NONPARAMETRIC ANALYSIS OF ATTITUDES TOWARD RISKY CROPS: A PLANT MOLECULAR FARMING CASE STUDY[1]

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ABSTRACT

Research on plant molecular farming (PMF) is supported by public and private sectors in Canada. This may lead to benefits of new or cheaper medicines, industrial products and foods, but also be the source of appreciable risks to food safety from contamination by PMF materials, as well as potential environmental risks and costs. This study uses data from a 2005 nation-wide Canadian survey to gain insights into citizens' perceptions of PMF benefits and risks. A series of nonparametric tests are conducted on ordinal survey data on risk and benefit assessments of respondents. PMF is not seen as a major threat to food safety or the environment, but as a moderate indirect risk. The use of PMF to produce better and cheaper medical drugs appears to have the best benefits-to-risks ratio, while using PMF to produce more nutritious and cheaper food has the least favorable ratio.

1. Introduction and Objectives

Plant biotechnology research is not confined to genetically-modified or genetically-engineered (GM/GE) food crops; it is directed also to plant-based production of non-food compounds, including medical and industrial products, commonly referred to as "plant molecular farming" (PMF). Few PMF products have been commercialized worldwide, but research trials of plant-based pharmaceuticals and industrial products have been occurring for some years. Research on PMF is typically supported by both public and private sectors. North American policy to regulate potential release and commercialization of PMF plants is under development.

Applications of PMF research are expected to involve both potential benefits and appreciable risks. Benefits could include large-scale, low-cost methods to produce new vaccines and pharmaceuticals and a variety of industrial products. However, concerns include the possibility of accidental contamination of the food chain by PMF materials, as well as potential environmental risks and costs from contamination of the natural environment and possible ingestion of PMF materials by wildlife (eg, see May, 1990; Veeman, 2009).

Public perceptions of safety are important aspects of social welfare. It is recognized that scientists' risk assessments ("quantitative risk" measures), which are necessary components of any effective risk management plan, do not always agree with public perceptions of risk ("qualitative risk"). It is difficult to determine the level of potential risk that is socially acceptable for a given potential PMF benefit because the risks and benefits of these applications are vaguely defined and, although some applications potentially could be widely distributed, some may be specific to narrow groups. These features highlight the prominent roles of ethics, politics and social issues in debates over emerging agricultural biotechnology applications and related public policy.

Understanding public views of these risks and benefits should aid in developing PMF policy and regulation (Huot, 2003). Little is known about public attitudes toward PMF research or applications. We use data from a 2005 nation-wide Canadian survey that sought insights into citizen's preferences for research directed to different types of plant biotechnology, including PMF applications and views of the related benefits and risks that are perceived to apply to these applications.

Nonparametric tests are conducted on ordinal survey data on ratings assessing both risks and benefits of various cited plant biotechnology applications. There are several reasons for our choice of nonparametric methods: these make relatively few assumptions, they tend to be widely applied, and are relatively robust. Consequently, they are often used to study people's attitudes, especially when these are expressed as rankings or ratings. Further, the methods chosen make it possible to reduce the problem of potential heterogeneity in scale use. On the latter point, it has long been known that survey respondents frequently vary in their use of rating scales (Cronbach, 1946; Lentz, 1938). While some individuals tend to use the upper portion of a rating scale, others use lower or middle portions. These ways of responding are referred to as “response styles” (Baumgartner and Steenkamp, 2001) and refer to a tendency to respond to questionnaire items independently of item content. (In contrast a “response set” indicates people’s desire to give a particular picture of themselves by the way they respond to questionnaire items, implying that their responses depend on the item content). Stylistic responding may inflate or deflate subjects' scores on measurement instruments and/or lead to erroneous conclusions about correlations between rating scores (Bagozzi, 1994).The nonparametric methods used in this analysis replace actual scores with their ranks, which mitigates potential scale usage heterogeneity. While our analysis uses Canadian data, the structure of the survey instrument and the nature of the inferences drawn are not country-specific and could be applied in a variety of settings.

2. Survey Instrument

Responses from 1574 respondents, aged 18 years or older, drawn from a national representative panel with the aid of an international market research company, provide the data analyzed in this paper. Based on existing literature on emerging applications of plant biotechnology and preliminary testing in focus groups, respondents were queried on risk, benefit and priority rankings for various types of GM crops and PMF applications.

Respondents were initially provided a brief summary of information on plant molecular farming. This provided definitions, together with examples of potential applications and potential risks. In the first set of questions (Q1) eliciting risk perceptions, opinions on a randomized listing of food risk issues were queried using a four point scale: “high risk,” “moderate risk,” “slight risk,” almost no risk’ and “don’t know/unsure” for: “bacteria contamination of food; pesticide residuals; use of hormones in food production; use of antibiotics; genetically modified/engineered crops to increase crop production; medicines made from plant molecular farming through genetic modification/engineering; genetically modified/engineered crops to increase nutritional quality of food; genetically modified/engineered crops to produce industrial products like plastics, fuel or industrial enzymes; BSE (mad cow disease); use of food additives; fat and cholesterol content of food.” A similar set of random-ordered questions (Q2) on possible environmental safety issues that might result from modern agriculture cited, in addition to the preceding five crop biotechnology applications, the following issues: “water pollution by chemical run-off from agriculture; agricultural waste disposal; soil erosion from agricultural activity; use of herbicides and pesticides; adverse effects of agriculture on biodiversity.”

The third set of risk perception questions (Q3) queried riskiness, overall, of three different PMF applications: “PMF to produce better and cheaper medical drugs; to produce better and cheaper industrial products; and to produce more nutritious and cheaper foods.” Using four-point attitude rating scales and the “don’t know/unsure” option, respondents were also queried on their beliefs concerning the extent to which contamination of food supplies and damage to the environment are major risks posed by PMF.

The fourth set of questions (Q4) queried potential benefits that might result from the preceding three types of PMF applications using a four point rating scale from “high benefit potential” to “almost no benefit potential” and “don’t know/unsure.” Using the same benefit scale respondents were also asked if they believed in benefits for Canada from the:

“Opportunity for Canada to lead and create job opportunities in a new industry;” and “Production of new drugs that may not be produced by conventional methods or increase in quantities of existing medical drugs at less cost.” People’s opinions on containment restrictions that should be put in place for PMF research were also queried (Q5). A sixth set of questions (Q6) queried views of the relationships between PMF benefits and costs by asking respondents to choose from seven assessments (from “risks probably significantly outweigh benefits” to “benefits probably significantly outweigh risks” plus “don’t know/unsure.”) A summary question on whether or not PMF should be pursued in Canada was also posed (Q7).

3. Major Statistical Methods

The Friedman test, or nonparametric two-way ANOVA, is the main inference instrument used in this paper. The test adjusts for scale use heterogeneity. It operates on the standard two-way layout:

$$X_{ij}^{*} = \mu + \beta_i + \tau_j + \varepsilon_{ij}, \qquad (1)$$

where X_{ij}^{*}, $i = 1...b,\ j = 1...k$, is the observed response of block (individual) *i* to treatment *j* (a rating item within a block of statements); μ is the common mean; β_i and τ_j are block and treatment effects, respectively, and ε_{ij} is an error term. Actual statement intensities X_{ij}^{*} in Equation (1) are not immediately observed; instead, scale rating scores X_{ij} that are observed are hypothesized to be the result of a mapping $f : \mathbf{R} \mapsto \{1,2,...,r\}$. That is, the unobserved $X_{ij}^{*} \in \mathbf{R}$ are mapped in a monotone manner to a set of *r* ordered discrete risk scores.

The Friedman test replaces the actual scores X_{ij}^* with their ranks (R_{ij}) for the whole set of alternatives (i.e. within blocks), which makes the test applicable for randomized complete block designs as in Equation (1). While using the actual scores can lead to dubious cardinality assumptions and can be vulnerable to scale usage heterogeneity, using ranks preserves only the ordinal nature of the data. Thus the test can be used with non-independent treatments (β_i, the block effects, are individual-specific). Consequently, it is not necessary to assume that a particular source of risk is independent of assessments of other risk issues. However, perceived risks are not directly observable, thus as applied in this study Friedman's test may have less power than if the underlying X_{ij}^* were available. Under the null hypothesis of all treatments having the same effect on respondents, the Friedman test statistic is distributed as a χ^2 variable with the degrees of freedom equal to the number of treatments minus one.

Associations between different measures of attitudes were evaluated using Kendall's concordance coefficient τ , a nonparametric association measure for a pair of variables, conceptually similar to correlation (Conover, 1999). This ranges between -1 and 1. Positive values (concordance) indicate that greater values of one variable correspond to greater values of the other, i.e. that the two change in the same direction. Negative values (discordance) indicate the opposite. Unlike the correlation measure of co-dependence, concordance is not limited to linear dependence and can be used meaningfully with arbitrarily associated variables. Other complementary tests (specifically the post-Friedman test of Dunn (1965), tests of equality of multivariate distributions by Szekely and Rizzo (2004; 2005), and tests of ambivalence/concordance by Gainous and Martinez (2005) and Thompson, Zanna, and Griffin (1995)) were also applied, as noted below.

4. Analysis, Results and Discussion

4.1. Risks to food

One major research question is: are GM/GE/PMF applications viewed by members of the public as more or less risky than other potentially risky practices of food production or other food safety threats? Information from 1284 complete scores (Q1) was available to compute the Friedman test statistic. With 11 treatments (i.e. the risk sources summarized in Table 1), there are 10 degrees-of-freedom for the test statistic. The value of the test statistic was 879.86, with associated p-value of nearly zero, indicating that the null hypothesis of differences in risk attitudes was soundly rejected in favor of the alternative hypothesis: at least one source of food risk was seen as more important than others. To assess possible clustering among risk sources, post-test paired comparisons were run using the technique of Dunn (1965). Average ranks ($\overline{R}_j$) and the summary of results from the two tests are presented in Table 1.

Table 1. Food Risks: Average Ranks and Comparisons

Source of risk	$\overline{R}_j$ [a]	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
Bacteria (a)	0.53	*	*	*	*	*	*	*	*		*
Pesticides (b)	0.43		*		*	*	*	*	*	*	
Hormones (c)	0.40			*	*	*	*	*	*	*	*
Antibiotics (d)	0.43				*	*	*	*	*	*	
GM crops (e)	0.48					*	*	*	*		*
PMF medicines (f)	0.59								*	*	*
PMF foods (g)	0.57							*		*	*
PMF industrial (h)	0.61								*	*	*
BSE (i)	0.55									*	*
Additives (j)	0.49										*
Cholesterol (k)	0.43										
Observations	1284										
Test statistic	879										
P-value	≈ 0										

[a] $\overline{R}_j$ are risk ranks (R_{ij}) averaged across the sample. Values closer to 1 indicate lower risk.
[b] Asterisk ('*') indicates statistically different sources of risk at least at 0.01 significance level from Dunn's post (Friedman) tests.

For comparability across similar questions, average ranks were transformed to fall in the interval [0, 1]: $\overline{R}_j \leftarrow \frac{\overline{R}_j - R_{\min}}{R_{\max} - R_{\min}}$, where $\overline{R}_j$ is the average rank for item *j* and $R_{\max}, R_{\min}$ are the maximum and minimum possible ranks, respectively. The closer is the transformed value to unity, the lower is the perceived risk. It can be seen that PMF medicines/foods/industrial products appear to be the least significant perceived sources of risk among the queried food risk issues. It is also of interest that the use of genetically modified/engineered crops to increase crop production is seen as more risky than these three types of PMF applications, as well as being riskier than some of the other cited food risk issues (specifically BSE and bacteria contamination).

The transformed rankings ($\overline{R}_j$ in Table 1) indicate that PMF medicine and nutritionally improved foods are seen as equally risky (ie, are not significantly different). Overall, PMF for industrial products is seen as the least risky PMF application. The highest food risk was perceived from using hormones in food production (0.40 rank), followed closely by concerns about pesticides, antibiotics, and high cholesterol foods (each ranking 0.43). Replacing actual risk scores with their within-block ranks helps remove block (individual-specific) effects β_i. However, Equation (1) does not include possible interactions between treatments and blocks. These may, if present, involve the influence of respondents' demographic characteristics on treatment effects. A convenient way to test for interactions involves testing for identical distributions of ranks in two or more sub-samples of interest into which respondents are grouped. A nonparametric test of equality of two or more multivariate distributions, reported by Szekely and Rizzo (2004; 2005), was applied to assess such possible interactions. The test E-statistic is based on Euclidian distance between sample elements and the test itself is a derivative of the bootstrap permutation test (Efron, 1993). As indicated in Table 2, groupings based on gender and education gave distinctively different distributions of risk score ranks. However, a rural-urban grouping did not show differences. We conclude that respondents' gender and education play a role in their assessments of food risk issues in Q1.

Table 2. Food Risks: Respondent Groups.

Groups	Composition	E-statistic (p-value)
Gender	Male (49%) vs. female (51%)	22.911 (0.009)
Residence location	Rural (33%) vs. metro area (67%)	14.305 (0.177)
Education	College+(43%) vs. before college (57%)	22.742 (0.008)

The influence of gender and education on food risk assessments is also demonstrated in Table 3 which gives the average ranks for each food risk issue by these two groups. Men and those with more education tended to rate the use of genetically modified/engineered crops to increase crop production and the use of PMF for industrial products as less risky than did other groups of individuals. With some exceptions, there is a tendency for lower levels of risk to be assessed by male and college-educated respondents.

Table 3. Food Risks: Average Ranks by Group.

	$\bar{R}_j$ [a]			
Source of risk	Gender		College+	
	M	F	Yes	No
Bacteria	0.52	0.54	0.53	0.53
Pesticides	0.44	0.42	0.41	0.45
Hormones	0.40	0.40	0.39	0.41
Antibiotics	0.43	0.43	0.41	0.44

GM crops	0.49	0.47	0.50	0.47
PMF drugs	0.59	0.59	0.60	0.58
PMF foods	0.56	0.57	0.57	0.56
PMF industrial	0.62	0.60	0.63	0.59
BSE	0.55	0.54	0.54	0.55
Additives	0.50	0.47	0.49	0.49
Cholesterol	0.41	0.45	0.44	0.42

[a] $\overline{R}_j$ are risk ranks (R_{ij}) averaged across the sample. Values closer to 1 indicate lower risk.

Histograms of risk rank distributions for PMF used to produce medicines, industrial products and nutritionally improved foods, assessed for both male and female respondents and for those with and without college education, also show differences in skewness, reflecting tendencies for lower levels of risk to be assessed by male and college-educated respondents[2]. However, there tend to be higher levels of variation of ranks for these groups. This is also the case for risk assessments of genetically modified/engineered crops to increase crop production.

4.2. Risks to the environment

Respondents were queried in Q2 on perceived risks to the environment from various agricultural practices, including GM/GE/PMF applications. To test the research question: "are applications of crop biotechnology, including PMF applications, seen as more or less risky from respondents' points of view, as compared to other potential risky agricultural practices," the Friedman test was applied to the 1304 available responses to Q2. The test statistic was 1690, with a p-value of nearly zero, indicating rejection of the no-difference null hypothesis with almost absolute confidence. These results are summarized in Table 4. PMF applications are seen as less risky than other cited sources of environmental damage. No

[2] These are available on request from the authors.

PMF treatment differs from the others at the test confidence level (< 0.01). The most prominent sources of perceived environmental risks from agriculture are chemical run-offs and related use of pesticides and herbicides (each ranked as 0.31, in contrast to the PMF applications which range from 0.59 to 0.61). Consistent with the rank-ordering of perceptions of food risks, the environmental riskiness of genetically modified/engineered crops to increase crop production is seen as more risky (in this case with an average rank of 0.53) than any of the three cited PMF applications, and with an average rank equivalent to the adverse effects of agriculture on biodiversity.

Table 4. Risks to the Environment from Agriculture: Average Ranks and Comparisons.

Source of risk	$\overline{R}_j$ [a]	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
Chemical runoff (a)	0.31	*	*	*	*	*	*		*
GM crops (b)	0.53		*	*	*			*	
PMF medicines (c)	0.60					*	*	*	*
PMF foods (d)	0.59					*	*	*	*
PMF industrial (e)	0.61					*	*	*	*
Waste disposal (f)	0.51							*	*
Soil erosion (g)	0.51							*	*
Herbi/pesticides (h)	0.31								*
Biodiversity (i)	0.53								
Observations	1304								
Test statistic	1690								
P-value	≈ 0								

[a] $\overline{R}_j$ are risk ranks (R_{ij}) averaged across the sample. Values closer to 1 indicate lower risk.
[b] Asterisk ('*') indicates statistically different sources of risk at least at 0.01 significance level.

4.3. Potential risks of PMF applications considered alone

Question 3 allows consideration of whether, despite differences in context and wording, respondents' perceptions of risks of contamination of food supplies and damage to the environment by PMF are consistent with opinions stated in Q1 and Q2. For the Q3 questions on the extent of risk from PMF for food contamination and environmental damage, the Friedman test statistic was 122.34, with a nearly zero p-value, giving rejection of the null hypothesis of no difference of the cited risk factors with almost absolute confidence. Dunn's post-test revealed that risk perceptions expressed in Q3 for the three cited PMF applications were significantly different (p-value < 0.01). The transformed average ranks (as before, higher ranks indicate less riskier uses) are presented in Table 5.

Table 5. Potential risks of PMF applications considered alone.

PMF application field	Q1	Q2	**Q3**
Production of better and cheaper medicines	0.59	0.60	**0.57**
Production of more nutritious and cheaper foods	0.57	0.59	**0.47**
Production of better and cheaper industrial products	0.61	0.61	**0.62**

[a] $\overline{R}_j$ are risk ranks (R_{ij}) averaged across the sample. Values closer to 1 indicate lower risk.

The Q3 rankings are generally consistent with those from Q1 and Q2. Use of PMF to produce better and cheaper industrial products is seen as relatively safest, followed by improved PMF-derived medicine. Again, the most risky use of the PMF applications is attributed to food production. Considering the three PMF applications queried in Q3 alone (omitting other risky practices) indicates more differentiation in people's risk attitudes toward these applications than is indicated in the responses to the first two sets of questions.

In parallel questions to Q3, Question 4 asked respondents to rank the potential benefits from PMF to produce: better and cheaper medical drugs; better and cheaper industrial products; and more nutritious and cheaper foods. The Friedman test statistic is 186.28, rejecting the null hypothesis of no difference between these responses. Dunn's post-test reveals that perceptions of potential benefits significantly differ between the applications to produce medicines versus foods and industrial products (p-value < 0.01). The transformed average ranks (for which higher ranks indicate more beneficial uses) are:

- PMF to produce better and cheaper medicines: 0.60,
- PMF to produce more nutritious and cheaper foods: 0.46,
- PMF to produce better and cheaper industrial products: 0.44.

Pharmaceutical uses of PMF are assessed as the most beneficial application by far, although, as recognized in responses to Q3, this application is recognized not to be the safest of these PMF applications. Production of PMF food and industrial products is not seen to be as beneficial as PMF applications for medicine, but PMF for industrial products is perceived as the safest application. The order of ranking of benefits assessed for the three types of applications are not identical to the order of their risk rankings. Rankings of benefits from production of improved and cheaper PMF foods are somewhat higher than for production of industrial products. However, the food category has the worst benefit-to-risks ratio (0.46:0.47) of the three PMF applications, while PMF medicines fare best (0.60:0.57). We note that benefit-to-risk rankings cannot readily be interpreted as benefit-to-cost ratios because, despite using the same types of scales, the concept of "risk" is not the same as "benefit" with a different sign, as "losses loom larger than gains" (Kahneman and Tversky, 1979). Our results are consistent with previous findings of generally positive attitudes toward medical PMF applications and dislike of GM/GE applications in food production observed for European consumers from studies using the Eurobarometer survey (see Costa-Font and Mossialos, 2005; Gaskell et al., 1999).

The additional queries of Q4 included two additional benefit-related questions, specifically whether respondents perceived benefits from "the opportunity for Canada to lead and create job opportunities in a new industry", and their belief in "benefits from new drugs that might not be produced by conventional methods or increases in quantities of existing medical drugs that might be produced at lower cost." The Friedman test statistic was 4.72 (p-value about 0.2), so the null hypothesis of no difference in responses to the two questions is not rejected. Apparently, survey respondents do not see an appreciable difference in PMF-derived potential benefits of new jobs, versus increased capacity to produce cheaper new medicines.

4.4. Containment of PMF plants

Question Q5 asked respondents to vote for one of six forms of containment restrictions that should apply to PMF research. These ranged from "allow to be grown in fields like conventional crops" (least restrictions) to "allow only in completely sealed facilities (e.g., underground)" (most restrictive). Kendall's concordance measure was calculated between the ranks in the first two risk-related questions Q1, Q2, and the required level of containment as indicated in people's responses to Q5 (see Table 6). These indicate a sharp contrast in levels

Table 6. Concordance between Risk Ranks and PMF Plant Containment Requirements.

	Risks to food supply (Q1)			Risks to the environment (Q2)		
	PMF drugs	PMF foods	PMF products	PMF drugs	PMF foods	PMF products
PMF using food crops to produce medicinal drugs	-0.04 (0.577)	-0.03 (0.166)	-0.04 (0.312)	0.13 (0.172)	0.40 (0.062)	-0.01 (0.822)
PMF using non-food crops to produce medicinal drugs	0.05 (0.333)	0.02 (0.725)	-0.01 (0.932)	0.21 (0.162)	0.25 (0.141)	0.15 (0.143)
PMF using food crops to produce industrial products	-0.03 (0.434)	-0.02 (0.211)	0.03 (0.175)	0.24 (0.071)	0.36 (0.006)	-0.04 (0.748)
PMF using non-food crops to produce industrial	0.03 (0.631)	0.01 (0.983)	-0.01 (0.905)	0.19 (0.242)	-0.07 (0.537)	0.24 (0.074)

products						
PMF using food crops to improve nutritional quality of foods	0.07 (0.256)	0.09 (0.146)	0.05 (0.176)	0.35 (0.051)	0.61 (0.024)	0.37 (0.042)

[a] Positive values indicate positive association: “higher risk means stricter containment requirements”. P-values are in parentheses.

of association between Q1 and Q5 as versus Q2 and Q5. Interestingly, the estimated concordance measures for Q1 and Q5 vary in sign and are all small (the maximum value is 0.09) and insignificant. This may suggest that risks of food supply contamination by PMF are not perceived to be related to how carefully PMF research plants are separated from conventional plants. In contrast, the estimated concordance measures for Q2 and Q5 are mainly positive, sometimes quite large (the maximum value is 0.61), and mainly significant at 10%. It appears that environmentally-conscious respondents were generally also concerned to have a high level of precaution in containment of PMF research plants.

4.5. Attitudes to PMF overall

Questions Q6 and Q7 summarize respondent's attitudes, overall, to PMF activities. Specifically, Q6 provided respondents the opportunity to weigh the pros and cons of PMF activities by indicating whether and to what extent PMF benefits exceed PMF risks. As an extension that seeks to sum up individuals’ assessment of PMF activities, Q7 asks if PMF should be pursued in Canada. It is of interest to test whether respondents were consistent in these two different assessments.

The regular (Pearson) correlation between the responses to the two questions is not a suitable measure of dependence for this purpose, since both questions solicited qualitative (but ordered) responses. Concordance, the tendency of two factors to change co-directionally, was measured and tested against the null hypothesis of responses to Q6 and Q7 being unrelated. To this end, Kendall's statistic was calculated and tested against zero: the null hypothesis is that neither concordance nor discordance are present.

The ordering in Q6 is apparent and responses to Q7 were coded for consistency with this test. The obtained value of Kendall's statistic was 0.406 (1396 complete responses available). The null hypothesis of no relationship between responses to Q6 and Q7 was soundly rejected with a p-value nearly zero. That is, there was a strong tendency among those respondents for whom PMF benefits outweigh risks to vote for PMF being pursued in Canada (and vice versa).

Nearly 25% of respondents who had given definite responses to questions Q3 and Q4 (risks and benefits of three different types of PMF applications), said they did not know or were unsure whether PMF should be pursued in Canada. Indecision in stated preference questions may have various causes (Bateman and Willis, 1999); two that are frequently cited are general unfamiliarity with the issue and ambivalence.

A recent study (Costa-Font and Mossialos, 2005) found that between 35% and 45% of European respondents displayed ambivalent attitudes towards biotechnology applications. The design of questions Q3 and Q4 allows assessment of the extent to which ambivalence about PMF may have caused indecision with respect to the Q6 assessment of whether PMF activities should be pursued in Canada. Ambivalence was measured from responses to Q3 and Q4 using the index method of Gainous and Martinez (2005) and Thompson, Zanna, and Griffin (1995):

$$I_j = \frac{Risk_j + Benefit_j}{2} - | Risk_j - Benefit_j |, \qquad (2)$$

where I_j is the ambivalence index for a PMF use *j*, and $Risk_j, Benefit_j$ are the scores obtained from questions Q3 and Q4. The ambivalence index ranges from -0.5 to 4 with intervals of 0.5. Risk and benefit scores were obtained by subtracting the initial responses from 5 so that the benefit/risk would increase with the score. Responses from Q7 were recoded so that 1 indicates indecision ("don't know/unsure") and 0 indicates a "yes" or "no" answer. Kendall's statistic was again used to test for absence of relationship between each of the constructed ambivalence indices and the indecision indicated in Q7 responses. The values of Kendall's association measures for these tests for the three types of PMF applications are:

- PMF to produce better and cheaper drugs: 0.088,
- PMF to produce more nutritious and cheaper foods: 0.077,
- PMF to produce better and cheaper industrial products: 0.073.

In all cases, the p-value of the test is below 0.0001, indicating a positive, though not strong, association between the ambivalence index and indecision of respondents on whether or not PMF should be pursued in Canada.

5. Concluding Remarks

The following conclusions can be drawn from the findings discussed in the previous section.

1. Survey respondents did not see PMF as major potential sources of food contamination or damage to the environment.
2. Even so, PMF was seen as the source of some risk. Average ranks for PMF risks were in the range of 0.4-0.6, corresponding to respondents' assessments of "slight" to "moderate" risk scores.
3. The use of genetically modified/engineered crops to increase crop production was seen as more risky than the various PMF applications. This finding is in accordance with observations, from risk perception literature, that activities that are perceived to have little benefit tend to be seen as more risky.

4. The use of PMF to produce better and cheaper medical drugs is viewed as having the best benefits-to-risks ratio, while using PMF to produce more nutritious and cheaper foods has the least favorable benefits-to-risks ratio.
5. Finally, consistent assessments of risks and benefits were found from several somewhat different sets of questions.

These findings suggest somewhat mixed feelings of Canadian citizens regarding PMF. While not seen as major threats to food safety or damage to the environment, the PMF applications considered are seen as moderate indirect risks. While use of PMF to produce more nutritious and cheaper food is not seen as highly risky, this does not have as favorable a benefits-to-risks ratio as for medicinal or industrial applications of PMF. This feature may not be surprising given that there tends to be a general lukewarm feeling by many (and active opposition by some) toward GM/GE foods in Western countries. Yet, the survey found that, overall, Canadians generally tend to be relatively comfortable with PMF applications, particularly if this relates to medical and industrial uses, but also if this leads to improvements in nutrition and price of food.

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