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Factors Impacting Growers' Adoption of Genetically Modified and Gene Edited Crops

Chengyan Yue[a], Yang Wang[b], Marie Abbey[c], Yufeng Lai[d], Corissa Marson[e], Alan G. Smith[f], and Carrie Stowers[g]

[a]*Professor, Department of Horticultural Science and Department of Applied Economics, 1970 Folwell Avenue, University of Minnesota, St. Paul, MN 55108, USA*

[b]*PhD student, Department of Applied Economics, 1994 Buford Avenue, University of Minnesota, St. Paul, MN 55108, USA*

[c]*Research Associate, Department of Horticultural Science, 1970 Folwell Avenue, University of Minnesota, St. Paul, MN 55108, USA*

[d]*Economist, Amazon Web Services, Minneapolis, MN 55401, USA*

[e]*PhD Candidate, Department of Applied Economics, 1994 Buford Avenue, University of Minnesota, St. Paul, MN 55108, USA*

[f]*Professor, Department of Horticultural Science, 1970 Folwell Avenue, University of Minnesota, St. Paul, MN 55108, USA*

[g]*Ag External Relations and Engagement Manager, 3675 Arboretum Drive, University of Minnesota Landscape Arboretum, Chaska, MN 55318, USA*

Abstract

To gain insights into how genetically modified (GM) or gene edited (GE) crops' benefits affect growers' willingness to grow, we conducted a survey with 111 Minnesota growers. We found growers are more familiar with GM crops than GE crops. Compared to a GM or GE crop without

ⒸCorresponding author: Tel: (612) 626-3974
Email: yuechy@umn.edu

specified benefits, growers are more willing to grow GM or GE crops that are healthier for consumers. Growers who perceive the benefits of GM or GE crops as outweighing the risks are attracted to multiple benefits, including healthier for consumers, lower production costs, higher yield, enhancing disease or pest resistance and reducing pesticides.

Keywords: specialty crops, benefits, risks, new technology

Introduction

By 2050, the world population is projected to reach 9.2 billion. To feed this population, global food production needs to increase by 70% (Clarke and Daniell, 2011). Many researchers believe that the cultivation of genetically modified (GM) crops can play a pivotal role in alleviating food insecurity (Huang, Pray, and Rozelle, 2002; Ali and Rahut, 2018). On one hand, genetic modification can enhance crop yields (Qaim, 2003; Finger et al., 2011). On the other hand, the cultivation of GM crops can bolster farmers' food security by increasing their income (Ali and Rahut, 2018). For instance, Qaim and Kouser (2013) found that the cultivation of GM cotton increased Indian farmers' household income, subsequently improving their calorie and nutritional intake. In addition, GM crops also have several important traits, such as herbicide tolerance and resistance to plant viruses and insect damage (U.S. Food and Drug Administration, 2022). With such beneficial traits, the global cultivation area of GM crops surged from 1.7 million hectares in 1996 to 190.4 million hectares in 2019 (International Service for the Acquisition of Agri-biotech Applications, 2017; International Service for the Acquisition of Agri-biotech Applications, 2020).

However, extensive cultivation of GM crops has raised many safety concerns. Many people and institutions worry about potential negative health impacts of GM crops, such as toxicity, allergenicity, antibiotic resistance, cancer, nutrition loss, or immune reactions (The Cornucopia Institute, 2009; Bennett, et al., 2013; Center for Food Safety, 2016). Given these concerns, GM crops have not gained widespread acceptance among consumers and growers. Gene editing technology is different from genetic modification technology in that it can swiftly and precisely alter specific DNA sequences to manipulate traits for crop improvement without introducing transgenic genes from other species or organisms, which may make gene edited (GE) crops much more readily accepted by growers and consumers (Muringai, Fan, and Goddard, 2020).

Given the diverse range of traits, widespread cultivation, and stakeholders' varying perceived risks associated with GM and GE crops, public perceptions of GM and GE crops are a complex yet widely studied issue. Muringai, Fan, and Goddard (2020) conducted a choice experiment to examine Canadian consumers' attitudes toward GM and GE potatoes. Their results suggest that consumers are more accepting of GE potatoes compared to GM potatoes. Consumers are willing to pay a premium for GM or GE crops that provide improved health benefits over environmental benefits. Pruitt, Melton, and Palma (2021) examined whether physical activity can influence consumers' acceptance of GE foods and whether consumers are willing to pay a premium for GE foods relative to GM foods. Although they found no effect of physical activity on consumer acceptance of GE foods, they did find evidence of price premiums for GE foods.

While there is a substantial body of literature on consumer attitudes and willingness to pay, there is limited focus on growers' perspectives. Most studies related to growers investigate the potential benefits GM and GE crops have on their business. For instance, using a dataset for corn, soybeans, and cotton cultivation in the United States, Gardner, Nehring, and Nelson (2009) estimated the labor time savings associated with adopting a GM crop and found significant household labor savings for GM soybean cultivation. Another example is the aforementioned study by Qaim and Kouser (2013). They identified the economic benefit from the cultivation of GM cotton, particularly increased household income. A meta-analysis of the agronomic and economic impacts of GM crops cultivation by Klümper and Qaim (2014) concluded that, on average, the cultivation of GM crops reduced chemical pesticide usage by 37%, increased crop yields by 22%, and increased farmer profits by 68%. Although there are some studies on growers' acceptance of GM and GE crops, such as Keelan et al. (2009), that examined how grower demographics affect their acceptance of GM crops, there is less attention given to how the beneficial traits of GM and GE crops affect growers' acceptance. We aim to address this gap in knowledge. Additionally, our findings provide implications for policy makers or marketing decision makers on how to promote GM and GE crops. Our findings also shed light on the most important beneficial traits researchers should focus on when improving crops using GM or GE technologies. For example, relevant decision makers can emphasize the beneficial traits when promoting the crops to growers, thereby increasing product adoption. Researchers can focus on improving these traits to better align with growers' needs to increase the growers' willingness to grow such crops.

Survey Design

Our online survey was developed and programed into Qualtrics software, and Minnesota farmers who completed the survey received a $10 Visa gift card. We obtained Institutional Review Board approval for our survey. The survey was comprised of questions aimed at understanding participating growers' willingness to grow (WTG) GM and GE crops with different benefits, their familiarities with GM and GE crops, and their attitudes toward the risks and benefits of GM and GE crops. Information about the characteristics of their farms and their demographics was also collected.

To gauge growers' WTG, we asked them to indicate the extent to which they were likely to grow a GM or GE crop with a specific benefit using a 5-point Likert scale, ranging from "very unwilling" to "very willing." Our questions covered seven potential benefits of GM or GE crops: enhanced disease or pest resistance, reduced use of pesticides and herbicides, higher yields, reduced greenhouse gas emissions, healthier crops for consumers, lower production costs, and increased consumer willingness to buy. For each benefit, growers were asked to choose their WTG for GM crops with that benefit and GE crops with that benefit, respectively. For example, when addressing the benefit of enhanced disease or pest resistance, growers were asked to indicate their levels of agreement with the following two statements: "I am willing to grow GM crops if they are more disease or pest resistant" and "I am willing to grow GE crops if they are more disease or pest resistant." We also asked growers to indicate their WTG for GM and GE crops in general (without specifying any benefit), which were used as a control group for model estimation.

Participants were also asked to choose their level of familiarity with GM or GE crops, with response options ranging from "not familiar at all" to "extremely familiar." Growers were asked to provide their opinions on how benefits compared to risks for GM and GE crops, using a 5-point Likert-scale that ranged from "risks strongly outweigh benefits" to "benefits strongly outweigh risks."

Regarding farm characteristics, growers were asked to identify the top five crops cultivated on their farms. In terms of demographics, the survey included questions related to growers' gender, age, education level, race, and income from their farm operations, among other factors.

Model

We employed Ordered Probit Models to assess the impact of the benefits associated with GM and GE crops on growers' WTG. The dependent variable is a discrete variable measuring the extent to which a grower is willing to grow GM or GE crops with specific benefits ("very unwilling" = 0; "somewhat unwilling" = 1; "neither willing nor unwilling" = 2; "somewhat willing" = 3; "very willing" = 4).

In the basic model, the independent variables include four groups. The first group includes the dummy variables of seven benefits, where each dummy variable equals 1 if GM or GE technology enhances the crop in a specific way (e.g., the dummy variable for increased disease or pest resistance = 1 if GM or GE makes the crop more disease or pest resistant; = 0, otherwise). The second group includes grower demographics, and the third group consists of the variables measuring farm characteristics (i.e., the indicators of main crops grown by the grower) and growers' familiarity of GM and GE crops. The fourth group consists of a single dummy variable indicating whether the benefits are from GE crops (= 1, if the benefit is from GE technology; = 0, if the benefit is from GM technology). The last three groups are control variables. Definitions and descriptive statistics for these variables are shown in Table 1 and Table 2.

Table 1. The Meaning of the Indicator Variables Used in Probit Models

Indicator	Meaning of the Indicator
GM	The crop is genetically modified; 1 = yes, 0 otherwise.
GE	The crop is gene edited; 1 = yes, 0 otherwise.
Resistance	GM or GE crops have enhanced disease or pest resistance; 1 = yes, 0 otherwise.
Reducing_pesticide	GM or GE crops have reduced use of pesticides and herbicides; 1 = yes, 0 otherwise.
Higher_yield	GM or GE crops have increased yield; 1 = yes, 0 otherwise.
Reducing_greengas	GM or GE crops have reduced greenhouse emissions; 1 = yes, 0 otherwise.
Healthier	GM or GE crops are healthier to consumers; 1 = yes, 0 otherwise.
Reducing_cost	GM or GE crops have reduced production cost; 1 = yes, 0 otherwise.
Purchase	GM or GE crops have higher consumer willingness to purchase; 1 = yes, 0 otherwise.
No_specified_benefit	GM or GE crops do not specify any specific benefits; 1 = yes, 0 otherwise.

Table 2. Summary Statistics of Variables Used in Probit Models (Sample Size = 111)

	Mean (S.D.)	Percent (in %)
Dependent variable		
WTG (the extent to which the grower is willing to grow the GM or GE crop)	2.33 (1.38)	
1 = Very unwilling		16.89
2 = Somewhat unwilling		10.19
3 = Neither willing nor unwilling		18.41
4 = Somewhat willing		31.64
5 = Very willing		22.86
Demographics		
Male	0.71 (0.45)	
1 = the grower is male		71.17
0 = otherwise		28.83
Age (the age of the grower)	47.42 (12.45)	
Education (the education level of the grower)	2.95 (0.94)	
1 = High school diploma or equivalent		9.91
2 = Some college, but no degree		17.12
3 = College degree		41.44
4 = Graduate degree		31.53
Experience (years of experience as a grower)	13.74 (8.03)	
2.5 = Less than or equal to 5 years		14.41
8 = 6 to 10 years		22.52
13 = 11 to 15 years		27.93
18 = 16 to 20 years		17.12
23 = 21 to 25 years		9.91
28 = 26 to 30 years		1.80
33 = More than 30 years		6.31
Ethnicity	0.15 (0.36)	
1 = the grower is Hispanic or Latino		15.32
0 = otherwise		84.68
White	0.90 (0.30)	
1 = the grower is white		90.09
0 = otherwise		9.91
Income		
Income_low	0.29 (0.45)	
1 = the grower's income from farming is less than $49,999		28.83
0 = otherwise		71.17

Table 2. (cont)

	Mean (S.D.)	Percent (in %)
Income_middle	0.38 (0.49)	
1 = the grower's income from farming is between $50,000 and $249,999		37.84
0 = otherwise		62.16
Income_high	0.33 (0.47)	
1 = the grower's income from farming is higher than $250,000		33.33
0 = otherwise		66.67
Familiarity with GM or GE crops		
Familiarity (grower's familiarity with the crop)	2.17 (0.99)	
0 = Not familiar at all		4.50
1 = Slightly familiar		20.27
2 = Moderately familiar		37.39
3 = Very familiar		29.73
4 = Extremely familiar		8.11
Indicators of the crops that growers mainly grow		
i_largescale	0.59 (0.49)	
1 = the grower mainly grows large-scale agricultural crops		58.56
0 = otherwise		41.44
i_ornamental	0.29 (0.45)	
1 = the grower mainly grows ornamental crops		28.83
0 = otherwise		71.17
Indicator of grower's attitude towards GM or GE crop		
i_benefit	0.69 (0.46)	
1 = the grower believe that GM (or GE, if the indicator of GM = 0) crops' benefits overweigh their risks		69.37
0 = the grower believe that GM (or GE, if the indicator of GM = 0) crops' risks overweigh their benefits		30.63

In the basic model, let WTG_{ijp} be the dependent variable, indicating the extent to which a grower is willing to grow a GM or GE crop with a specific benefit. $\boldsymbol{Benefits}_{ijp}$ is the vector of benefit indicators. $\boldsymbol{Controls}_{ijp}$ is the vector of control variables (encompassing the last three groups of independent variables). I denotes grower, j represents the type of crop (GM or GE), and p represents the specific benefit (increased disease or pest resistance, reduced pesticide and herbicide use, higher yields, reduced greenhouse gas emissions, healthier for consumers, lower production costs, increased consumer willingness to purchase, or unspecified benefits). Assume that the value of WTG_{ijp} is determined by grower i's evaluation V^*_{ijp} of crop j with benefit p. The evaluation is affected by crop's benefit ($\boldsymbol{Benefits}_{ijp}$), the control variables ($\boldsymbol{Controls}_{ijp}$), and a standard normal distributed error term e_{ijp}. Hence, the evaluation V_{ijp}^{*} can be defined as, for any *i, j* and *p*,

$$V_{ijp}^{*} = \boldsymbol{\alpha}'\boldsymbol{Benefits}_{ijp} + \boldsymbol{\beta}'\boldsymbol{Controls}_{ij} + e_{ijp} \quad (1)$$

Then, assume that, for any i, j and p,

$WTG_{ijp} = 0$ ("Very unwilling"), if $V_{ijp}^{*} \leq v_0$;

$WTG_{ijp} = 1$ ("Somewhat unwilling"), if $v_0 < V_{ijp}^{*} \leq v_1$;

$WTG_{ijp} = 2$ ("Neither willing nor unwilling"), if $v_1 < V_{ijp}^{*} \leq v_2$;

$WTG_{ijp} = 3$ ("Somewhat willing"), if $v_2 < V_{ijp}^{*} \leq v_3$;

$WTG_{ijp} = 4$ ("Very willing"), if $v_3 < V_{ijp}^{*}$;

Equations 2–6 define the probability of a growers' willingness to cultivate a GM or GE crop with a specific benefit at levels 0, 1, 2, 3 and 4.

$$\Pr\left(WTG_{ijp} = 0 \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = \Pr\left(V_{ijp}^{*} \leq v_0 \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = \Pr\left(e_{ijp} \leq v_0 - \left(\boldsymbol{\alpha}'\boldsymbol{Benefits}_{ijp} + \boldsymbol{\beta}'\boldsymbol{Controls}_{ij}\right) \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = \Phi\left[v_x - \left(\boldsymbol{\alpha}'\boldsymbol{Benefits}_{ijp} + \boldsymbol{\beta}'\boldsymbol{Controls}_{ij}\right)\right] \quad (2)$$

$$\Pr\left(WTG_{ijp} = 1 \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = \Pr\left(v_0 < V_{ijp}^{*} \leq v_1 \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = \Phi\left[v_1 - \left(\boldsymbol{\alpha}'\boldsymbol{Benefits}_{ijp} + \boldsymbol{\beta}'\boldsymbol{Controls}_{ij}\right)\right] - \Phi\left[v_0 - \left(\boldsymbol{\alpha}'\boldsymbol{Benefits}_{ijp} + \boldsymbol{\beta}'\boldsymbol{Controls}_{ij}\right)\right] \quad (3)$$

$$\Pr\left(WTG_{ijp} = 2 \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = \Pr\left(v_1 < V_{ijp}^{*} \leq v_2 \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = \Phi\left[v_2 - \left(\boldsymbol{\alpha}'\boldsymbol{Benefits}_{ijp} + \boldsymbol{\beta}'\boldsymbol{Controls}_{ij}\right)\right] - \Phi\left[v_1 - \left(\boldsymbol{\alpha}'\boldsymbol{Benefits}_{ijp} + \boldsymbol{\beta}'\boldsymbol{Controls}_{ij}\right)\right] \quad (4)$$

$$\Pr\left(WTG_{ijp} = 3 \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = \Pr\left(v_2 < V_{ijp}^{*} \leq v_3 \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = \Phi\left[v_3 - \left(\boldsymbol{\alpha}'\boldsymbol{Benefits}_{ijp} + \boldsymbol{\beta}'\boldsymbol{Controls}_{ij}\right)\right] - \Phi\left[v_2 - \left(\boldsymbol{\alpha}'\boldsymbol{Benefits}_{ijp} + \boldsymbol{\beta}'\boldsymbol{Controls}_{ij}\right)\right] \quad (5)$$

$$\Pr\left(WTG_{ijp} = 4 \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = \Pr\left(v_3 < V_{ijp}^{*} \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right) = 1 - \Phi\left[v_3 - \left(\boldsymbol{\alpha}'\boldsymbol{Benefits}_{ijp} + \boldsymbol{\beta}'\boldsymbol{Controls}_{ij}\right)\right] \quad (6)$$

In the equations , Φ(.) denotes the cumulative distribution function (CDF) for standard normal distribution. Additional details for Ordered Probit Models can be found in Chapter 26.10 of Hansen (2022).

With equations (2)–(6), the log-likelihood function of the Ordered Probit Model can be written as equation (7).

$$logL(\boldsymbol{\alpha};\boldsymbol{\beta}) = \sum_{i=1}^{n}\sum_{j=1}^{2}\sum_{p=0}^{7}\sum_{x=0}^{4}\mathbf{1}\{WTG_{ijp} = x\}log\left[Pr\left(WTG_{ijp} = x \middle| \boldsymbol{Benefits}_{ijp}, \boldsymbol{Controls}_{ij}\right)\right] \quad (7)$$

In equation (7), $\mathbf{1}\{WTG_{ijp} = x\}$ equals 1 when $WTG_{ijp} = x$; otherwise, it equals 0.

By the Maximum Likelihood Estimation, we can get the Ordered Probit estimates $(\widehat{\boldsymbol{\alpha}};\widehat{\boldsymbol{\beta}})$ satisfying

$$(\widehat{\boldsymbol{\alpha}};\widehat{\boldsymbol{\beta}}) = argmax\{logL(\boldsymbol{\alpha};\boldsymbol{\beta})\} \quad (8)$$

$\widehat{\boldsymbol{\alpha}}$ is a vector of the estimated coefficients of benefit indicators and $\widehat{\boldsymbol{\beta}}$ is the vector of the estimated coefficients for control variables.

In addition to the basic model, we conducted estimations using two other Ordered Probit Models. First, we added interactions between each of the eight benefit indicators and an attitude indicator reflecting whether the grower believes GM or GE crops' benefits overweigh risks. These interactions aim to assess whether the effects of benefits from GM or GE technology on growers' WTG change based on their attitudes toward GM or GE technologies. Second, we added interactions between demographics and the attitude indicator into the model.

Results and Discussion

Comparison between Sampled Growers' Demographics and Census Data

In total, 111 growers completed all the questions used in this study. The summary statistics of our grower sample are shown in Table 1. The sample used in this study is a subsample of the study of Abbey et al. (2024). Several observations were dropped due to incomplete answers to the questions of interest in this research. Our sample's gender distribution closely mirrors the census data (US Department of Agriculture, 2019), with approximately 71% of participants who were male compared to approximately 70% in the census data. The growers in our sample tended to be relatively younger, with an average age of 47 years old, compared to the census data, which averages 57 years old. When considering years of farm operation experience, our sample showed 14% with 0–5 years, 23% with 6–10 years, and 63% with 11 or more years of experience. On the other hand, the census data reports 11% with 0–5 years, 10% with 6–10 years, and 79% with 11 or more years of experience. But the median years of experience of our sample is the same as the census data (both have 11 or more years of experience). Our sample included a higher percentage of growers with Hispanic, Latino, and Spanish origins (15%) compared to those in the census data

(0.5%). Our sample had a lower percentage of White growers (90%) compared to those in the census data (99%). Furthermore, our sample had slightly higher income compared to those in the census data. Given these differences, the extrapolation of our findings to the whole population of Minnesota growers or growers in other states or regions should be done with caution.

Growers' Familiarities with GM and GE Crops

Table 3 presents the distributions of participants' familiarities with GM and GE crops. For both GM and GE crops, the largest share corresponds to the option "moderately familiar" (42.34% and 32.43% for GM and GE, respectively). Compared to GE crops, participants exhibited greater familiarity with GM crops, as evidenced by the larger share of participants who selected "very familiar" (34.23%) and "extremely familiar" (10.81%) for GM crops. The difference may be attributed to the longer history of GM crops.

Table 3. Growers' Familiarities with GM and GE Crops (Sample Size = 111)

Familiarity	GM Crops (in %)	GE Crops (in %)
Not familiar at all	0.90	8.11
Slightly familiar	11.71	28.83
Moderately familiar	42.34	32.43
Very familiar	34.23	25.23
Extremely familiar	10.81	5.41

Growers' Attitudes toward the Risks and Benefits of GM and GE Crops

Table 4 displays the distributions of participants' responses regarding how benefits are compared to risks for GM and GE crops. Notably, 18.92% of participants believe that GE crops' benefits strongly outweigh risks, while only 10.81% of participants think that GE crops' risks strongly outweigh benefits. This finding suggests a greater receptiveness among growers toward GE crops. However, for GM crops, 19.82% of participants believe that benefits and risks are about the same, while only 14.41% participants hold this view for GE crops. Additionally, compared to GM crops, more participants think that GE crops' risks somewhat outweigh benefits. Nevertheless, these results alone do not conclusively indicate a higher level of acceptance for GE crops among growers.

Table 4. Growers' Attitudes toward the Risks and Benefits of GM and GE Crops (Sample Size = 111)

	GM Crops (in %)	GE Crops (in %)
Risks strongly outweighs benefits	17.12	10.81
Risks somewhat outweighs benefits	11.71	21.62
Benefits and risks are about the same	19.82	14.41
Benefits somewhat outweigh risks	34.23	34.23
Benefits strongly outweigh risks	17.12	18.92

The Impact of GM or GE Benefits on Growers' WTG: The Role of Growers' Attitudes

Table 5 presents the results of three Ordered Probit Models. The first (Column 1) includes the benefit indicators and control variables. The second (Column 2) is the Ordered Probit Model with the interactions of the attitude indicator and benefit indicators. Compared to the second model, the third model (Column 3) includes additional interactions of the attitude indicator and demographic variables.

Table 5. The Impact of Benefits on Growers' WTG of GM or GE Crops: The Role of Growers' Attitudes (Sample Size = 111)

Variable	(1) Ordered Probit Model	(2) Ordered Probit Model with Interactions for Benefit Indicators	(3) Ordered Probit Model with Interactions for Benefit Indicators and Demographics
Resistance	0.036	-0.135	-0.146
	(0.102)	(0.191)	(0.193)
Reducing_pesticide	0.075	0.017	0.016
	(0.101)	(0.189)	(0.191)
Higher_yield	0.051	-0.097	-0.107
	(0.102)	(0.191)	(0.193)
Reducing_greengas	-0.030	0.205	0.216
	(0.101)	(0.188)	(0.190)
Healthier	0.174*	0.352*	0.380**
	(0.101)	(0.188)	(0.190)
Reducing_cost	0.085	-0.085	-0.093
	(0.102)	(0.191)	(0.193)
Purchase	0.074	0.123	0.126
	(0.101)	(0.188)	(0.190)
Resistance*ibene		1.472***	1.003**
		(0.165)	(0.447)
Reducing_pesticide*ibene		1.326***	0.846*
		(0.163)	(0.446)
Higher_yield*ibene		1.444***	0.972**
		(0.165)	(0.447)
Reducing_greengas*ibene		0.898***	0.397
		(0.160)	(0.446)
Healthier*ibene		1.005***	0.498
		(0.161)	(0.445)
Reducing_cost*ibene		1.484***	1.013**
		(0.165)	(0.448)
Purchase*ibene		1.178***	0.695
		(0.161)	(0.446)

Table 5. (cont)

Variable	(1) Ordered Probit Model	(2) Ordered Probit Model with Interactions for Benefit Indicators	(3) Ordered Probit Model with Interactions for Benefit Indicators and Demographics
No_specified_benefit*ibene		1.228***	0.741*
		(0.163)	(0.447)
Male	0.269***	-0.089	0.098
	(0.064)	(0.068)	(0.117)
Age	-0.012***	-0.010***	-0.005
	(0.003)	(0.003)	(0.005)
Education	0.100***	0.078**	0.087
	(0.032)	(0.033)	(0.064)
Experience	0.008*	0.006	-0.032***
	(0.005)	(0.005)	(0.007)
Ethnicity	0.464***	0.381***	-0.340
	(0.083)	(0.084)	(0.248)
White	0.041	-0.044	-0.413*
	(0.095)	(0.096)	(0.220)
Income_middle	0.374***	0.410***	0.124
	(0.076)	(0.077)	(0.127)
Income_high	0.409***	0.535***	1.243***
	(0.093)	(0.095)	(0.165)
Male*ibene			-0.314**
			(0.149)
Age*ibene			-0.012*
			(0.006)
Education*ibene			-0.003
			(0.074)
Experience*ibene			0.066***
			(0.009)
Ethnicity*ibene			0.994***
			(0.265)
White*ibene			0.503**
			(0.245)
Income_middle*ibene			0.435**
			(0.169)
Income_high*ibene			-0.789***
			(0.181)
Familiarity	0.034	0.046	0.080***
	(0.029)	(0.030)	(0.030)
i_largescale	0.138**	-0.122*	-0.329***
	(0.069)	(0.072)	(0.081)
i_ornamental	0.219***	0.205***	0.245***
	(0.066)	(0.067)	(0.069)

Table 5. (cont)

Variable	(1) Ordered Probit Model	(2) Ordered Probit Model with Interactions for Benefit Indicators	(3) Ordered Probit Model with Interactions for Benefit Indicators and Demographics
GM	-0.039	-0.100*	-0.103*
	(0.053)	(0.054)	(0.054)
v_0	-0.388*	-0.109	-0.562
	(0.201)	(0.230)	(0.397)
v_1	0.002	0.371	-0.052
	(0.200)	(0.230)	(0.396)
v_2	0.548***	1.006***	0.617
	(0.200)	(0.230)	(0.396)
v_3	1.461***	2.006***	1.662***
	(0.202)	(0.233)	(0.398)
Log likelihood	-2621.3981	-2428.7787	-2359.7759

Note: Standard errors in parentheses (***$p < 0.01$, **$p < 0.05$, *$p < 0.1$).

Based on our likelihood ratio test results (see Table A in the Appendix), the third model has the best goodness of fit. In Column 3 of Table 5, most coefficients of benefit indicators are not statistically significant, except for "healthier for consumers." This suggests that, for participants who believe that GM or GE crops' risks outweigh the benefits (hereafter referred to as "risk growers"), the benefits of GM or GE crops are insufficient to increase their WTG. However, five out of eight coefficients of the interaction terms for benefits indicators (including enhanced disease or pest resistance, reduced pesticide and herbicide use, higher yields, lower production costs, and no specified benefit) are positive and statistically significant. This finding implies that, compared to "risk growers," participants who believe that GM or GE crops' benefits outweigh the risks (hereafter referred to as "benefit growers") are more likely to grow GM or GE crops and are more easily to be attracted by the associated benefits. The second model reveals similar conclusions.

When considering the demographic variables in the third model, it becomes apparent that "risk growers" with more farming experience who are White are significantly associated with a lower WTG GM or GE crops. Besides, "risk growers" with high income levels are more likely to adopt GM or GE crops. The results of the interaction terms for demographics suggest that, compared to the "risk growers," "benefit growers" are more inclined to adopt a GM or GE crop when they have more farming experience, are Hispanic or Latino, White, or have middle-level income; whereas, when they are a male and older, or have high-level income, "benefit growers" are less likely to adopt GM or GE crops.

Familiarity with GM or GE crops has a significantly positive coefficient in Column 3, indicating that participants who are more familiar with GM or GE crops are more willing to grow them. Both indicators for participants' main crops have significant coefficients, suggesting that participants' WTG and attitudes toward GM and GE crops are affected by their primary crops. The coefficient for the indicator of large-scale agricultural crops (e.g., corn, soybeans, wheat, oilseeds, etc.) is significantly negative, which indicates that growers primarily involved in growing large-scale agricultural crops are less inclined to adopt GM or GE crops. Conversely, the coefficient for the indicator of ornamental crops is significantly positive, likely because ornamental crops are not typically used for foods, and growers may believe GM or GE ornamental crops are more easily acceptable to consumers. Therefore, participants are more willing to grow GM or GE ornamental crops. Besides, the indicator of GM has a negative significant coefficient, indicating participants are more willing to grow GE crops compared to GM crops, possibly due to the perception that GE crops are more natural or healthier than GM crops.

Conclusions

To understand how GM or GE crops' benefits impact growers' WTG, we conducted a survey with growers in Minnesota, with 111 growers participating. We employed ordered Probit Models on the survey data, leading to several key findings. First, compared to GE crops, growers are more familiar with GM crops. Second, growers who believe that GM or GE crops' risks outweigh the benefits can still be attracted by the "healthier for consumers" benefit. Third, compared to growers who believe that GM or GE crops' risks outweigh the benefits, growers who believe that the benefits outweigh the risks are more likely to grow GM or GE crops. They are particularly drawn to the benefits of enhanced disease or pest resistance, reduced pesticides and herbicides used, higher yield, and lower production cost offered by the GM or GE technology.

We can draw several implications from our findings. First, the growers' varying levels of familiarity with GM and GE crops suggest a need for targeted education initiatives to enhance understanding of these technologies. Efforts should focus on providing comprehensive information about the differences between GM and GE crops and their potential benefits and risks to ensure that growers are well-informed when making decisions about crop selection and adoption. Second, growers prioritize factors that directly impact yield and production costs. This finding suggests that initiatives promoting the economic advantages of GM or GE technology, such as potential savings on inputs and increased profitability, may be effective in encouraging adoption among growers. The emphasis on benefits such as reduced pesticide and herbicide usage indicates growers' recognition of the potential environmental benefits associated with GM or GE crops. It underscores the importance of promoting the environmental sustainability aspects of GM or GE technology, such as reduced chemical inputs and conservation of natural resources, to align with growers' priorities and promote adoption. Policy makers and GM and GE marketers can leverage public information platforms, such as social media, to effectively communicate the appealing benefits of GM and GE crops to growers. Lastly, growers' responsiveness to the benefits offered by GM or GE technology reflects a willingness to embrace agricultural innovation to address their challenges. It suggests opportunities for further research and development in biotechnology to continue delivering solutions that meet the evolving needs of growers. Researchers can work on improving the GM or GE crops' benefits that matter most to growers to increase the adoption rate and success of GM and GE crops.

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Appendix

Table A. Likelihood Ratio Test for three Ordered Probit Models

Assumption	**Likelihood Ratio Test Statistics**	***P*-value**
"Ordered probit model" nested in "ordered probit model with interactions for benefit indicators"	385.24	< 0.001
"Ordered probit model" nested in "ordered probit model with interactions for benefit indicators and demographics"	523.24	< 0.001
"Ordered probit model with interactions for benefit indicators" nested in "ordered probit model with interactions for benefit indicators and demographics"	138.01	< 0.001