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The opinions of first adopters in the introduction of Bt maize in Spain: A success story

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Abstract: Spain is one of the few EU countries that adopted genetically modified maize as a crop (1998) and has continued to harvest it ever since. This article aims to contribute to the history of the adoption of transgenic maize in the EU, where the Mediterranean (*Sesamia nonagrioides*) and European (*Ostrinia nubilalis*) corn borers are two of the most destructive pests. Our aim is to identify Spanish farmers' motivations and opinions on adopting this technology. Our model is a binary logistic regression that estimates the probability of adopting Bt maize. Our results reveal that the odds of adopting Bt are at least 44.0 times greater if the farm is in an area with corn borer infestation episodes than if it is not. The odds of adopting Bt are at least 4.9 times greater if farmers place a high importance on economic outcomes than if they do not. More adopters than non-adopters believe that Bt corn causes less damage to the environment than sulphates against the borer. No other opinion variable was clearly significant. We conclude that the most important reasons for Bt adoption were exposure to corn borer and concerns about the economic losses the borer could cause to the crop.

Keywords: adoption of innovations; farm decision-making; logit model; survey

Genetically modified (GM) plants, such as GM soybeans, GM maize and GM rapeseed, began to be marketed worldwide in 1996. They were intended for animal feed with attributes of great value for adopting farmers, reducing pesticide use and improving crop yields. A decade later, they were being cultivated on a large scale worldwide. In that period, the countries most committed to growing these crops were the United States (54.6 million ha), Argentina (18 million ha), Brazil (11.5 million ha), and Canada (6.1 million ha) (James 2009). In Europe, however, although most EU member states (MS) were in favour of the application of biotechnology in agriculture (Moschini 2008), this position began to change with the arrival of American GM soybeans in European ports in 1997 and the protests deployed by anti-genetically modified organism (GMO) groups (Schurman 2004), derailing the cultivation of GM crops (GMC) and changing the history of GM maize adoption in Europe. From the beginning, the European Commission allowed imports of GMC varieties and in 1998 also authorised the cultivation of an insect-resistant GM maize in response to a proposal by the French government (Sato 2013). This insect-resistant maize producing the Cry1Ab toxin of *Bacillus thuringiensis* (Bt maize) was approved for cultivation in the EU in 1998 to control the corn borers Mediterranean, *Sesamia nonagrioides* (Lefebvre), and European, *Ostrinia nubilalis* (Hübner).

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There were potential alternatives to GMOs for pest control, some of which are still under study, such as the parasitoid *Cotesia typhae* and the spore-forming fungus *Nosema pyrausta*, which could be population regulators of the Mediterranean and European corn borers, respectively, but they have not yet been widely applied commercially (Lewis et al. 2009; ANR 2024). Even the FAO (2004, 2011, 2022) considered that biotechnology offered a powerful strategy for the development of sustainable agriculture. However, the public debate in several EU countries about the possible risks that GMC could have on human health and on ecosystems halted its adoption (Braun 2001; Moschini 2008; Anyshchenko and Yarnold 2021).

In 2008, the MS with a significant maize area (≥ 200 000 ha: France, Italy, Germany, Greece and Austria) adopted safeguard measures [Directive 2001/18/EC and emergency measure relating to Regulation (EC) No. 1829/2003] that prohibit the cultivation of transgenic maize in their territories. Despite these plans, safeguard clauses submitted to the European Food Safety Authority (EFSA) were declared scientifically unfounded (European Commission 2016). Spain first authorised the cultivation of GM maize (event MON 810) in 1998. For adopting farmers, the advantages arose from increased yields and reduced pesticide use (Gómez-Barbero et al. 2008). All Bt maize production was purchased by the national feed industry (Gómez-Barbero and Rodríguez Cerezo 2008). For the meat industry, a direct benefit of Bt maize production was the higher quality of the grain due to low levels of mycotoxins. This is important because maize is a basic component of the animal diet. Studies carried out in pigs, cattle and poultry that were fed transgenic maize have shown that there are no significant differences (weight, milk, eggs etc.) with conventional maize feed (Scott and Pollak 2005). In recent decades, several studies on the effects of Bt maize on other conventional crops or on biodiversity have demonstrated the positive externalities that Bt crops have on these crops and on non-target insects (Hutchison et al. 2010; Comas et al. 2014; Dively et al. 2018). Furthermore, research centres and health authorities continue monitoring for early detection of resistance. No control failures have been reported, confirming that Cry1Ab-producing Bt maize remains effective against both pests (EFSA et al. 2021; García et al. 2023).

In Spain, the adoption of this transgenic cereal has also been assisted by the favourable position of successive Spanish governments and national professional agricultural and livestock organisations. In fact, during the moratorium (1998–2004) its cultivation continued in Spain but not in the rest of the EU (Figure 1). Furthermore, in countries such as Romania, Czech Republic and Slovakia, farmers stopped cultivating (between 2016 and 2017) due to strict administrative requirements for cultivation and subsequent marketing (ISAAA 2017). Currently, GM maize is only grown in two MS: Spain with around 120 000 ha, which

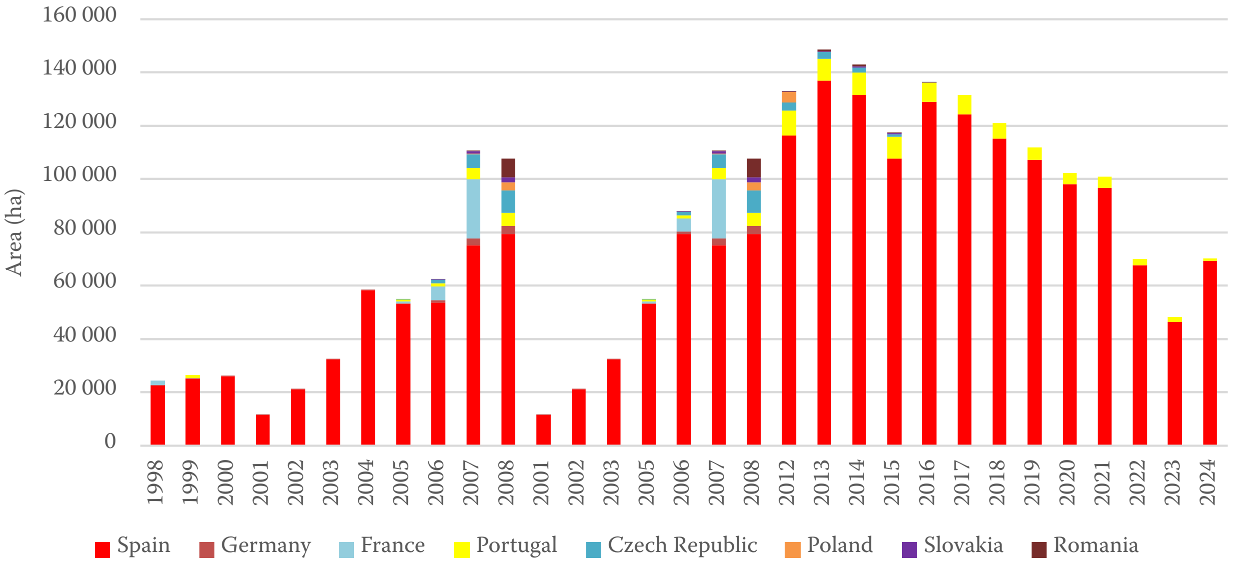

Figure 1. Genetically modified maize area in the EU, 1998–2024

Source: Own elaboration based on ISAAA (2018), MAPA (2025) and DGAV (2025) represents 38% of the total Spanish maize area, and Portugal with 4 754.8 ha, which represents 36% of the planted maize area in Portugal. Presently, 61 different varieties of Bt maize can be grown in Spain with the MON 810 gene package. The evolution of the European surface area of GM maize can be seen in Figure 1. The last few years of Figure 1 correspond to a severe drought experienced on the Iberian Peninsula.

During the initial years, several Eurobarometer series were carried out to measure the general level of consumer attitudes towards biotechnology in the EU. Consumers were questioned about the environmental and moral concerns that the use of GMOs represented for them. The results indicated that Europeans had relatively neutral opinions towards genetically modified foods as a technology, but over time their opinion became more negative in terms of usefulness, moral acceptability, and promotion of such technologies (Frewer et al. 2004).

Farmers' opinions were mostly absent from the debate on GMC and yet their decisions about whether to grow genetically modified foods were and are basic for this technology in European agriculture (Guehlstorf 2008; Hall 2008). Most studies, in the initial years, focused on farmers' economic expectations towards GMC and concentrated mostly on the effects of the economic profitability of the new GM seed and the socioeconomic characteristics of adopters, not on farmers' opinions and ethical concerns about GMC (Fernandez-Cornejo and Caswell 2006; Mauro and McLachlan 2008; Skevas et al. 2009; Fernandez-Cornejo et al. 2014). Kaup (2008), following classical studies on adoption and diffusion of innovations, also incorporates social theories and biotechnology, exploring their influences on the use of Bt maize by farmers. Research carried out in the EU showed that in some countries, such as France and Hungary, where the cultivation of GMC was prohibited, most farmers agreed with the prohibition. However, in other countries, such as Greece, Poland and Belgium, where the cultivation was also forbidden, most farmers surveyed would adopt GM maize if the respective governments lifted the ban on its cultivation (Skevas et al. 2012; De Steur et al. 2019). The results indicate that farmers' opinions may or may not coincide with the country's legal regulations and that public attitudes are very important. The few empirical studies surveying farmers about their perceptions and opinions concerning potential environmental advantages and disadvantages of growing genetically modified crops (Chong 2005; Guehlstorf 2008; Hall 2008; Lehrman and Johnson 2008; Skevas et al. 2012) consistently find that participating farmers tended to evaluate GM crops quite pragmatically. In general, attitudes were more positive when a direct benefit to agricultural production was indicated, and there were some concerns about environmental and human health issues.

Our article analyses the characteristics, opinions and beliefs of farmers in the North-East of Spain regarding the adoption of genetically modified (GM) maize during the first years of adoption of this technology. On writing the history of GM maize adoption in Europe, it is necessary to know the role that farmers played in its development. This article aims to contribute to the writing of this history, identifying the reasons that led Spanish farmers to adopt GM maize. We are interested in identifying the singularities, if any, of Spanish farmers that could explain the initial Spanish position on this issue. Our data allow us to characterise farmers' motivations for growing Bt maize. The results suggest that farmers surveyed were aware of the potential problems that could arise from the introduction of genetically modified crops, but also felt, mainly in areas that have been infested by corn borer, the fear of corn borer infestation and the economic damage that it could cause. Avoiding corn borer infestation increases the expectation of larger economic benefits that Bt could bring. These expectations acted as a positive incentive to adopt.

Some previous papers have been written on this issue. In Spain, Gómez-Barbero et al. (2008) compared the socioeconomic profile (farm size, tenure, main crop, age, education, farm experience, among others) of Bt maize adopters versus non-adopters and found that there were no significant statistical differences between the two groups. We try to explain these differences not only with the socioeconomic variables but also with farmers' opinions. In addition, the opinion of European farmers has also been the subject of study (Breustedt et al. 2008; Lawson et al. 2010; De Steur et al. 2019). Their results indicate that profits differences between GM and non-GM crops is one of the main drivers for adoption of the technology. Further, in Keelan et al. (2009) the size of the farms was the most important explanatory variable. However, farmers also showed ethical concerns regarding the use of this technology (Hall 2008; Lawson et al. 2010), but despite these concerns they were willing to adopt it if it were to become available in the EU (De Steur et al. 2019). Further, Chvátalová (2021) explored the attitudes of Czech farmers who grew GM and conventional non-GM maize for commercial purposes continuously from 2005 to 2016. Many interviewees argued that growing GM crops was beneficial for the environment and rated genetic engineering and its products as 'progress' and innovation. On the other hand, Czech farmers who opposed GM crops were unique in their ethical considerations and in their questioning of the legitimacy of industrial studies. The main difference between these documents and ours is that in the first ones, the questions and answers were hypothetical, since GM crops were not allowed in most EU countries. However, in Spain, transgenic maize has been harvested since 1998 and therefore in our article the answers come from farmers with experience in both, traditional and Bt maize.

MATERIAL AND METHODS

In Spain, the first insect-resistant transgenic Bt maize varieties for sowing were officially registered in March 1998, being cultivated on 22 317 ha. In 2009, the cultivated area of Bt maize was estimated at 79 700 ha and in 2019 it reached 107 126 ha (30% of the total maize hectares in Spain). The regions of Catalonia and Aragon accounted for 74% of the national area dedicated to Bt maize (MAPA 2025). The farmers interviewed belonged to these regions, specifically to the Ebro Valley (Figure 2) part of these regions. The questionnaire included questions related to the characteristics of the farmer, to the general aspects of the farm, and to the opinions and beliefs of the farmers. Farmers were asked in depth about their perception, use and adoption decisions concerning Bt maize, including ethical convictions and the reasons that led to Bt crop adoption (questionnaires and data available upon request).

The target population was randomly and representatively selected from members of agricultural cooperatives, agrarian transformation societies, irrigation communities and agricultural trade unions. The proportion of surveys between adopters and non-adopters was close to the proportion of surface area dedicated to Bt in the study areas, 57% in Catalonia and 55% in Aragon. The surveys were conducted with a face-to-face methodology, through a representative and *ad hoc* sample between December 2008 and December 2009. The interviews took place at the facilities of the corresponding associations in the localities involved, having previously agreed by telephone the day and time of the survey. The farmers that did not agree were not surveyed. The final sample population consisted of 170 farmers, of which only 12 were women, that traditionally had been farming maize, whether conventional or Bt varieties.

The questionnaires were made up of two parts, the first asked general questions related to farm and farmer characteristics, and the second focused on their opinions and beliefs regarding the adoption of Bt maize. The interviews were conducted by professional personnel. The suitability of the sample was verified by comparison with statistics from the Spanish Agricultural Census of the National Statistics Institute, to ensure

Figure 2. Ebro Valley studied area

Source: Ebro Hydrographic Confederation (https://iber.chebro.es/geoportal/)

that the surveyed farmers' characteristics were representative of the study area.

We represented the decision to grow Bt instead of conventional maize using a dichotomous discrete variable, *Adopt*, that takes value 1 for farmers that seeded Bt maize in the area in 2009, and 0 otherwise. We model the log-odds of growing maize as a linear combination of a set of independent variables. Our aim was to analyse Bt maize adoption decisions, to discover what factors influenced farmers to adopt Bt. Our chosen statistical model is a binary logistic regression. Logit models estimate the probability of the dependent variable to take value 1. The logistic regression models the logit-transformed probability as a linear relationship of the predictor variables. Thus, our model will be equal to:

$$\log it(p) = \log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \ldots + \beta_x x_x \tag{1}$$

where: logit (p) – logit function; p – probability of success; $1 - p$ – probability of failure; x_i – set of explanatory variables. Or, in terms of probabilities:

$$p = \frac{\exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_x x_x)}{1 + \exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_x x_x)} \tag{2}$$

where: exp () – exponential function.

The software used for our estimations was Stata 16 (StataCorp, USA).

According to the models on adoption and spread of innovations, we introduced explanatory variables that account for farm and farmer characteristics (Kaup 2008). We also included variables related to farmers' opinion and convictions. We introduced variable *FSize* that indicates the total farm size in hectares. We expected it to be positive and statistically significant, as we expected large farms to be more prone to introduce innovations. The variable *PercIL* represents the percentage of irrigated land with respect to the total size of the farm. We also expected this coefficient to be positive and significant, as maize requires abundant irrigation in this zone. That is, the larger the percentage of the farm irrigated area, the larger the interest of the owner in growing Bt maize.

In terms of corn borer pressure, some areas of the region subject to study have been infested by *S. nonagrioides* or *O. nubilalis* (Brookes 2003). We expected that farms located in areas that have been damaged by the corn borer would be more likely to adopt Bt maize. To ascertain if the surveyed farmer knew about the effects of the corn borer not only because he had experienced them himself, but also because a neighbour, friend, or close person had suffered from them we introduced *CorkArea*, a dummy variable that takes value 1 if the farmers answer positively to the question: 'Do you know if in your area maize is attacked by a pest called the corn borer?', and zero otherwise (with the options: a. No, I don't. and b. Yes). We expected its coefficient to be positive and significant, indicating that corn borer pest exposed farmers, have a greater propensity to adopt Bt maize than non-exposed farmers. Additionally, variable *Cattle* was introduced in our regressions to ascertain whether farmers that grow Bt maize also pursue cattle activity, as Bt maize cultivated in Spain is exclusively used for animal feed. *Cattle* takes value 1 if farmers also have cattle activity, and 0 otherwise. If this variable were positive and significant, it could suggest that most of the GM maize was used as animal feed on the same farm.

The variable *Age* (of the farmer in years old) has been widely used in innovation literature, and although it was thought that younger farmers were more attracted to new technologies (Rogers 2003), the numerous studies carried out demonstrate that the influence does not always present the same sign (Alexander et al. 2003; Payne et al. 2003; Qaim and de Janvry 2005; Fernández-Cornejo et al. 2014). Furthermore, we define the variable *Edu* that captures the effect of farmers' education level on Bt adoption. This dummy variable singles out the farmers that achieved a high education level, taking value 1 if farmers have a high school or university degree, and 0 otherwise. We expected a positive and significant result, indicating that higher education is associated with a higher propensity to adopt. Additionally, to analyse the influence of farmers' education on adoption in more detail, we included a variable accounting for their specific agricultural academic training, *EduAgri*, a dummy variable that takes value 1 when farmers have completed specialised agricultural studies, and 0 otherwise. As with the previously depicted variable, we expected positive and significant behaviour.

Variable *Inc100* is a dummy variable that takes value 1 if the percentage of the annual family income that comes from agricultural or livestock production is 100, and 0 otherwise. A positive and significant coefficient would show that families whose income was derived only from the agricultural and livestock activity present a larger propensity to adopt Bt maize. We introduced Backup, a dummy variable that takes value 1 if farmers have continuity in the farm, and 0 otherwise. Our hypothesis in this case was that having anyone in the family or nearby to continue the farm activity would promote a positive adoption decision.

We pursued the idea of introducing a *Gender* variable to capture differences in adoption behaviour between male and female farmers. We did not have any preliminary hypothesis about the propensity to adopt, in favour of men or women. However, women in charge of the farm activity constituted only 7% of the sample and this variable was therefore not included.

Farmers' beliefs about the introduction of innovations such as Bt maize, with potential negative side effects, had rarely been asked about before 2009. To our knowledge, no scientific publication has addressed the inclusion of this kind of variables so far (Alexander 2007; Guehlstorf 2008). Kaup (2008) incorporated some similar concepts, listed as reasons for farmers to plant Bt maize, but not as variables. A set of questions was thus introduced to capture farmers' opinion and convictions on the use of Bt maize. The opinion of the farmers was gathered with several questions in which farmers expressed their level of agreement on a Likert scale from 1 to 5: strong disagreement = 1; disagreement = 2; maybe = 3; agreement = 4; strong agreement = 5. However, unlike dichotomous or continuous variables, categorical variables cannot be entered in a regression equation just as they are. Categorical variables relate to measurements that are not made on any measurable scale, which contrasts with measurements that have a scale such as age or distance and, therefore, increases in the category of the response have no clear interpretation. We introduced these variables, as is usually done, redesigning them as dichotomous variables. In each of these questions, the corresponding dichotomous variable takes value 1 if the surveyed farmer expressed their level of concordance with the statement proposed in as 'agreement' or 'strong agreement', and zero otherwise.

First, farmers were asked about the economic advantage of sowing Bt maize, one of the main reasons that the related literature points out for using Bt maize instead of conventional maize (Fernandez-Cornejo and McBride 2002; Gómez-Barbero et al. 2008). We used variable *BtEcon* to compare the Bt adoption odds among farmers that have different beliefs about the economic convenience of adopting Bt. We introduced the binary variable *BtEcon* that takes value 1 if the surveyed farmer expressed agreement with the sentence 'I would sow Bt maize if it suited me economically', and zero otherwise. We expected that farmers agree with that statement when they give great importance to the economic results of their farming activity. Almost 50% of the farmers clearly agreed with the convenience of using Bt maize from the economic point of view, while less than 5% of them disagreed with it. A significant and positive coefficient for this variable would indicate that farmers that prioritise their economic results have a larger probability of adopting Bt.

Further, we introduced *BtvsChem*, which takes value 1 if farmers express their agreement with the sentence 'Bt maize causes less damage to the environment than sulphates against borer', and zero otherwise. A positive and significant coefficient would show that farmers that believe that Bt maize is less dangerous than sulphates present a larger probability of adopting Bt. Additionally, we considered variable *BtRefuse* which takes value 1 if the farmer expresses agreement with the sentence 'My convictions make me refuse to sow Bt maize', and zero otherwise. A negative and significant coefficient of this variable would mean that convictions matter and farmers that agree with this sentence have a lower likelihood of planting Bt for moral reasons. Also, the questionnaire requested the opinion of farmers about their agreement with the sentence 'In no case would I sow transgenic Bt maize', and we created variable *BtNever*, that takes value 1 if farmers agree with this sentence and 0 otherwise. Note that the answers to these last two statements were expected to be similar; variables *BtRefuse* and *BtNever* represent similar opinions and both variables could not be included in the regression simultaneously due to multicollinearity. Furthermore, we introduced variable *GMOFear* to capture fear of GMOs, created considering the level of concordance with the sentence 'Fear of GMOs, especially among consumers, is justified'. *GMOFear* takes value 1 if the farmer expresses agreement with the sentence and zero otherwise. Finally, we introduced variable *BtWait*, a dummy that takes value 1 if farmers agree with the sentence 'We would have to wait a few years to see what the effect of GMOs on the environment and health is, before authorising the marketing of new varieties of GMOs', and zero otherwise.

To address the heterogeneity associated with unobserved explanatory variables, we estimated our logistic model with fixed effects (FE). There were several sets of fixed effects to be considered. First, agriculture in the Ebro Valley is mainly characterised by irrigated crops, where the farmers belong to an irrigation community (IC) that organises the collective use of public water. The surveyed farmers belong to four different IC: (*i*) Canal d'Algerri-Balaguer, (*ii*) Riegos del Alto Aragon, (*iii*) Canal de Aragón y Cataluña, and (*iv*) Canal d'Urgell. Irrigation management greatly differs among IC, for example, in the price of water or in the level of modernisation of the irrigation system. These differences may have influenced their farmers' Bt maize adoption decisions, since a low price for irrigation water increases the profitability of maize. We reasonably took these effects into account with the introduction of dummy variables that allowed us to distinguish farms depending on the IC where they were located, and with the estimation of logistic FE models. Dummy variables were not, however, significant in any regression, and there were no significant differences among models with and without FE, revealing the lack of unobserved relevant differences among these IC and suggesting that, despite the different irrigation prices, maize was the most profitable crop in the area. Furthermore, although there is a common Spanish legal corpus in Catalonia and Aragon, there are also differences in local laws regarding environmental regulations that may have some effects on Bt adoption. We introduced a dummy variable that took value 1 if the farm was in Aragon and 0 otherwise, but it was not significant in any regression. We have also approximated this problem with a FE model, and we obtained a similar result; there were no significant differences among models with and without fixed effects. We present summary statistics of the main survey variables in Table 1. In the case of a dichotomous variable, the mean value can be interpreted as an estimate of the proportion of observations that satisfy a property.

RESULTS AND DISCUSSION

We estimated a binary logistic regression with a dichotomous discrete dependent variable, *Adopt*, to represent the adoption of Bt maize. For the dependent variable, 84 of the 170 farmers surveyed answered yes to the question of whether Bt maize had been adopted and 86 no. We consider the differences between parameters significant with a P-value < 0.05. The estimated coefficients of any of the continuous independent variables can be interpreted as elasticities, and those introduced in levels as ratios, if in both cases we calculate their exponential values.

Variable *Age* was positive and significant, showing that the odds of using Bt maize increase with the farmer's age. We present our estimated results in Table 2. These odds range between 1.047 ($e^{0.046}$) and 1.060 ($e^{0.059}$); with each additional year of age the odds of adopting Bt increase by 4.6% or 5.9%, depending on the model. This could seem a contradictory result, as older farmers may be expected to follow conservative behaviour and to have a reduced tendency to adopt innovations. The age of the surveyed farmers ranges from 20 to 78 years old (Table 1). The average age of adopters is 49.48 years, it ranges between 20 and 73 years. The average of non-adopters is 44.86 years and ranges between 21 and 78. However, this finding aligns with other studies on genetically modified organisms conducted in different countries, which have yielded mixed results: positive in Todua

Table 1. Summary statistics of the main survey variables

Variable	Adopters					Non-Adopters				
	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max
Age	84	49.48	11.44	20	73	86	44.86	12.93	21	78
FSize	84	66.30	74.84	3.9	370	86	48.53	50.74	0.5	310
PercIL	84	87.88	21.02	18.18	100	86	75.33	30.44	0	100
Cattle	84	0.37	0.48	0	1	86	0.55	0.50	0	1
CorkArea	84	0.95	0.21	0	1	86	0.21	0.41	0	1
BtEcon	84	0.79	0.41	0	1	86	0.19	0.34	0	1
BtvsChem	84	0.39	0.49	0	1	86	0.04	0.18	0	1
BtRefuse	84	0.01	0.19	0	1	86	0.02	0.15	0	1

Age – age of the farmer (years old); *BtEcon* – takes the value 1 if farmers agree with the statement 'I would sow Bt maize if it suited me economically', and 0 otherwise; *BtRefuse* – takes the value 1 if farmers agree with the sentence 'My convictions make me refuse to sow Bt maize', and 0 otherwise; *BtvsChem* – takes the value 1 if farmers agree with the sentence 'Bt maize causes less damage to the environment than sulphates against borer', and 0 otherwise; *Cattle* – takes the value 1 if farmers also have cattle activity, and 0 otherwise; *CorkArea* – takes the value 1 if farmers answer Yes, to the question: 'Do you know if in your area maize is attacked by a pest called corn borer?', and 0 otherwise; *FSize* – total size of the farm (ha); Obs. – observations; *PercIL* – percentage of irrigated farm size vs total farm size (%)

Source: Authors' own elaboration based on questionnaires data

Table 2. Logistic estimated regression models of the influences upon farmers' use of Bt maize

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Age	0.046 (0.018)*	0.053 (0.012)*	0.058 (0.012)*	0.059 (0.013)*	0.057 (0.014)*
FSize	0.017 (0.000)***	0.019 (0.001)**	0.019 (0.001)**	0.019 (0.001)**	0.019 (0.000)***
PercIL	0.043 (0.000)***	0.054 (0.000)***	0.052 (0.001)**	0.052 (0.001)**	0.045 (0.002)**
Cattle	–1.118 (0.039)*	–1.371 (0.032)*	–1.335 (0.036)*	–1.348 (0.038)*	–1.208 (0.039)*
CorkArea	4.709 (0.000)***	3.786 (0.000)***	4.003 (0.000)***	3.987 (0.000)***	4.699 (0.000)***
BtEcon	–	2.253 (0.001)**	1.608 (0.021)*	1.636 (0.025)*	–
BtvsChem	–	–	1.784 (0.053)	1.759 (0.061)	2.712 (0.013)*
BtRefuse	–	–	–	0.181 (0.831)	–0.620 (0.485)
Constant	–9.129 (0.000)***	–10.717 (0.000)***	–11.117 (0.000)***	–11.177 (0.000)***	–10.326 (0.000)***
Number of observations	170	170	170	170	170
Pseudo R^2	0.570	0.628	0.649	0.649	0.626

***, ** and *significance at 0.001, 0.01 and 0.05 levels, respectively; P-value presented in parentheses

Age – age of the farmer (years old); *BtEcon* – takes the value 1 if farmers agree with the statement 'I would sow Bt maize if it suited me economically', and 0 otherwise; *BtRefuse* – takes the value 1 if farmers agree with the sentence 'My convictions make me refuse to sow Bt maize', and 0 otherwise; *BtvsChem* – takes the value 1 if farmers agree with the sentence 'Bt maize causes less damage to the environment than sulphates against borer', and 0 otherwise; *Cattle* – takes the value 1 if farmers also have cattle activity, and 0 otherwise; *CorkArea* – takes the value 1 if farmers answer Yes, to the question: 'Do you know if in your area maize is attacked by a pest called corn borer?', and 0 otherwise; *FSize* – total size of the farm (ha); *PercIL* – percentage of irrigated farm size vs total farm size (%)

Source: Authors' own elaboration based on questionnaires data

et al. (2017); negative in Breustedt et al. (2008) and Xu et al. (2016); and non-significant in Evans et al. (2017); De Steur et al. (2019); Ngcinela et al. (2019) and Ethen et al. (2025).

Furthermore, we included the variable *Edu* (farmers' level of education) in our regression; its coefficient was negative and significant, suggesting that the higher the level of education the lower the level of adoption. However, this variable presented multicollinearity with *Age*, losing its significance when both variables were included in the regression. This result indicates a highly likely relationship in this area – the older the farmer the lower the level of formal education – and we dropped the variable *Edu* from our estimations. Further, the variable *EduAgri* was not significant, that is, having or not having specialised agricultural studies did not affect the likelihood to adopt Bt maize.

On the other hand, *FSize* ranges between 0.5 and 370 ha with a mean of 57.3 and a median of 32, showing that there are large differences in the size of the sample farms. The average farm size of adopters is 66.30 ha and non-adopters of 48.53 (Table 1). It was expected that the larger the farm the larger the capability of introducing innovations, and these expectations were fulfilled. The odds of adopting Bt increase by about 1.7–2.0% with each additional ha of surface. Other authors find similar results in the adoption of Bt maize and other transgenic crops, such as Breustedt et al. (2008); Useche et al. (2009) and Evans et al (2017). On the other hand, Ethen et al. (2025) gets a non-significant result.

The variable percentage of irrigated area (*PercIL*) shows that at least 50% of the surveyed farmers managed only irrigated land. The rest of the farmers managed both irrigated and non-irrigated land. This shows a clear predominance of irrigated land among the sample farmers. The coefficient of variable $PercIL_i$ turned out to be positive and significant in all regressions and, therefore, the larger the proportion of irrigated land in a farm the larger the probability of adoption. The odds of adopting Bt increase by about 4.3% and 5.5% (depending on the model) with each unit of irrigated land. On the other hand, some of the proposed variables were not significant. *Inc100* was always not significant, showing that the odds of Bt adoption do not increase with the proportion of the annual farm income coming from agriculture and livestock. *Backup* was also not significant; to have continuity in the farm did not increase the odds of adopting Bt maize.

Furthermore, about 45% of the sample develop cattle activity; the coefficient of variable *Cattle* turned out to be negative and significant in all regressions, showing that the odds of a farm with cattle activity of adopting Bt was about 33% lower that the odds of a farm without cattle activity. This result shows that there is no positive relationship between Bt adoption and farm cattle activity. On the contrary, our result suggests that farmers that rise piglets are less likely to sow GM maize. Farms are likely to be vertically integrated with large meat companies, which provide the farmers with piglets and their feed and do not require self-grown maize.

Likewise, in our sample, more than 57% of farmers answered affirmatively when asked if they knew whether corn in their area was attacked by a pest called corn borer. Our results show that the coefficient of variable $CorkArea_i$ is positive and significant in all models. Furthermore, if farm *i* is in a corn borer infested area, the odds of Bt maize adoption are larger than when farm *i* is in a non-infested area. The odds of adopting Bt range from 44.071 to 111.013; that is, the odds of adopting Bt if the farm is in an area that has been infested by the corn borer can be more than 100% higher than the odds for farmers that have not suffered from an infestation. This becomes the most relevant explanatory variable of the model. Of the 84 Bt adopters, 80 respond affirmatively (95%), but only 18 of the 86 non-adopters (21%) do so (Table 1). Recall, that in this case, the mean of the variable *CorkArea* can be interpreted, in the case of adopters, as the proportion of adopters who have had some experience with the corn borer, and similarly for non-adopters.

Farmers that know of infestations of corn borer were aware of the losses that it could represent for their economy. It has been assessed that, in areas of high bore pressure, annual crop losses range from 10–40% in the absence of insecticide use, and with insecticide use such losses would be from 5–20% (Gómez-Barbero et al. 2008).

The variable *BtEcon* always has a positive and significant estimated coefficient in the regression equations, meaning that the odds of adopting Bt were larger if the farmers agreed with the statement: 'I would sow Bt if it suited me economically'. Agreement with this statement shows that the farmer assigns great importance to economic results when choosing their crop options. 79% of adopters agree with it but only 19% of non-adopters do (Table 1). In fact, the odds of adopting Bt are from 4.9 to 9.5 times larger if the farmer attached great importance to economic results than if they did not. Additionally, Demont and Tollens (2004) calculated, with a bio-economic model developed to estimate the impact of biotechnological innovation in agriculture, that, in Spain, during the period 1998–2003, farmers were generally the main beneficiaries of agricultural biotechnological innovations in the short term. In fact, they calculated that, in the short term, farmers could have appropriated 66% of the total benefits of Bt adoption and the phytosanitary industry only 34%. Also, Areal et al. (2011) show that Spanish farmers perceived a good reason to adopt Bt maize based on economic reasons. Xu et al. (2016); Rashid et al. (2018); De Steur et al. (2019); Mustapa et al. (2021) and Ethen et al. (2025), among others also found that positive economic expectations are a factor that increases the willingness to adopt and/or the actual adoption of GM crops.

Furthermore, variable *BtvsChem*, which shows farmer concordance with the sentence 'Bt maize causes less damage to the environment than sulphates against borer', presents a positive and significant estimated coefficient in model 5 and model 3 (Table 2). This means that farmers that believe that Bt causes less damage to the environment than sulphates will adopt more often than farmers that do not believe this. Chvátalová (2021) reaches similar conclusions as the Czech farmers she interviewed argued that growing Bt maize was more beneficial for the environment and safer than agricultural chemicals. The rest of the opinion variables introduced in the questionnaire, such as *BtRefuse, BtNever, GMOFear,* and *BtWait* were never significant. The reason for this lack of significance, for example in the case of the *BtRefuse* variable, is that most non-adopters did not express strong agreement with the statement

'My convictions make me refuse to plant Bt maize'. In fact, the majority of non-adopters (84%) responded by choosing the middle response, 'maybe', to the statement. This lack of strong agreement with the statement by non-adopters made their response difficult to distinguish from the response of adopters. Xu et al. (2016) also found similar results, environmental effects, in some models, were not significant with respect to the adoption of Bt transgenic rice; while Useche et al. (2009); Mustapa et al. (2021) and Ethen et al. (2025) observed that increases in the concern or the perception of the environmental risk associated with GM crops decreased the willingness to adopt them.

The results of our model suggest that in Spain the most important reasons for Bt adoption were exposure to corn borer and concerns about the economic losses that corn borer could cause to the crop and the potential economic gains that Bt could bring.

CONCLUSION

The aim of this paper was to analyse Bt maize adoption decisions and identify the main factors that influenced Spanish farmers to choose Bt maize instead of the conventional crop. Moreover, we aimed to investigate whether the beliefs of farmers who adopted Bt differed significantly from those of non-adopters. Our findings indicated that support for Bt maize adoption was more prevalent among older farmers, those with larger farms and a higher percentage of irrigated land, as well as those located in regions that have previously been impacted by the corn borer. Our results showed that to develop the farming activity in an area that has been infested by corn borer at least once (even if the own crop was not affected) is the most important predictor for adoption. Moreover, as noted, the likelihood of adopting Bt was significantly higher when farmers would sow Bt if it suited them economically. This suggests that farmers that prioritise economic outcomes will adopt Bt more often than those who do not. That is, the concern about the damage that the corn borer could cause to the harvest and the potential economic benefits that could be obtained on adopting Bt are the most decisive variables in explaining farmers' attitudes in our model.

Our results do not allow to assign a large weight to role of beliefs about the potential Bt harm on the decision of whether to adopt it. Only few non-adopters strongly agree with statements such as 'I would never plant transgenic Bt maize' and 'My convictions make me refuse to plant Bt maize'. The lack of strong objections to Bt by non-adopters suggests that farmers were aware of the potential harm caused by Bt, but their moral concerns were tempered with the concern about the damage that the corn borer could cause to the harvest and the economic gains generated by Bt. The results of our model suggest that in Spain the most important reasons for Bt adoption were exposure to corn borer and concerns about the economic losses that corn borer could cause to the crop and the potential economic gains that Bt could bring.

Our conclusions are similar to those of the works carried out by Hall (2008); De Steur et al. (2019) and Chvátalová (2021), but in our case the farmers surveyed had knowledge and experience of the new seed technology, and the possible environmental damage of traditional pesticides also affected their concern. In Chvátalová (2021), farmers' concern also considered the potential environmental harm caused by traditional pesticides. These similarities suggest that the opinions of Spanish farmers that supported the introduction of Bt maize in Spain and that have allowed that crop to be maintained until now were similar to those of other farmers in European countries where Bt adoption was not allowed.

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REFERENCES

Alexander C., Fernandez-Cornejo J., Goodhue R.E. (2003): Effects of the GM Controversy on Iowa corn-soybean farmers' acreage allocation decisions. Journal of Agricultural and Resource Economics, 28: 580–595.

Alexander C. (2007): Insect resistance management plans: The farmers' perspective. AgBioForum, 10: 33–43.

ANR (2024): Biocontrol against Sesamia nonagrioides Using the Larval Parasitoide Cotesia typhae – BIOCOSMA. Paris, Agence Nationale de la Recherche (ANR). Available at https://anr.fr/Project-ANR-23-ECOM-0003 (accessed Oct 2025).

Anyshchenko A., Yarnold J. (2021): From 'mad cow' crisis to synthetic biology: Challenges to EU regulation of GMOs beyond the European context. International Environmental Agreements: Politics, Law and Economics, 21: 391–404.

Areal F.J., Riesgo L., Rodríguez-Cerezo E. (2011): Attitudes of European farmers towards GM crop adoption. Plant Biotechnology Journal, 9: 945–957.

Braun R. (2001): Why are Europeans scared of biotech food? Agro Food Industry Hi-Tech, 12: 32–34.

Breustedt G., Müller-Scheeßel J., Latacz-Lohmann U. (2008): Forecasting the adoption of GM oilseed rape: Evidence from a discrete choice experiment in Germany. Journal of Agricultural Economics, 59: 237–256.

Brookes G. (2003): The farm level impact of using Bt maize in Spain. In: ICABR conference, Ravello, Italy (July, 2003).

Chong M. (2005): Perception of the risks and benefits of Bt eggplant by Indian farmers. Journal of Risk Research, 8: 617–634.

Chvátalová V. (2021): Czech farmers' attitudes towards genetically modified crops. Journal of Rural Studies, 83: 246–256.

Comas C., Lumbierres B., Pons X., Albajes R. (2014): No effects of Bacillus thuringiensis maize on nontarget organisms in the field in southern Europe: A meta-analysis of 26 arthropod taxa. Transgenic Research, 23: 135–143.

Demont M., Tollens E. (2004): First impact of biotechnology in the EU: Bt maize adoption in Spain. Annals of Applied Biology, 145: 197–207.

De Steur H., Van Loo E.J., Maes J, Gheysen G., Verbeke W. (2019): Farmers' willingness to adopt late blight-resistant genetically modified potatoes. Agronomy, 9: 280.

Dively G.P., Venugopal P.D., Bean D., Whalen J., Holmstrom K., Kuhar T.P., Doughty H.B., Patton T., Cissel W., Hutchison W.D. (2018): Regional pest suppression associated with widespread Bt maize adoption benefits vegetable growers. Proceedings of the National Academy of Sciences, 115: 3320–3325.

DGAV (Direção-Geral de Alimentação e Veterinária) (2025): Regras para o Cultivo de Plantas Genéticamente Modificadas. Lisbon, DGAV. Available at https://www.dgav.pt/plantas/conteudo/autorizacoes-de-cultivo/variedades-geneticamente-modificadas/regras-para-o-cultivo-de-plantas-geneticamente-modificadas

EFSA (European Food Safety Authority), Messéan A., Álvarez F., Devos Y., Camargo A.M. (2023): Assessment of the 2021 post-market environmental monitoring report on the cultivation of genetically modified maize MON 810 in the EU. EFSA Journal, 21: e8411.

Ethen D.Z., Barua S., Deltomme B., Guo Y., Alam M.J., De Steur H. (2025): The path to adoption: Farmers' willingness, behavior and willingness-behavior consistency in cultivating Bt brinjal. China Agricultural Economic Review, 18: 254–272.

European Commission (2016): Commission Staff Working Document: Genetically Modified Commodities in the EU. Brussels, European Commission. Available at: https://data.consilium.europa.eu/doc/document/ST-6954-2016-INIT/en/pdf

Evans E.A., Ballen F.H., De Oleo B., & Crane J.H. (2017): Willingness of south Florida fruit growers to adopt genetically modified papaya: An ex-ante evaluation. AgBioForum, 20: 156–162.

FAO (2004): The State of Food and Agriculture 2003–2004: Agricultural Biotechnology: Meeting the Needs of the Poor? Rome, FAO. Available at http://www.fao.org/docrep/006/Y5160E/Y5160E00.HTM

FAO (2011): Second Global Plan of Action on Plant Genetic Resources for Food and Agriculture. Rome, FAO. Available at https://www.fao.org/4/i2624e/i2624e00.htm

FAO (2022): Gene Editing and Agrifood Systems. Rome, FAO. Available at https://doi.org/10.4060/cc3579en

Fernandez-Cornejo J., McBride W.D. (2002): Adoption of Bioengineered Crops. Economic Research Service. Agricultural Economic Report No. 810. Washington, D.C., USDA. Available at https://www.ers.usda.gov/publications/pub-details?pubid=41423

Fernandez-Cornejo J., Caswell M. (2006): The First Decade of Genetically Engineered Crops in the United Status. Economic Information Bulletin No. 11. Washington, D.C., USDA. Available at https://www.ers.usda.gov/publications/pub-details?pubid=43741

Fernandez-Cornejo J., Wechsler S., Livingston M.J., Mitchell L. (2014): Genetically Engineered Crops in the United States. Economic Research Report No. 162. Washington, D.C., USDA. Available at https://www.ers.usda.gov/publications/pub-details?pubid=45182

Frewer L., Lassen J., Kettlitz B., Scholderer J., Beekman V., Berdal K.G. (2004): Societal aspects of genetically modified foods. Food and Chemical Toxicology, 42: 1181–1193.

García M., García-Benítez C., Ortego F., Farinós G.P. (2023): Monitoring insect resistance to Bt maize in the European Union: Update, challenges, and future prospects. Journal of Economic Entomology, 116: 275–288.

Gomez Barbero M., Rodriguez Cerezo E. (2008): Adoption and Impact of the First GM Crop Introduced in EU Agriculture: Bt Maize in Spain. EUR 22778 EN. Luxembourg, European Commission. Available at https://publications.jrc.ec.europa.eu/repository/handle/JRC37046

Gómez-Barbero M., Berbel J., Rodríguez-Cerezo E. (2008): Bt corn in Spain – The performance of the EU's first GM crop. Nature Biotechnology, 26: 384–386.

Guehlstorf N.P. (2008): Understanding the scope of farmer perceptions of risk: Considering farmer opinions on the use of genetically modified (GM) crops as a stakeholder voice in policy. The Journal of Agricultural and Environmental Ethics, 21: 541–558.

Hall C. (2008): Identifying farmer attitudes towards genetically modified (GM) crops in Scotland: Are they pro- or anti-GM? Geoforum, 39: 204–212.

Hutchison W.D., Burkness E.C., Mitchell P.D., Moon R.D., Leslie T.W., Fleischer S.J., Abrahamson M., Hamilton K.L., Steffey K.L., Gray M.E., Hellmich R.L., Kaster L.V., Hunt T.E., Wright R.J., Pecinovsky K., Rabaey T.L., Flood B.R., Raun E.S. (2010): Areawide suppression of European corn borer with Bt maize reaps savings to non-Bt maize growers. Science, 330: 222–225.

ISAAA (2017): Global Status of Commercialized Biotech/GM Crops: 2017. ISAAA Brief No. 53. Ithaca, ISAAA. Available at https://www.isaaa.org/resources/publications/briefs/53/

ISAAA (2018): Global Status of Commercialized Biotech/GM Crops: 2018. ISAAA Brief No. 54. Ithaca, ISAAA.

Available at https://www.isaaa.org/resources/publications/briefs/54/

James C. (2009): Global Status of Commercialized Biotech/GM Crops: 2009. ISAAA Brief No. 41. Ithaca, ISAAA. Available at https://www.isaaa.org/Resources/publications/briefs/41/default.asp

Kaup B.Z. (2008): The reflexive producer: The influence of farmer knowledge upon the use of Bt corn. Rural Sociology, 73: 62–81.

Keelan C., Thorne F.S., Flanagan P., Newman C., Mullins E. (2009): Predicted willingness of Irish farmers to adopt GM technology. AgBioForum, 12: 394–403.

Lawson L.G., Larsen A.S., Pedersen S.M., Gylling M. (2010): Perceptions of genetically modified crops among Danish farmers. Acta Agriculturae Scandinavica, Section C – Food Economics, 6: 99–118.

Lehrman A., Johnson K. (2008): Swedish farmers' attitudes, expectations and fears in relation to growing genetically modified crops. Environmental Biosafety Research, 7: 153–162.

Lewis L.C., Bruck D.J., Prasifka J.R., Raun E.S. (2009): Nosema pyrausta: Its biology, history, and potential role in a landscape of transgenic insecticidal crops. Biological Control, 48: 223–231.

MAPA (2025): Public Register of GMOs. Madrid, Ministerio de Agricultura, Pesca y Alimentación, Dirección General de Producciones y Mercados Agrarios. Available at https://www.mapa.gob.es/en/agricultura/temas/biotecnologia/omg/registro-publico-omg/superficie_cultivada.aspx

Mauro I.J., McLachlan S.M. (2008): Farmer knowledge and risk analysis: Post release evaluation of herbicide-tolerant canola in Western Canada. Risk Analysis, 28: 463–476.

Moschini G. (2008): Biotechnology and development of food markets: Retrospect and prospects. European Review of Agricultural Economics, 35: 331–355.

Mustapa M.A.C., Batcha M.F.N., Amin L., Arham A.F., Mahadi Z., Yusoff N.A.M., Yaacob M., Omare N.A., Hussain W.H.W. (2021): Farmers' attitudes towards GM crops and their predictors. Journal of the Science of Food and Agriculture, 101: 5457–5468.

Ngcinela S., Mushunje A., Taruvinga A., Ngarava S., Mutengwa C.S. (2019): Determinants of genetically modified (GM) maize adoption and the intensity of adoption in OR Tambo District Municipality, Eastern Cape Province, South Africa. GM Crops & Food, 10: 1–11.

Payne J., Fernandez-Cornejo J., Daberkow S. (2003): Factors affecting the likelihood of corn rootworm Bt seed adoption. AgBioForum, 6: 79–86.

Qaim M., de Janvry A. (2003): Genetically modified crops, corporate pricing strategies and farmers' adoption: The case of Bt cotton in Argentina. American Journal of Agricultural Economics, 85: 814–828.

Rashid M.A., Hasan M.K., Matin M.A. (2018): Socio-economic performance of Bt eggplant cultivation in Bangladesh. Bangladesh Journal of Agricultural Research, 43: 187–203.

Rogers E. (2003): Diffusion of Innovations. 5th Ed. New York, The Free Press: 292–293.

Sato K. (2013): Genetically modified food in France: Symbolic transformation and the policy paradigm shift. Theory and Society, 42: 477–507.

Schurman R. (2004): Fighting 'Frankenfoods': Industry opportunity structures and the efficacy of the antibiotech movement in Western Europe. Social Problems, 51: 243–68.

Scott M.P., Pollak L.M. (2005): Tansgenic maize. Starch, 57: 187–195.

Skevas T., Wesseler J., Fevereiro P. (2009): Coping with ex-ante regulations for planting Bt maize: The Portuguese experience. AgBioForum, 12: 60–69.

Skevas T., Kikulwe E.M., Papadopoulou H., Skevas I., Wesseler J. (2012): Do European Union farmers reject genetically modified maize? Farmer preferences for genetically modified maize in Greece. AgBioForum, 15: 242–256.

Todua N., Gogitidze T., Beka P. (2017): Georgian farmers' attitudes towards genetically modified crops. Economics World, 5: 362–369.

Useche P., Barham B.L., Foltz J.D. (2009): Integrating technology traits and producer heterogeneity: A mixed-multinomial model of genetically modified corn adoption. American Journal of Agricultural Economics, 91: 444–461.

Xu R., Wu Y., Luan J. (2016): Analysis of farmers' willingness to adopt genetically modified insect-resistant rice in China. China Agricultural Economic Review, 8: 368–382.

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