed by contracted landowners, Monsanto, and the federal government (Warick 2003). At least some farmers were concerned that RRW might escape from these trials and disrupt markets and their livelihoods (Bell 2004). Despite the serious impacts RRW might have for farmers, their experiences and concerns have been excluded from decision-making.

The local knowledge (LK) of farmers represents a rich and reliable source of information regarding the impacts associated with agricultural technology (Mauro and McLachlan 2008). It is experience-based, place-specific, holistic in nature, and enriches and complements scientific data (Kloppenburg 1991; Brook and McLachlan 2006). Although regularly used to better understand the socioeconomic and environmental implications of agricultural technology in the Global South (Eyzaguirre 1992), it is rarely incorporated into research in the North where scientists, policymakers, and industry often discount it as being subjective and unreliable (Tsouvalis et al., 2000). Most of the social research on GM crops conducted in North America has been restricted to the economic benefits associated with canola in Canada (Fulton and Keyowski 1999), soybeans and cotton in the US (McBride and Books 2000), and both benefits and risks of GM corn in the US (Wu 2004), and has generally discounted LK. To date, only two studies have explicitly explored the importance of farmer LK in the risk analysis of GM crops, these focusing on the post-release evaluation of GM canola (Mauro and McLachlan 2008) and the combined impacts of GM canola and GM wheat (Mauro et al. 2005) in Canada. Indeed, there is a gap in the literature regarding a priori public input in the pre-release evaluation of GM crops, particularly from farmers.

The overall goal of this study was to explore the role that this farmer knowledge might play in the a priori risk analysis of GM crops and more generally agricultural technology. Our specific objectives were to:

- Characterize farmer perceived benefits and risks associated with RRW;
- Evaluate underlying variables contributing to benefit and risk perceptions, especially trust in government and corporations and concern for rural communities and the environment; and
- Identify farmer concerns regarding RRW field trials and future commercialization of the crop.

2 Materials and methods

2.1 Study area

This study was carried out in the provinces of Alberta, Saskatchewan, and Manitoba (Fig. 1). This region, the Canadian Prairies Ecozone is characterized by a continental climate having short warm summers and long, cold winters, and strong winds (Smith et al. 1998). Chernozem soils dominate this ecozone. Agricultural crops have largely replaced native vegetation, and it now comprises over 60% of Canada's cropland (Smith et al. 1998). Wheat and canola are the main crops grown across the prairies, and over a 10-year average, are harvested on 10 million and 5 million ha, respectively (Statistics Canada 2008).

2.2 Data collection

This farmer-focused research on GM wheat used a mixed methodology (Creswell 2002) and was approved by the Joint-Faculty Human Subject Research Ethics Board Protocol at the University of Manitoba (#J2001:060). Interviews were conducted with 15 farmers across western Canada between June and October of 2002. We purposefully sampled these farmers to participate in an in-depth interview process, in order to explore attitudes and experiences with HT canola and wheat. Data collected during these interviews in part assisted in the development of questionnaires, ensuring that their content and wording were appropriate.

This information was used to create a 12-page survey that queried farmers and rural residents on their attitudes and experience with GM crops, with respect to this study specifically GM wheat, and about agriculture as a whole. It included a seven-point Likert scale (from strongly disagree to strongly agree) and open-ended (where respondents were encouraged to write their own perspectives) questions. A shorter, four-page survey, comprising a subset of questions from the larger questionnaire, was also developed, allowing participants who had been unable to complete or misplaced the longer version (Dillman 2000). University and industry researchers as well as farmers reviewed the survey for comprehensiveness, technical accuracy, and impartiality. The survey was further pre-tested with ten farmers from Manitoba.

A stratified random sampling approach was used to locate the research. Within each province, four separate sampling regions were identified in regions where wheat was grown. In each of these four sampling regions in each

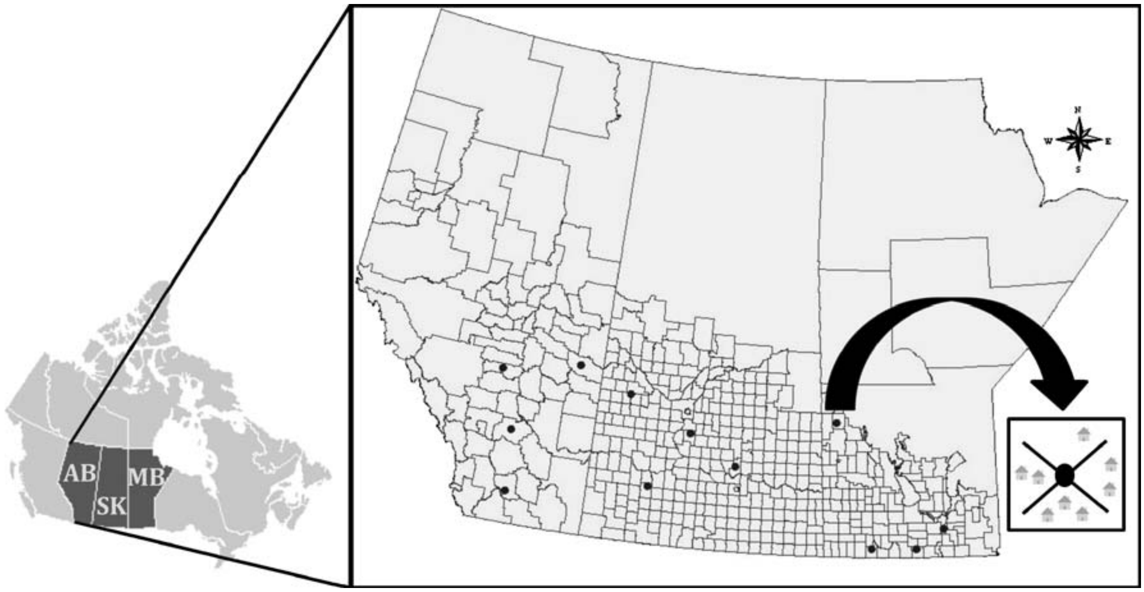

Fig. 1 Farmers were surveyed across the Canadian prairies in the provinces of Alberta (*AB*), Saskatchewan (*SK*), and Manitoba (*MB*; *left*). In each province, four separate regions were identified (*right*) and a central sampling point allowed us to randomly select farms in each of the four polar directions (*right inset*). In total, we sent surveys to 225–235 farms in each of the 48 sampling districts (n=11,040), and our adjusted response rate was 33%

province, a central sampling point was located and one sampling district identified along each of the four polar directions originating from each point, representing 48 sampling districts across the prairies (see Fig. 1). Rural post offices were randomly selected in each sampling district using Canada Post databases such that no one post office exceeded 80 farms and that each sampling district comprised 225–235 test farms, and an equal number of homes self-identifying as farms with Canada Post were identified surrounding this point. In total, 11,040 farms were randomly selected and unaddressed ad mail was used to send questionnaires to each of these farms as no comprehensive mailing list is available for farms across the prairies.

All recipients were sent a questionnaire on February 23, 2004. A post card and letter were sent on March 1 and March 15, 2004, respectively, to encourage participation (Dillman 2000). The shorter survey was sent on April 12 2004 and further increased participant response. Questionnaires were sent with self-addressed business reply envelopes allowing them to be returned at no cost to the recipient. During this period, reminders were also printed in farm newspapers across the prairies. In total, 1,814 farmers and rural residents responded to our questionnaire. Responses from non-farmers were eliminated and the response rate was calculated by dividing the number of all eligible farmers (n=1,566), this combined from the completed large (n=903) and small surveys (n=663), by the total number of sent surveys verified as farms growing wheat (n=4746) according to Statistics Canada census of agriculture data. The adjusted response rate for the survey was 33%. Response rates for natural resource management surveys have been declining over time (Connelly et al. 2003), and are particularly low for rural research as few farmers fill out surveys (Penning et al. 2002).

We conducted a telephone survey to test for non-response bias, using ten agbiotechnology-related questions that were selected from the original questionnaires. Communities were identified in each of the sampling districts used in the mailout and, within each, residents were randomly selected using rural telephone directories. Post offices that had received surveys were matched with the corresponding telephone exchanges in order to contact farmers who had received the surveys but who had not responded. In total, 20 farmers in each of the three provinces were contacted, although only six had completed the surveys. The reasons cited for not filling out the survey, in declining order of importance, were ineligibility, being too busy, and a refusal to fill out a survey of any kind. Overall, there was no significant (p=0.6351) difference between responders and non-responders for these ten questions.

The majority (85%) of respondents were male and averaged 52 years of age (SE=0.33), had an average farm size of 686.8 ha (SE=21.83), and 56% had some college/university education. Although respondents were similar in age (52 years; Statistics Canada 2006a), they were more educated (36%; Statistics Canada 2001) with slightly larger farms (473 ha; Statistics Canada 2006b) when compared with census data across the prairies. Farmers practiced minimum and zero tillage on 55% of reported acres, this lower than the national average of 72% (Statistics Canada 2006c). The proportion of organic farmers (10% vs. 6.8%) was slightly higher than the national average (Statistics Canada 2006c). Many farmers (61%) reported having previously grown (HT) canola, including Roundup Ready (50%), Liberty Link (17%), Clearfield (11%), and combinations of these (21%), these usage rates being similar to national data (Buth 2006, personal communication).

2.3 Data analyses

Respondents were classified into four mutually exclusive groups: organic, HT, non-HT, and conservation tillage users. Where farmers practiced multiple techniques, the most suitable class was selected using farm-level data. Because many respondents used both HT and conservation tillage, they were classified as HT users; the proportion of those indicating either positive or negative attitudes to agbiotechnology was calculated for each of the four groups. Mean values of these attitudes were analyzed using analysis of variance (ANOVA), and when the overall ANOVA model was significant, post-hoc Student–Newman–Keuls (SNK) tests were used to separate means (SPSS 2006). Perceptions of risks and benefits were summarized using mean, standard error (SE), and Cronbach's alpha (Cronbach 1951). Alpha values were high, between 0.94 and 0.96 for all questions, substantially above the 0.70 standard required for multivariate variable reduction (Nunnally and Bernstein 1994). Group structure for 13 benefit and 19 risk questions was evaluated with principal components factor analysis and promax rotation was used to reduce cross loading arising from the dominance of the first factor (SAS 2007).

Independent variables identified in the survey were used to explain differences in risk perceptions. These variables included farm and demographic data. Indices were created from multiple questions in the survey, measuring trust in government and corporations as well as the importance of community and environment. The government index measured trust in regulatory competency and impartiality related to agbiotechnology. The corporate index measured trust in industry motives associated with the development of agricultural technology. The community index measured general attitudes towards the intrinsic value of these rural areas. The environmental index measured the degree to which respondents valued and considered themselves part of the natural world. Multicollinearity among the eleven explanatory variables was evaluated using Spearman rank correlations and all variables were found to be independent.

Factor scores for benefits and risks were sorted into thirds, each representing high, medium, and low categories. The medium category was eliminated for each to create binary responses, and any respondents with missing data were removed from further analysis. Formal statistical inference was based on all the risk and benefit models (multi-model inference; Burnham and Anderson 2002). Akaike's information criterion difference with small sample bias adjustment (ΔAIC_c) and Akaike weights (w) were used to evaluate each model (Burnham and Anderson 2002). Cumulative AICc weights ($w+$) were calculated for each independent variable by running all possible combinations of logistic regression models (n=2,047) for all covariates and summing the AICc weights of every model containing that variable (Burnham and Anderson 2002). Variables with the highest cumulative AICc weights have the greatest influence on perceived risks and benefits associated with RRW.

Qualitative data arising from open-ended questions in the survey were recorded, systematically evaluated, and coded, and any emerging themes identified (Maxwell 2005). These themes were matched with quantitative findings. This mixed methods approach was used to both triangulate responses and to further interpret the results.

3 Results

3.1 Farmer attitudes toward Roundup Ready wheat

Farmers showed a remarkably uniform negative response to RRW. In total, 83.2% of respondents at least moderately disagreed that RRW should have unconfined release into the environment. This held true even when respondents (n=1,391) were categorized as organics, HT users, non-HT users, and conservation tillage (Table 1). Indeed, there was no significant difference (p=0.033, mean=2.09±0.04) among these groups and their resistance to RRW being approved for unconfined release in the environment. They were highly unlikely to grow RRW if it was on the market (mean = 1.98±0.04), and farmers practicing organics and conservation tillage were most against its use (p<0.0001). A main reason for not growing it was consumer antipathy (mean = 6.39±0.04), this of least concern to HT users (p<0.0001). Most indicated that herbicide tolerance in wheat is not a major benefit, although HT farmers felt less strongly in this regard (p<0.0001). Farmers were largely critical of the notion that companies need to patent GM wheat, although organic, non-HT, and conservation till users felt more strongly about this than did those growing HT crops (p<0.0001). Only half of HT farmers agreed that GM wheat would damage the social fabric of rural Canada, whereas most organic, non-HT, and conservation tillage users were significantly more likely (p<0.0001) to anticipate this decline.

Table 1 Farmer perspectives (n=1,391) on agbiotechnology, particularly Roundup Ready Wheat (RRW), across different production classes, including organics, herbicide-tolerant (HT) crop users, non-HT users, and conservation till users

	Proportion[a] of respondents for each class								Mean[b] and one-way ANOVA[c] on Likert scale					
	Organics (n=141)		HT users (n=847)		Non-HT users (n=255)		Cons till users (n=150)		Organics (n=141)	HT users (n=847)	Non-HT users (n=255)	Cons till users (n=150)	F value	P value
	–	+	–	+	–	+	–	+						
RRW should be approved for unconfined release into the environment	0.89	0.08	0.80	0.11	0.89	0.07	0.86	0.10	1.86	2.32	2.13	2.03	2.93	0.0331
If RRW were on the market this year – how likely would you be to grow it?	0.94	0.02	0.83	0.11	0.88	0.03	0.94	0.06	1.51^{a}	2.19^{b}	2.38^{b}	$1.84^{a,b}$	7.10	<0.0001
I won't grow GM wheat if consumers don't want it	0.08	0.88	0.05	0.88	0.02	0.93	0.01	0.98	$6.30^{a,b}$	6.17^{a}	$6.47^{a,b}$	6.61^{b}	7.17	<0.0001
Herbicide tolerance in wheat is not an improvement, as farmers currently have adequate weed control options	0.10	0.86	0.21	0.74	0.11	0.85	11.00	0.84	6.02^{a}	5.32^{b}	5.81^{a}	5.86^{a}	11.29	<0.0001
Companies need the ability to patent GM wheat in order to encourage future innovations	0.88	0.05	0.67	0.22	0.84	0.07	0.80	0.14	1.96^{a}	2.86^{b}	2.37^{a}	2.25^{a}	12.45	<0.0001
GM wheat will damage the social fabric of rural Canada	0.23	0.72	0.37	0.49	0.17	0.71	0.23	0.66	5.48^{a}	4.52^{b}	5.56^{a}	5.22^{a}	21.92	<0.0001

[a] Proportions represent positive (+) and negative (−) sides of a seven-point Likert scale for associated questions, and neutral values are eliminated.

[b] Means followed by different letters are significantly different at $p<0.006$ according to SNK post-hoc test

[c] One-way ANOVAs were conducted with an alpha set at 0.006 to minimize errors associated with multiple tests

3.2 Risks associated with RRW

Farmer perceptions regarding risks associated with RRW were ranked high and separated into four themes using factor analysis (Table 2). The first factor, 'market impact' (eigenvalue = 11.36) was dominant. Accounting for 88.2% of the variance, it included economic, logistical, and biological issues that might compromise consumer confidence and ultimately affect markets. Reflecting the holistic way that farmers viewed these issues, one HT user from Manitoba stated:

> *"I feel there is absolutely no way that RRW can be kept separate from regular wheat during growing, harvesting or at the elevator and shipping levels. If our importers do not want RRW, why is Monsanto pushing to develop it? The high standard of Canadian wheat will be contaminated and the market will disappear. It is difficult enough to survive in farming without having Monsanto take away any export markets Canadian farmers have. NO RRW."* (m162).

The second factor, 'corporate impact' (eigenvalue = 0.76), accounted for 5.9% of the variance, and focused on corporate control over seeds and farmer rights. Corporate domination over agriculture was of concern to many respondents in all user groups. As one HT user from Manitoba indicated:

> *"Farmers are treated like serfs or slaves to the large corporations and chemical companies. If allowed to do so our food supply is in danger. Our very existence as farmers is in danger."* (m64).

The third factor, 'agronomic impact' (eigenvalue = 0.58), retained 4.5% of the variance and highlighted the effect of RRW on the management of farm systems, particularly weeds (i.e., HT volunteers and RR resistance). Many indicated that RRW volunteers would be much harder to control than RR canola, which might compromise the gains associated with conservation tillage, as stated by this HT user from Alberta:

> *"Controlling RR canola volunteers is easy, just a small amount of 2–4, D does the trick. Volunteer wheat is a whole different story. None of the chemicals to do that are cheap, so the cost of [conservation tillage] becomes a lot more expensive, and add that to the cost of paying a TUA* [technology use agreement] *on wheat and the cost would outweigh the benefits."* (A82).

The fourth factor, 'contamination impact' (eigenvalue = 0.53), accounted for 4.1% of the variance and demonstrated the implications of contamination for conventional and organic farmers, as indicated by this organic farmer from Alberta:

> *"If GM wheat is ever approved by the government...it will totally destroy the organic and conventional*

Table 2 Factor analysis of farmer risk perceptions regarding Roundup Ready Wheat (n=771)

	Variance	Alpha	Load	Mean	SE	Rank
Factor 1[a]: market impact (eigenvalue = 11.36)						
Markets	88.15%	0.96	0.70	6.41	0.04	1
Consumer confidence		0.96	0.85	6.33	0.05	2
Inability to segregate		0.96	0.72	6.31	0.05	3
Grain system containment		0.96	0.79	6.29	0.04	5
Cost of segregation		0.96	0.61	6.24	0.05	7
Seedlot purity		0.96	0.47	6.16	0.05	9
Factor 2: corporate impact (eigenvalue = 0.76)						
Increased seed cost	5.92%	0.96	0.70	6.31	0.04	4
Corporate control		0.96	0.60	6.27	0.05	6
Contracts restricting rights		0.96	0.66	6.15	0.05	11
Increased bureaucracy		0.96	0.59	6.07	0.05	14
Seed saving		0.96	0.65	5.92	0.06	15
Factor 3: agronomic impact (eigenvalue = 0.58)						
Selection pressure	4.48%	0.96	0.55	6.18	0.04	8
RRW volunteers		0.96	0.66	6.16	0.05	10
Weed resistance		0.96	0.62	6.12	0.05	12
Wheat and canola rotations		0.96	0.61	6.12	0.05	13
Minimum and no till		0.96	0.63	5.64	0.06	16
Factor 4: contamination impact (eigenvalue = 0.53)						
Cross-pollination contamination	4.08%	0.96	0.80	5.61	0.06	17
Organic livelihood		0.96	0.45	5.35	0.07	18
Animal vectors for RRW		0.96	0.74	5.24	0.07	19

Variance, Cronbach's alpha, mean, standard error (SE), and relative ranking are also presented. Rank represents the relative importance of the reported means

[a] Factor analysis conducted with promax rotation

> *farmers because wheat…will cross pollinate into wheat fields many miles away by wind and birds and water, etc. This will contaminate all farms."* (A111).

3.3 Benefits associated with RRW

Respondents did identify benefits associated with RRW, although the mean rankings were neutral, or lower, and they were generally viewed as far less compelling than potential risks. These benefits separated into two major themes through factor analysis (Table 3). The first factor, 'weed control' (eigenvalue = 7.85), dominated the analysis, representing 94.9% of the variance, and included options for better and easier weed management. As one HT user from Manitoba indicated:

> *"I have on my fields wild oat and millet that is resistant to Group 1 and Group 4 herbicides. I need RRW."* (m259).

The second 'agronomic' (eigenvalue = 0.51) factor accounted for 6.2% of the variance, and included various production benefits. Affirming this, another HT user from Manitoba indicated:

> *"I believe that the sooner we can sow RRW, the sooner I can benefit from…higher yield, with less input costs."* (m142).

3.4 Independent variables that contributed to benefit and risk perception

Although most respondents were uniformly against RRW, attitudes varied among farmers. For the primary risks, relating to 'market impact', these factor scores ranged from 0.74 (high risk) to −4.64 (low risk). For the primary benefits, relating to 'weed control', these factor scores ranged from 1.82 (high benefit) to −2.00 (low benefit). Eleven independent variables (Table 4) were selected to analyze all 2,047 possible models for both risk and benefit perceptions using logistic regression and Akaike's information criterion.Of the 11 variables that were tested, those that most effectively predicted 'high risk' perception were low trust in government (β=−4.46) and corporations (β=−4.00),

Table 3 Factor analysis of farmer benefit perceptions regarding Roundup Ready Wheat (n=722)

	Variance	Alpha	Load	Mean	SE	Rank [a]
Factor 1[b]: Weed control (eigenvalue = 7.85)						
Group 1 resistant wild oat control		0.95	1.00	4.56	0.07	1
Different in-crop mode of action		0.95	0.86	4.38	0.07	2
Broad spectrum weed control		0.94	0.73	4.36	0.07	3
Simplified weed management	94.85%	0.95	0.74	4.23	0.07	4
Single pass weed control		0.95	0.72	4.14	0.07	5
Volunteer cereal control		0.95	0.81	3.93	0.07	7
No herbicide carry over		0.95	0.92	3.85	0.07	8
Factor 2: Agronomic (eigenvalue = 0.51)						
Cleaner grain		0.94	0.73	3.96	0.07	6
Facilitating conservation tillage		0.95	0.78	3.81	0.07	9
Early seeding	6.18%	0.95	0.93	3.63	0.07	10
Higher yields		0.95	0.99	3.48	0.07	11
More uniform final product		0.95	1.00	3.29	0.07	12
Increased crop safety		0.95	0.65	3.19	0.07	13

Variance, Cronbach's alpha, mean, standard error (SE), and relative ranking[a] are also presented

[a] Rank represents the relative importance of the reported means

[b] Factor analysis conducted with promax rotation

and a strong belief in the importance of community (β= 5.41) and environment (β=4.00; Table 5). One non-HT farmer from Saskatchewan indicated:

> *"With a lifetime of experience in farming, I've found out that both government and agribusiness information can often be misleading; giving us only information that will benefit them, to the detriment of rural communities, the environment, and health."* (S292).

Farmer experience with already released HT canola (β= 0.81) was also an important predictor of 'high risk' (see Table 5). Many indicated problems with contamination and volunteers. This contamination, in turn, contributed to risk and (ironically) to an increase in the use of these varieties, as indicated by an HT user from Alberta:

> *"The reason I grow Roundup Ready canola is that my neighbor grew it and the seed blew into my fields. My fields are now contaminated."* (A160).

Table 4 Independent variables used to explain farmer attitudes regarding benefits and risks of Roundup Ready Wheat

Abbreviation	
Age	Age of respondent (years)
Com	Importance of community (index)
Corp	Trust in corporations (index)
Ctill	Minimum or zero-tillage production (yes, no)
Edu	Formal education of respondent (grade/high school, college/university)
Env	Importance of environment (index)
Fin	Financial wellbeing
FS	Farm size, including owned and rented land (ha)
Gov	Trust in government (index)
HT	Previous use of HT canola (yes, no)
Org	Organic production (certified and non-certified) (yes, no)

Table 5 Cumulative AICc weights (w+), beta-coefficients (B), and standard error (SE) for all eleven independent variables hypothesized to influence farmers risk and benefit perceptions associated with Roundup Ready wheat

Variable	Risks			Benefits		
	w+	*B*	*SE*	*w+*	*B*	*SE*
Gov	1.00	–4.46	0.08	1.00	5.81	0.17
Com	1.00	5.41	0.06	0.96	–3.54	0.29
Corp	1.00	–4.00	0.11	0.30	0.20	0.28
Env	0.98	4.00	0.20	0.27	–0.08	0.12
HT	0.96	0.81	0.09	0.95	0.70	0.07
Fin	0.60	–0.54	0.43	0.27	–0.03	0.06
Age	0.55	–0.57	0.51	0.66	–0.82	0.57
Ctill	0.51	0.20	0.19	0.27	0.01	0.02
Org	0.32	–0.09	0.13	0.56	–0.32	0.29
FS	0.30	0.23	0.33	0.34	–0.40	0.52
Edu	0.29	0.10	0.15	0.39	0.29	0.36

AICc—Akaike's Information Criterion with small sample bias adjustment (Burnham and Anderson 2002). Model averaged weights were computed by summing the AICc weights of every model containing that particular variable

The most important variable that predicted 'high benefits' perception was substantial trust in government (β=5.81; see Table 5), as indicated by an HT user from Alberta:

> *"So long as* [GM technologies] *are sufficiently tested by independent, knowledgeable, responsible bodies (i.e., government or entities under the direct control of government) for both short-term and long-term effects, I think we should employ such technology."* (A143).

A low belief in the importance of community (β=–3.54) was also important in predicting 'high benefits' (see Table 5). Some farmers dismissed the impacts RRW might have on rural communities. They believed that industry-led technology development should be a priority for agriculture and, in turn, contribute to these communities. Farmer experience with HT canola (β=0.70) was also an important predictor of farmer 'high benefits' for RRW, as indicated by an HT user from Alberta:

> *"Roundup ready canola has changed the amount of canola that can be grown. The dockage is as low as 1.5% compared to 10% plus for conventional canola. It has put a lot of money in the farmers' pockets in this area."* (A40).

3.5 A priori risk assessment: Roundup Ready wheat field trials and future commercialization

Throughout the debate surrounding RRW, the crop was being field tested in open-air research trials across the western Canada in little-known locations. While most farmers (65%) believed that these trials were important to assess the safety of RRW, they (68%) also felt that Monsanto should not be carrying out this research throughout the prairies. Many (58%) believed that regulatory oversight of these test plots was inadequate, while fewer (29%) felt they were sufficient. Most (82%) believed that they should have a say regarding the location of test plots, and many (66%) were frustrated that this research was taking place in secret. While only a few farmers (2%) thought RRW might have escaped trials and be in their fields, many (55%) suspected that this was possible. Believing that these test plots might cause harm, and concerned that farmer perspectives on RRW were being ignored, one HT user from Manitoba stated:

> *"I believe the biggest issue driving GM wheat research is the money there is to be made for the chemical companies, namely Monsanto. I believe they manipulate the research results in order to give the Government the information they want to hear...RRW test plots...might hurt our wheat markets and hurt zero till and minimum till farmers. How come those concerns have not been listened to?"* (M257).

Amidst the RRW controversy, Monsanto promised the industry and farmers that they would need to achieve certain 'milestones' before introducing the world's first GM wheat. Farmers in both surveys were queried on the likelihood of Monsanto achieving these objectives and found that a minority believed market acceptance (17%), regulatory approvals (19%), a reliable segregation system (12%), and a solution for weed problems associated with RRW volunteers (20%) were possible. Few farmers (16%) indicated they would grow RRW even if Monsanto achieved these outcomes. Many expressed frustration over Monsanto's ongoing research into RRW and its push towards commercialization. Importantly, the great majority of farmers (90%) believed that rural communities had knowledge that was important and useful for assessing the impacts of GM crops, and some further commented on the limitations of science in assessing these risks as indicated in the following comment by an organic farmer from Saskatchewan:

> *"Higher education is a wonderful thing as it can broaden the mind and prepare individuals to think for themselves, but so many areas (e.g., agriculture and medicine) the education tends to be biased and corrupt, so, yes indeed, rural knowledge should be incorporated* [into decision making]." (S187).

Another HT user from Manitoba believed that farmers were the only stakeholders that should be able to direct decision-making regarding the approval of RR:

> *"The decision to have RRW should be made by all farmer stakeholders not Monsanto and not by the Government."* (m80).

4 Discussion

The LK of farmers, as presented in this study was highly effective for assessing a priori impacts associated with the release of RRW across the Canadian prairies. Rooted in individual lived experiences, their LK was surprisingly uniform, regardless of farming approach and indicated that risks associated with the unconfined release of RRW were ranked substantially higher than the benefits. Other studies indicate that over 80% of wheat sales might be harmed by the introduction of RRW in Canada (CWB 2004) and the US (Wisner 2003), in part explaining why 'market harm' was the major risk identified by farmers. Few farmers expressed interest in growing RRW even if market acceptance, segregation, and solutions to biological problems should become feasible.

Farmers had a sophisticated understanding of how GM trait confinement was intrinsically tied to grain system segregation, and ultimately market accessibility. Moreover, most felt that gene flow in RRW would not be contained. Other studies show that RRW will likely outcross across the prairies (Van Acker et al. 2004) and, due to difficulties in segregating GM from non-GM wheat, would threaten to devalue all North American wheat (Furtan et al. 2005). Although current risk assessment practices in Canada and the US effectively ignore societal implications of agbiotechnology, these results show that biological and socio-economic impacts are inextricably linked.

Organic farmers were particularly critical of RRW, in part because certification standards generally prohibit the presence of GM traits. The release of GM canola contaminated seed supply and farm fields across the prairies (Friesen et al. 2003), costing organic farmers upwards of $2 million CDN in lost markets (Smyth et al. 2002). Organic farmers in this study were concerned that contamination would also occur in wheat, one of their most important crops, and fundamentally compromise their operations and livelihoods. Indeed, organic farmers in Saskatchewan were prepared to sue Monsanto to halt the introduction of RRW, in order to protect their markets and livelihoods (Bouchie 2002).

Farmers practicing conservation tillage were also at relatively great risk. These farmers use glyphosate herbicides (e.g., Roundup) instead of tillage to control weeds prior to seeding, which increases soil health and carbon sequestration, retains soil moisture, and reduces fuel use and overall costs (Van Acker et al. 2004). They were concerned that RRW volunteers resistant to glyphosate would increase in abundance due to heightened selection pressure and would become increasingly difficult and costly to control. Indeed, frequent applications of glyphosate in conservation tillage systems increase the RRW trait in volunteer populations, despite relatively low rates of gene flow in wheat (Brule-Babel et al. 2006). The need to use additional and more expensive herbicides could cost conservation till farmers an additional $5–52 CDN per ha to control RR volunteers (Van Acker et al. 2004), thus undermining the viability of conservation tillage and its associated benefits.

Many recognized that RRW volunteers, in combination with RR canola volunteers, would cause cumulative adverse effects, increasing the potential for glyphosate resistant weeds and further undermining conservation tillage systems. HT volunteers are already primary determinants of risks associated with GM canola (Mauro and McLachlan 2008), are ubiquitous in field and roadsides (Knispel et al. 2008) and will be difficult to control in RRW (Mauro et al. 2005). A recent study suggests that RRW is best suited for regions where other RR crops are grown infrequently (Howatt et al. 2006). However, these cumulative effects are not presently recognized in risk assessment, as crops are evaluated on a 'case-by-case' basis (Nap et al. 2003).

Another farmer concern overlooked by conventional science-based risk assessment is an increasing corporate control over agriculture, which was identified as an important risk associated with RRW. Most respondents were against wheat seed patents, which they believed would increase costs while restricting their ability to save, exchange, and reuse seed. Currently, 76% of wheat seed in Canada is regularly saved by farmers (Kuyek 2007), which represents an untapped market for large seed companies, ten of which now own over 55% of commercial seed worldwide (USC and ETC 2008). Some argue that patenting seeds is the nexus for corporate control over all of agriculture, in turn forcing farmers onto a 'genetic treadmill' that increases their reliance on external inputs (Kloppenburg 2004). These changes in seed saving compromise generations of plant breeding by farmers, which helps prevent 'genetic erosion' and the loss of agricultural biodiversity (Fowler and Mooney 1990).

Yet, some farmers recognized that RRW had advantages. The most important benefits were associated with weed control, particularly for wild oat resistant to an important group of grass herbicide products (Group 1). Between 1996 and 1997, Group 1 resistant oat occurred in 50% of fields across the prairies, representing a significant threat to crop yields and quality (Beckie et al. 2001). RRW provides over 95% efficacy in controlling wild oat (Blackshaw and Harker 2002), and, as recognized in this study, generally, increased the ease of weed management in wheat production (Harker et al. 2005).

Farmers generally did not view other 'agronomic' benefits associated with RRW as important. They disagreed that RRW would increase yields, contrasting with field trial research that predicts up to a 10% increase in yields (Blackshaw and Harker 2002; Howatt et al. 2006). Nor did farmers see RRW providing cleaner grain, facilitating conservation tillage, early seeding, greater product uniformity, or crop safety as predicted by other studies (e.g., Wilson et al. 2003, Carter et al. 2005). Indeed, many were skeptical of expert-based research regarding RRW, in part reflecting their lived expertise, but also reflecting the broader public distrust of risk assessment regarding complex technology, especially GM crops (Taylor-Gooby and Zinn 2006).

Thus, trust in expert-based institutions was an important predictor of individual benefit and risk perception regarding RRW. Farmers perceiving high risk had low trust in government and corporations unlike those recognizing high benefit. This, in part, reflects the hostility of many farmers to the multinational corporations that have come to dominate agriculture. Other studies have also shown that trust in government (Barnett et al. 2007) and corporations (Siegrist 2000) are good predictors of 'lay' public attitudes towards genetic technologies. However, it is important to recognize that farmers have decade-long experiences with GM crops, and thus have a much more pragmatic and arguably relatively rich understanding of agbiotechnology. While the general public often employs trust in decision-making, this is especially important when there is a lack of direct information or experience regarding these technologies (Siegrist and Cvetkovich 2000). In contrast, farmer attitudes toward risk, trust, and experts regarding agriculture is highly influenced by their rich-lived expertise of these agroecosystems and the socio-cultural factors embedded in rural communities (Neufeld and Cinnamon 2004). The holistic nature of these knowledge systems was further emphasized by the importance of environment and community (i.e., social) concerns in determining heightened perceptions of risk associated with RRW, showing that environmental, social, and economic risks are inextricably intertwined.

Most respondents were also concerned about their lack of input in decision-making regarding RRW, which aggravated concerns about the technology. Although RRW has not yet been commercially released in Canada, it was field tested in undisclosed locations across the prairies. Moreover, the design of these plots was uncertain at best, such that associated buffer zones increased from 3 m in 2000 to 300 m in 2004 (Bell 2004). Most respondents in our study felt that they should have input regarding the location of these plots and were frustrated that the locations were hidden. 'Afraid of contamination', the Saskatchewan Area of Rural Municipalities passed a resolution in 2003 demanding that the locations of test plots be made public, so that farmers could assess whether they were at risk.

Widespread resistance to agbiotechnology is attributed, in part, to the lack of public involvement in policy and decision-making (Abergel and Barrett 2002) and farm organizations have been no exception, leading actions against the crop across Canada. These included ad campaigns in newspapers stating, 'we're not ready for Roundup Ready wheat' (Warick 2003) and 'the greatest threat to wheat farming isn't hail or drought, it's Roundup Ready wheat' (NFU et al. 2004), as well as a prairie-wide tour that engaged many rural communities regarding risks associated with the technology (Magnan 2007). In stark contrast to our findings and widespread Canadian farm organization resistance, the US National Association of Wheat Growers (NAWG) recently found that 76% of farmers across 30 states support biotechnology traits in wheat (NAWG 2009). This report was based on a single question that asked farmers to respond to a NAWG petition that advocated for and highlighted the benefits of biotech traits in wheat, and was affiliated with the biotechnology industry itself. Farmer concerns reflected in our study may have been further heightened by the imminent release of RRW which has now been withdrawn, at least for the immediate future. Yet, these contrasting results may also reflect a divergence in attitudes toward GM traits in wheat between American and Canadian farmers, a divergence which may ultimately adversely affect bilateral trade and regulation between the two countries.

5 Conclusions

This research is the first of its kind to include farmer knowledge in the a priori risk analysis of GM crops and, arguably, given its prairie-wide scope, is the largest scale independent-farmer-focused study on GM crops ever conducted. The surprising uniformity in attitudes between users and non-users of GM technology and among organic, conventional, conservation tillage and GM using farmers speaks to the ability of farmers to discriminate among HT varieties. Most of those farmers that were opposed to RRW were also users of, and therefore at least somewhat supportive of, HT canola. In contrast to this highly pragmatic view of agbiotechnology, the general public seems to evaluate the desirability of the technology according to ideology and concern regarding human and environmental health. Our outcomes suggest that this distinction arises from the lived expertise and experiences of farmers and their neighbors. The great majority of participants in this study felt that farmer knowledge would be useful in assessing the impacts of GM crops, for those that have already been planted and those that have yet to be introduced.

6 Recommendations and perspectives

These local knowledge systems are holistic in nature, incorporating socioeconomic, cultural, political, and agro-ecological factors that all can contribute meaningfully to the pre-release evaluation of GM crops. That this lived expertise generally contrasts strongly with expert science-based knowledge further suggests that it can play a complementary role in decision-making regarding existing and new forms of agbiotechnology. This is especially important when the consequences of these technologies are little understood, and particularly when they have the potential to create great socioeconomic and environmental harm. The inclusion of farmers and other stakeholders in decision-making regarding these issues will also help enhance and even restore public confidence in science-based approaches to risk assessment. Although farmers are clearly highly knowledgeable regarding RRW and arguably any agricultural technology, their expertise continues to be overlooked by decision-makers and regulators across North America.

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