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RESEARCH ARTICLE

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Farmers' attitude toward CRISPR/Cas9: The case of blast resistant rice

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Abstract

New breeding techniques (NBTs) for genetically modified (GM) crops, such as CRISPR/Cas9, could represent a valuable solution for achieving a sustainable agricultural system. This study examines Italian farmers' attitudes toward CRISPR/Cas9-modified blast-resistant rice in a hypothetical context. It is one of the first studies to investigate farmers' attitudes toward NBTs. Additionally, it explores the role of sociodemographics, farm characteristics, knowledge, perceived risks, and the locus of control (LOC) in shaping attitudes toward CRISPR/Cas9-modified rice. The results show that farmers are open to this innovation and will cultivate CRISPR/Cas9-modified rice if it is available in the market. Moreover, we find subjective knowledge, practice experience, and low perceived risk in the agri-food business to be positively associated with attitudes toward CRISPR/Cas9-modified blast-resistant rice. Notably, LOC is found to be inversely related to attitude, indicating that having an external LOC improves attitudes toward CRISPR/Cas9-modified rice. The findings suggest that farmers are generally favorable to the introduction of CRISPR/Cas9 technology; thus, a revision of the current European Union policies on

Abbreviations: CRISPR/Cas9, Clustered regularly interspaced short palindromic repeats/Cas9; ECJ, European court of justice; EU, European Union; GMO, vasovagal genetically modified organism; LOC, Locus of control; NBTs, New breeding techniques.

GM crops could meet their needs. [EconLit Citations: Q18, Q16].

KEYWORDS
attitude, CRISPR/Cas9, farmer, locus of control, rice

1 | INTRODUCTION

One of the major challenges of the agricultural sector is improving the sustainability of food production. Agriculture and climate change have a close and mutual relationship. On the one hand, droughts, floods, and soil degradation negatively affect farming; on the other hand, agricultural practices generate greenhouse gas emissions and pollute water and land (Tubiello et al., 2014). Therefore, to formulate viable future food strategies and meet sustainable development goals, it is crucial to develop innovative and efficient methods for improving agricultural production to feed the increasing world population while simultaneously reducing environmental damage (Adenle et al., 2019).

In particular, the application of gene technology could represent a large-scale solution to achieve a sustainable production system (Qaim, 2020; Zilberman et al., 2018). In fact, gene technology can improve plants' production both in terms of quality and quantity, by requiring less use of natural resources while reducing the use of agrochemicals (Barrows et al., 2014; Hudson & Richards, 2014; Klümper & Qaim, 2014; Perry et al., 2016). Several gene technologies have been developed. Genetically modified organisms (GMOs), for example, have been commercially available since the 1990s. More recently, new genetic modification techniques (Eckerstorfer et al., 2019) have been developed, which are commonly referred to as new breeding techniques (NBTs). NBTs include different techniques such as cisgenesis and gene editing (Schaart et al., 2016).

Among gene-editing techniques, CRISPR/Cas9 is particularly highlighted, as it differs from other gene technologies in that it allows modification of the genome without the use of transgenesis (Lusk et al., 2018). It is a novel gene-editing system that has become more common than other techniques because it has a high success rate and is less expensive compared to other NBTs (Borrelli et al., 2018). Several plants have been modified using CRISPR/Cas9 to improve their traits and generate crop improvement in terms of yield production, adaptation to climate change, and resistance to pathogens (Shah et al., 2018, Zhang et al., 2018). However, similar to GMOs, the application of CRISPR/Cas9 technology is debated, with a share of consumers having concerns about CRISPR/Cas9-modified products (Shew et al., 2018). Nevertheless, plants produced using NBTs differ from GMOs, which shows the need for a new policy framework to regulate them. For example, the United States, Argentina, Japan, Canada, and Australia regulate NBTs with less strict regulations than GMOs (Eriksson et al., 2019; Lema, 2019). Conversely, the European Union (EU), in accordance with the ruling of the European Court of Justice (ECJ) in July 2018 (ECJ, 2018), considered that organisms obtained by NBTs, such as CRISPR/Cas9, are subject to the same GMO regulations (Directive 2001/18/EC; Callaway, 2018). Nevertheless, several civil society components, farmers' organizations, and scientists are asking for a review of the current regulations (Hundleby & Harwood, 2018). In fact, as suggested by Wesseler et al. (2019), this policy could lead Europe to an unfavorable position in the development of these techniques, thus losing competition in the agri-food market.

Owing to the novelty of these technologies, their application is still limited (Qaim, 2020), and the literature on NBTs is scant because their effects on the economy and the environment cannot be easily observed. Furthermore, the extant NBT literature focuses on consumers' rather than farmers' attitudes toward NBTs. For example, most recent studies have highlighted that consumers are willing to accept gene-edited food (Ferrari et al., 2020; Gatica-Arias et al., 2019), and pay for cisgenic (Colson et al., 2011; Delwaide et al., 2015; Edenbrandt, 2018; Shew et al., 2018; Yang & Hobbs, 2020) and gene-edited food (Muringai et al., 2020) slightly more than for transgenic food. Furthermore, consumers acknowledge that CRISPR/Cas9-modified crops could improve food security and protect the environment (Gatica-Arias et al., 2019). Yang and Hobbs find consumers' acceptance of CRISPR/Cas9 to be influenced by individual risk perception and personal cultural values, which affect the individual propensity for innovation (Yang & Hobbs, 2020). However, to our knowledge, no study has investigated farmers' attitudes toward CRISPR/Cas9-modified crops. Nevertheless, the effects of GMOs have been extensively studied, and the literature on GMOs can offer valuable insights into NBTs (Qaim, 2020). Farmers' attitudes toward genetic modification techniques are mostly influenced by sociodemographic characteristics (Breustedt et al., 2008), knowledge (Hou et al., 2012), farm characteristics (Gyau et al., 2009), financial and economic benefits (Kamrath et al., 2019), and perceived risks (De Steur et al., 2019). Additionally, a growing branch of behavioral economics argues that noncognitive skills might also play a role in shaping farmers' attitudes toward innovation, as growing NBTs-modified crops represent, for farmers, an investment in innovation (Kreft et al., 2020; Sharma & Tarp, 2018; Wuepper et al., 2019). Noncognitive skills refer to psychological traits, such as perceived self-efficiency, time preference, and locus of control (LOC; Wuepper et al., 2019), which could generate cognitive bias, thus influencing individuals' attitudes.

This study investigates farmers' attitudes toward CRISPR/Cas9-modified blast-resistant rice in Northern Italy in a hypothetical context. Italy is the largest rice-producing country in Europe (Kraehmer et al., 2017), with Lombardy and Piedmont being the leading production regions (Zampieri et al., 2019). However, crops may be affected by several pathogens, including rice blast. Rice blast is a common disease that is widespread and causes a loss of 30% of rice production worldwide, contributing to food insecurity (Nalley et al., 2016). To combat this pathogen, farmers use agrochemicals, which are associated with higher economic costs for their activity, as their usage causes negative externalities in the environment (Chen et al., 2019; Durand-Morat & Nallet, 2019) and might affect human health (Lai, 2016). Moreover, there is a public concern regarding pesticide residues (Cerroni et al., 2013). To reduce the use of agrochemicals in cultivating rice crops, a possible solution is the introduction of a production system of rice plants that are intrinsically resistant to blast. The introduction of CRISPR/Cas9-modified blast-resistant rice in the Italian market can help farmers combat this pathogen (Borrelli et al., 2018). Several blast-resistant rice varieties have been developed (Wang et al., 2016), but their cultivation is not allowed in Europe.

Nevertheless, farmers can play a crucial role in determining the successful application and diffusion of CRISPR/Cas9-modified crops if this technology is approved by European policy makers. Thus, understanding farmers' attitudes toward this new technology is fundamental.

Within this context, this study contributes to the ongoing discussion on biotech food products by being the first attempt to investigate farmers' attitudes toward CRISPR/Cas9-modified rice. We investigate the role of standard variables such as sociodemographics, farm characteristics, knowledge, and perceived risks in shaping farmers' attitudes toward CRISPR/Cas9-modified rice. Additionally, we extend the traditional model of standard variables by including noncognitive skills, such as LOC.

2 | LITERATURE REVIEW

2.1 | European legislation for NBTs

At the beginning of 2018, the Advocate General of the ECJ suggested that organisms obtained by old and new mutagenesis techniques should not fall under the Directive 2001/18/CE (the so called "GMO Directive"). Despite this conclusion, on July 25, 2018, the ECJ ruled that organisms obtained by new mutagenesis techniques, including genome editing techniques, must be considered GMOs and consequently regulated in accordance with the GMO Directive on the release of GMOs into the environment. Specifically, the ECJ reported that organisms obtained using new techniques must be considered GMOs because "the direct modification of the genetic material of an organism through mutagenesis makes it possible to obtain the same effects as the introduction of a foreign gene into the organism (transgenesis) and those new techniques make it possible to produce GM varieties at a rate out of all" (ECJ ruling of July 25, 2018, C-528/16), thus posing risks similar to those of transgenic products.

In accordance with this ruling, the definition of new-directed mutagenesis techniques includes gene-editing techniques such as CRISPR/Cas9. Currently, only the insect-resistant maize MON810 cultivation is allowed in Europe, but every member state can restrict it. According to the precautionary principle, certain member states (Austria, Bulgaria, Germany, Greece, France, Hungary, Italy, Luxembourg, and Poland) do not allow the cultivation of MON810 in their territory (Hundleby & Harwood, 2018).

2.2 | Factors affecting farmers' attitudes toward technology adoption

2.2.1 | Factors affecting biotech adoption

Several studies have investigated the effects of sociodemographic characteristics, knowledge, and perceived risks and benefits on farmers' attitudes toward GMOs (Breustedt et al., 2008; Kamrath et al., 2019; Xu et al., 2016). The evidence on sociodemographic characteristics is ambiguous. Some studies have shown that older and less-educated farmers are less likely to adopt GMOs (Breustedt et al., 2008; Kamrath et al., 2019), whereas other studies suggested that age has a positive effect on attitudes toward GMOs (Fernandez-Cornejo et al., 2005). However, sociodemographics have been often found to be statistically insignificant (Areal et al., 2012; De Steur et al., 2019; Xu et al., 2016). Additionally, knowledge of GMOs is a predictor of farmers' attitudes toward GMOs. Xu et al. (2016) affirmed that when knowledge of GM rice is limited, farmers are not able to make decisions about GM rice cultivation. Moreover, knowledge about GM technologies can reduce the indifference toward GM products (De Steur et al., 2019) and improve farmers' awareness (Luh et al., 2014; Todua & Gogitidze, 2017; Michelson, 2017). Nevertheless, knowledge of GMOs was also found to be a positive but insignificant variable (Evans et al., 2017).

Farm size is a key factor in determining farmers' attitudes toward biotech innovations, with a generally positive effect (Evans et al., 2017; Fernandez-Cornejo et al., 2005; Kamrath et al., 2019). Moreover, as reported in the review conducted by Kamrath et al. (2019), farming experience was included in previous studies, with mixed results. For example, farming experience (both years and practices) has been found to both positively (Keelan et al., 2009) and negatively (Evans et al., 2017) affect farmers' attitudes toward GM corps, but it was also found to be insignificant (De Steur et al., 2019).

Perceived risk is a determining factor in farmers' attitudes toward new technologies and innovations. Abadi Ghadim (1999) found adoption of new technologies to be significantly related to the degree of farmers' risk perception, while Marra et al. (2003) found perceived risk to have a negative influence on the adoption of new technologies. Furthermore, risk aversion is negatively correlated to other factors, such as farm size, farming experience, and income (Feder, 1980; Marra et al., 2003). Moreover, perceived risk might increase with age, whereas farming experience can reduce it (Abadi Ghadim, 1999). In this context, perceived environmental and business risks are considered key determinants for analyzing attitudes toward GM products. Rzymski and Królczyk (2016) highlighted that perceived environmental risk significantly reduces the propensity for growing GM crops, while Hall (2008) suggested that farmers are open to GM crops if these applications are beneficial to the environment. Furthermore, attitudes toward GMOs improved when farmers perceive fewer economic risks associated with them (Kamrath et al., 2019).

2.2.2 | LOC and technology adoption

LOC is a noncognitive skill that refers to the extent to which individuals believe that they have control over what happens in their lives. It is defined as "a generalized attitude, belief, or expectancy regarding the nature of the causal relationship between one's own behavior and its consequences might affect a variety of behavioral choices in a broad band of life situations" (Rotter, 1966). The concept of LOC, also known as "control of reinforcement," was introduced by Rotter (1954, 1966, 1990). According to the author, LOC emerges when individuals perceive a causal relationship between their behavior and reinforcements. Owing to this learning process, people believe that a specific behavior will result in a specific outcome, in the presence of rewards or reinforcements (Rotter, 1966).

When the individual expects that her personal characteristics influence the outcome of her actions, she has an internal LOC, while when the person believes that her life is controlled by circumstances outside her control, such as luck or others' actions, she has an external LOC. Existing evidence suggests that people with an internal LOC are more confident and determined, whereas people with an external LOC are more likely to see themselves as influenced by forces outside their control and with less ability to reach their goals (Galvin et al., 2018).

The concept of LOC was developed in the psychological context to unravel individuals' behavior, but it was quickly adopted by economists to investigate how personality traits are related to technology adoption. Individuals with an internal LOC were found to be more likely to adopt new technologies and innovations, whereas individuals with external LOC were found to be less willing to adopt them (Sharma & Tarp, 2018). These findings were also found within the agricultural context. In fact, farmers with internal LOC have a more positive attitude toward technology adoption than farmers with external LOC. However, existing evidence is mainly based on studies conducted in African countries (Abay et al., 2017; Taffesse & Tadesse, 2017; Wuepper et al., 2019), and China (He & Veronesi, 2017), which found that farmers with an internal LOC are more willing to accept chemical fertilizers, improved seeds, irrigation (Abay et al., 2017; Taffesse & Tadesse, 2017), smart technologies (Wuepper et al., 2019), and biogas technology (He & Veronesi, 2017).

3 | METHODOLOGY

3.1 | Survey

A face-to-face survey was developed and pretested on 10 farmers. Using a convenience sampling procedure, the survey was distributed among rice growers in three Italian provinces, which are well-known as rice-growing areas (Pavia in Lombardy; Vercelli and Novara in Piedmonts) from September to November 2019. A total of 152 farmers were surveyed. Owing to missing data, the final sample included 143 farmers. The survey consisted of five parts. The first part included a brief description of CRISPR/Cas9 and its possible application in rice cultivation to achieve blast resistance. The information reported that “CRISPR/Cas9 is a gene-editing technique that allows the modification of an organism's DNA. Although it is based on a genetic modification approach, this technique differs from transgenesis (which generates GMOs), as it employs a non-transgenic approach. Using CRISPR/Cas9, it is possible to grow blast-resistant rice varieties, thus allowing the reduction of agrochemical usage.” The information was collected based on the existing literature (Aglawe et al., 2018; Borrelli et al., 2018) and was checked by a biotech expert. Afterwards, farmers' attitudes toward CRISPR/Cas9-modified rice (ATT_CRISPR) were measured. Farmers were asked to rank on a 7-point Likert scale the following statement: *I think that the adoption of CRISPR/Cas9 technology applied to rice would be acceptable for my farm*. Then, following Abay et al. (2017) and Rotter (1966), farmers' LOC was measured using a scale that consists of 10 items ranked on a 6-point Likert scale, ranging from 1 (strongly disagree) to 6 (strongly agree). The third part included questions testing farmers' genetic modification knowledge. Following House et al. (2004), farmers were asked to self-rank their knowledge of GM on a 9-point Likert scale, from 1 (very low) to 9 (very high). This was followed by four true/false statements to assess the farmers' objective knowledge (House et al., 2004). The fourth part included questions related to perceived environmental and agri-food business risks. Both perceived risks were measured using four statements on a 9-point Likert scale, ranging from 1 (strongly disagree) to 9 (strongly agree) (House et al., 2004). Information was reported to the respondent at the beginning of each measurement. The fifth part collected sociodemographic information such as gender (1 = female, 0 = male), age, agricultural education (1 = yes, 0 = no) and farm characteristics such as farming experience, farm size (measured in hectares), and practice experience with Clearfield® rice (1 = yes, 0 = no). Clearfield® rice is created using a mutagenesis technique that is allowed in Italy. However, some opponents have argued that it should be considered a GMO; thus, its cultivation was considered a proxy for practice experience.

3.2 | Variables measurement

Statistical analyses were performed using Stata 13 and IBM SPSS Statistics 26. Several composite variables were constructed. Regarding the creation of the objective knowledge index, following House et al. (2004), the score for each of the four true/false statements was 1 when the respondent answered correctly and 0 when the given response was wrong. Accordingly, the sum of the four individual scores was used to generate an objective knowledge index (OBJKNOW) ranging from 0 to 4 (House et al., 2004; Cronbach's $\alpha = 0.50$). Since Cronbach's α might be low when the number of statements is small, in this context, this value for OBJKNOW suggest medium reliability (Hinton, 2004). An index for the perceived environmental risk caused by the new genetic modification technologies (PERC_ENV) was obtained by summing the related items (Cronbach's $\alpha = 0.65$; House et al., 2004). The index ranged from 4 to 36. Items that measured the perceived benefit (items 1 and 4) were reverse-coded, with higher scores indicating higher perceived risk. Similarly, an index for the perception of risk related to the agri-food business (PERC_BUSN) was generated by summing the corresponding four items (Cronbach's $\alpha = 0.77$). The index ranged from 4 to 36. Items that measured perceived benefit (Item 1) were reverse-coded, with higher scores indicating a higher perceived risk.

An index for LOC was generated. First, an explanatory factor analysis was conducted to classify which items identified latent factors that could be interpreted as internal or external LOC. The factor analysis (Figure SA and Table SA) highlighted that the first five items were associated with the internal LOC, whereas the last five items were associated with the external LOC. Items associated with external LOC (Items 6, 7, 8, 9, and 10) were reverse-coded, and a composite factor from the factor analysis was used as unidimensional index (Abay et al., 2017; Cronbach $\alpha = 0.60$). Then, scores were standardized, and *z*-scores were used in the regression (Abay et al., 2017; Sharma & Tarp, 2018). Thus, the LOC index increases with internality. Raw values of internal and external LOC were used in the descriptive analysis. For descriptive purposes, two indices were generated as a mean for individual scores for the five internal and five external LOC statements. Gender was not included in the statistical analysis because of the unbalanced presence of males in the sample.

3.3 | Ordered logit model

An ordered logit model was chosen as the regression model (Göb et al., 2007; Greene & Hensher, 2010). The ordered logit model is based on the cumulative probabilities of distribution of the dependent variable, and it is also called the cumulative link model (Agresti, 2002).

Let Y_i be an ordinal dependent variable with J categories and explanatory variables x_i for the ith observation. The model with this logit link can be defined as:

$$\text{logit}[\text{Prob}(y_i \le j|x_i)] = \log \frac{\text{Prob}(y_i \le j|x_i)}{1 - \text{Prob}(y_i \le j|x_i)} = \alpha_j + \beta' x_i, \quad j = 1, ..., 7 - 1, \tag{1}$$

where $\text{Prob}(y_i \le j|x_i)$ is the cumulative probability. The parameters $\alpha_{1...7}$ are the cutpoints, which are in an increasing order: $\alpha_1 < \alpha_2 < ... < \alpha_{7-1}$.

β Shows how an increase of one unit in an independent variable is associated with a shift in the response scale, that is, a change in the log odds of being higher than category j (Agresti, 2002; Greene & Hensher, 2010).

In the current analysis, the model is estimated as follows:

$$\begin{aligned} y_i(\text{ATT\_CRISPR}) = {} & \alpha_i + +\beta_1\text{AGE} + \beta_2\text{AGRI}_{\text{EDU}} + \beta_3\text{FARMING}_{\text{EXP}_i} + \beta_4\text{FARM}_{\text{SIZE}_i} + \beta_5\text{CLEARFIELD}^{®}{}_i \\ & + \beta_6\text{SUBNOW}_i + \beta_7\text{OBJKNOW}_i + \beta_8\text{PERC}_{\text{ENV}_i} + \beta_9\text{PERC}_{\text{BUSN}} + \beta_{10}\text{LOC}_i, \end{aligned} \tag{2}$$

where the dependent variable y_i, that is, the attitude toward the adoption of CRISPR/Cas9-modified rice is explained by age (AGE), agricultural education (AGRI_EDU), years of farming experience (FARMING_EXP), farm size

(FARM_SIZE), experience with Clearfield rice® (CLEARFIELD), subjective (SUBKNOW) and objective (OBJKNOW) knowledge of genetic modification technologies, perceived environmental risk (PERC_ENV), perceived agri-food business risk (PERC_BUSN), and LOC.

Agricultural education and experience with Clearfield® rice were entered as dummy variables, while age, years of farming experience, farm size, objective and subjective knowledge, perceived environmental and business risks, and LOC were entered as continuous variables. For the analysis, results were estimated as odd ratios to indicate the change in odds resulting from a unit change in the independent variables.

3.4 | Cluster analysis

Additionally, a cluster analysis was performed to determine clusters of farmers with different attitudes toward CRISPR/Cas9-modified rice. A *k*-means cluster analysis (MacQueen, 1967) was conducted using the SPSS IBM Statistics 26. The clustering problem is defined as the minimization of the overall distance between the points and the centroid of the cluster.

$$\min \sum_{j=1}^{J} \sum_{i=1}^{N^J} p_i^j - c_{j2},$$

where J is the number of clusters ($J = 3$), N^J is the number of points in cluster j, p_i^j is the ith data point, and c_j is the centroid.

Owing to their different nature, variables were measured in different units; thus, data were standardized before clustering (Johnson, 1998). To detect statistical differences in the variables between clusters, *t*-tests were performed.

4 | RESULTS

4.1 | Sample characteristics

The sample included 127 males (88.81%) and 16 females (11.19%), with a median age of 53 years. Almost half of the respondents (47.5%) received an agricultural education. On average, farmers have run their businesses for 26 years. The average farm area was 123.75 hectares. More than 80% of the respondents cultivated Clearfield rice. Socioeconomic characteristics are displayed in Table 1.

Farmers generally had a positive attitude toward CRISPR/Cas9-modified rice ($M = 5.67$, $SD = 1.74$), with approximately 69% of them showing a positive attitude, scoring 6 or 7 on a 7-point Likert scale, while about 20% were neutral, scoring 4 or 5 on the scale. Conversely, only 11% of farmers showed a negative attitude toward CRISPR/Cas9-modified rice, scoring 1, 2, or 3 on the Likert scale (Table 2).

Farmers had good knowledge of genetic modification techniques. Overall, the sample was characterized by mid-subjective knowledge ($M = 5.42$, $SD = 2.34$). Additionally, the farmer's objective knowledge of genetic modification tools was good: On average, they answered three out of four questions correctly, with 42% of the respondents answering the four questions correctly (Table 3).

Regarding the perceived environmental risk caused by new technologies such as CRISPR/Cas9, farmers seemed to be slightly worried about the associated risks ($M = 18.70$, $SD = 7.02$; Table 4).

When farmers were asked to rank their perceptions regarding risks associated with CRISPR/Cas9 and the agri-food business, they shared a slight concern ($M = 16.40$, $SD = 8.05$). On average, they perceived less risk related to the agri-food business than to the environment $t\ (284) = -2.57$, $p < 0.005$.

TABLE 1 Sociodemographic characteristics

Variable		Description	Variable distribution N	%
Gender (*GENDER*)				
	0	Male	127	88.81
	1	Female	16	11.19
Age (*AGE*)				
		18–24 years	10	6.99
		25–34 years	11	7.69
		35–44 years	14	9.79
		45–54 years	33	23.08
		≥55 years	75	52.45
Agri_edu (*AGRI_EDU*)				
	0	No	68	47.55
	1	Yes	75	52.45
Farming experience (*FARMING_EXP*)				
		Years ≤ 9	22	15.38
		10–19 years	21	14.69
		20–29 years	42	22.37
		30–39 years	28	19.58
		40–49 years	18	12.59
		Years ≥ 50	12	8.39
Farm size (*FARM_SIZE*)				
		10–24 ha	8	5.59
		25–99 ha	63	44.06
		100–1000 ha	72	50.35
Clearfield® (*CLEARFIELD*)				
	0	No	28	19.58
	1	Yes	115	80.42

TABLE 2 Attitude toward CRISPR/Cas9 rice

	Authors	Scale	Measurement statement	Mean	*SD*
Attitude					
ATT_CRISPR	Self-constructed	1–7	I think that the adoption of CRISPR/Cas9 technology applied on rice would be acceptable for my farm	5.67	1.74

Note: Item is measured on a 7-point Likert scale, from 1 (strongly disagree) to 7 (strongly agree).

TABLE 3 Subjective and objective knowledge

	Authors	Scale	Measurement statements	Mean	*SD*
Knowledge	House et al. (2004)				
Subjective knowledge (SUBKNOW)					
SUBKNOW *index*		0–9	Self-ranked	5.41	2.32
Objective knowledge (OBJKNOW)					
OBJKNOW *index*		0–4		2.97	1.09
OBJKNOW *statements*		0–1		% True	% False
			1. Ordinary fruit does not contain genes, but genetically modified fruit does. (F)	22.38	77.62
			2. By eating genetically modified fruit, a person's genes could also be changed. (F)	17.48	82.52
			3. Genetically modified animals are always larger than ordinary animals. (F)	29.37	70.63
			4. It is impossible to transfer animal genes to plants. (F)	33.57	66.43

Note: Subjective knowledge is self-ranked from 0 (=very low) to 9 (=very high). Objective knowledge index is a composite variable calculated based on false (=0) or true (=1) statements. (F) and (T) indicate a false or true statement, respectively.

TABLE 4 Perception of risks and benefits of new genetic modification (CRISPR/Cas9) in food production

	Authors	Scale	Measurement statements	Mean	*SD*
Perception of risk	House et al. (2004)				
Perceived environmental risk (PERC_ENV)					
PERC_ENV *index*		4–36		18.7	7.02
PERC_ENV *statements*		1–9			
			1. New genetic modification (like CRISPR/Cas9) in food production will not pose risks for the environment.[a]	4.65	2.39
			2. The environment could be exposed to great risks from new genetic modification (like CRISPR/Cas9) in food production.	4.55	2.62
			3. The environment will not benefit from new genetic modifications (like CRISPR/Cas9) in food production.	4.38	2.55
			4. New genetic modification (like CRISPR/Cas9) in food production could provide benefits for the environment.[a]	5.58	2.43
Perceived agri-food business risks (PERC_AGRI_BUSN)					
PERC_AGRI_BUSN *index*		4–36		16.40	8.05
PERC_AGRI_BUSN *statements*		1–9			
			1. Agricultural and food businesses could be exposed to great risk from new genetic modification (like CRISPR/Cas9) in food production.	4.8	2.87
			2. New genetic modification (like CRISPR/Cas9) in food production will pose risks for agricultural and food businesses.	4.12	2.77
			3. Agricultural and food businesses could receive great benefits from new genetic modification (like CRISPR/Cas9) in food production.[a]	6.20	2.24
			4. New genetic modification (like CRISPR/Cas9) in food production will not provide benefits for agricultural and food businesses.	3.68	2.53

Note: Statements are ranked from 1 (=totally agree) to 9 (=totally disagree). Perceived risk indexes are composite variables calculated on the basis of respective items.

[a]Item is reverse-coded.

Regarding LOC, farmers were generally likely to have an internal rather than an external LOC. On average, they agreed more with items that described an internal LOC (Items 1, 2, 3, 4, and 5; $M = 4.49$, $SD = 0.83$) than those associated with external LOC (Items 6, 7, 8, 9, and 10; $M = 2.81$, $SD = 1.11$; t (284) = 14.42, $p < 0.005$; Table 5).

4.2 | Attitudes toward CRISPR/Cas9-modified blast-resistant rice

Table 6 shows the correlation coefficient matrix of the explanatory variables included in the regression model and cluster analysis. Correlations were less than 0.7; thus, multicollinearity was avoided (DeLong & Grebitus, 2017; Landau & Everitt, 2004).

The ordered logit model explored attitudes toward CRISPR/Cas9-modified blast-resistant rice (Table 7). Four explanatory variables were found to be statistically significant in determining farmers' attitudes. The results showed that growing Clearfield® rice positively affected farmers' attitudes since it increased the odds by a factor of 3.317. Regarding knowledge, only subjective knowledge had a positive influence on attitudes toward CRISPR/Cas9-modified rice. Specifically, a unit increase in subjective knowledge increased the odds of favorable attitude toward CRIPR/Cas9-modified rice by a factor of 1.175. Furthermore, farmers'

TABLE 5 Locus of control

	Authors	Scale	Measurement statements	Mean	*SD*
Locus of control (LOC)	Abay et al. (2017)	1–6			
Internal				4.49	0.83
			1. My life is determined by my own actions.	5.35	1.13
			2. When I get what I want, it is usually because I worked hard for it.	5.36	1.18
			3. I am usually able to protect my personal interests.	4.90	1.13
			4. I can mostly determine what will happen in my life.	3.48	1.53
			5. When I make plans, I am almost sure to make them work.	3.35	1.44
External				2.81	1.11
			6. To a great extent my life is controlled by accidental/chance happenings.[a]	3.44	1.62
			7. I feel like what happens in my life is determined by others.[a]	2.66	1.48
			8. It is not always wise for me to plan too far ahead because many things turn out to be a matter of good or bad fortune.[a]	3.62	1.9
			9. My life is chiefly controlled by other powerful people.[a]	1.95	1.45
			10. People like me have little chance of protecting personal interest.[a]	2.38	1.64

Note: Statements are ranked from 1 (=totally agree) to 6 (=totally disagree).
[a]Item is reverse-coded.

TABLE 6 Explanatory variable correlation matrix

	ATT_CRISPR	AGE	AGRI_DU	FARMING_EXP	FARM_SIZE	CLEARFIELD	SUBJKNOW	OBJKNOW	PERC_ENV	PERC_BUSN	LOC
ATT_CRISPR	1										
AGE	−0.036	1									
AGRI_EDU	0.0618	−0.255**	1								
FARMING_EXP	−0.0124	0.557***	−0.232**	1							
FARM_SIZE	0.1416	−0.094	0.057	0.003	1						
CLEARFIELD	0.303***	0.025	0.024	0.046	0.192*	1					
SUBKNOW	0.1904*	0.010	0.112	−0.067	−0.004	−0.055	1				
OBJKNOW	0.195*	−0.112	0.194*	−0.245**	0.169*	0.003	0.253**	1			
PERC_ENV	−0.3189***	0.037	−0.163	0.245	−0.105	−0.162	−0.266**	−0.299***	1		
PERC_BUSN	−0.3834***	0.066	−0.138	0.161	−0.07	−0.083	−0.214*	−0.340***	0.637***	1	
LOC	−0.0738	−0.026	0.096	−0.047	0.153	0.088	−0.034	0.142	−0.153	−0.243**	1

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

TABLE 7 Determinants of attitude toward CRISPR/Cas9 rice

	OR	95% CI
AGE	1.018 (0.153)	0.758–1.367
AGRI_EDU (1 = yes)	1.393 (0.479)	0.71–2.731
FARMING_EXP	1.249 (0.171)	0.954–1.634
FARM_SIZE	1.483 (0.423)	0.848–2.593
CLEARFIELD (1 = yes)	3.317** (1.421)	1.433–7.68
SUBKNOW	1.175* (0.091)	1.009–1.369
OBJKNOW	1.187 (0.190)	0.867–1.625
PERC_ENV	−0.990 (0.034)	0.925–1.057
PERC_BUSN	−0.911** (0.028)	0.857–0.969
LOC	−0.626* (0.127)	0.419–0.933
/cut1	−0.533 to 1.323	−3.127 to 2.061
/cut2	−0.417 to 1.318	−3.000 to 2.167
/cut3	−0.031 to 1.303	−2.584 to 2.523
/cut4	0.605–1.291	−1.924 to 3.135
/cut5	1.607–1.301	−0.942 to 4.157
/cut6	2.951–1.325	0.354–5.548

Note: Standard errors are reported between brackets. The sign of each coefficient is reported closed to the respective odds. For dummy variables, the reference category is indicated between brackets.
Likelihood ratio χ^2 (10) = 48.25, ($p < 0.001$), pseudo-R^2 = 0.1132, log-likelihood = −189.060, n = 143.
Abbreviations: CI, confidence interval; LOC, locus of control; OR, odds ratio.
*$p < 0.05$.
**$p < 0.01$.

attitudes were inversely related to the perception of risks associated with the agri-food business. An increase of one unit in the perception of risk related to the agri-food business negatively affected the attitude toward CRISPR/Cas9-modified rice by a factor of 0.911. Contrary to expectations, the LOC negatively affected attitude toward CRISPR rice: A unit increase in the LOC decreased favorable attitude by a factor of 0.626; thus, an internal LOC was linked to a negative attitude.

4.3 | Cluster analysis results

A *k*-means cluster analysis was then conducted. First, to determine the number of clusters, a hierarchical cluster analysis was performed (Gyau et al., 2009), with the results indicating that three clusters that subdivided the sample could be identified. After identifying the number of clusters, *k*-means clustering was performed. Convergence was achieved after six iterations, and the final cluster centers are listed in Table 8. Bonferroni correction was then performed to test the hypothesis that the cluster means are equal (Table 8).

Cluster 1 (*n* = 57) grouped older farmers owning small farms with consolidated farming experience, who grew Clearfield® rice on their farms. Farmers in this cluster did not generally receive an agricultural education; furthermore, they did not have a high knowledge of genetic modification techniques. Moreover, they were characterized by an external LOC and showed a moderately high perception of risk related both to the environment and the agri-food business caused by new GM techniques such as CRISPR/Cas9. Nevertheless, farmers in this cluster had a moderately positive attitude toward CRISPR/Cas9-modified blast-resistant rice. Therefore, this cluster is identified *as Supporters* (of CRISPR/Cas9-modified rice) *with external LOC*.

Cluster 2 (*n* = 62) included younger farmers with large farms on average. They had a low farming experience, but they grew Clearfield rice. Farmers in cluster 2 received an agricultural education and were highly knowledgeable about genetic modification techniques. They perceived low risks to the environment and the agri-food business caused by CRISPR/Cas9. Contrary to farmers in cluster 3, and similar to farmers in cluster 1, they showed a positive attitude toward CRISPR/Cas9-modified blast-resistant rice. However, they showed an internal LOC. Hence, cluster 2 is identified as *Supporters* (of CRISPR rice) *with internal LOC*.

Finally, *cluster 3* (*n* = 24) grouped farmers owning, on average, the smallest farms and with moderate farming experience. Contrary to other farmers, on average, they did not grow Clearfield rice. Moreover, in contrast to

TABLE 8 Cluster analysis results

	Cluster 1 (*n* = 57) Supporters with external LOC	Cluster 2 (*n* = 62) Supporters with internal LOC	Cluster 3 (*n* = 24) Opponents
ATT_CRISPR	0.330[a]	0.393[a]	−1.799[b,c]
AGE	0.426[c]	−0.424[b]	0.083
AGRI_EDU (1 = yes)	−0.521[c]	0.498[b,a]	−0.049[c]
FARM_SIZE	−0.190[c]	0.302[b,a]	−0.328[c]
FARMING_EXP	0.560[c]	−0.637[b,a]	0.314[c]
CLEARFIELD (1 = yes)	0.403[a]	0.087[a]	−1.182[b,c]
SUBKNOW	−0.120	0.242[a]	−0.340[c]
OBJKNOW	−0.478[c]	0.572[b,a]	−0.317[c]
PERC_ENV	0.278[c,a]	−0.580[b,a]	0.838[b,c]
PERC_BUSN	0.216[c,a]	−0.512[b,a]	0.810[b,c]
LOC	−0.25[c]	0.27[b]	−0.12

Note: Bonferroni comparisons was conducted as post hoc test.
For dummy variables, the reference category is indicated between brackets.
Abbreviation: LOC, locus of control.
[a]*t*-Test indicates that the mean value is statistically different from Cluster 3′s respective mean value at the 5% level.
[b]*t*-Test indicates that the mean value is statistically different from Cluster 1's respective mean value at the 5% level.
[c]*t*-Test indicates that the mean value is statistically different from Cluster 2′s respective mean value at the 5% level.

farmers in cluster 2, they did not have an agricultural education and were less knowledgeable about genetic modification technologies. Compared to other groups, farmers in cluster 3 perceived the highest risks to the environment and their business caused by CRISPR/Cas9. Thus, they showed a negative attitude toward CRISPR/Cas9-modified blast-resistant rice. Despite having a slightly external LOC, it was not significantly different from the LOC of farmers in other clusters. Thus, this cluster is identified *as opponents* (to CRISPR/Cas9).

5 | DISCUSSION AND CONCLUSIONS

This exploratory study examines farmers' attitudes toward CRISPR/Cas9-modified blast-resistant rice in Italy, which is the largest rice-producing country in Europe (Kraehmer et al., 2017). It was conducted in a hypothetical context since the cultivation of CRISPR-modified plants is not allowed by the current European regulations. By offering a first insight into farmers' attitudes toward the use of CRISPR/Cas9 technology, the present study contributes to the growing body of research on new gene technologies.

In accordance with the most recent literature on attitudes toward innovations and technology acceptance, this study evaluates the influence of noncognitive skills (i.e., LOC) in addition to standard indicators (i.e., socio-demographic variables, farm characteristics, knowledge) on farmers' attitudes toward CRISPR/Cas9-modified blast-resistant rice. Blast is one of the most damaging diseases affecting rice worldwide. Thus, to combat such disease, rice growers must apply agrochemicals, thus generating both private costs for the farmers and social costs, since they can affect the environment (Chen et al., 2019; Nalley et al., 2016). Thus, the implementation of a CRISPR/Cas9-modified blast-resistant rice may improve the sustainability of rice production. Nevertheless, an initial exploration of farmers' attitudes toward its application is needed.

Overall, farmers were likely to have a positive attitude toward CRISPR/Cas9-modified rice, as roughly 69% of them affirmed that they would adopt it in their farms. This is in line with findings on attitudes toward GMOs, which reported a high degree of acceptance of GM crops among farmers, in contrast to the generally low level of acceptance among consumers (Lucht, 2015). In detail, the current results highlight that having farming experience with Clearfield® rice positively influences attitudes toward CRISPR/Cas9-modified rice. This finding is similar to the results of Keelan et al. (2009), who found that previous experience with specific farming practices is positively linked to having a positive attitude toward GMOs.

Knowledge regarding genetic modification technologies was then included as an explanatory variable to investigate farmers' attitudes, with both subjective and objective knowledge analyzed. Overall, farmers in this sample were knowledgeable about the scientific aspects of GM technologies, since most of them were able to correctly respond to the majority of the related questions, in line with their own perceived knowledge. According to the present findings, knowledgeable farmers are more willing to accept CRISPR/Cas9-modified rice. However, only subjective knowledge was significant. The results are in line with the existing evidence, which indicates that knowledge improves farmers' attitudes and awareness toward GMOs (De Steur et al., 2019; Xu et al., 2016).

A further key determinant of farmers' attitudes toward innovation is the perception of related risks. Past literature indicates that farmers' attitudes decrease when the perceived risks related to innovations increase (Abadi Ghadim, 1999; Marra et al., 2003). In the present study, the perception of risk to the environment and the agri-food business caused by new gene technologies were measured. Both perceived risks were negatively related to attitudes toward the use of CRISPR technology, which is consistent with previous findings (Kamrath et al., 2019; Rzymski & Królczyk, 2016); however, only the latter was significant.

Finally, the influence of LOC on farmers' attitudes was analyzed. Contrary to what was expected (Abay et al., 2017; Hu & Veronesi, 2017; Taffesse & Tadesse, 2017), LOC was significantly negatively related to attitudes toward CRISPR/Cas9-modified rice, meaning that having an external LOC improved attitudes toward the innovative technology. This is surprising, since the literature unanimously points out that individuals with internal LOC believe more in their inner capacity and are more likely to accept innovations, whereas individuals with external capacity believe that events happen by chance or are influenced by forces out of their control (e.g., Galvin et al., 2018; Rotter, 1966). Nevertheless, it is important to consider the policy scenario in which the study was conducted. In fact, the attitudes toward CRISPR/Cas9-modified rice was measured in a hypothetical context since the cultivation of CRISPR/Cas9-modified crops is not allowed in Europe. Furthermore, Italy bans the cultivation of GM maize MON810, despite being allowed by the European Commission (Hundleby & Harwood, 2018). This means that Italian farmers have no experience with GM seeds; thus, it is difficult for them to evaluate the effects of GM rice such as CRISPR/Cas9-modified rice. Furthermore, past studies have investigated the effects of LOC on innovation and technology adoption only under feasible scenarios. In this study, neither sociodemographic characteristics (age and agricultural education) nor farm characteristics (farm size and farming experience) were significant. Although insignificant results for sociodemographics and farming experience were expected in line with several studies on GMOs (Areal et al., 2012; Kamrath et al., 2019; Xu et al., 2016), surprisingly, farm size did not significantly influence attitude toward CRISPR/Cas9-modified rice, as this result differs from the findings of most existing studies (Evans et al., 2017; Fernandez-Cornejo et al., 2005; Kamrath et al., 2019).

Finally, cluster analysis suggested that tailored information regarding CRISPR/Cas9 should be addressed. For example, to improve attitudes toward CRISPR/Cas9-modified rice among *opponents*, information regarding the positive impact on cultivation that CRISPR-Cas9 technology could generate (Ribeiro & Rodriguez, 2020) should be highlighted to reduce their perceived risk associated with gene technologies. Furthermore, policy intervention to increase knowledge dissemination regarding genetic modification techniques, with an emphasis on NBTs and gene editing, could positively affect farmers' attitudes toward CRISPR/Cas9-modified rice. Although *supporters with external LOC* had a generally positive attitude toward CRISPR/Cas9-modified rice, their knowledge of genetic modification techniques was low, and their perception of risk related to CRISPR/Cas9 was moderate. Thus, developing intervention strategies to improve their knowledge and provide information to reduce their perception of risk might be useful to improve their confidence in the CRISPR-Cas9 technology. Regarding the last category, *supporters with internal LOC* might represent innovators, that is, young farmers who are ready to grow CRISPR/Cas9-modified rice, if the EU changes its GM policy and allows its cultivation.

This study has the following limitations. First, it was conducted in a hypothetical context since the cultivation of CRISPR/Cas9-modified rice is not allowed in Europe. Additionally, GM crops are banned in Italy; thus, only hypothetical situations involving the application of genetic modification technologies can be investigated. Second, due to the hypothetical context, socioeconomic aspects associated with CRISPR/Cas9-modified rice cultivation were not evaluated. Future studies might analyze the perceived costs and benefits associated with this new technology. Third, owing to the convenience sampling procedure, the sample may suffer from selection bias. Fourth, a unidimensional index was generated for the measurement of LOC. Although the methodology is well established and used extensively in the literature (Abay et al., 2017; He & Veronesi, 2017; Rotter, 1966), it has been criticized by some authors (e.g., Guan et al., 2013). Finally, the questionnaire mentioned the term "(new) genetic modification." Although the information provided in the survey reported that CRISPR/Cas9-modified products differ from GMOs, this term might be misleading for some farmers, since it is usually referred to as synonymous with GMOs.

Nevertheless, this study offers the first investigation of farmers' attitudes toward the adoption of CRISPR/Cas9 technology, and further research in this context is needed. Allowing the cultivation of NBTs and gene-edited seeds, such as those produced using the CRISPR/Cas9 technology, could lead to increased food production in a more sustainable manner, thus helping to meet future food needs (Adenle et al., 2019; Qaim, 2020; Zilberman et al., 2018).

In summary, this study highlights the potential of CRISPR/Cas9 at the farm level. The majority of farmers in this study indicated that they would adopt the cultivation of CRISPR/Cas9-modified rice if it became available in Italy, with knowledge, practice experience, and a low level of perceived risk increasing farmers' favorable attitudes toward the adoption of CRISPR-Cas9 technology. Surprisingly, in contrast with the literature (e.g., Abay et al., 2017; Hu & Veronesi, 2017; Taffesse & Tadesse, 2017; Wuepper et al., 2019), external LOC increased farmers' attitudes toward CRISPR/Cas9-modified rice. Therefore, this result must be contextualized in the European policy scenario, which does not permit the cultivation of CRISPR/Cas9-modified products.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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