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New innovations in agricultural biotech: Consumer acceptance of topical RNAi in rice production

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A B S T R A C T

To test the market viability of a non-GMO topical RNAi insect control, we conducted a Willingness-To-Pay (WTP) survey in the USA, Canada, Australia, France, and Belgium to elicit whether consumers need a premium or discount for: (1) a hypothetical **GMO** rice variety using the ***Bacillus thuringiensis* (*Bt*)** gene for insect control; and (2) a hypothetical **non-GMO** rice variety using topical **RNAi** spray for insect control. The survey was designed based on a Multiple Price List (MPL) format where respondents selected their preferred insect control technology; i.e., conventional, GMO *Bt*, or non-GMO RNAi, at different prices. Participants' responses were analyzed using an interval regression model to generate WTP premiums and discounts for each country with control variables for demographic influences. Further, we asked consumers their Willingness-To-Consume (WTC) food produced with GM and RNAi technologies respectively and evaluated WTC differences using a McNemar matched pairs test in each country. The results from our study clearly show that: (1) consumers in the USA, Canada, Australia, and France still require a discount for rice produced with topical RNAi compared to conventionally-produced rice ($p < 0.05$), (2) consumers in the USA, Canada, Australia, France, and Belgium would need an additional 30–40% discount to purchase *Bt* rice over rice produced with topical RNAi ($p < 0.05$), and (3) consumers in all countries were more willing to consume rice produced with non-GM RNAi than with GM *Bt* technology ($p < 0.05$). These findings suggest consumers differentiate among biotechnology solutions and consumers may prefer topical RNAi insect control to transgenic GMO insecticides.

1. Introduction

1.1. Running the gauntlet: consumers and GMOs

In May of 2016, the National Academies of Sciences, Engineering, and Medicine concluded that Genetically Modified Organisms (GMOs) are safe for human consumption (NASEM, 2016), yet a substantial amount of public resistance persists (Kollipara, 2016). By 2050, agricultural production needs to increase by 70 percent to meet the projected increase in global food demand (FAO, 2009), and this must happen with a reduction in environmental impacts and resource use (Tilman, Balzer, Hill, & Befort, 2011). Advances in agricultural biotechnologies such as GMOs have helped producers increase production and improve resource-use efficiency (Taheripour, Mahaffey, & Tyner, 2015); accordingly, these advancements may be some of humanity's greatest assets in minimizing food insecurity and meeting the growing global food demand by 2050 (Godfray et al., 2010). However, due to government regulatory prohibitions and consumer opposition to GMOs (Davison, 2010), biotechnology solutions involving GM crops have been limited mainly to *Z. mays* (maize), *G. max*(soybeans), and *G. hirsutum* (cotton), and these have been produced primarily in the United States. In most cases, these crops are not consumed in their unprocessed form, but instead they are processed into various food ingredients or used as fiber and fodder.

By contrast, staple foods such as *O. sativa* (rice) and *T. aestivum* (wheat) are field-to-plate crops, predominantly consumed in a similar form as when they are harvested from the field. Notably, there has been no commercial release and production of a GMO rice or wheat cultivar globally, despite the fact that in scientific trials GMO cultivars for rice and wheat have increased yields, strengthened pest-resistance packages, and reduced input requirements such as fungicide. To illustrate, *Bacillus thuringiensis (Bt)* rice has

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been grown successfully in field trials and has proven effective against certain insect pests (Tu et al., 2000). *Bt* rice has also been tested and confirmed as nutritionally equivalent to conventional varieties (High, Cohen, Shu, & Altosaar, 2004), yet it is not available for commercial production. Additionally, *Golden Rice*, a GM rice enriched with Vitamin A was donated by Syngenta for humanitarian use in lower-income countries where Vitamin A deficiency (VAD) is common. However, *Golden Rice* is still rejected in countries such as the Philippines and India where VAD is most prevalent. To drive home the importance of this issue, Wesseler and Zilberman (2014) estimated that 1.4 million life years were lost to VAD in India over the previous decade. This rejection of *Golden Rice* is partly due to the negative publicity and lobbying efforts conducted by anti-GMO organizations (Lynas, 2013). Thus, the current lack of GMO rice and wheat in commercial production is primarily the result of regulations and also the concern that consumers' resistance to GMO technology would stifle sales and damage exports.

Public perception and consumer acceptance have played crucial and often impeding roles in the development, dissemination, and use of GMOs in agricultural production. As a result, agricultural companies have begun exploring alternative biotechnology applications. Some of these alternative biotechnologies do not require the direct genetic modification of crops, and at least for now, do not fall under the same stringent regulatory protocols of GMOs in regions such as Europe. One prospective technology that is being developed for commercial release by the private sector uses RNA interference (RNAi) to control target pests in the form of a topical liquid application. 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 for the purpose of this study is the death of the targeted sub-species.

Fire et al. (1998) received a Nobel Prize in 2006 for the discovery of RNAi. Since its invention, scientists have used RNAi extensively in medical and agricultural biotechnology applications. In many cases, RNAi has been used as an integral tool in the genetic modification of crops (Saurabh, Vidyarthi, & Prasad, 2014), such as introducing the non-browning characteristic in the Arctic Apple (Waltz, 2015) and virus resistance in various other crops (Waterhouse, Graham, & Wang, 1998). In these GMO applications of RNAi, the target crop is transgenically modified, wherein an RNAi expression vector is transferred into the target crop's genome and remains stable. The RNAi expression vector becomes a permanent and integral part of the crop's genome and effectively kills the targeted insect upon consumption by suppressing vital genes in the insect. As a stable part of the crop's genome, this GMO RNAi application is effective for the duration of the crop's life.

Conversely, scientists have begun exploring how to use topical RNAi as a non-GMO biological control for pests in crop production. In this case, RNAi has the potential to be sprayed on conventional crops to control for specific, targeted pests by suppressing vital genes in the target pest upon ingestion. Herein, the RNAi does not integrate foreign genetic material into the crop genome as in the case of former uses of transgenic RNAi (Gordon & Waterhouse, 2007; Niu et al., 2006; Price & Gatehouse, 2008). However, topical RNAi insect control may only be effective for a short period of time on the surface of the crop because it breaks down naturally in the environment. Moreover, RNAi as a liquid application leaves no residual pesticide in the environment, which is an environmental concern with many conventional pesticides (Miyamoto, Kearney, & Greenhalgh, 2013).

GM pesticides such as *Bt* introduce an insecticidal protein into the target crop itself, and it is possible, though never observed in past studies, that the *Bt* protein could hypothetically create an allergic reaction in a consumer (Mendelsohn, Kough, Vaituzis, & Matthews, 2003). The introduction of potential allergens into crops is one of the main drivers of anti-GMO lobbies, even if scientifically unverifiable. The allergic potential exists because most food allergies come from an individual's reaction to large protein molecules like those introduced in *Bt* crops (Huby, Dearman, & Kimber, 2000). With RNAi, no proteins are created in the plant, and in fact, RNAi often suppresses the creation of particular proteins, i.e., genes which create proteins are silenced or downregulated (Jaubert-Possamai et al., 2007; Turner et al., 2006). So while *Bt* and other GM produced agricultural goods could hypothetically cause allergic reactions due to an introduced protein, RNAi mitigates the possibility for an allergen to develop (Astwood, Leach, & Fuchs, 1996; Huby et al., 2000).

The use of topical RNAi as an insecticide could be a solution for agricultural biotechnologists looking for ways to forego the GM regulatory process, as well as potentially appeasing a skeptical consumer base. However, throughout 2015 a number of blogs and online news producers devoted attention to topical non-GMO RNAi spray technology, questioning its acceptance by the public (Jacobs, 2015; Regalado, 2015). Those 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 noted that consumer acceptance is yet unknown, even to the public relations staff of these companies.

Numerous hypothetical and non-hypothetical studies have confirmed that many consumers require a discount to purchase GM food products (Frewer et al., 2013; Klümper & Qaim, 2014; Lusk, Jamal, Kurlander, Roucan, & Taulman, 2005), but until now, the literature has been devoid of studies investigating how consumers may value forthcoming non-GM innovations in agricultural biotechnology, including topical RNAi applications. Previous studies have focused only on GM biotechnologies compared with non-GM technologies in food production. 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 conducted until now. Finding differences in consumer acceptance of diverse biotechnologies could be a critical turning point in how agricultural biotechnologies are developed, specifically whether non-GM biotechnologies are valued differently than their GM counterparts.

Therefore, this study shows the potential for non-GM RNAi biotechnology as a topical insecticide application compared to GM *Bt* insecticide from a market demand perspective, which is crucial for developing industry plans and investment decisions in agricultural biotechnology markets around the world. The results on WTP for GM *Bt* are not novel or new, but to date, there have been no studies of consumer valuation of RNAi, a non-GM agricultural biotechnology. More importantly, little is known about (1) how consumers might value non-GM RNAi technology over a GM counterpart, or (2) how consumers might rank either RNAi or GM compared to a conventionally-produced rice. This study provides these analyses so that researchers, policy-makers, and agricultural practitioners have a basis for valuing future biotechnology applications in agriculture.

2. Material and methods

2.1. Multi-country survey design and analytics

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 emphasized in the public sphere as well as in the peer-reviewed literature (Klümper & Qaim, 2014; Lusk et al., 2005;