Consumers' Willingness-To-Pay for RNAi versus Bt Rice:
Are all biotechnologies the same?

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Abstract

Consumers' valuation of food products derived from Genetically Modified Organisms (GMOs) have played a pivotal and often constraining role in the development of biotechnology advances in agriculture. As a result, agricultural companies have started exploring new biotechnologies that do not require the genetic modification of crops. One of these emerging biotechnologies is a non-GMO RNA interference (RNAi) liquid application that could be used to control specific insect pests. When ingested by a targeted sub-species of an insect during production, RNAi blocks the expression of a vital gene, which in turn kills it. RNAi is non-toxic to humans and kills only targeted sub-species of insects, which differs from most conventional pesticides. For example, RNAi could selectively eliminate a specific sub-species of caterpillar pest, while not harming a monarch butterfly caterpillar. In contrast, conventional pesticides often kill insects indiscriminately and vary in human toxicity levels. Since agricultural producers and researchers have faced opposition to GMOs, this may be an alternative to controlling commonly encountered insects; however, consumers' valuation of traditional GM compared to RNAi derived foods has not been evaluated in the scientific literature. Thus, we conducted a Willingness-To-Pay (WTP) survey in the USA, Canada, Australia, France, and Belgium to analyze whether consumers need a premium or discount for: (1) a hypothetical **GMO** rice using the ***Bacillus thuringiensis* (*Bt*)** gene for insect control; and (2) a hypothetical **non-GMO** rice using **RNAi** for insect control. Since there is currently no commercially-available GMO rice, measuring consumers' valuation of rice produced by alternative biotechnologies provides vital information for crop breeders and policy makers. The results suggest that consumers require a discount for RNAi and *Bt* rice compared to a conventionally produced rice, but the discount

required for the non-GMO RNAi rice was 30-40 percent less than that needed to purchase GMO *Bt* rice ($p < 0.01$).

Introduction

Agricultural scientists have developed biotechnologies such as Genetically Modified Organisms (GMOs) to help increase agricultural production. By 2050, agricultural production needs to grow by 70 percent to meet the projected increase in global food demand (FAO 2009), and this has to happen with a reduction in environmental impacts and resource use (Tilman et al. 2011). Agricultural biotechnologies such as GMOs have helped producers increase production and improve resource use efficiency (Taheripour et al. 2015), and these advancements may be some of humanity's greatest assets in minimizing food insecurity and meeting global food demand by 2050 (Godfray et al. 2010). However, due to varying government regulations and opposition to GMOs primarily in the European Union (Davison 2010), biotechnology solutions involving GM crops have been limited mostly to *Z. mays* (maize), *G. max* (soybeans), and *G. hirsutum* (cotton). Traditionally, these crops are not consumed in their unprocessed form, but instead they are used as fiber and fodder, or processed into various indistinguishable food ingredients.

In contrast, staple foods such as rice and wheat are field-to-plate crops, consumed in a similar form as when they are harvested from the field. Even though the biotechnology exists to increase yields and strengthen resistance packages for biotic and abiotic stresses, there has been no commercial release and production of GMO rice or wheat globally. This is primarily because of regulations and a fear that consumers' resistance to GMO technology will stifle sales and exports. For example, *Bacillus thuringiensis (Bt)* rice has been grown successfully in field trials and proved effective against certain insect pests (Tu et al. 2000). It was also tested and confirmed to be of dietary equivalence to conventional varieties (High et al. 2004), yet it is not available for commercial production. To further illustrate this point, *Golden Rice* was developed as a micronutrient enriched crop to help alleviate Vitamin A deficiency (VAD). Though created as a GM under the company Syngenta, *Golden Rice* technology was donated to a non-profit for humanitarian use in lower-income countries with high frequencies of VAD. Still, countries such as the Philippines and India do not produce *Golden Rice* due to the negative publicity and lobbying efforts conducted by anti-GMO organizations.[1]

Since public perception and consumer acceptance have played crucial and often negative roles in the development, dissemination, and use of GMOs in agricultural production, agricultural companies have begun exploring biotechnology applications that do not require the genetic modification of crops, and at least for now, do not fall under the same stringent regulatory protocols of GMOs in places such as Europe. One of these prospective technologies being developed for commercial release by industry uses RNA interference (RNAi) to control target pests.[2] RNAi is a biological mechanism used to selectively silence or block the expression of a specific gene in a target organism (such as the sub-species of an insect) in order to derive a particular benefit, which in this case is the death of the targeted sub-species. RNAi has been used extensively in medical and agricultural biotechnology applications since its discovery by Fire et al. (1998), who received a Nobel Prize in 2006. In many cases, RNAi has been used as an integral tool in the genetic modification of crops (Saurabh et al. 2014), such as introducing the non-browning characteristic in the Arctic Apple (Waltz 2015) and virus resistance in various

[1]http://www.slate.com/blogs/future_tense/2013/08/26/golden_rice_attack_in_philippines_anti_gmo_activists_lie_about_protest_and.html

[2] Although RNAi as a non-GM application does not undergo GMO regulations, its evaluation as a pesticide is still required. Monsanto's BioDirect is an example of industry developments that use RNAi as distinct from a component of GMO applications. http://www.monsanto.com/products/pages/biodirect.aspx.

other crops (Waterhouse et al. 1998). More recently, scientists have begun exploring how to use RNAi as a non-GMO biological control for pests in crop production. RNAi has the potential to be sprayed on crops to control for specific, targeted pests by suppressing vital genes in the target pest upon ingestion. In this case, the genetic code of the crop is not altered by RNAi as in the case of former uses of RNAi. Furthermore, RNAi as a liquid application would leave no residual pesticide in the environment, which is a problem with many conventional pesticides (Miyamoto et al. 2013). GM pesticides such as *Bt* introduce an insecticidal protein into the crop itself, and though never observed in past studies, it is possible the *Bt* could create an allergic reaction in a consumer. The introduction of potential allergens into crops is one of the main drivers of anti-GMO lobbies. This potential exists because most food allergies come from an individual's reaction to large protein molecules (Huby et al. 2000). With RNAi, no proteins are created in the plant, and in fact, RNAi often suppresses the creation of particular proteins. So while *Bt* could cause allergic reactions due to an introduced protein, RNAi removes the possibility for an allergen to develop.

This usage of RNAi could be a solution for agricultural biotechnologists looking for ways to forego the GM regulatory process, as well as appease an increasingly skeptical consumer base. However, throughout 2015 a number of blogs and online news producers devoted attention to non-GMO RNAi spray technology, questioning its acceptance by the public (Jacobs 2015; Regalado 2015). These articles discussed industry developments of RNAi spray as a non-GMO product (Monsanto's BioDirect line is one example of this), but the authors also note that consumer acceptance is yet unknown, even to the public relations staff of these companies. Even though RNAi could provide a more generally accepted alternative to GMOs in biotechnology R&D, no academically-rigorous study of RNAi acceptance or willingness-to-pay (WTP) has been carried out until now. Our study uses observations collected from the USA, Canada, Australia, Belgium, and France in order to represent a range of consumer preferences under varying regulatory regimes. The USA, Canada, and Australia tend to be more accepting of GMOs in terms of production and consumption, while Belgium and France tend to be more averse (Delwaide et al. 2015). We described the technologies to survey respondents as having insecticidal attributes in rice production and compared the technologies to a conventionally-produced rice variety. In the survey, we use the hypothetical market availability of *Bt* and RNAi rice to compare consumers' valuation of GMO and RNAi biotechnologies with conventionally-grown, non-GMO rice.

Methodology

Consumers increasingly value food products based on production characteristics, which has direct implications for both producers and the agricultural marketing industry. In recent years, GMOs, organic foods, and animal welfare are a few of the sensitive issues highlighted in the public sphere as well as in research (Klümper and Qaim 2014; Lusk et al. 2005; Murray and Maga 2016). To better understand the prominence of these issues among consumers, we conducted a WTP survey to elicit consumers' valuation for different types of GMO and RNAi rice in the USA, Canada, Australia, Belgium, and France. A similar survey conducted by Delwaide et al. (2015) focused on the difference between cisgenic, another potential GMO alternative, and transgenic rice in consumers' WTP in five European countries. The survey was replicated in India and Ghana (Shew et al. 2016; Tsiboe et al. 2015). In January 2016, we administered an online survey with a Multiple Price List (MPL) through Survey Sampling International (SSI) in the USA, Canada, Australia, France, and Belgium, and used an interval regression model to estimate consumers' WTP for a non-GM rice variety produced with RNA interference technology compared to a GM *Bt* rice variety with similar insecticidal characteristics.

In the survey, respondents first read an introductory paragraph:

> Rice is a staple food for more than three billion people worldwide. Scientists have estimated that up to 37% of rice yields may be lost to pests and diseases.[3] These yield losses and pest problems affect the quality and affordability of rice globally, and can create food insecurity for many of the world's poor. Rice producers often use synthetic insecticides to address these issues, and some of those insecticides are considered toxic to human health. Scientists have created two technologies to help manage caterpillar pests in rice production without using synthetic insecticides. Currently, neither of these technologies is used commercially. We are interested in how you value these prospective technologies when compared to rice grown using synthetic insecticides.

After this, two information sets were presented to all respondents where they chose between a conventional rice at varying prices and an alternative rice (non-GM RNAi or GM *Bt*) at a fixed price. In the first information set, respondents provided their WTP for one of the two randomly selected technologies, RNAi rice or *Bt* rice. Then, in the second information set, they decided between the remaining alternative rice and conventional rice. The conventional rice in both information sets was described as:

> Conventionally-produced non-Genetically Modified rice uses broad-spectrum, synthetic insecticides to control caterpillars and other rice pests. These insecticides tend to kill indiscriminately. The synthetic insecticides also vary in their toxicity levels for humans.

This was followed by the RNAi and *Bt* rice descriptions in the respective information sets. The RNAi rice was described as:

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[3] Savary, S., et al. 2000. Rice pest constraints in tropical Asia: quantification of yield losses due to rice pests in a range of production situations. Pl. Disease. 84[3]:357-369. Also noted at—IRRI Article.

> RNA interference (RNAi) is an emerging technology that would be sprayed on rice plants to control for specific species of caterpillar pests. The spray is toxic to only a specific, targeted caterpillar species. Therefore, beneficial and other non-target insects would not be harmed by the spray. When a targeted caterpillar pest consumes the RNAi spray while feeding on the rice, the RNA suppresses the expression of an insect gene through RNAi. This suppression of a gene that is vital to the insect's survival results in the death of the targeted insect. The technology is non-toxic to humans because the RNA is digested naturally in the human gut. This RNAi technology does not genetically alter the plant; thus, the plant is not Genetically Modified, and the RNAi breaks down naturally in the environment.

And in the other information set, the *Bt* rice was described as:

> *Bt* rice has been Genetically Modified by the insertion of a gene from a naturally occurring *Bacillus thuringiensis* bacterium. The new gene in *Bt* rice produces a protein that is toxic to caterpillar pests when they consume part of the rice plant. Beneficial and other non-target caterpillars could also be harmed by the *Bt*. Proteins are the natural cause of allergic reactions and *Bt* rice could be allergenic for some people, though this has never been observed. Seeds produced by *Bt* rice after the first generation also contain the insecticidal proteins. While *Bt* rice is not commercially produced, over one billion acres of other *Bt* crops have been grown globally since 1996 and have an extensive and documented history of safe human consumption.

The respondents were asked to select the rice they would purchase at the presented prices if they were purchasing a 5 lbs. (2.5 KG) bag of non-fragrant long grain white rice. The alternative rice varieties (either non-GMO RNAi or GMO *Bt*) were presented at a fixed price of $5.00, which was an approximate per pound price for rice at the time of the survey, and the conventionally-produced rice began at $25.00. So long as respondents selected the alternative variety, the conventional price would descend but when they selected the conventional variety, the next information set was presented. The price of the conventional variety descended through 11 intervals in each information set in this order: $25.00, $20.00, $15.00, $10.00, $7.50, $6.25, $5.00, $4.00, $3.00, $2.00, and $1.00. The starting value of $25.00 was chosen based on the highest price per pound of organic rice available at the time of the survey. These prices were converted to respective currencies in each country based on the following exchange rates: EUR 0.92, CAD 1.40, and AUD 1.42, and rounded to the nearest 0.50 in the respective currency.

Based on respondents' selections, we derived consumers' WTP for RNAi versus *Bt* rice using an interval regression model. There were 400 respondents in Australia, 399 in Canada, and 400 in Belgium and another 439 each from France and from the USA. Before launching the full survey, pre-tests of 40 surveys were conducted in the USA and France to ascertain whether the selected prices and descriptions seemed appropriate. Based on these responses, there was no significant clustering at the highest and lowest price levels. As a result, no changes to the survey were made, so these pre-test surveys were included in the final analysis of WTP. Demographic data gathered in the survey included gender, age, education, income, and the number of children in each household. Consumers' WTP was estimated using an interval regression model that included those demographic variables. The WTP model is represented by Equation (1):

$$Y_i^* = \beta_0 + \beta_1 Information_i + \beta_2 Age_i + \beta_3 Children_i + \beta_4 Education_i + \beta_5 Income_i + \beta_6 Gender_i + \varepsilon_i, \quad (1)$$

where β_0 is a constant intercept term and the other β_j are vector coefficients for respective demographics that are included as categorical variables. The estimated constant (β_0) is WTP for RNAi (presented in the first set of information) by a male, with an income below $20,000, high school education or less, no children, and under age 30; the base level for all countries was equivalent to these USA categories. The $5.00 fixed price (the price of the alternative rice) was subtracted from all responses prior to estimation so that coefficients represent premiums or discounts from a conventionally produced non-GMO rice variety. Each respondent provided WTP for both RNAi and *Bt* rice (elicited in a random order). These observed WTP were included in the sample along with variables representing ordering effects. Coefficients were estimated by maximum likelihood with clustered standard errors to account for multiple observations from a given respondent. However, in this study, only results from the first information set are discussed, since this captures a respondent's initial reaction to the RNAi or *Bt* rice products. Lastly, the survey inquired whether respondents would consumer food produced with RNAi and *Bt* technologies respectively, and a McNemar test was conducted using matched pairs to determine if there were statistical differences in respondents' choices.

Results

From the interval regressions for each country presented in Table 1, we found that the USA demanded the largest discount to purchase RNAi rice at an estimated $7.62 below the conventional rice for the base categories ($p < 0.01$). This implies that the USA is more averse to RNAi than other countries. However, in all countries, the consumer discount needed to purchase *Bt* rice compared to conventionally-produced rice was significantly greater than that needed for consumers to purchase RNAi rice ($p < 0.01$). The USA, Canada, Australia, France, and Belgium needed discounts of $12.56, $8.97, $7.95, $13.35, and $8.66 respectively to purchase the *Bt* rice, and all were significantly different from the discount required to purchase RNAi rice ($p < 0.01$). The discounts required for RNAi rice for the base demographic categories was $7.62, $4.38, $4.24, and $4.92 for the USA, Canada, Australia, and France respectively. In Belgium, consumers in the base demographic categories valued the RNAi rice at -$0.05 compared to conventional rice, which means it was nearly equivalent and possibly warranted a small premium. With exception to the RNAi rice in Belgium, these results are relatively consistent with other WTP studies for GMO food in the USA, France, and other countries (Delwaide et al. 2015; Lusk et al. 2005).

Moreover, of all the demographic variables included, age was the only significant category for all countries; in all countries except for Belgium, the results show that people ages 50 and older would actually pay a premium for RNAi compared to the lowest age category ($p < 0.01$). Furthermore, having a Bachelor degree in the USA led to a decrease of $4.81 in the required discount compared to the base education level of high school or less ($p < 0.01$), bringing the WTP discount for RNAi to $2.81. Similarly, a Bachelor degree in France led to a decrease of $4.45 in the discount compared to the lowest education level ($p < 0.05$). Most demographic variables were not significant in the model. Thus, the major finding of this study was that in all countries RNAi was more palatable to consumers than *Bt* when compared to a conventionally-produced rice, though RNAi still required a discount for consumers when compared to the conventionally-produced rice.

Table 1. Interval Regression on Consumers' WTP for RNAi and *Bt* Rice compared to a conventionally-produced rice variety.

	USA	**Canada**	**Australia**	**France**	**Belgium**
Intercept	7.62**	4.38*	4.24*	4.92*	-0.05
Information					
RNAi (Order 1)					
Bt (Order 1)	4.94**	4.59**	3.71**	8.43**	8.71**
RNAi (Order 2)	1.96	1.47	0.83	3.61*	4.47**
RNAi (Order 2)	1.64*	2.61**	1.60*	4.25**	7.88**
Age					
Less than 30 years old					
30 - 39 years old	-1.56	-3.81*	-2.38	2.09	2.16
40 - 49 years old	-3.38	-3.90*	-6.97**	-3.98*	-3.70
50 - 59 years old	-7.83**	-6.67**	-5.74**	-6.53**	-5.30*
60 +	-8.16**	-5.19**	-7.17**	-8.14**	-4.26
Children					
None					
One or more	4.82*	3.81*	1.55	0.93	0.14
Education					
High School and Below					
Trade School/Some College	-1.98	0.26	2.37	-1.59	1.48
Bachelor Degree	-4.81**	0.87	2.74	-4.45*	-1.60
Higher than Bachelor	-0.72	2.23	3.31*	-2.88	0.07
Income					
Less than $20,000					
$20,000 - $34,999	2.73	-0.66	2.57	1.61	2.06
$35,000 - $49,999	0.18	0.64	-1.86	1.39	-0.21
$50,000 - $69,999	3.11	-1.67	-0.49	4.86	3.48
$70,000 or more	4.02	0.77	-0.13	2.41	5.19
Gender					
Male					
Female	-2.62*	0.06	-0.60	-2.14	-1.40
Sigma[1]	12.25	11.43	11.07	14.33	15.60

[1] *Sigma* is an estimate of the error term from equation (1).
* Significant at the p < 0.05 level.
** Significant at the p < 0.01 level.

In the survey, we asked respondents directly if they would consume food produced with both RNAi technology and *Bt* technology because scientists are combining these technologies for more effective insect management strategies. If they respondent answered “No”, two questions followed, one asking respondents if they would consume food produced only with *Bt* and one asking if they would consumer food produced only with RNAi. These three questions were included to gauge consumers’ acceptance of each biotechnology in food production. In the USA, Canada, Australia, France, and Belgium, 74, 74, 69.5, 48, and 49.5 percent of respondents in each country respectively said they would consume food produced with both RNAi and *Bt* technologies. In contrast, 6, 8, 10.5, 14, and 10.5 percent of respective respondents said they would consume food produced with RNAi technology only, and a 2, 0.5, 2.5, 3 and 4 percent said they would consume food produced with *Bt* technology. In all countries, consumers’ willingness-to-consume food produced with RNAi compared to *Bt* technology was significantly different based on the McNemar Test ($p < 0.01$). See Table (2) for country-level acceptance of food produced by RNAi or *Bt* biotechnologies or the two technologies combined. From the table, it can be observed that consumers’ acceptance is primarily dichotomous. They were either willing to consume food produced with combined RNAi and *Bt* technologies or neither.

Table 2. Respondents’ Willingness-To-Consume food produced with RNAi and *Bt* technologies.

	USA	**Canada**	**Australia**	**France**	**Belgium**
Both Biotechnologies	74%	74%	69.5%	48%	49.5%
Only RNAi Biotechnology	6%	8%	10.5%	14%	10.5%
Only *Bt* Biotechnology	2%	0.5%	2.5%	3%	4%
Neither Biotechnology	18%	17.5%	17.5%	35%	36%
McNemar’s S	11.11*	25.48*	19.69*	30.26*	11.66*

*Significant at the p < 0.01 level

Conclusions

The results of this study show the potential for non-GM RNAi biotechnology in agriculture compared to GM *Bt* from a market perspective, which is crucial for developing industry plans and investment decisions in agricultural biotechnology markets around the world. To date, there have been no studies of consumer valuation of RNAi. More importantly, little is known about why consumers might value (1) one of these technologies over the other, or (2) how consumers might rank them compared to a conventionally-produced rice. Thus, this study provided these analyses so that researchers, policy-makers, and agricultural practitioners have a basis for valuing future biotechnology applications in agriculture.

It is clear from these findings that (1) survey respondents in the USA, Canada, Australia, and France still require a discount for RNAi rice compared to conventionally-produced rice, and (2) consumers in the USA, Canada, Australia, France, and Belgium would need an extra discount to purchase *Bt* rice over RNAi. While respondent age was a significant factor in all countries, other demographics did not explain why consumers' WTP for these products differ. Furthermore, 80, 82, 80, 62, and 60 percent of respondents in the USA, Canada, Australia, France, and Belgium respectively would consume food produced with RNAi biotechnology. Based on these findings, agricultural biotechnologists should consider the implications of discounts alongside the costs of producing these solutions. Moreover, a more-in-depth evaluation of consumers' risk-benefit perceptions and environmental worldview might reveal the mechanisms driving consumers' choices, so future studies could analyze these factors in WTP models as control variables. As companies and farmers explore biotechnology solutions for production enhancement, information on consumer acceptance and WTP is critical. The findings in this study suggest that all biotechnology solutions are not the same from the perspective of consumers in the USA, Canada, Australia, France, and Belgium. In this case, non-GM RNAi may be a better market alternative to more traditional biotechnologies like *Bt*. Nonetheless, consumers appear to remain skeptical of biotechnology solutions when it comes to food on their plate.

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