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Farmers' Willingness to Adopt Late Blight-Resistant Genetically Modified Potatoes

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Abstract: The commercialization of genetically modified (GM) crops remains highly contested in the European Union (EU). While research has mainly focused on public and consumer opinions, few studies have investigated farmers' reactions towards such crops. This study aims to determine farmers' willingness to adopt a late blight-resistant (LBR) GM potato cultivar (Bintje) in Flanders, Belgium (n = 384). The findings demonstrate that more than half (54.7%) of the farmers have the intention to adopt this GM potato if it becomes available. Farmers' willingness to adopt is mainly influenced by ethical concerns about Genetically Modified Organisms (GMOs) (negative) and perceived economic benefits of LBR GM potatoes (positive). Knowledge about GM technology decreases the likelihood of being indifferent, as compared to being willing to adopt or being opposed. As such, efforts to improve knowledge alone would not be considered an effective strategy to improve adoption rates among farmers. Socio-economic concerns about GMOs, environmental benefit perceptions of LBR GM potatoes, and socio-demographic and farm variables were not significant as potential determinants of farmers' likelihood to adopt this GM potato. Our findings lend support to a potentially favorable climate to introduce this GM potato in Flanders, Belgium, an EU region where opt-out measures to restrict cultivation of approved GM crops were not taken.

Keywords: Adoption, attitude; Belgium, farmer; genetic modification; GM; potato

1. Introduction

Genetically modified (GM) crops are considered the fastest adopted crop technology in the world, especially in developing regions [1]. In the European Union (EU), however, adoption rates of GM crops remain very low and are limited to the cultivation of GM maize (Mon810) [2]. Nevertheless, a variety of applications are still being developed in the EU [3], which may offer opportunities for new GM crops entering this market in the future. This is particularly the case for GM crops aimed at improved productivity and sustainability, e.g., through the decreased use of agrochemicals. However, while such GM crops have demonstrated their ability to contribute to more sustainable agriculture [4], and to the Sustainable Development Goals in general [5], different stakeholders will ultimately determine whether applications will be successful if approved by policy makers. Therefore, farmers play a pivotal role, as they are the ones who will eventually need to decide whether to adopt the cultivation of GM crops and, hence, offer them to food processors and consumers that are willing to purchase it.

While the majority of stakeholder research on GM crops looks at consumers' reactions towards GM foods [6–8], less research has focused on the farmers' points of view [9–11]. In developing regions, researchers have mainly examined farmers' adoption of already cultivated GM crops, both for food [12–16] and nutrition security [17,18]. Also, in developed regions, research has targeted GM crop producing countries, such as the United States [19–21]. For Europe, the few available adoption studies looked at farmers in, for example, Denmark [22], Germany [23,24], Scotland [25], Ireland [26], and Georgia [27].

The adoption process of farmers with regard to agricultural innovations, like GM technology, is complex and may be determined by a large number of factors. The aforementioned adoption studies identified various drivers and barriers of farmers' willingness to adopt GM technology. While most evidence referred to extrinsic factors related to farm characteristics and socio-demographics, intrinsic factors, such as knowledge, and risk and benefit perceptions, also play a crucial role in farmers' decision processes on GM crop cultivation. As such, the present study addresses the need to consider both types of factors in farmer research on agricultural innovations [10].

Knowledge about GM technology, for example, has been shown to positively influence GM adoption, as demonstrated in studies with farmers of GM oilseed rape in Germany [23], and GM corn [28] or GM papaya in the United States [20].

Attitudes towards genetically modified organisms (GMOs), such as ethical and socio-economic concerns, as well as perceptions of their benefits, such as improvements at an economic or environmental level, are also likely to influence farmers' willingness to adopt GM technology. Socio-economic concerns about GM technology were frequently reported in farmer studies [29], similar to in consumer research [30]. Such concerns relate to, for example, the monopolies of multinationals in the seed and agrochemical sector, which are linked to increased corporate control over agricultural development and farmers [29], the rights over [31] and price of seed material [32], as well as regulatory issues [31,32]. Additionally, the role of GM technology on food security has been debated [5,33], as it may affect farmers' willingness to adopt a GM crop.

Ethical concerns, such as the belief that GM food is artificial and unnatural, influence the acceptance of GM technology. This has been demonstrated not only at the consumer level [7] but, given that farmers are worried about the impacts of consumer perceptions on their business [25,29,34], also at the farmer level [25,35].

Farmers' perceptions of economic benefits refer to the impact of the specific agronomic traits that are improved or the type of GM technology used [31], similar to in public acceptance studies [36–38]. Potential economic benefits of improved traits, like enhanced productivity, are found to be one of the most crucial factors determining farmers' willingness to adopt applications of GM technology [16,19, 22,23,25,32,39]. Potential adopters of GM crops in six European countries, for example, expected a higher income as a result of increased yield and reduced costs for crop protection [32].

Aside from the potential economic benefits, GM crops can also provide environmental benefits, such as lowering the need for pesticide use [40] or conserving biodiversity [41,42]. According to a study in Scotland [25], for instance, farmers perceived GM technology to be acceptable if it is beneficial and poses few risks to the environment, in line with other stakeholders [43]. The influence of perceived environmental benefits was particularly present in research on GM crops that reduce pesticide use, such as insect resistant crops [11,14].

With respect to the role of socio-demographics and farm-related characteristics in farmers' adoption processes, a large number of variables have been examined in studies on GM crops. Age, farm size, and education have been shown to be key factors, though findings are often not consistent. For age, which is tightly connected to farming experience [26], both positive [16,26,27,44] and negative effects have been reported [19,23], while in other studies no significance was obtained [20,24]. With respect to farm size, large-scale farmers are generally more likely to adopt GM crops [19,20,24,26,44], except for the study on nutritious GM cassava in Uganda [17,23]. Finally, the positive effect of education has been demonstrated in many [20,24,27,44], but not all studies [19,23].

The current study aims to identify the key determinants of farmers' willingness to adopt a specific GM crop, namely late blight-resistant (LBR) GM potato, in Flanders, Belgium. Late blight is a common potato disease that results in yield and income losses [45], and therefore farmers commonly apply fungicides to control it [4]. While an LBR GM potato might contribute to more sustainable potato cultivation, it is uncertain whether farmers would be willing to cultivate it. Thereby, it is important to gain insight into what influences farmers' decisions to adopt the cultivation of an LBR GM potato. Thereby, key determinants of willingness to adopt GM technology are considered—knowledge, attitudes towards GMOs in general (socio-economic and ethical concerns) and towards LBR GM potatoes in particular (environmental and economic benefit perceptions, stemming from the improved traits of the LBR GM potato), and socio-demographics and farm-related characteristics.

This study is targeted at farmers in Flanders, Belgium. While currently no GM crops are commercially cultivated in Belgium, this study location is highly relevant for examining the potential farmers' interest in LBR GM potatoes. First of all, Belgium has a long history of potato cultivation and is one of the main producers and exporters of processed potato products. Second, with a yearly fungicide use of more than 1000 tons of fungicides for 80,000 ha of potato crops, i.e., one of the highest amounts of fungicides compared to other crops in this region [46], the need for alternative, more sustainable late blight treatment or prevention strategies is high. Furthermore, as a member of the EU, Belgium has the opportunity to restrict or prohibit the cultivation of EU-authorized GMOs on its territory. However, it only requested a partial opt-out of the EU legislation on GM crops for the region of Wallonia, whereas the region of Flanders did not opt-out [47], making the latter an appropriate study location for farmer research on GM crops. Furthermore, the targeted cultivar is Bintje (*Solanum tuberosum* L.), which is a major potato cultivar grown in Belgium. While this cultivar is very suitable for processing into a variety of potato derived products and has a flavor and texture that are highly valued by Belgian consumers, it is very susceptible to late blight [48].

This study addresses the need for more farmer adoption studies, specifically with a focus on the EU [25,32], and the evaluation of the role of intrinsic factors [10]. Regarding GM potatoes in particular, it is the first quantitative study on farmer adoption and therefore complements the Norwegian qualitative, explorative study on farmer opinions, which highlighted the potential importance of ethical, economic, and environmental concerns [31].

2. Materials and Methods

2.1. Case: LBR GM Potatoes

Late blight is a common potato disease caused by the oomycete *Phytophthora infestans*, which can lead to large yield losses if not adequately controlled [45], causing economic losses for potato producers. As more than 1.7 million hectares of potatoes are cultivated in the EU per year [49], reducing the burden of potato diseases is highly important to the European agricultural sector.

To control for late blight, the cultivation of potatoes heavily depends on the use of fungicides. High fungicide use is associated with substantial economic costs (e.g., cost for the agrochemicals, energy, labor, and machinery for applying fungicides), and also environmental costs [50]. In addition, pesticide residues are a food safety issue for which public concern in the EU has increased [36,51].

Instead of using fungicides to control late blight, cultivars resistant to *P. infestans* offer a more sustainable way to control this potato disease and present a solution to the societal pressure to reduce the use of pesticide. While traditional breeding has resulted in some resistant cultivars, they are not widely adopted, as they do not offer a competitive yield and optimal consumption and processing qualities [52]. GM technology offers a faster method to develop potato cultivars resistant to *P. infestans* while maintaining other desired traits. Additionally, by using multiple resistance genes, it is expected to ensure more durable late blight resistance [53,54]. As such, the cultivation of the LBR GM potato could prevent late blight from destroying the harvest due to a natural resistance to *Phytophthora*, while drastically reducing fungicide use [4].

Several LBR GM potatoes are currently available and more are being developed. In 2011, the Germany-based chemical company BASF started the application for approval of its LBR GM potato Fortuna, after six years of successful field trials, but decided to halt development and commercialization of GM crops in the EU, referring to consumer and political resistance. The company Simplot, whose first generation, non-browning, innate® potatoes have been cultivated in the United States since 2016, targets LBR in its second generation. In Europe, The Sainsbury Laboratory, among others, are developing a transgenic LBR GM potato [55], while Wageningen University in The Netherlands and a team of Belgian researchers (Ghent University, VIB (Flemish Institute for Biotechnology), and ILVO (Institute for Agricultural and Fisheries Research)) are focusing on cisgenic LBR GM potatoes [4,56]. Cisgenesis introduces only genes from the same species or from a close relative, from which these genes could also be transferred by traditional breeding techniques. The present paper used this cisgenic LBR GM potato as a case for studying farmer adoption, though differences in attitudes towards cisgenesis and transgenesis were also examined. Unless otherwise stated, all findings refer to the cisgenic variety.

2.2. Data Collection Method and Sample

An online survey with potato farmers was conducted in January 2015. The study protocol was approved by the Medical Ethics Committee of Ghent University Hospital (approval registration number B670201423034). Farmers were informed about potential participation in the study through an online newsletter of the Belgian farmers' union. The link to the online questionnaire, together with an invitation letter, was sent to 2700 potato farmers, of whom 647 participated (total response rate of 24.0%). After removing all respondents who failed to complete at least 75% of the questions or did not respond to the specific questions probing about their willingness to adopt LBR GM potatoes, 384 entries were used for the analysis (valid response rate of 14.2%).

2.3. Survey

The survey consisted of two parts: (1) knowledge about GM technology, attitudes towards GMOs and LBR GM potatoes (including willingness to adopt) and (2) socio-demographic and farmer profile. While the former dealt with intrinsic factors, the latter contained questions on extrinsic factors. With respect to the intrinsic factors, farmers' objective knowledge about GM technology was measured using five true/false statements about genetics (e.g., 'ordinary tomatoes do not contain genes while genetically modified tomatoes do') and the commercial status of GM crops (e.g., 'in the EU, the cultivation of genetically modified crops is not allowed'), based on Gaskell et al. [36]. Possible answers were 'true', 'false', or 'I don't know'. The measure of objective knowledge was computed as the total number of correct answers, thus ranging from 0 to 5.

Attitudes refer to the way one thinks, feels, or acts towards an issue. Here, various components of attitudes were included—ethical and socio-economic concerns (related to GMOs), perceived economic and environmental benefits, and willingness to adopt (related to cisgenic potato LBR GM potatoes). Farmers' ethical concerns about GMOs were measured using five statements (e.g., 'genetically modified food is artificial') [13,30,34,57]. Each statement was scored on a five-point Likert (agreement) scale, ranging from 'strongly disagree' (1) to 'strongly agree' (5). Ethical concerns about GMOs were calculated as the average of the five item scores (Cronbach's $\alpha = 0.80$). A higher score reflected a stronger concern about ethical aspects. Socio-economic concerns related to GMOs were measured using four statements (e.g., 'the cultivation of genetically modified products only benefits multinationals') [25,30,57]. Each statement was scored on a five-point Likert scale and, after reversing the scale of the positively framed statements, the resulting score was obtained as the average of the items (Cronbach's $\alpha = 0.76$). A higher score reflected stronger concern about the socio-economics aspects of cultivating GMOs. Next, specific questions about the benefits of LBR GM potatoes (Bintje) were asked, while assuming that it would be available on the Belgian market. As these LBR GM potato questions referred to the cisgenic variety, an explanation was given for both cisgenesis and transgenesis. In this way, farmers' attitudes towards two different forms of genetic modification

were measured, with six items each (Cronbach's $\alpha = 0.90$ and 0.88), based on Gaskell et al. [36] (e.g., 'cisgenesis/transgenesis should be encouraged'). Regarding the benefits of (cisgenic) LBR GM potatoes, farmers' beliefs about environmental (e.g., 'I think the cultivation of this GM potato will reduce the amount of pesticide residues in the environment') and economic benefits (e.g., 'I think the cultivation of this GM potato will guarantee higher yield') of adopting LBR GM potatoes were assessed with five and seven items, respectively, measured on a five-point Likert scale (Cronbach's $\alpha = 0.79$ and 0.82, respectively). Regarding the former, the scale of two negatively framed statements was reversed before calculating the Cronbach's α and summated scale. Finally, farmers' willingness to adopt an LBR GM potato was measured with a single statement ('if a genetically modified Bintje with late blight resistance would be available in Belgium, how likely is it that you would adopt the cultivation of this potato?') on a five-point interval scale ranging from 'very unlikely' (1) to 'very likely' (5).

With respect to extrinsic factors, questions dealt with socio-demographic variables, such as gender, age, and education, as well as farm-related characteristics, such as farm size, cultivation area of potatoes, experience in the cultivation of potatoes, and the number of fungicide applications on potatoes.

2.4. Statistical Analysis

Bivariate Pearson correlation analysis was performed to evaluate the association between attitudinal variables. Paired sample t-tests were performed to test for differences in the means for attitudes towards cisgenesis and transgenesis. Multinomial logistic regression was carried out in order to identify significant determinants of farmers' willingness to adopt LBR GM potatoes. Therefore, the dependent variable was transformed into a variable with three categories (willing/indifferent/not willing) by allocating the response categories 'very likely' and 'likely' as 'willing' (54.7%), 'unlikely' and 'very unlikely' as 'not willing' (15.1%), and 'indifferent' as is (30.2%). This approach was implemented because our interest was predominantly in predicting the probability of willingness to adopt the LBR GM potato (willing/not willing), while allowing for the evaluation of differences between the indifferent farmers and the intended adopters or non-adopters. Due to a high correlation between farm size (ha) and cultivation area of potatoes (ha), the latter was not entered in the model. For the socio-demographic variables, gender was not included, due to its highly unbalanced distribution in favor of male farmers. As such, the following multinomial logistic regression model was estimated to model the willingness to adopt (WTA) decision of participant *i*:

$$\begin{aligned} \text{mlogit WTA}_i = {} & \beta_0 + \beta_1 \text{ Knowledge}_i + \beta_2 \text{ Ethical\_concerns}_i + \beta_3 \text{ Socio-Economic\_concerns}_i + \beta_4 \\ & \text{Economic\_benefits}_i + \beta_5 \text{ Environmental\_benefits}_i + \beta_6 \text{ Farm\_size}_i + \beta_7 \text{ Education\_level}_i + \beta_8 \\ & \text{Fungicide\_applications}_i + \beta_9 \text{ Age}_i + \beta_{10} \text{ Experience}_i \end{aligned} \quad (1)$$

Knowledge about GM technology, ethical and socio-economic concerns, and economic and environmental benefits were entered in the model as continuous variables, whereas farm size, farmers' education level, number of fungicide applications, age, and experience in cultivation of potatoes were included as dummy variables. Correlations between the metric explanatory variables in the model are presented in Table 1. Strong negative and positive correlations were found between the two types of concerns and between the two types of perceived benefits, respectively. Still, these values were lower than 0.7, suggesting no major problems with multicollinearity [58]. Collinearity diagnostics of the final model showed VIF (variance inflation factor) values well below 10, indicating a lack of collinearity problems in the estimated model.

The results are presented as odd ratios. The odds ratio is an indicator of the change in odds resulting from a one unit change in the predictor variable. Depending on the reference category, odds refer to the ratio between the probability that a farmer is willing to adopt the cultivation of LBR GM potatoes, is indifferent, or is not willing. The model fit was evaluated by the goodness of fit statistics of Cox and Snell, and Nagelkerke.

Table 1. Bivariate correlations between the attitudinal explanatory variables in the model (n = 384).

	Knowledge about GM Technology	**Attitude towards GMOs**		**Attitude towards LBR GM Potato**	
		Socio-economic concerns	Ethical concerns	Economic benefits	Environmental benefits
Knowledge about GM technology	1				
Attitude towards GMOs					
Socio-economic concerns	−0.124	1			
Ethical concerns	−0.228 **	0.682 **	1		
Attitude towards LBR GM potato					
Economic benefits	0.060	−0.633 **	−0.511 **	1	
Environmental benefits	0.153 **	−0.671 **	−0.684 **	0.601 **	1

* $p < 0.05$, ** $p < 0.01$.

3. Results

3.1. Sample Descriptives

The socio-demographic and farm profile of the participants demonstrate that the sample consisted of a pool of farmers with characteristics reflecting the diversity of the study population (Table 2). The sample consisted of 91.2% males, which reflects the typically male agricultural profession. The majority (69.8%) were aged between 40 and 59 years. Most farmers' highest education level was secondary school (66.0%). The total farm size ranged from smaller than 25 ha (23.9%) to larger than 100 ha (12.5%), with the majority of farmers (33.7%) having farmland acreages between 25 and 49 ha. Furthermore, the majority of farmers (61.2%) used less than 9 ha of farmland for potato agriculture. Only 12.2% cultivated potatoes on more than 25 ha. Participants also differed in their potato cultivation experience: 14% had cultivated potatoes for 10 years or less, 25% had between 11 and 20 years of experience, while 61% had more than 20 years of experience with potato growing. To prevent yield loss by late blight infections, more than half of the potato farmers (52.3%) sprayed between 10 and 14 times with fungicides per growing season. Nearly one fifth (19.6%) sprayed fungicides less than 10 times per growing season, while 26.3% sprayed between 15 and 20 times and 1.9% sprayed more than 20 times.

Table 2. Socio-demographic and farm-related characteristics (n = 384).

Socio-Demographic Variables	**% of Sample**	**Farm-Related Characteristics**	**% of Sample**
Gender		Farm size (ha)	
Male	91.2	<25	23.9
Female	8.8	25–49	33.7
Age category (years)		50–75	20.2
<20	0.3	76–100	9.8
20–29	6.1	>100	12.5
30–39	11.1	Cultivation area of potatoes (ha)	
40–49	30.8	<5	35.2
50–59	39.0	5–9	26.0
60–70	11.4	10–14	15.6
>70	1.3	15–19	7.0
Education		20-24	3.9
Elementary school	1.3	≥25	12.2
Secondary school	66.0	Experience in cultivation of potatoes (years)	
Higher education but not university	25.2	0–5	3.7
University	6.1	6–10	10.6
Other	1.3	11–20	24.7
		21–30	28.1
		>30	32.9
		Fungicide applications on potatoes (#)	
		Never	1.9
		1–4	2.7
		5–9	15.1
		10–14	52.3
		15–20	26.3
		>20	1.9

3.2. Knowledge and Attitudes

3.2.1. Knowledge about GMOs

On average, farmers evaluated three out of the five knowledge statements about GM technology correctly (Table 3). For four out of the five statements, more than 50% of the participants answered correctly. For the statement referring to the EU regulatory environment ('in the EU, the cultivation of GM crops is not allowed' (false)), only 41% reported the correct answer, while 42% wrongly indicated it as 'true', suggesting a rather poor awareness of the concerned regulatory environment among farmers.

Table 3. Knowledge of GM (genetically modified) technology and attitudinal variables related to genetically modified organisms (GMOs) and late blight-resistant (LBR) GM potato (n = 384).

Variables/Items	**Source**	**Mean ± SD % of Sample** [5]	
Knowledge about GM Technology [1]		**2.97 ± 1.50**	
		Correct (%)	Incorrect (%)
Ordinary tomatoes do not contain genes while genetically modified tomatoes do (*False*)	[36]	63.0	2.3
The yeast for brewing beer consists of living organisms (*True*)	[36]	70.3	4.7
Genetically modified animals are always bigger than ordinary ones (*False*)	[36]	70.6	2.9
In Belgium, all soy products in grocery stores are genetically modified (*False*)	Self-constructed	51.8	14.8
In the EU, the cultivation of genetically modified crops is not allowed (*False*)	Self-constructed	41.1	41.7
Attitude towards GMOs			
Ethical concerns about GMOs [2]		**2.58 ± 0.67**	
		(Totally) disagree	(Totally) agree
Genetically modified food is artificial	[57]	37.0	13.0
Genetic modification is unethical	[13]	58.1	10.4
Genetically modified food is unnatural	[57]	53.1	17.7
People using genetic modification are playing God	[30]	69.3	8.0
Genetically modified organisms should not be introduced to the market due to uncertainties about long-term effects	[34]	35.9	30.2
Socio-economic concerns about GMOs [2]		**2.67 ± 0.76**	
		(Totally) disagree	(Totally) agree
The cultivation of genetically modified products only benefits multinationals	[30]	50.0	24.0
The cultivation of genetically modified products can offer a solution to world food problems (R)	[57]	18.0	56.3
Belgian farmers would benefit from the cultivation of genetically modified crops (R)	[25]	19.3	52.3
Small farmers would not benefit from the cultivation of genetically modified products	[57]	50.5	27.6
Patents on genetically modified seed makes farmers dependent on multinationals *	Self-constructed	7.0%	76.3%

Table 3. *Cont.*

Variables/Items	Source	Mean ± SD % of Sample [5]	
Attitude towards cisgenesis (focus of this study) [2]		**3.67 ± 0.71**	
	[36]	(Totally) disagree	(Totally) agree
Cisgenesis should be encouraged		8.3	64.1
Cisgenesis makes me feel uncomfortable (R)		64.1	10.4
Cisgenesis is unnatural (R)		56.3	17.7
Cisgenesis is bad for the environment (R)		71.9	3.7
Cisgenesis is not safe (R)		62.2	5.5
Cisgenesis is useful		8.6	68.0
Attitude towards transgenesis [2]		**3.16 ± 0.70**	
	[36]	(Totally) disagree	(Totally) agree
Transgenesis should be encouraged		24.5	28.9
Transgenesis makes me feel uncomfortable (R)		35.4	25.5
Transgenesis is unnatural (R)		23.4	40.1
Transgenesis is bad for the environment (R)		43.8	6.2
Transgenesis is not safe (R)		33.9	11.2
Attitude towards LBR GM potato			
Environmental benefits of LBR GM potato [3]		**3.78 ± 0.59**	
I believe the cultivation of this GM potato will [2]		(Totally) disagree	(Totally) agree
reduce the number of sprayings per season	[32]	2.6	92.4
positively affect nature	[59]	8.1	63.5
reduce biodiversity (R)	[25]	37.5	21.4
reduce the amount of pesticide residues in the environment	[57]	2.6	92.4
have a negative impact on the environment that cannot be reversed (R)	[25]	58.1	8.1
Economic benefits of LBR GM potato [3]		**3.37 ± 0.58**	
I believe the cultivation of this GM potato will [2]		(Totally) disagree	(Totally) agree
guarantee greater yield	[32]	11.5	51.3
guarantee higher quality of the harvest	[32]	6.8	68.2
guarantee higher income for the farmer	[32]	27.6	30.7
benefit the economy of our country	[59]	18.2	37.0
guarantee the reduction of yield losses	[32]	12.5	64.1
result in a higher efficiency	Self-constructed	11.7	50.8
lower production costs	[25]	22.7	49.0
Willingness to adopt an LBR GM potato [3]		**3.40 ± 0.05**	
	(Very) unlikely	Indifferent	(Very) likely
How likely is it that you would adopt the cultivation of this LBR GM potato? [4]	15.1	30.2	54.7

EU, European Union; GM, genetically modified; LBR, late blight-resistant; (R) Reversed scale. "R" denotes a statement that was reversed in order to calculate the Cronbach's α and the summated scale (overall mean). The percentage frequencies reported refer to the original statements. [1] Measured on nominal scale: 1 'True', 2 'False', 3 'I do not know', and recoded into a dummy (correct, incorrect), by which the latter ('3'—'I don't know') is also treated as incorrect. [2] Measured on five-point Likert interval scale ranging from 1 'Totally disagree' to 5 'Totally agree'. [3] All attitudinal variables related to LBR GM potato refer to the cisgenic variety of Bintje (cfr. 2.1), under the assumption that it would be available on the Belgian market. [4] Measured on five-point interval scale ranging from 1 'Very unlikely' to 5 'Very likely'. [5] With respect to the attitudinal statements, percentage frequencies are presented for two groups, each containing two response categories, i.e., disagree or totally disagree; and agree or totally agree. Percentage frequencies for the neutral midpoint are not shown but can be calculated by subtracting the total, reported percentage frequency from 100%.

3.2.1.1. Attitudes towards GMOs and LBR GM Potato

Regarding ethical concerns about GMOs, more farmers disagreed rather than agreed with each of the five statements (Table 3). More than half of the participants did not perceive GMOs as unnatural (53.1%) or unethical (58.1%), while only 18% and 11% indicated GMOs to be unnatural or unethical,

respectively. The mean score for ethical concerns about GMOs (mean = 2.58; SD = 0.67) was below the mid-point of the scale, indicating relatively low ethical concerns on average.

For all four statements related to socio-economic concerns about GMOs, only 28% or less indicated they were concerned. Farmers generally believed they would benefit from GM crop cultivation (52.3% (totally) agreed, while only 19.3% (totally) disagreed). Half of the participants (totally) disagreed with the statement 'the cultivation of genetically modified products only benefits multinationals', while only 24% (totally) agreed. Furthermore, 56.3% (totally) agreed that 'GM can offer solutions to world food problems', as compared to only 18.0% of the sample who (totally) disagreed. The majority (76.3%) also (totally) agreed with the statement 'patents on genetically modified seeds make farmers dependent on multinationals'. The resulting construct for socio-economic concerns has a mean of 2.67 (SD = 0.76), just below the mid-point of the scale.

Although this study focused on cisgenic LBR GM potatoes, farmers' attitudes towards both cisgenesis and transgenesis were measured. The difference in the mean score between the attitude towards cisgenesis and attitude towards transgenesis was 0.52 (SD = 0.63) and is significantly different from zero (paired *t*-test, t (383) = 16.03; $p < 0.01$). Thus, farmers have, on average, more positive attitudes towards cisgenesis than towards transgenesis. While the mean attitude score towards transgenesis was around the mid-point of the scale (3.16, SD = 0.70), the mean score for attitude towards cisgenesis was above the mid-point (3.67, SD = 0.71). When evaluating the individual items, a consistently higher share of respondents positively evaluated the statement about cisgenesis (between 56% and 72%), while for transgenesis the share was much lower (23% to 44%). For example, more than 60% of the farmers indicated they (strongly) agreed with the statements 'cisgenesis should be encouraged' (64%) and 'is useful' (68%)', while they much less (strongly) agreed with this statement for transgenesis (29% and 40%, respectively).

With respect to attitudes towards cisgenic LBR GM potatoes, farmers generally believed that they would offer environmental benefits (mean = 3.78, SD = 0.59). Most farmers also agreed that the cultivation of LBR GM potatoes would positively affect the environment (63.5%), would reduce the number of treatments with pesticides (92.4%), and would result in fewer pesticide residues in the environment (92.4%).

From an economic perspective, farmers generally believed that the GM potatoes would provide economic benefits (mean = 3.37, SD = 0.58). Most participants (totally) agreed that the cultivation of GM potatoes might increase yield (51.3%), reduce yield losses (64.1%), and yield potatoes that are of higher quality (68.2%). However, only 30.7% of the participants believed that cultivation of GM potatoes might increase farmers' income, while many (41.7%) indicated they neither agreed nor disagreed that the cultivation of GM potato would impact farmers' income.

Finally, a large share of the sample would be willing to adopt LBR GM potatoes. More than half of the farmers (54.7%) were positive towards the cultivation of LBR GM potatoes, with 7.3 % indicating they would 'very likely' adopt its cultivation if it were available in Belgium. Meanwhile, 47.4% indicated they would 'likely' do so. Only 6.5 % of the farmers answered to be 'very unlikely' to cultivate LBR GM potatoes, while 8.6% indicated 'unlikely'. About one out of three farmers was indifferent (30.2%).

3.3. Determinants of Willingness to Adopt LBR GM Potato

Multinomial logistic regression was performed to evaluate the impact of nine explanatory variables on the likelihood that farmers would be (not) willing or indifferent to adopt LBR GM potatoes. The results of the three binary logistic regressions, including the odds ratios (Exp(β)) and their confidence intervals and significance levels, and goodness-of-fit statistics of the model are presented in Table 4. The full model with all nine predictors was statistically significant, with $\chi^2 = 125.80$ ($p < 0.001$), demonstrating that it performs well in distinguishing between farmers who are willing to adopt the cultivation of GM potatoes, those who are indifferent, and those who are not willing.

Table 4. Determinants of farmers' willingness to adopt cultivation of the LBR GM potato, by multinomial logistic regression (n = 377).

	Willing Versus Not Willing			**Willing Versus Indifferent**			**Indifferent Versus Not Willing**		
	OR	**(95% CL)**	***p***	**OR**	**(95% CL)**	***p***	**OR**	**(95% CL)**	***p***
Knowledge about GM technology	**0.960**	**0.757–1.216**	0.735	**1.204**	**1.002–1.446**	**0.047**	**0.797**	**0.637–0.999**	**0.049**
Attitude towards GMOs									
Ethical concerns	**0.453**	**0.213–0.960**	**0.039**	**0.487**	**0.268–0.886**	**0.019**	0.929	0.447–1.931	0.843
Socio-economic concerns	0.506	0.248–1.033	0.061	0.694	0.402–1.198	0.190	0.729	0.363–1.465	0.375
Attitude towards LBR GM potato									
Environmental benefits	1.852	0.753–4.556	0.180	1.464	0.725–2.956	0.288	1.265	0.534–2.999	0.593
Economic benefits	**2.310**	**1.021–5.224**	**0.044**	1.991	1.077–3.679	**0.028**	1.160	0.517–2.602	0.718
Socio-demographic/farm-related									
Farm size (<25 ha)	0.514	0.237–1.115	0.092	1.480	0.861–2.544	0.157	**0.347**	**0.162–0.743**	**0.006**
Education level (low)	1.325	0.601–2.919	0.485	0.991	0.531–1.848	0.977	1.337	0.618–2.891	0.461
Fungicide applications (<15 times)	0.486	0.206–1.150	0.101	0.605	0.336–1.090	0.094	0.803	0.332–1.942	0.627
Age (<50 years)	0.640	0.276–1.484	0.298	0.677	0.360–1.275	0.228	0.945	0.414–2.160	0.893
Experience (<30 years)	0.922	0.405–2.099	0.847	0.883	0.479–1.630	0.692	1.044	0.464–2.350	0.917
Model									
Likelihood ratio test, χ^2	**140.29**								
p-value	**0.001**								
Pseudo R^2: NagelkerkeCox & Snell	**0.362**								
	0.311								

CL, confidence level; GM (O), genetically modified (organisms); OR, Odds ratio. Note: Willingness to adopt LBR GM potato, the dependent variable, consists of three categories: adoption ('willing'), indifferent and rejection ('not willing'). Therefore, the multinomial logistic regression is split up into two three binary logistic regressions: willing versus not willing (reference category), willing versus indifferent (reference category), and indifferent versus not willing (reference category). Both Odds ratios and confidence intervals are provided. Bold indicates significance at 0.05 level. In case of independent, dummy variables, the reference category is mentioned between brackets.

As shown in Table 4, four explanatory variables were found to have a significant contribution to the prediction of willingness to adopt—three intrinsic factors (knowledge about GM technology, ethical concerns about GMOs, economic benefit beliefs about LBR GM potatoes), and only one extrinsic factor, i.e., farm size (<25 ha). Therefore, farmers are more likely to adopt LBR GM potatoes when they are less concerned about the ethical aspects surrounding GMOs or when they hold stronger beliefs about the economic benefits of the LBR GM potato. A one unit increase in ethical concerns decreases the odds of willingness to adopt ('willing') by a factor of 0.45 (against 'not willing') or 0.49 (against 'indifferent'), while the same odds are increased by a factor of 2.31 (versus 'not willing') or 1.99 (versus 'indifferent') for each unit increase in the perceived economic benefits. Furthermore, the likelihood of being indifferent, as compared to being willing to adopt or being opposed, increases as knowledge about GM technology reduces. The non-significance of knowledge in the comparison between potential adopters ('willing') and non-adopters ('not willing') suggests poorer knowledge among indifferent farmers. Also, in consumer research on GMOs, objective knowledge has been associated with those taking an opinion, i.e., by either accepting or rejecting GM technology [60]. Regarding the socio-demographic and farm-related variables, only farm size emerged as a significant factor. A large farm size negatively influenced the likelihood to be indifferent as compared to not willing. The odds that farmers with a large farm are indifferent are 0.35 of the odds of those with a small farm size. The two other attitudinal variables (concerns about socio-economic aspects of GMOs and environmental benefits of LBR GM potatoes), as well as education level, number of fungicide applications, age, and experience with potato farming did not significantly affect the willingness to adopt LBR GM potatoes.

4. Discussion

As primary producers, farmers are indispensable when deciding whether or not newly developed crops will be cultivated and, thus, become available on the market. This study investigated the key determinants underlying farmers' willingness to adopt LBR GM potatoes. This GM potato is resistant to late blight disease and, hence, offers both economic (increased yield) and environmental benefits (reduced fungicide use). This research contributes to the current state of stakeholder analysis on GM crops by addressing the need for farmer adoption studies, especially studies in a European context that examine the role of both intrinsic and extrinsic determinants. Moreover, by examining the market potential of LBR GM potatoes (Bintje) for Belgian farmers, our study builds upon the scarce adoption literature on GM potatoes [31]. Our study targeted a highly relevant study region (Flanders), where not only are potato consumption and production high, but also potato diseases, such as late blight disease, are widespread. Given that this EU region did not request to restrict cultivation (the so-called opt-out measures), our findings provide important insights to underpin future commercialization and the potential adoption of this GM potato in Belgium and beyond.

4.1. Knowledge and Attitudes towards GMOs

On average, farmers' knowledge of GM technology was moderate, but still higher than knowledge rates observed in a developing context [13,14,16]. Our results indicate that most farmers (60% and above) were able to correctly answer three out of five questions related to GMOs. However, our study also indicates a lack of knowledge about the regulatory status of GM crops and the commercialization process among farmers. This finding is disquieting, since farmers are professionally involved with the production and commercialization of crops. It clearly illustrates the need for information provision and agricultural extension, similar to that for other GMOs reducing the use of agrochemicals [61].

With respect to GMO-related attitudes, less than 20% of the farmers agreed with statements that genetic modification is artificial, unethical, or unnatural. Nevertheless, the perceived naturalness of GMOs, as well as the associated socio-economic concerns, such as the fear of the power of multinationals, may be considered barriers to the commercialization of GMOs, in line with previous research [25,29,62].

Indeed, our study also indicated that more than three out of four farmers were concerned about the impact of patents on GM seeds on farmers' dependency on multinationals.

While our study targeted cisgenic LBR GM potatoes, GM potatoes can also be produced using transgenesis. Currently, both transgenic [55] and cisgenic [63] LBR GM potatoes are being developed. Cisgenic crops offer more possibilities, as several studies found consumers' attitudes towards cisgenic crops to be more positive than those towards transgenic crops [36,38]. In addition, while cisgenic crops currently have to comply with GM regulation, it is possible that cisgenesis may become exempted from the GM regulation or at least would fall under a lighter regulatory regime [64]. Our study shows that farmers' attitudes towards cisgenesis are indeed rather positive, similar to those reported for consumers in the EU and US [36,38].

4.2. Attitude towards and Willingness to Adopt LBR GM Potatoes

Farmers' attitudes towards LBR GM potatoes are relatively positive. On average, farmers believed that cultivating LBR GM potatoes would provide both economic and environmental benefits. The majority of Flemish farmers acknowledged the potential for LBR GM potatoes to reduce fungicide use, although they did not necessarily believe it would positively influence their income. While a meta-analysis has shown that GM crops can effectively increase farmers' income [40], many farmers in our sample were not really convinced about this. Nevertheless, aside from potentially higher costs of GM potatoes, this LBR GM potato might potentially result in a higher profit for farmers, through reducing the number of fungicide treatments, the associated economic costs, and social and environmental externalities [50].

The findings on willingness to adopt further underline Flemish potato farmers' interest and rather positive attitude towards GM potato cultivation. More than half of the farmers (54.7%) stated that they would (very) likely to be willing to cultivate LBR GM potatoes if these became available. These findings correspond partly with the results of the study of Areal et al. [32], where more than 50% (in Germany) and 30% (in France) of the farmers claimed to be willing to adopt GM herbicide-tolerant (HT) oilseed rape. When taking into account the indifferent farmers (30.2%) in our sample, our results exceed these acceptance rates and other adoption figures observed in European studies [26].

4.3. Determinants of Willingness to Adopt LBR GM Potatoes

This study identified different determinants of farmers' adoption of LBR GM potatoes, and highlighted the importance of intrinsic factors (knowledge and attitudes) [10], as compared to the role of extrinsic factors (socio-demographic and farm profile). First of all, knowledge had a significant negative effect on the likelihood to be indifferent towards adoption. In other words, the more farmers are knowledgeable about GM technology, the more likely they are to take a stand on LBR GM potatoes, i.e., be either willing or reluctant. As such, it shows that improving knowledge about GM technology alone would be ineffective to improve adoption rates. This contradicts other research in Europe [23] and the United States [20,28], where only a positive effect of knowledge was found on the willingness to adopt. In other words, our study suggests that better knowledge may as well result in rejection as in adoption of GM crops among farmers.

Second, while farmers were generally concerned about the ethical and socio-economic aspects of GMOs, only their ethical concerns were a significant factor influencing the likelihood to adopt LBR GM potatoes or not. This underpins the importance of ethical concerns as key barriers to the adoption of GM crops [25,35]. Being concerned about ethical aspects may relate to the belief of a lack of consumer acceptance of GM food. In a qualitative study on GM potatoes in Norway, for example, possible consumers' rejection of GMOs was pointed out as the main obstacle for farmers' adoption [31]. Socio-economic concerns about GMOs, however, did not influence the willingness to adopt the LBR GM potato. Some of these concerns, especially those related to the impact of multinationals (e.g., on small-scale farmers) appear to be shared by a large share of farmers, regardless of their willingness to adopt GM potatoes.

Third, when looking at attitudes towards LBR GM potatoes in particular, farmers' perceptions of the economic benefits, but not the environmental benefits, are an important predictor of willingness to adopt. The importance of economic benefits in farmers' decision-making process confirms past adoption studies, particularly those targeting GM crops with improved agronomic traits [19,22,23,25,32]. Furthermore, the potential reduction in fungicide use through LBR GM potatoes would decrease human health risks and environmental risks [65], an asset that is considered crucial, according to potato farmers in a Norwegian stakeholder study [31], but not in the present farmer study. Unlike other farmer studies looking at GM crops that reduce the use of agrochemicals, such as pest-resistant Bt crops, where environment-related perceptions influenced adoption [11,14], the importance of economic benefits in our study prevailed, at the expense of environmental benefits.

Fourth, farm size was the only factor of the farmer profile that significantly affected willingness to adopt LBR GM potatoes, but only when indifferent and reluctant farmers were compared. The negative effect that was observed, indicating that small-scale farmers were more likely to be indifferent rather than reluctant, was not in line with studies that compared adoption ('willing') versus non-adoption ('not willing') [19,20,26], although these studies were conducted in a different context, e.g., targeting large-scale farmers in the United States. The other profiling variables, such as the number of fungicide applications, age, and experience in potato farming and education, did not play a role. While previous results on the effect of age were inconsistent [16,19,23,27], findings on the role of education were more consistent, leaning towards a positive effect on adoption [20,24,44]. Nevertheless, our findings correspondent with previous studies reporting the non-significance of age [20,24] and education [19,23].

The present study faces some limitations. Our results were based on self-reported data and may therefore be subject to hypothetical and social desirability bias. Since the cultivation of an LBR GM potato for commercial purposes is not yet allowed in the EU, only hypothetical situations can be investigated at this moment. Furthermore, at present, no GM crops are commercially cultivated in Flanders, which might make it difficult for farmers to evaluate the socio-economic issues and other consequences associated with the future cultivation of a GM potato. Potential social desirability bias has been reduced through guaranteeing the collection of data anonymously and online, and through storing and analyzing the data in a non-identifiable format. A substantial amount (14%) of the total population of Flemish potato farmers are included in this study's valid sample, yet there may be an issue of self-selection bias, as farmers with a stronger interest in the topic, higher involvement with the issue and/or more outspoken views (which could be both positive or negative) on GM crops might have had a higher likelihood of taking part in the study. Nevertheless, willingness to adopt LBR GM potatoes was operationalized as a three-dimensional (willing, indifferent, not willing) instead of a dummy variable (willing versus not willing), which made it possible to also analyze indifferent farmers, and therefore may reflect a more comprehensive view on the determinants of the potential adoption of LBR GM potatoes.

In summary, this study highlighted the potential of LBR GM potatoes at the farmer level. Flemish potato farmers generally hold positive attitudes towards the benefits of LBR GM potatoes, in line with their relatively positive beliefs about ethical and socio-economic aspects, except for their worries about the role of multinational companies. The majority of farmers in our study indicated they would be willing to adopt the cultivation of LBR GM potatoes if they became available. Therefore, beliefs about ethical concerns about GMOs, as well as beliefs about the economic benefits of LBR GM potatoes, emerged as the main drivers of farmers' willingness to adopt this potato. Nearly one third of the farmers were indifferent to the adoption, which can be linked to smaller farms and lower knowledge levels. As increasing their knowledge would not necessarily lead to an increased rate of adoption, future research is needed to examine how communication about GM technology and concerns about GMOs or crop-specific benefits may impact farmers' knowledge, attitudes, and, thus, future adoption. This could further exploit the potential benefits of LBR GM potatoes, as they were generally well embraced by the farmers in our study, and avoid the adverse impact of misunderstanding, poor knowledge, and eventual negative attitudes [14,15,66]. However, the success of LBR GM potatoes will not only

hinge on farmers' adoption. The views of other stakeholders in the potato supply chain are also crucial, and could influence the interest of consumers [67] and farmers. While previous stakeholder research highlighted conditions for a successful commercialization of LBR GM potatoes [31], our study provided valuable insights on the role of intrinsic and extrinsic factors at the farmer level.

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