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ATTITUDE TOWARD GENE-EDITED FOOD: AN ECONOMIC ANALYSIS FROM DIVERSE STAKEHOLDERS' VIEWPOINT

PhD in Economics
Research area: Environmental and Energy Economics

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CONSUMER STUDY AMONGST MILLENNIALS AND GENERATION Z

Per aspera ad astra

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LIST OF ACRONYMS

CRISPR/Cas9 Clustered Regularly Interspaced Short Palindromic Repeats/Cas9

EU European Union

FAO Food and Agriculture Organization

GE Gene Editing

GHG Greenhouse gas

GMO(s) genetically Modified Organism(s)

LOC Locus of Control

NBT(s) New breeding technique(s)

NCS Non-cognitive skill

NPBT(s) New plant breeding technique(s)

SDGs Sustainable Development Goals

TALEN Transcription Activator-Like Effector Nucleases

WMO World Meteorological Organization

ZFN Zinc-Finger Nuclease

ABSTRACT

The fast-growing global population is increasingly confronted with the need to produce enough food, while coping with growing environmental challenges. To address this issue, food technologies and innovations are more and more put forward as a potential solution to help reaching a more sustainable food system. Gene technologies, for example, have the potential to increase crop productivity, improve resource efficiency, and reduce agrochemical use, alongside additional social benefits. Nevertheless, the public debate on genetically modified organisms (GMOs) is still ongoing. Genetically modified (GM) foods have been strongly criticized because a substantial share of consumers defines them as unnatural, risky, and unsafe for human health and the environment. In Europe, in particular, negative public opinion and the political climate have hindered the spread of GMOs.

Recently, new genetic engineering techniques such as gene editing (GE) have been proposed as valuable solutions to overcome people's concerns about GMOs. GE includes several tools, and one of the most prominent is CRISPR/Cas9. The key advantage of these new tools over transgenic breeding techniques is the fact that DNA can be edited without the need to insert foreign material, and their outcomes are seen as more natural products than their counterparts. Moreover, they can be done in a more precise, rapid and efficient way than GMOs. Nevertheless, the European Court of Justice (ECJ) ruled in July 2018 that products derived from new genetic modification techniques must be considered as GMOs (i.e. they must be subject to the same safety assessments and require the same label, thus they must undergo the European Commission Directive 2001/18).

Europe is currently experiencing a heated debate on GE food at political and scientific level, with many researchers calling for a revision toward a two-fold regulation.

Beyond these regulatory challenges, public acceptance of GE food needs to be further explored, as there has been little research on this subject to date. In particular, farmers and

consumer attitude toward these technologies needs to be deeply investigated. In fact, they represent the main actors of the food supply chain that can address the future development of GE food. On the one hand, farmers have to implement GE seeds and can spread their diffusion; on the other hand, consumers have the power to influence the diffusion of GE products through their consumptions and behavior.

This doctoral dissertation examines attitude toward GE food among different stakeholders. In fact, the debate surroundings the application of modified seeds and food in the agri-food system involves several actors, in particular farmers, who play a crucial role in determining the application of such technologies, and consumers, who represent the general public and can influence the market through their consumption behaviour.

This dissertation contributes to the ongoing literature on gene-edited acceptance in several ways. First, it examines farmers' attitude toward CRISPR/Cas9 blast resistant rice, which represents a particular application of the GE technology. Secondly, it examines consumers' attitude toward GE food and GE labelling preferences. Both studies identify the key

determinants of attitudes toward GE food.

In more detail, the study conducted on farmers offers valuable insights on a hypothetical application of CRISPR/Cas9 blast resistant rice. Then, the analysis investigates the effect of a non-cognitive skill (NCS), namely the locus of control (LOC) on farmers attitude toward CRISPR rice. It represents an empirical research and the analysis was based on primary data. The study conducted on consumers aims to explore attitudes toward GE food and preferences for GE food labelling. In addition, the study addresses young adults, that is Millennials and Generation Z. These population segments include young adults who are expected to play a key role in the debate on agricultural biotechnologies of the next future. Furthermore, the existing literature is scanty focused on these potential consumers. As for the study conducted on farmers, this was an empirical study on consumers, data was collected through survey.

Results provided in the doctoral dissertations suggest an overall positive attitude toward gene-edited food.

Farmers generally showed a positive tendency toward CRISPR rice resistant to blast. Subjective knowledge, prior farming experience, and a low perception of risk on the agri-food

business caused by CRISPR/Cas9 positively affected their attitude. Notably, having an external LOC improved attitude toward CRISPR rice. This result is surprisingly, but it has to be contextualised in the EU policy scenario, where the cultivation of CRISPR plants is not allowed.

Young consumers, i.e. Millennials and GenZers, generally showed a positive attitude toward GE food. Key determinants were objective knowledge, which positively affected attitude, and environmental concern, which negatively affected it. Regarding GE food labelling preferences, key determinants were educational background, objective knowledge of EU GMO regulation (positive), and attitude toward GE food (negative). Moreover, the preference for applying a similar labelling policy to both GM and GE was negatively linked to objective knowledge.

For both studies, results suggest several policy interventions. For example, more information regarding new plant breeding techniques should be provided to improve knowledge on breeding technologies, particularly among farmers, and the positive impact that these technologies might have on the

environment and on the economy should be highlighted.

Chapter 1

GENERAL INTRODUCTION

1.1 Scenario Description

By the end of 2050 the world population will count more than nine billion people (FAO, 2017) and adverse climate conditions will further affect coming years (WMO, 2020). Thus, the agri-food system is increasingly faced with the need of meeting the growing demand for food, while maintaining environmental sustainability. To reach the food security in a more sustainable manner is one of the main challenges of our society, as also prioritized by the Sustainable Development Goals (SDGs) (Campbell et al., 2018). The agriculture and the environment have a mutual effect, since agriculture must directly face with the effects of the climate change, while the environment is affected by agricultural practices, which can generate harmful consequences such as soil degradation, land and water pollution (Tubiello et al., 2014). The current central position of food security has been further highlighted by the Norwegian Nobel Committee, which has awarded the World Food Program with the Nobel Peace Prize 2020.

Technological innovation such as gene technologies could help to face the challenge of producing more food with less

resources. During the last twenty years, GM crops have been extensively grown, and several benefits have been linked to their adoption. For example, the adoption of GM crops (i.e. insect-resistant crops) has contributed to the reduction of greenhouse gas (GHG) emissions (Brookes and Barfoot, 2020) and soil erosion since it has allowed to implement more sustainable soil management practices, thus it has improved land and biodiversity conservation (Klümper and Qaim, 2014). Furthermore, it has been linked to several direct health benefits to consumers when considering biofortified food (De Steur, 2015), and indirect health benefits for farmers (Klümper and Qaim, 2014). Moreover, the meta-analysis conducted by Klümper and Qaim, 2014, shown that farm-households improved their socio-economic conditions and wellbeing after the adoption of GM crops, in particularly in developing countries.

Nevertheless, GMOs are strongly criticized by a large part of the population, particularly among consumers, and their usage is continuously debated. GMOs are produced with transgenic techniques, that is foreign material is inserted in the DNA sequence of the receiving plant/living organism. Contrary to

conventional breeding, GMOs are thus considered unnatural and harmful both for human health and the environment (Deng et al., 2019), and several countries, like Europe or Japan, strongly limit their diffusion (Eriksson et al., 2019).

The mid-90s marked a new era for genetic engineering for agricultural products through the development of gene-editing. Unlike the first generation of genetic modification techniques, gene-editing can make highly specific changes in the DNA of a living organism without necessarily inserting foreign DNA, thus essentially differing from GMOs. Gene-editing includes several techniques, like TALEN, ZFN, but the most prominent is the CRISPR/Cas9, whose developers, Emanuelle Charpentier and Jennifer A. Doudna, have been recently rewarded with the 2020 Nobel Prize in Chemistry. To date, both crops (Shah et al., 2018; Zhang et al., 2018) and animal-based products (Tait-Burkard et al., 2018) have been developed through these new techniques.

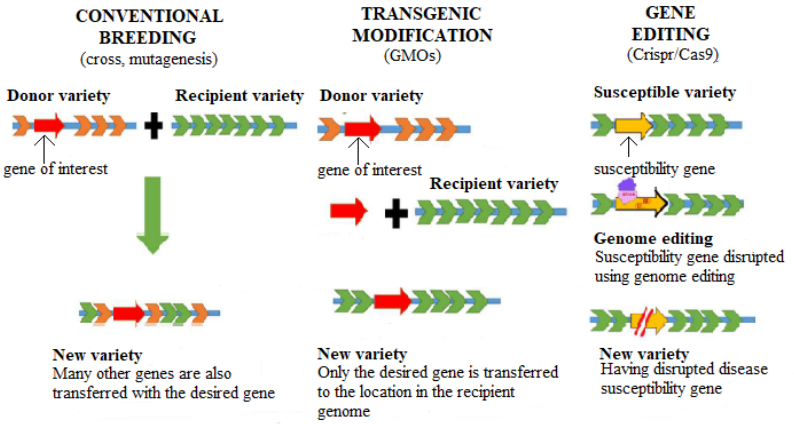

Figure 1. Zafar et al., 2020, adapted. Comparison of conventional breeding, genetic modification, and gene-editing.

As well as GMOs, gene-editing generates several benefits such as pest resistance (Wang et al., 2016) and environmental benefits (Bierbaum et al., 2020), and they could improve food quality and nutritional enhancements (Waltz, 2016). Moreover, gene editing represents a more efficient breeding method than genetic modification, since it is more efficient when developing crops with desired traits and it is less expensive (Borrelli et al., 2018). Because of its characteristics, gene-editing holds the potential to transform the food industry. Moreover, genetic engineering (both transgenesis and gene editing) represents a

key component of the modern bio-economy (Zilberman et al., 2018). Despite the first generation of genetic modification was strongly limited by regulations and rejected by consumers, the spare literature on gene-editing confirmed that GMOs and GE differs in consumer eyes (Muringai et al., 2020; Shew et al., 2018). Furthermore, due to the substantial difference between GMOs and GE products, scientists felt hopeful that regulators could rule GE differently from GMOs, also under the most restrictive policy scenario, like that of Europe.

However, despite several countries, like the US, Japan, Argentina, and Canada (Eriksson et al., 2018), imposed a less restrictive regulation on GE products, this did not happen in Europe. In July 2018, the European Court of Justice (ECJ), applying the precautionary principle, ruled that organisms obtained by new genetic modification techniques must undergo the same safety assessment of GMOs and follow the same policy. Nevertheless, this sentence has been strongly debated, and a revision is still required (Ferrari et al., 2020).

In case of this approach will be confirmed, unrevised European policy and regulations will impact on the economy. First, a hostile policy scenario would negatively affect the cost of

research and development in plant breeding (Barrows et al., 2014). Then, an unrevised regulatory policy will have implications for labelling policy (Purnhagen and Wesseler, 2020), and for international trade, since major countries regulates GE differently from GMOs, considering them often as conventional products. This could lead to an European import ban for countries which cultivate GE food and feed (Purnhagen and Wesseler, 2020). Moreover, several environmental benefits were associated with the production of GE food (Bierbaum et al., 2020), thus its ban might affect also the environment and thus the public utility.

To date, little is known about attitude toward GE food, both from consumption and production side. More research is thus needed to understand the scenario that the introduction of GE in the European context could face with.

1.2 Aims and structure of the thesis

The thesis aims to provide novel insights on attitude toward GE food in the European context. The research studies included in this dissertation respond to some general research problems

which can be summarized by the following questions: How do the diverse stakeholders evaluate GE food products? Which critical variables define attitude toward GE?

The main objective is to explore which determinants define attitude toward GE food among different actors of the food supply chain, i.e. farmers and consumers, who might have different interests toward food derived from novel technologies. Both research studies provided in this doctoral dissertation were conducted at microlevel, and several regressions were performed for data analysis. Due to the novelty of the topic of this thesis, a conceptual framework based on the main variables defined by the existing economic literature on GM was built. In line with the well-established literature on GM, for both studies the effect of educational background, socio-demographic characteristics, objective and subjective knowledge, and environmental concern on attitude toward CRISPR rice (for farmers) and GE food products (for consumers) was analysed. Then, further specific variables were added for the two research studies. Particularly, farmers' locus of control was included in the first study, while the research study on consumers also evaluated their attitude toward

GM/GE label. More details regarding the variables are given in the next chapters.

The methodologies of this thesis were based on the analysis of primary data for both research studies, thus surveys based on validated Likert scale were constructed. Following this, as suggested by the main literature, ordered logit models were used to identify significant variables (Agresti 2002). Furthermore, ordinary least squares (OLSs) and further data analyses were conducted. The thesis contributes to the economic literature offering novel and original results. To date, since the novelty of the topic, little is known about GE public perception. Despite GE can be referred as a recent genetic engineering, and economic literature concerning GMOs is well established, results of GE studies might significantly differ from GM counterparts, due to the intrinsic characteristics of new gene technologies.

Results might provide insights for future policies and show a valuable economic impact.

In detail, two scientific economic works will be introduced in the following chapters. The first study aims to explore farmers' attitude toward CRISPR/Cas9 rice and identify the key

determinants, while the second study examines consumers attitude toward GE food and their GE labelling preferences.

In what follows, the content of the next chapters is listed.

Chapter 2, entitled *Farmers' attitude toward CRISPR/Cas9: the case of blast resistant rice*, reports an analysis focused on Italian farmers. This chapter describes farmer attitude toward a specific GE application, the CRISPR/Cas9 rice, and considers the main determinants. Determinants include also non-cognitive skill, i.e. locus of control, that is the extent to which individuals believe that they can control what happens in their life.

Chapter 3, entitled *Attitude and labelling preferences towards Gene-edited food: a consumer study among Millennials and Generation Z*, specifically focuses on attitude toward GE food among young consumers, i.e. Millennials and Generation Z, and on their labelling preferences for GE food. The study has been conducted in two Dutch speaking regions. It is currently in press in the *British Food Journal, Vol. ahead-of-print, No. ahead-of-print.*

Chapter 4 reports conclusions and comments on the results.

Finally, an additional systematic review, *Can nudging improve the environmental impact of the food supply chain? A systematic review* is provided at the end of the present document as additional work. The review summarizes different nudging interventions that have been developed to push famers and consumers though a more sustainable behaviour when producing and consuming food. Despite the focus of this systematic review, that is, green nudges, does not coincide with the main topic of the thesis, this work has been included because this kind of behavioural intervention might be implemented to spread the diffusion of innovations in the agri-food system. Furthermore, this review was the first work done during the PhD program. The paper has been published in *Trends in Food Science and Technology, 2019, vol. 91, pages 184-192*.

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Chapter 2

FARMERS' ATTITUDE TOWARD CRISPR/Cas9: THE CASE OF BLAST RESISTANT RICE

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ABSTRACT

Genetically modified crops and new breeding techniques (NBTs), like CRISPR/Cas9 (CRISPR), could represent valuable solutions to achieve a sustainable agricultural system. This paper aims to examine Italian farmers' attitude toward CRISPR/Cas9 blast resistant rice in a hypothetical context, and it is one of the first study to investigate farmers' attitude toward new breeding techniques. The study explores the role of socio-demographics, farm characteristics, knowledge, perceived risks, and the role of the locus of control (LOC) in shaping attitude toward CRISPR rice. Results indicated that farmers were generally open to this innovation and they would cultivate CRISPR rice, if it would be available on the market. Subjective knowledge, practice experience and low perceived risk on the agri-food business were positively related to attitude toward CRISPR rice resistant to blast. Notably, LOC was inversely related to attitude, meaning that having an external LOC improved attitude toward CRISPR rice. The findings suggested that farmers would be generally favorable to the

introduction of CRISPR, thus a revision of the current EU GM policy might meet their needs.

2.1 Introduction

Being able to produce food in a more sustainable manner is one of the major challenges of the agricultural sector. Agriculture and climate change have a close and mutual relationship: droughts, floods, and soil degradation negatively affect farming, while agricultural practices generate greenhouse gas emissions and pollute water and land (Tubiello et al., 2014). To improve the agricultural production in order to feed the increasing world population, while at the same time reducing the environmental damage, innovation and efficiency in plant production are fundamental to meet future food strategies and sustainable development goals (Adenle et al., 2019).

In light of this, the application of gene technology could represent a large-scale solution to meet a sustainable production system (Qaim, 2020; Zilberman et al., 2018). In fact, plants improved through gene technology could improve the production both in terms of quality and quantity, 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). Among years, several

gene technologies have been developed. Genetically modified organisms (GMOs), for example, have been on the market since the 90s. More recently, new genetic modification techniques (nGMs) (Eckerstorfer, 2019) have been developed, which are commonly referred as new plant breeding techniques. NBTs include different techniques, and the most known are cisgenesis and gene editing (GE) (OECD, 2018; Schaart et al., 2016).

Among GE, one of the most prominent techniques is the CRISPR/Cas9. CRISPR/Cas9 differs from other gene technologies since it allows modifying 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 GE techniques because it has a high success rate and is less expensive compared to other breeding techniques (Borrelli et al., 2018). Several CRISPR/Cas9 plants have been developed to improve their traits and generating crop improvement in terms of yield production, adaptation to climate change, and resistance to pathogens (Shah et al., 2018, Zhang et al., 2018). However, their application is debated, since a share of consumers showed concerns about CRISPR products, such as for GMOs (Shew et al., 2018). Nevertheless, plants derived from

NBTs differ in technique from GMOs, and this has raised the need for a new policy framework to regulate them. For example, the US, Argentina, Japan, Canada, and Australia regulate NBTs with less strict regulation compared to that of GMOs (Eriksson et al., 2019; Lema, 2019). Opposite, the European Union (EU), in accordance with the sentence of the EU Court of Justice of July 2018, ruled out that organisms obtained by NBTs, like CRISPR/Cas9, must be compared to GMOs, thus they are subject to the obligations of the GMO Directive (Directive 2001/18/EC) (Callaway, 2018). Nevertheless, several exponents of civil society, farmers' organizations, and scientists are asking for a review of the current regulation (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 on the agri-food market. Because of the novelty of these technologies, their application is still limited (Qaim, 2020), and literature on NBTs is scant since their effects on the economy and on the environment cannot be easily observed. Furthermore, past literature on NBTs is focused on consumers' rather than farmers' attitude toward

NBTs. For example, most recent studies highlighted that consumers were willing to accept GE food (Ferrari et al., 2020; Gatica-Arias et al., 2019), and they are willing pay for cisgenic food (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 agreed that CRISPR crops could improve food security and bring benefits to the environment (Gatica-Arias et al., 2019). Consumers' acceptance of CRISPR was found to be influenced by individual risk perception, and by personal cultural values, which influenced individual propensity toward innovation (Yang & Hobbs, 2020). Opposite, no studies were found targeted on investigating farmers' attitude toward CRISPR/Cas9. However, the effects of GMOs have been extensively studied, and literature on GMOs can offer a first insight also on NBTs (Qaim, 2020). Farmers' attitude toward genetic modification is mostly influenced by socio-demographic characteristics (Breustedt et al., 2008), knowledge (Hou et al., 2012), farms characteristics (Gyau et al., 2009), financial and economic benefits (Kamrath et al., 2019), and perceived risks (De Steur et al., 2019). However, a growing

branch of the behavioral economics argued that also non-cognitive skills might play a role on farmers' attitude toward innovation, as growing NBTs represents for farmers an investment on innovation(Kreft et al., 2020; Sharma & Tarp, 2018; Wuepper et al; 2019). NCS 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 they could influence individuals' attitude. This study investigates farmers' attitude toward CRISPR/Cas9 blast resistant rice in the North of Italy in a hypothetical context. Italy is the first rice-producing country in Europe (Kraehmer et al., 2017), and the Lombardy and Piedmonts regions count for the highest production (Zampieri et al., 2019). However, crops might be affected by several pathogens, included rice blast. Rice blast is a common disease *diffused worldwide.* Because of the rice blast, 30% of rice production is lost globally, contributing to food insecurity (Nalley et al., 2016). To control for it, farmers must imply agrochemicals, which are associated with higher economic costs for their activity; then, their usage cause negative externalities on the environment (Chen et al., 2019; Durand-Morat & Nallet, 2019) and they might affect the human

health (Lai, 2016). Moreover, there is public concern on pesticide residues (Cerroni et al., 2013). A possible solution to decrease the use of agrochemicals on rice crops is represented by the introduction in the production system of rice plants which are intrinsically resistant to blast. The introduction of the CRISPR blast resistant rice in the Italian market would help farmers to cope with this pathogen (Borrelli et al., 2018). Nowadays, several blast resistant rice varieties have been developed (Wang et al., 2016), but their cultivation is not allowed in Europe.

Nevertheless, farmers would play a crucial role in determining successful application and diffusion of CRISPR/Cas9 crops if this application would be approved by the European policy makers, thus understanding farmers' attitude toward this new technology is fundamental.

Within this context, this paper represents a first attempt to investigate farmers' attitude toward CRISPR/Cas9 rice and contributes to the ongoing discussion on biotech food products. The analysis investigated the implication of standard variables such as socio-demographics, farm characteristics, knowledge and perceived risks in shaping farmers' attitude toward

CRISPR rice. Additionally, it went beyond standard variables and included also non-cognitive skills such as the locus of control.

2.2 Literature Background

2.2.1 European Legislation for new breeding techniques

At the beginning of 2018, the Advocate General of the European Court of Justice (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 25 July 2018 the European Court of Justice ruled that the organisms obtained by new mutagenesis techniques, including genome editing techniques, must be considered GMOs and must be regulated in accordance with the GMO Directive on the release of genetically modified organisms into the environment. Specifically, the Court reported that the organisms obtained by 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 genetically modified varieties at a rate out of all' (ECJ judgment of 25 July 2018, C-528/16), thus having similar risks of transgenic products.

In accordance with this sentence, the definition of new techniques of directed mutagenesis includes GE techniques such as CRISPR/Cas9. Nowadays, only the insect-resistant maize MON810 cultivation is allowed in Europe, but every Member State has the possibility to restrict it. According to the precautionary principle, certain Member States (Austria, Bulgaria, Germany, Greece, France, Hungary, Italy, Luxembourg, and Poland) are not allowing the cultivation of MON810 on their territory (Hundleby & Harwood, 2018).

2.2.2 Factors affecting farmers' attitude toward technology adoption

Factors affecting biotech adoption

Socio-demographic characteristics, knowledge, and perceived risks and benefits were factors which have been deeply

analyzed to investigate farmers' attitude toward GMOs (Breustedt et al., 2008; Kamrath et al., 2019; Xu et al., 2016). The evidence on sociodemographic characteristics was quite ambiguous. Older farmers and less educated farmers seemed to be less likely to adopt GMOs (Breustedt et al., 2008; Kamrath et al., 2019), while other findings suggested that age had a positive effect in shaping attitude toward GMOs (Fernandez-Cornejo et al., 2005). However, socio-demographics were often found to be statistically insignificant (Areal et al., 2012; De Steur et al., 2019; Xu et al., 2016). Knowledge on GMOs was then a further predictor of farmers attitude toward GMOs. Xu et al. (2016) affirmed that when knowledge on GM rice was limited, farmers were not able to take decisions about GM rice cultivation. Moreover, knowledge about GM technology decreased the indifference toward GM products (De Steur et al., 2019) and increased farmers' awareness (Luh, 2014; Todua & Gogitidze, 2017). Nevertheless, knowledge on GMOs was also found to be a positive but insignificant variable (Evans et al., 2017).

Then, farm size was a key factor in determining farmers' attitude toward biotech innovations, and it generally positively affected attitude (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, but mixed results were found. 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' attitude toward GM, but it was also found to be insignificant (De Steur et al., 2019).

Perceived risk was a determining factor in farmers' attitude toward new technologies and innovations. The adoption of new technologies was significantly related to the degree of farmers' risk perception (Abadi Ghadim & Pannell, 1999), and perceived risk had a generally negative influence on the adoption of new technologies (Marra et al., 2003). Furthermore, being risk averse negatively affected other factors such as farm size, farming experience, and income (Feder, 1980; Marra et al., 2003). Moreover, the perceived risk might increase with age, while farming experience could reduce it (Abadi Ghadim & Pannell, 1999). In such context, perceived environmental risk and perceived business risk were considered key determinants for analyzing attitude toward GM products. Rzymski & Kròlczyk

(2016) highlighted that the perceived environmental risk significantly decreased the propensity to grow GM crops, while Hall (2008) findings suggested that farmers were open to GM crops if these applications were beneficial to the environment. Furthermore, attitude toward GMOs improved when farmers perceived less economic risks related to them (Kamrath et al., 2019).

Locus of control and technology adoption

The locus of control is a non-cognitive skill and refers to the extent to which individuals believe that they have the control on what happens in their life. 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 locus of control, also known as 'control of reinforcement', was introduced by Rotter (1954, 1966, 1990). According to the author, the LOC emerges when individuals perceive a causal relationship between their behavior and reinforcements. Because of this learning process, people believe that a specific behavior will

result in a specific outcome, even in presence of rewards or reinforcements (Rotter, 1966).

When the individual expects that her personal characteristics influence the outcome of her actions, it is said to have an internal locus of control, while when the person believes that her life is controlled by circumstances outside her control, like luck, or others' power, it is said to be having an external locus of control. The existing evidence suggested that people with an internal LOC were more confident and determined. Conversely, people with an external LOC were more likely to see themselves as influenced by facts outside their authority, and with less ability in reaching their outcomes (Galvin et al., 2016).

The concept of LOC was developed in the psychological context to comprehend individual's 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, while individuals with external LOC were less willing to adopt them (Sharma & Tarp, 2018). These findings were found also within the frame of the agricultural context. In

fact, farmers with internal LOC were more willing to have a positive attitude toward technology adoption compared to farmers with external LOC. The 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 suggested that farmers with an internal LOC were 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).

2.3 Methodology

2.3.1 Survey

A face-to-face survey was developed and pre-tested on ten farmers. By using a convenience sampling procedure, the survey was distributed among the rice-growers of three Italian provinces, which are well-known as rice-growing areas (Pavia in Lombardy; Vercelli and Novara in Piedmonts) from September to November 2019. In total, 152 farmers were

surveyed. Due to missing data, the final sample included 143 farmers. The survey consisted of five parts. The first part included a brief description on CRISPR/Cas9 and its possible application on rice for achieving blast resistance. The information reported that "CRISPR/Cas9 is a gene editing technique that allows to modify an organism's DNA. Despite it is a genetic modification, this technique differs from transgenesis (which generates GMOs), as it implies a non-transgenic approach. Thanks to CRISPR/Cas9, it is possible to create a blast resistant rice. Thus, the new CRISPR rice allows the reduction of agrochemicals usage." The information was built in accordance with the existing literature (Aglawe, 2018; Borrelli et al., 2018) and it was checked by a biotech expert. After that, farmers' attitude toward CRISPR rice (ATT_CRISPR) was 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 on rice would be acceptable for my farm*. Then, the locus of control scale (Abay et al., 2017; Rotter, 1966) elicited farmers' locus of control. The scale presented 10 items ranked on a 6-point Likert scale, from 1 (totally disagree) to 6 (totally agree). The third part included questions testing farmers'

knowledge on genetic modification. In accordance with House et al. (2004), farmers were asked to self-rank their knowledge on GM on a 9-point Likert scale, from 1 (very low) to 9 (very high). This was followed by 4 true/false statements to assess their objective knowledge (House et al., 2004). The fourth part dealt with questions related to perceived environmental and agri-food business risk. Both perceived risks were measured by 4 statements on a 9-point Likert scale, from 1 (totally disagree) to 9 (totally agree) (House et al., 2004). The survey included several Likert scales for measuring different farmers' characteristics. The scales used were taken from the existing literature and adapted for the present context (Abay et al., 2017; House et al., 2004), thus the Likert-point scales implemented by authors were followed. However, the lowest point indicated "strongly disagree", while the highest point indicated "strongly disagree", and this information was reported to the respondent at the beginning of each measurement. The order of all questions was not randomized. The fifth part collected socio-demographic information such as gender (1=female, 0=male), age, agricultural education (1=yes, 0=no) and farm characteristics like farming experience, farm size (measured in

hectares), and practice experience with Clearfield® rice (1=yes, 0=no). Clearfield® rice is created with mutagenesis technique, which is allowed in Italy. However, some opponents argued that it should be considered as a GMO, thus its cultivation was considered as a proxy for practice experience.

2.3.2 Variables measurement

Statistical analysis was performed in Stata 13 and IBM SPSS Statistics 26. Several composite variables were constructed. Regarding the creation of the objective knowledge index, in accordance with House et al., 2004, each of the four true/false statements was scored 1 when respondent responded correctly to the item, while the statement was scored 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 alpha=0.50) (Table 3). The Cronbach's alpha might be low when the number of statements is small, so, in this context, this value for OBJKNOW could suggest medium reliability (Hinton, 2004). An index for the perceived environmental risk caused by new genetic modification

PERC_ENV) was obtained by summing the related items (Cronbach alpha=0.65) (House et al., 2004). The index ranged from 4 to 36 (Table 4). Items that measured the perceived benefit (items 1 and 4) were reverse-coded, thus higher scores indicated higher perceived risk. Similarly, an index for the perception of risk on the agri-food business PERC_BUSN) was generated by summing the corresponding four items (Cronbach alpha= 0.77). The index ranged from 4 to 36 (Table 4). Items which measured perceived benefit (item 1) were reverse-coded so that higher scores indicated higher perceived risk.

An index for the locus of control (LOC) was generated. First, an explanatory factor analysis was run to classify which items identified latent factors that could be interpreted as internal or external locus of control. The factor analysis (Figure A, Table A) highlighted that the first five items were associated with the internal locus of control, while the last five items were associated with the external locus of control (Table 5). Items associated with external locus of control (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 increased with internality. Raw values of internal LOC and external LOC were used in the descriptive analysis. For descriptive purposes, two indexes were generated as a mean for individual scores for the 5 internal and 5 external LOC statements (Table 5). Since the unbalanced presence of males in the sample, gender was not included in the statistical analysis.

2. 3.3 Ordered logit model

The dependent variable was an ordinal response variable, thus an ordered logit model was chosen as regression model, as usually done(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 called also cumulative link model (Agresti, 2002).

Let Y_i be an ordinal dependent variable with J categories and explanatory variables x_i for the i^{th} observation. The model with this logit link can be defined as

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

where $Prob(y_i \leq j|x_i)$ is the cumulative probability. The parameters α_7 are the cutpoints, which are in increasing order $\alpha_1 < \alpha_2 < \cdots < \alpha_{7-1}$.

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

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

$$y_i(\text{ATT\_CRISPR}) = \alpha_i + +\beta_1 \text{AGE} + \beta_2 \text{AGRI\_EDU} + \beta_3 \text{FARMING\_EXP}_i + \beta_4 \text{FARM\_SIZE}_i + \beta_5 \text{CLEARFIELD®}_\text{i} + \beta_6 \text{SUBNOW}_i + \beta_7 \text{OBJKNOW}_i + \beta_8 \text{PERC\_ENV}_\text{i} + \beta_9 \text{PERC\_BUSN}_\text{i} + \beta_{10} \text{LOC}_\text{i} \quad (2)$$

where the dependent variable y_i, that is, the attitude toward the adoption of CRISPR 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 on genetic modification, perceived environmental risk (PERC_ENV), perceived agri-food business risk (PERC_BUSN), and the locus of control (LOC).

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

2. 3.4 Cluster analysis

Additionally, a cluster analysis was performed to determine clusters of farmers with different attitude toward CRISPR/Cas9 rice. A *k*-means cluster analysis (MacQueen, 1967) was completed using SPSS IBM Statistics 26. *K*-means cluster is usually not recommended with small dataset: however, due to its advantages, like the easy interpretation and accuracy, it was chosen for the present analysis. Nevertheless, before conducting it, a hierarchical cluster analysis, which suits better with small dataset, was performed. The clustering problem is given as the minimization of the overall distance between points and the centroid of the cluster.

$$\min \sum_{j=1}^{J} \sum_{i=1}^{N^J} \left\| p_i^j - c_j \right\|^2 \qquad (3)$$

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; c_j is the centroid. Because of their different nature, variables were measured in different units, thus data were standardized before clustering

(Johnson, 1998). To detect statistical differences of the variables between clusters, *t*-tests were performed.

2.4 Results

2.4.1 Sample characteristics

The sample included 127 men (88.81%) and 16 females (11.19%), and the median age was 53 years. Almost half of the respondents (47.5%) had any agricultural education. On average, farmers run their business for 26 years. Farms had, on average, 123.75 hectares. More than 80% of the sample declared to cultivate Clearfield® rice. Socioeconomic characteristics are displayed in Table 1.

Table 1 Socio-demographic characteristics

Variable		Description	Variable distribution	
Gender (*GENDER*)			N	%
	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
Agricultural education (*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

Farmers had generally a positive attitude toward CRISPR rice (M=5.67 SD=1.74); nearly 69% of them showed a positive attitude toward CRISPR rice, scoring their attitude 6 or 7 on a 7-point Likert scale;; about 20% were neutral, scoring their attitude 4 or 5 on the scale. Roughly 11% of farmers showed a negative attitude toward CRISPR rice, scoring their attitude 1, 2, or 3 on the Likert scale (Table 2).

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

Farmers had a quite good knowledge on genetic modification. Overall, the sample was characterized by mid-subjective knowledge (M=5.42, SD=2.34). However, farmers' objective

knowledge on genetic modification tools was good: on average, they answered three out of four statements correctly, and mostly 42% of the sample responded to the four statements correctly. Objective knowledge was significantly positively correlated to subjective knowledge, implying that farmers were aware of their knowledge on genetic modification.

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	17.48	82.52

	could also be changed. (F)		
	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.

Regarding the perceived environmental risk caused by new technologies like CRISPR/Cas9, farmers seemed to be slightly worried about risks that new genetic modification could cause (M=18.70, SD=7.02).

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

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.*	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 modification (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.*	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 s*tatements*	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.*	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. * indicates that item is reverse-coded.

Turning to the locus of control, 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 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).

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*.	3.44	1.62
			7. I feel like what happens in my life is determined by others*.	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*.	3.62	1.9
	9. My life is chiefly controlled by other powerful people*.	1.95	1.45
	10. People like me have little chance of protecting personal interest*.	2.38	1.64

Note: Statements are ranked from 1 (=totally agree) to 6 (=totally disagree). * indicates that item is reverse-coded.

2. 4.2 Attitude toward CRISPR/Cas9 blast resistant rice

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

Table 6 Explanatory variable correlation matrix.
Significance level: ***p< 0.001, **p< 0.01 *p<0.05.

	ATT_CRISPR	AGE	AGR_EDU	FARMING_EXP	FARM_SIZE	CLEARFIELD	SUBJKNOW	OBJKNOW	PERC_ENV	PERC_BUSN	LOC
ATT_CRISPR	1										
AGE	-0.04	1									
AGRI_EDU	0.06	-0.25**	1								
FARMING_EXP	-0.01	0.55***	-0.23**	1							
FARM_SIZE	0.14	-0.09	0.06	0.00	1						
CLEARFIELD	0.30***	0.02	0.02	0.05	0.19*	1					
SUBKNOW	0.19*	0.01	0.11	-0.07	-0.00	-0.05	1				
OBJKNOW	0.19*	-0.11	0.19*	-0.24**	0.17*	0.00	0.25**	1			
PERC_ENV	-0.32***	0.03	-0.16	0.24	-0.10	-0.16	-0.27**	-0.30***	1		
PERC_BUSN	-0.38***	0.06	-0.14	0.16	-0.07	-0.08	-0.21*	-0.34***	0.64***	1	
LOC	-0.07	-0.02	0.10	-0.05	0.15	0.09	-0.03	0.14	-0.15	-0.24**	1

The ordered logit model explored attitude toward CRISPR/Cas9 rice resistant to blast (Table 7). Four explanatory variables were found to be statistically significant to determine farmers' attitude. Outcomes showed that growing Clearfield® rice positively affected farmers' attitude, since it increased the odds by a factor of 3.317. Regarding knowledge, only the subjective one had a positive influence on attitude toward CRISPR rice. Specifically, a unit increase in subjective knowledge increased the odds of attitude toward CRIPR rice by a factor of 1.175. Furthermore, farmers' attitude was inversely related to the perception of risk associated to the agri-food business. An increase of one unit in the perception of risk on the agri-food business, decrease the attitude toward CRISPR rice by a factor of 0.911. Contrary to the expectations, the locus of control negative affected attitude toward CRISPR rice: a unit increase in the LOC decreased the odds by a factor of 0.626.

Table 7 Determinants of attitude toward CRISPR/Cas9 rice

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

Note: OR, odds ratio, CI, confidence interval. 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 (LR) χ^2 (10) =48.25, (p<0.001), pseudo-R^2=0.1132, log-likelihood=-189.060, n=143. Significance level: ***p< 0.001, **p< 0.01 *p<0.05.

2.4.3 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). Results indicated that three clusters that subdivided the sample could be identified. After identifying the number of clusters, the k-means was performed. The convergence was achieved after six iterations, and the final cluster centers are reported in Table 8. The Bonferroni correction was then performed to test the hypothesis that cluster means are equal (Table 8).

Cluster 1 (n=57) grouped older farmers with small farms, with a consolidate farming experience, who grown Clearfield® rice in their farm. Farmers in this cluster did not generally receive agricultural education; furthermore, they did not have a high knowledge on genetic modification. Moreover, they were generally characterized by an external LOC, and they showed a

moderate high perception of risk related both to the environment and to the agri-food business caused by new genetic techniques like CRISPR/Cas9. Nevertheless, farmers grouped in this cluster had a moderate positive attitude toward CRISPR/Cas9 blast resistant rice. Based on this, the cluster could be recalled *Supporters* (of CRISPR rice) *with external LOC.*

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

Finally, *cluster 3* (n=24) grouped farmers with on average the smallest farms and with moderate farming experience. Opposite to other farmers, on average they did not grown Clearfield® rice. Moreover, in contrast to farmers of cluster 2,

they did not have an agricultural education, and were less knowledgeable on genetic modification. Compared to other groups, farmers of cluster 3 perceived the highest risks on the environment and on their business caused by CRISPR/Cas9, and they showed a negative attitude toward CRISPR/Cas9 blast resistant rice. Despite they had a slightly negative LOC, it was not significantly different from LOC of farmers in other clusters. Thus, this cluster could be renamed *Opponents* (to CRISPR/Cas9).

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[c]	0.393[c]	-1.799[a, b]
AGE	0.426[b]	-0.424[a]	0.083
AGRI_EDU (1=Yes)	-0.521[b]	0.498[a, c]	-0.049[b]
FARM_SIZE	-0.190[b]	0.302[a, c]	-0.328[b]
FARMING_EXP	0.560[b]	-0.637[a, c]	0.314[b]
CLEARFIELD (1=Yes)	0.403[c]	0.087[c]	-1.182[a, b]
SUBKNOW	-0.120	0.242[c]	-0.340[b]
OBJKNOW	-0.478[b]	0.572[a, c]	-0.317[b]
PERC_ENV	0.278[b, c]	-0.580[a, c]	0.838[a, b]
PERC_BUSN	0.216[b, c]	-0.512[a, c]	0.810[a, b]
LOC	-0.25[b]	0.27[a]	-0.12

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

2.5 Discussion and Conclusions

This exploratory study examines farmers' attitude toward CRISPR/Cas9 rice with resistance to blast 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 plants is not allowed by the current European regulation. The present study contributes to the growing body of research on new gene technologies, since it offers a first insight on farmers' attitude toward CRISPR/Cas9 In accordance with the most recent literature on attitude toward innovation, this study aimed at evaluating the influence of non-cognitive skills (locus of control) in addition to standard indicators (sociodemographic variables, farm's characteristics, knowledge) on famers' attitude toward CRISPR rice resistant to blast. Blast is one of the most damaging diseases which affect rice worldwide; to cope with it, rice growers must imply agrochemicals, which generate 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 rice resistant to blast may improve the

sustainability of rice production. Nevertheless, an initial exploration on farmers' attitude toward it is needed.

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

Knowledge of genetic modification was then included as explanatory variable for investigating farmers' attitude, and both subjective and objective knowledge were analyzed. Overall, farmers of this sample were well knowledgeable about the scientific aspects of this technology, since most of them were able to correctly respond to the majority of the related questions, and this was in line with their own perceived

knowledge. According to the present findings, knowledgeable farmers were more willing to accept CRISPR/Cas9 rice. Nevertheless, only the subjective knowledge was significant. Results were in line with the existing evidence, which stands that knowledge improved farmers' attitude and awareness toward GMOs (De Steur et al., 2019; Xu et al., 2016).

A further key determinant of farmers' attitude toward innovations was the perception of the related risk. Past literature referred that farmers' attitude decreased when perceived risk related to innovations increased (Abadi Ghadim & Pannell, 1999; Marra, 2003). In the present study, the perception of risk on the environment and on the agri-food business caused by new gene technologies were measured. Both perceived risks were negatively related to attitude toward CRISPR, and this is consistent with the previous findings (Kamrath et al., 2019; Rzymski & Kròlczyk, 2016); however, only the latter was significant.

Finally, the influence of LOC on farmers' attitude was analyzed. Opposite to what expected (Abay et al., 2017; Hu & Veronesi, 2017; Taffesse & Tadesse, 2017), LOC was significantly negatively related to attitude toward CRISPR rice, meaning that

having an external LOC improved attitude toward the innovation. This is surprisingly, since the literature unanimously pointed that individuals with internal LOC believed more in their inner capacity and were more likely to accept innovations, while individuals with external capacity believed that events were influenced by chances or forces out of their control (for example,; Galvin et al., 2016; Rotter, 1966;). Nevertheless, it is important to consider the policy scenario in which this study was conducted. In fact, attitude toward CRISPR rice was measured in a hypothetical context, since the cultivation of CRISPR is not allowed in Europe. Furthermore, Italy bans the cultivation of the GM maize MON810, despite it is allowed by the EC (Hundleby & Harwood, 2018). This means that the Italian farmers have never experienced with genetically modified seeds, thus it could be hard for them evaluating the effects of a modified rice such as CRISPR rice. Furthermore, past studies investigated the effects of LOC on innovations and technology adoption only under feasible scenario. Despite LOC measures personal characteristics, the fact that the current EU GM policy bans CRISPR could be strongly perceived by farmers as an external force that they cannot control, thus this feeling

emphasized their external LOC, even if their attitude toward CRISPR blast resistant rice is positive. In this study, neither sociodemographic characteristics (age, agricultural education) nor farm characteristics (farm size and farming experience) were significant. Insignificant results for socio-demographics and farming experience were expected and in lines with those of 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 rice, and this differs from the majority of existing studies (Evans et al., 2017; Fernandez-Cornejo et al., 2005; Kamrath et al., 2019). Finally, the cluster analysis suggested that a tailored information regarding CRISPR/Cas9might be addressed. For example, deepen information on benefits related to CRISPR might increase attitude among the *opponents* and it might increase self-confidence among other farmers, like the *supporters with external LOC*. (Ribeiro & Rodriguez, 2020).Finally, *supporters with internal LOC* might represent innovators, that is young farmers who might be ready to grow CRISPR rice, if the EU GM policy would allow its cultivation. Nevertheless, this research represents a first study on attitude

toward CRISPR rice, and results should be taken cautiously. This study is not without limitations. First, it was conducted in a hypothetical context, since the cultivation of CRISPR rice is not allowed in Europe. Moreover, GM cultivation is not allowed in Italy, thus only hypothetical situations on genetic modification can be investigated. Furthermore, due to the hypothetical context, socio-economic aspects associated with CRISPR rice cultivation were not evaluated. Future studies might analyze perceived costs and benefits associated with this new technology. Then, due to the convenience sampling procedure, the sample may suffer from selection bias. Moreover, the questionnaire mentioned the term '(new) genetic modification'. Despite the information provided in the survey reported that CRISPR products differ from GMOs, this term might be misleading for some farmers, since it is usually referred as a synonymous for GMOs. The analysis was based on data collected through validated Likert scales included in the questionnaire: since the layouts of the scales changed, farmers might have not notice this aspect, even if it was underlined, and this might have influenced their responses. Moreover, several reversed-score statements are presented. Even if this

methodology is well established in the literature, it is not without critics (Hartley, 2013). Finally, results obtained thought k-means clustering should be taken carefully due to the small dataset, even if an initial hierarchical cluster analysis was done.

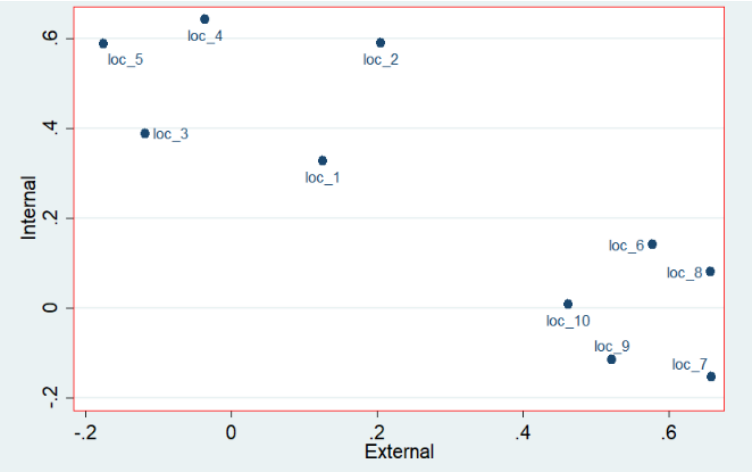
This study offers a first investigation on farmers' attitude toward CRISPR, and further research in this context is needed. Allowing the cultivation of NBTs and gene editing seeds, like those derived with CRISPR/Cas9, could lead to increase food production in a more sustainable manner, thus helping to reach the future needs (Adenle et al., 2019; Qaim, 2020; Zilberman et al., 2018).

In summary, this study underlined the potential of CRISPR/Cas9 at farm level. The majority of farmers in this study indicated that they would accept the cultivation of CRISPR rice if it would be available in Italy. Knowledge, practice experience and low level of perceived risk increased farmers' attitude. Surprisingly, in contrast with the literature (Abay et al., 2017; Hu & Veronesi, 2017; Taffesse & Tadesse, 2017; Wuepper et al., 2019) external LOC increased farmers' attitude toward CRISPR rice. Nevertheless, this result must be

contextualized in the European policy scenario, which does not permit the cultivation of CRISPR products.

Appendix

Figure 1A Factor loadings of the LOC items scale.



Note: Items 1, 2, 3, 4, 5 describe the internal LOC, items 6, 7, 8, 9, 10 describe the external LOC (Abay et al., 2017; Rotter, 1966).

Figure 2A Exploratory Factor Analysis for LOC items.

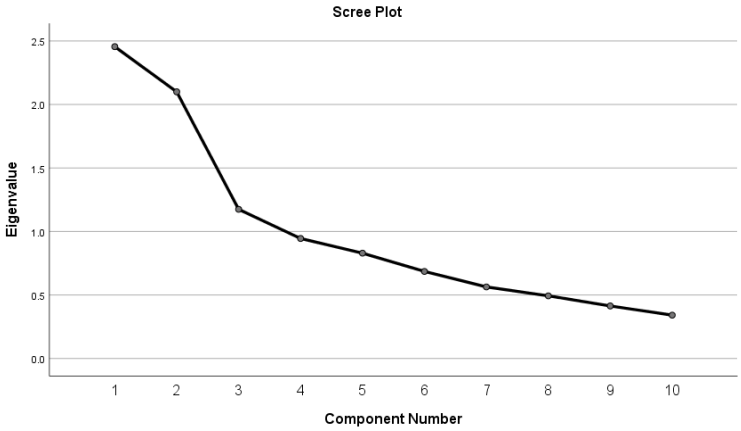


Table 1A Factor loadings for LOC items.

LOC items	Factor 1	Factor 2
Item 1	0.156	0.445
Item 2	0.238	0.711
Item 3	-0.157	0.522
Item 4	-0.045	0.754
Item 5	-0.205	0.683
Item 6	0.680	0.177
Item 7	0.744	-0.168
Item 8	0.758	0.105
Item 9	0.624	-0.144
Item 10	0.569	0.006

Note: The items 1, 2, 3, 4 and 5 are correlated to the second latent factor (factor 2), referred as internal LOC; the items 6, 7, 8, 9 and 10 are correlated to the first latent factor (factor 1), referred as external LOC.

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Chapter 3

ATTITUDE AND LABELLING PREFERENCES TOWARDS GENE-EDITED FOOD: A CONSUMER STUDY AMONG MILLENNIALS AND GENERATION Z

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ABSTRACT

Purpose: This study jointly examines consumer attitudes towards Gene-edited (GE) food and their preferences for labelling such products. Thus, it contributes to understanding the role of educational background, objective/subjective knowledge, environmental concern and socio-demographics in the context of GE food.

Design/methodology/approach: An online survey was administered to two generations of young individuals (Millennials and Generation Z; n=234) from two neighbouring EU regions (Belgium and the Netherlands), which have a stringent policy on (labelling) genetically modified (GM) food. Ordinary least squares (OLS) and ordered-logit models (OMS) were performed to identify key determinants of attitudes towards GE food and GE labelling preferences, respectively.

Findings: Attitudes towards GE food were determined by environmental concern (negative) and objective knowledge (positive). Key factors influencing preferences for GE labelling were: a non-hard scientific background, knowledge about relevant policies, and a negative attitude towards GE food.

Preference for applying a similar labelling policy to both genetically modified (GM) and GE was itself linked to having low, objective EU policy-related GM food knowledge and one's nationality.

Originality/value: This is one of the first studies to examine consumer attitudes towards GE food products, while also addressing a lack of research on GE food labelling preferences. By highlighting the preferences of young generations for a revised policy approach, this study sheds new light on the current GE debate, notably, by promoting a deeper understanding of a group which has so far received limited attention in the discourse on the acceptance of novel plant-breeding technologies.

Keywords: Attitude, Consumer, Gene-edited food, Generation Z, labelling, Millennials.

Paper type: Research paper

3.1 Introduction

Fast and extensive growth in global population is increasingly prompting discussion of how to produce enough nutritious food without triggering ever further environmental degradation, as also reflected in the Sustainable Development Goals (SDGs). To address these twin challenges, food technologies and innovations are put forward (Adenle *et al.*, 2020; Campbell *et al.,* 2018; Zilberman *et al.,* 2018). Gene technologies, for instance, have been touted for their potential to increase crop productivity, improve resource efficiency, and reduce agrochemical use, alongside additional benefits for the environment and the society (Adenle *et al.,* 2020; Barrows *et al.*, 2014; Qaim, 2020). Through the direct and indirect economic and environmental benefits that are engendered, genetically modified organisms (GMOs) have improved conditions of many farmers in developing countries (Klümper and Qaim, 2014; Perry *et al*., 2016; Taheripour *et al*., 2016). Moreover, through elevating micronutrient levels in staple crops, genetically modified (GM) food could potentially reduce micronutrient deficiencies in at-risk populations (De Steur *et al*., 2015; Van Der Straeten *et al*., 2020). Nevertheless, the public

debate on GM food is still ongoing, with consumer rejection towards GM food present and well-documented (Hess *et al.*, 2016; Mielby *et al.*, 2013) and a substantial share judging GM food to be unsafe, unnatural, and risky for human health and the environment (Delwaide *et al.*, 2015; Frewer *et al.*, 2013). This is particularly the case in the European Union (EU), where the negative public opinion and political climate have been pointed to as significant obstacles for the diffusion of GMOs (Qaim, 2020).

More recently, new plant breeding techniques (NPBTs), and gene editing (GE) in particular, have been proposed as relatively novel applications of agricultural biotechnology that could represent a valuable alternative to overcome consumer concerns of GMOs (Bartkowski and Baum 2019; Butkowski *et al.*, 2017; De Marchi *et al.*, 2020; Edenbrandt *et al.*, 2017). Gene editing includes several tools, of which the most prominent is CRISPR/Cas9. Such tools represent noteworthy opportunities for improvements in crop production to enhance yield, offer nutritional supplements, promote disease resistance, and potentially decrease environmental impact (Jaganathan *et al.*, 2018; Limera *et al.*, 2017). Furthermore, one of the key

advantages of GE over transgenic breeding techniques include the fact that DNA can be edited without inserting external material and is expected to lead to more precise, fast and efficient modifications (Limera et al, 2017). Because of their intrinsic differences to their GM counterparts, many countries such as Argentina, the US, Australia, Canada are moving ahead with the implementation of a specific regulatory framework for NPBTs and GE crops (Eriksson *et al.*, 2019; Parrott *et al.*, 2020). This development stands in contrast to the status quo in the EU, where, in July 2018, the European Court of Justice (ECJ) ruled that organisms obtained by new genetic modification techniques must be regarded and labelled as GMOs, in accordance with European Commission Directive 2001/18 (Callaway, 2018): this means that products developed through NPBTs such as GE, must undergo the same safety assessments and comply with similar labelling requirements as GMOs. As a consequence, the EU threshold for labelling GM ingredients would need to be applied to food derived from NPBTs such as GE food (Callaway, 2018), thus signalling a divergence from the policies in several other countries, where either no or a different labelling system is required for the two (Friedrichs *et al.*, 2019).

Indeed, the prevailing approach to NPBTs in the EU has fomented a strong debate at the political, scientific, and public levels, with many researchers calling for a revision of the prevailing approach to GE in the EU, whereby GE plants would not be classified as traditional GMOs, unless they contain transgenic elements (Lassoued *et al.*, 2020).

Aside from these regulatory challenges, there is an important societal component of the public acceptance of GE food and GE labelling that needs to be studied further (Ishii and Araki, 2016; Bartkowski and Baum 2019). As of today, little research on acceptance of NPBTs has taken place. The limited evidence that does exist suggests that consumers may be more willing to consume CRISPR/Cas9 vis-à-vis GM food products (Muringai *et al.*, 2020; Shew *et al.*, 2018; Yang and Hobbs, 2020), and they may be more willing to accept CRISPR crops if this technology were to be associated with environmental, health, and economic benefits (Gatica-Arias *et al.*, 2019). When it comes to GMOs, there is a large body of literature that has examined public acceptance across a range of potential applications. This research has demonstrated, *inter alia*, that knowledge, risk perceptions, and socio-demographics all play a crucial role in

determining consumer attitudes towards GM food (Frewer *et al.,* 2013; Kamrath *et al.,* 2019; McPhetres *et al.,* 2019). Accordingly, given the paucity of research around the public acceptance of GE food, or the use of CRISPR in this context, these factors represent a valuable starting point for developing an appreciation of the relevant determinants.

For instance, knowledge about GMOs has been shown to influence attitudes towards GM food though the direction of this effect is not necessarily consistent, instead depending on the type of knowledge being considered. The first thing to note is that consumer scientific literacy of GM food is generally low (Ardebili and Rickertsen, 2020; McPhetres *et al.,* 2019; Wuepper *et al.,* 2018). Therefore, it is crucial to differentiate between subjective and objective knowledge, which are respectively defined as the self-reported level of individual knowledge with regard to GM and the knowledge demonstrated, e.g., by means of objective testing. Evidence on the impact of such knowledge however remains inconclusive. Some studies establish a significant effect only for subjective knowledge, positive (House *et al.,* 2004) and negative (Zheng *et al.,* 2018), but not for objective knowledge, while others find the opposite (Zhang and

Liu; 2015). Other researchers point to an effect of objective knowledge, mostly positive (McPhetres *et al.*, 2019; Wunderlich and Gatto, 2015; Zhang and Liu; 2015), though this effect can also be quadratic in nature (e.g. U-shaped effect) (De Steur et al. 2010). Even if the majority of studies find a positive effect of knowledge on acceptance of GM food (Costa-Font *et al.*, 2008), the fact that inconsistent findings do exist signals the need to investigate the effect of both types of knowledge on consumer attitudes towards GE.

Risk perceptions of GM technology have also been established as a key determinant of consumer attitudes (Costa-Font *et al.*, 2008; De Steur et al. 2010), particularly in the context of health and environmental risks (Frewer *et al.*, 2015; Kamrath *et al.*, 2019). In specific, Hudson et al. (2015) have illustrated the large importance that perceptions of the environmental impact of this technology has in orienting consumer approval towards GM food in EU member states, something also confirmed in country-specific EU studies. For example, Butkowski et al. (2017) found that consumer perceptions of the environmental risk of GM food were the highest among the four different dimensions considered, while Grunert et al. (2003) suggested

that greater perceptions of environmental risks fostered more negative attitudes towards GM food among European consumers.

With respect to socio-demographic variables, several studies indicated that male and younger consumers tend to be more willing to accept GM food (Elder et al. 2018; Hudson *et al.*, 2015). Such findings are also echoed in the context of GE, with gender and age also having a significant influence on attitudes towards GE technology (Muringai *et al.*, 2020). Nevertheless, contradictory results have been reported for these and other socio-demographic indicators (Kamrath *et al.*, 2019). Furthermore, educational background has been shown to influence GM food attitudes: e.g. life scientists were more favourable towards GMOs (Scott *et al.*, 2018), while those with a nutrition background were more aware of, though not necessarily more positive about GM food (Hekmat and Dawsib, 2018). The importance of educational background was further emphasized in consumer research with youth (Florek-Łuszczki *et al.*, 2016), with studies demonstrating a positive influence of biology-related education (Maes *et al.*, 2017). A meta-analysis by Frewer et al. (2013), however, concluded that the majority of

consumer studies did not even consider socio-demographics as potential determinants of attitude towards GM food.

Aside from identifying determinants of attitude towards GE food, there is a particular lack of research into labelling preferences for NPBTs. While no consumer studies have specifically examined GE food labelling, consumer research on GM food labels is well-established. Past research in the EU context has confirmed the general tendency of consumers to be willing to pay slightly more to avoid GM food (Delwaide *et al.*, 2015; Shew *et al.*, 2018). As such, these findings suggest a preference for GM food labelling, whether in the form of a positive (i.e. GM label) (Sörqvist *et al.*, 2016) or negative (i.e. GM-free) label (Liaukonyte *et al.*, 2013). With regard to interest in such a label, the available evidence indicates that those who are younger, highly educated, male, and more risk-averse are less likely to be supportive (DeLong and Grebitus, 2017; Kolodinsky *et al.*, 2018) – echoing determinants of attitudes towards GM food. In contrast, women and those with lower levels of education were more likely to highlight the importance of GM food labels (DeLong and Grebitus, 2017). Lusk et al. (2018) reported a belief among consumers that plant-breeding

techniques should be regulated in accordance with their impact on the environment rather than the process involved to create the final product. Then, knowledge could also play a role. In fact, while consumer awareness of GM labelling policies is expected to be poor (Tas *et al.*, 2015), little is currently known about consumer knowledge vis-à-vis GM labelling policy in the EU let alone how such knowledge impacts GE labelling preferences.

Within this context, this study aims to explore and identify key determinants of (1) consumer attitudes towards this innovative product as well as (2) consumer preferences with regard to the labelling of GE food. Regarding the former, specific attention is devoted to environmental concern, subjective/objective knowledge, and socio-demographic factors (generation, gender, nationality, and educational background). The latter is analysed with an eye on attitudes towards GE food, environmental concern, knowledge of GM policy, and socio-demographic factors.

Furthermore, we considered two open letters sent to the European Commission, one in favour and one opposed to GE food, to identify attitude towards GE food. In fact, policy

decisions in the EU often lead to the publication of such letters from various sources, e.g. academics, NGOs, and consumer and producer organizations, in order to communicate their requests to policymakers. After the ECJ ruling of July 2018 on regulation of GM and GE, both supportive and unfavourable open letters were addressed to members of the European Commission. These letters respectively requested either revision of the current EU GE regulation or emphasized the importance of maintaining the same regulation policy and safety assessment for GM and GE. Accordingly, by analysing and extracting statements from these letters, we were able to ascertain level of agreement in our sample with various positive and negative arguments, and moreover to combine these responses to develop a unique measure of consumer attitudes towards GE food.

In addition, this study compares attitudes and labelling preferences of Millennials (23-38 years old) and GenZers (Generation Z; 18-22 years old). These segments of the population include young adults generally known to be more educated and more informed about scientific issues compared to older generations (Valente and Chavres, 2018). Furthermore,

by targeting Millennials and GenZers, we are able to provide insight into attitudes of these younger/next-generation consumers, which are expected to further shape the debate on agricultural biotechnology and NPBTs in particular. Indeed, if increasing political and social engagement around issues such as climate change is any indication (vis-à-vis movements such as Fridays for Future), it is necessary to understand and engage with the viewpoints of such individuals, and wrestle with their growing impact on policy discussions, earlier rather than later.

3.2 Materials and Methods

3.2.1 Survey

An online, standardized survey was developed and pre-tested using Qualtrics. The use of electronic sampling procedures and data-collection methods could be associated with a bias towards (more highly) educated, younger people. However, as younger generations are considered as the target population in this study, our selection of method is deemed appropriate. By using a non-probability (convenience) sampling procedure, our survey was distributed to two Dutch-speaking, neighbouring

regions in the EU (East-Flanders, Belgium, and South-Netherlands, Netherland). Nationality is often included as explanatory socio-demographic variable in cross-country studies, but very few studies have specifically considered neighbouring regions (e.g. Shew *et al.*, 2018; Delwaide *et al.*, 2015). Although the EU has a common legal framework for approving GM/GE crops (EC DG SANCO, 2011; Callaway, 2018), GM food perceptions are known to differ between EU regions (Gaskell, et al 2010; USDA, 2012; Hess, et al, 2016). Therefore, nationality was included in our analysis to allow for a regional comparison. In both regions, the targeted sample focused on Millennials, people born between 1981 and 1996, and GenZers, that is people born after 1996 (with a minimum age of 18 years old). In total, 276 consumers were surveyed. After removing incomplete responses (42), the final sample consisted of 234 consumers. The questionnaire consisted of five parts. The first part collected information on socio-demographic characteristics such as nationality, birth year, gender, and educational background. Based on their age (birth year), consumers were assigned to a dummy variable reflecting their generation (1=Millennials; 0=Generation Z). Regarding

education, consumers were asked whether they had obtained a degree in social sciences, i.e. arts and philosophy, law, economics, psychology and educational sciences, political science and sociology (hereafter referred to as "Soft science"); in science, applied sciences such as engineering and bioscience engineering (hereafter referred as "Hard science"); in the field of medicine, including health, veterinary, and pharmaceutical sciences ("Medical science"); or whether they had another educational background ("Other"). The second part consisted of questions related to knowledge about genetic modification. Building upon House *et al.*, 2004, self-rated knowledge on GM, GE, and European GM policy, respectively, were measured on a scale from 1 (low) to 5 (very high). These questions were followed by a series of true/false statements to assess the corresponding level of objective knowledge: consisting of six statements related to genetic modification (Mielby *et al.*, 2013; House *et al.*, 2004) and four on European GM policy. The third part comprised the revised New Ecological Paradigm (NEP) scale, which used a 15-item Likert scale to assess consumer environmental concern (Dunlap *et al.*, 2000). The fourth part measured attitudes towards GE food, with basic objective

information about plant breeding and gene editing provided to ensure a minimal level of understanding. Then, to explore consumer attitudes towards GE food, we employed ten statements that mirrored the content of two open letters sent to members of the European Commission by two organizations falling on different sides of the issue: a biotech research institute (the Flemish Institute of Biotechnology, VIB) (5 statements; pro-GE food viewpoint) (VIB, 2019) and an agroecology organization ("Voedsel Anders") (5 statements; anti-GE food viewpoint) (Voedsel Anders, 2018). Participants were asked to evaluate all statements on a 5-point Likert scale, from 1 (totally disagree) to 5 (totally agree). In the fifth and final part, we then assessed consumer attitudes towards labelling strategies with regard to GM and GE food products by inviting participants to rate, from 1 (totally disagree) to 5 (totally agree), the two following statements: *GE food products must be labelled (GE_LABEL)*, and *GM and GE food products should get the same label (SAME_LABEL)*.

3.2.2 Data analysis

Statistical analyses were performed using Stata 13 and IBM SPSS Statistics 26. Subsequent to factor and reliability analyses, several composite variables were constructed by calculating a mean score of all respective items. Notably, the mean of the individual scores of GM objective knowledge was derived to obtain an objective GM knowledge index (*OBJKNOW)*, ranging from 0 to 1 (House *et al.*, 2004), while an objective knowledge index for EU GM policy (*EUREG_OBJKNOW*), ranging from 0 to 1, was created by calculating the mean of the individual statement scores. An index for NEP (*NEP)* was created as a mean of all 15 statements, whereby scores that highlighted an anthropocentric view (items 2, 4, 6, 8, 10, 12) were reverse-coded with higher scores thus indicating higher environmental concern (Dunlap and Van Liere, 1978; Dunlap *et al.*, 2000). To facilitate a comparative discussion of the different perspectives on GE, as expressed by the two open letters, we moreover opted to generate two indexes as a mean for individual scores for the 5 pro statements and 5 anti-statements, respectively (see also Table 4-5). However, for the purposes of identifying determinants of consumer attitudes towards GE, we generated

a composite factor by considering all ten statements, irrespective of their source material, together. Principal components analysis using varimax rotation on the 10 items revealed that 8 of the items – with the exception of items 3 and 4 – loaded strongly onto a single factor, renamed 'attitude towards GE' (*ATT_GE*).[1] Scree plot and factor loadings are presented in Annex (Figure A1 and Table A1). Internal consistency of the scale was checked using Cronbach's alpha, revealing adequate reliability (α=0.78).

Mann-Whitney and Kruskal-Wallis tests were performed to explore the existence of differences regarding knowledge, environmental concern and labelling policy preferences vis-à-vis generational cohort, nationality and educational background. On the basis of all this, ordinary least squares (OLS) and ordered logit models (OLM) were then carried out to identify the key determinants of attitudes towards GE food (model 1, *ATT_GE*) and GE labelling policy preferences (model 2, *GE_LABEL*; model 3, *SAME_LABEL*), respectively. The OLS

[1] Items 6, 7, 8, 9, 10 were first reverse-coded so that higher scores indicated a more positive attitude toward GE food.

assumptions were tested (i.e. multicollinearity, homoskedasticity of residuals, normality of residuals, linearity). All models were checked for multicollinearity, with results interpreted at the 5% level of significance.

3.3 Results

3.3.1 Descriptive Analysis

The sample consisted of 234 consumers (122 Belgian and 112 Dutch consumers), also split between 124 "Millennials" and 110 "GenZers". Table 1 presents the descriptives for each generation. The age of participants ranged from 18 to 37 years, with a mean of 27 years (SD=3.81) for Millennials and of 20 years (SD=1.42) for Generation Z (Table 1). The minority of the overall sample had a hard-scientific (26.07%) or medical (6.41%) background.

Table 1 Socio-demographic characteristics of the sample, per generation

	Millennials		Generation Z		Total	
	N	%	N	%	N	%
Generation	124	53.00	110	47.00	234	100.00
Gender						
Male	58	46.77	49	44.55	107	45.73
Female	66	53.23	61	55.45	127	54.27
Nationality						
Belgian	49	39.52	73	66.36	122	52.14
Dutch	75	60.46	37	33.64	112	47.86
Education type						
Soft science	41	33.06	18	16.36	59	25.21
Hard science	39	31.45	22	20	61	26.07
Medical science	12	9.68	3	2.73	15	6.41
Other	32	25.81	67	60.91	114	42.31

The overall level of environmental concern for each of the two generational cohorts and the sample as a whole, as derived from the specific statements of the NEP scale, is presented in the Annex (Table A2). On average, consumers reported a medium to high score on the NEP scale (M=3.67, SD=0.44). Mann-Whitney test revealed that the level of environmental concern did vary by educational background ($\chi^2(3) = 13.73$, $p<0.005$). In

specific, participants with soft-scientific background showed higher levels of environmental concern (M=3.83, SD=0.38), while those with a hard-scientific background were significantly less worried about environmental issues (M=3.58, SD=0.49).

3.3.2 Knowledge

Overall, the sample was characterized by mid-level scores of subjective knowledge on GM and GE, but subjective knowledge on GM policy in the EU was significantly lower (Table 2). Lack of knowledge on labelling policy was confirmed by the objective knowledge scores: on average, participants correctly answered 4.9 out of 6 questions on general objective GM knowledge, versus only 1.27 out of 4 questions on GM policy (Table 3). A significant positive correlation between subjective and objective GM knowledge was identified, for Millennials ($\chi^2(24) = 56.17$, $p<.001$) and GenZers ($\chi^2(16) = 41.80$, $p<.001$). A significant positive correlation was also identified between subjective and objective knowledge on EU policy for GenZers ($\chi^2(16) = 51.80$, $p<.001$). The Mann-Whitney tests revealed significant differences in knowledge across generations only for

GE subjective knowledge (p=0.001), with GenZers scoring higher. Significant differences in policy-related knowledge were moreover detected for nationality (p=0.000), with Belgian consumers found to be more knowledgeable than their Dutch counterparts.

Table 2 Subjective and objective knowledge indices, per generation

	Millennials		**Generation Z**		**Total**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Subjective knowledge (1-5)						
GM	2.73	1.13	2.99	1.11	2.85	1.12
GE	2.24	1.21	2.76	1.28	2.48	1.27
EU GM policy	1.83	0.89	2.18	1.04	2.00	0.98
Objective knowledge (0-1)						
Genetic Modification	0.79	0.22	0.84	0.16	0.81	0.19
EU GM policy (0-1)	0.30	0.32	0.34	0.32	0.32	0.32

Note: Objective knowledge indices are composite variables, as calculated based on true or false statements, as presented in Table 3.

Table 3 Objective knowledge statements on Genetic Modification (**Table 3a**) and EU GM policy (**Table 3b**), % correct and incorrect responses, per generation

Table 3a	**Millennials**		**Generation Z**		**Total**	
	Correct (%)	**Incorrect (%)**	**Correct (%)**	**Incorrect (%)**	**Correct (%)**	**Incorrect (%)**
Genetic Modification						
1. Ordinary fruit does not contain genes, but genetically modified does (F).	91.13	8.87	91.82	8.18	91.45	8.55
2. By eating genetically modified fruit, a person's genes could also be changed (F).	77.42	22.58	89.09	10.91	82.91	17.09
3. Genetically modified animals are always larger than ordinary animals (F).	8.06	91.94	90.91	9.09	91.45	8.55
4. It is impossible to transfer genes to plants (F).	51.61	48.39	56.36	43.64	52.14	47.86
5. More than half of human DNA is similar to that of mouse (T).	74.19	25.81	78.18	21.82	76.07	23.93
6. All plants and animals have DNA (T).	92.74	7.26	95.45	4.55	94.02	5.98

Note: (T) and (F) indicate a true or false statement, respectively.

Table 3b	Millennials		Generation Z		Total	
	Correct (%)	Incorrect (%)	Correct (%)	Incorrect (%)	Correct (%)	Incorrect (%)
Genetic Modification						
1. More than half of food products available in European supermarkets contain GMOs (F).	68.55	31.45	71.82	28.18	70.09	29.91
2. According to EU regulations, food products containing GMOs must be labelled (T).	44.35	55.65	44.55	55.45	44.44	55.56
3. The EU imports substantial amounts of GMO feed, but no GMO food products (T).	29.03	70.97	34.55	65.45	31.62	68.38
4. GMOs are being cultivated in the majority of EU member states (F).	84.68	15.32	72.73	27.27	79.06	20.94

Note: (T) and (F) indicate a true or false statement, respectively.

Turning to educational background, Kruskal-Wallis tests revealed significant differences in subjective knowledge on GM ($\chi^2(3) = 68.19$, $p<.001$), GE ($\chi^2(3) = 62.45$, $p<.001$), and EU GM policy ($\chi^2(3) = 37.12$, $p<.001$). Participants with a hard science background displaying the largest degree of subjective knowledge on GM, GE, and GM EU policy. Significant differences were also found with respect to objective knowledge, both for GM (χ^2 (3) =22.53, $p<.001$) and GM EU policy (χ^2 (3) =15,70 $p<.01$). Those with a hard-scientific background also scored the highest on objective GM knowledge (M=5.41, SD=0.86), whereas those with a medical background were on average more informed about EU GM policy (M=1.8, SD=1.26).

3.3.3 Attitude towards GE food, and GE labelling policy preferences

Consumers generally had a positive attitude towards GE, regardless of generation (Table 4). Overall, the mean average for pro-statements (M=3.72 SD=0.60) was significantly higher than that for the anti-statements (M=3.07 SD=0.72), $t(466) = 10.58$, $p<0.005$ (Table 5). The correlation was most pronounced for

consumers with a background in the hard sciences (r = -0.63, $p \leq 0.001$), though ultimately not significant for those with a medical background (r= -0.03, p = 0.923). Those with an overall negative attitude towards GE food (M < 3), meanwhile, tended to rate the anti-statements more highly than they were necessarily against (i.e. assigning a lower rating to) the pro-statements, $t(32) = 6.63$, $p<0.005$. Conversely, those with a more broadly positive attitude were significantly more likely to rate the pro-statements more highly than they were to rate the anti-statements lower, $t(432) = 13.53$, $p<0.005$).

With respect to labelling policy, consumers were generally inclined to demand a label for the use of both GM (M=3.79, SD=1.09) and GE for food products (M=3.71, SD=1.12). When comparing both labels however, consumers were less supportive that a similar labelling policy be applied to GM and GE products (M=2.44, SD=1.02), $t(466)=13.87$, $p<0.005$ (Table 6).

Table 4 Overall attitude towards GE food, and Pro-GE attitudinal statements, per generation

	Millennials		Generation Z		Total	
	Mean	SD	Mean	SD	Mean	SD
Attitude towards GE food (final 8-item measure)	3.23	0.78	3.4	0.71	3.31	0.75
Evaluation of pro-GE statements (composite)	3.57	0.57	3.89	0.58	3.72	0.59
1. Technological innovation (i.e. gene editing) is necessary to secure food production in the future.	3.67	1.03	3.9	0.92	3.78	0.99
2. Gene editing can be considered as a modern version of traditional plant breeding.	3.56	1.01	3.93	1.01	3.73	1.03
3. There is a clear difference between GM and GE; treating them as the same within EU GM regulations is wrong. [+]	3.45	1.05	3.7	1	3.57	1.04
4. EU GM regulations are outdated. Science progresses rapidly, meaning that regulations should be updated regularly. [+]	4.14	0.75	4.44	0.66	4.28	0.72
5. Due to strict GM regulations companies prefer not to locate themselves within the EU. This will cause reduced work opportunities and innovation in the agricultural sector.	3.02	1.05	3.47	0.94	3.23	1.02

Note: Items are measured on a 5-point Likert Scale, from 1 (strongly disagree) to 5 (strongly agree).
'+' item is removed due to low factor loading.

Table 5 Anti-GE attitudinal statements, per generation

	Millennials		Generation Z		Total	
	Mean	SD	Mean	SD	Mean	SD
Evaluation of anti-GE statements (composite)	3.12	0.72	3.01	0.72	3.07	0.72
1. GM and GE techniques have high potential risks associated with them. Science cannot guarantee that they are safe and therefore should not be allowed. *	2.48	1.11	2.38	0.96	2.44	1.04
2. Gene-editing techniques alter the genetic material of an organism in an unnatural manner. *	3.36	1.13	3.21	1.23	3.29	1.18
3. The focus on potential benefits of GMOs is a distraction from the real solutions towards sustainable food production. *	2.81	1.2	2.74	1.16	2.78	1.18
4. When GMOs are imported from other countries without traceability or labeling, consumers will lose their freedom of choice. *	3.8	0.91	3.64	0.94	3.73	0.92
5. There are thousands of traditional and local plant varieties in Europe that are better adjusted to our climate than GMOs. Importing GMOs can be a threat to the existence of these varieties. *	3.17	1.03	3.07	1.05	3.12	1.03

Note: Items are measured on a 5-point Likert Scale, from 1 (strongly disagree) to 5 (strongly agree).
'*' item is reverse-coded.

Table 6 Labelling preferences, per generation

	Millennials		**Generation Z**		**Total**	
	Mean	SD	Mean	SD	Mean	SD
GM food products must be labeled (*GM_LABEL*).	3.80	1.10	3.80	1.08	3.79	1.09
GE food products must be labeled (*GE_LABEL*).	3.73	1.09	3.70	1.15	3.71	1.12
GM and GE food products should get the same label (*SAME_LABEL*).	2.50	1.05	2.37	0.98	2.44	1.02

Note: Items are measured on a 5-point Likert Scale, from 1 (strongly disagree) to 5 (strongly agree).

3.3.4 Determinants of consumer attitudes and labelling preferences regarding GE food

Based on results of the OLS and OLMs, determinants of attitude towards GE and GE labelling preferences were respectively examined, with the findings reported in Table 7 (OLS) and Table 8 (OLMs).

For the OLS (model 1), the variance inflation factor (VIF) was measured to check for the absence of multicollinearity (mean VIF=1.75). The homoscedasticity of residuals was confirmed by the Breusch-Pagan test (p=0.235). The model did not suffer from omitted-variable bias (p=0.999). The Shapiro-Wilk test highlighted that the residuals were not normally distributed (p=0.000). However, because of the central limit theorem, we concluded that the OLS estimators satisfy asymptotic normality (Wooldridge, 2012). OLS multiple regression was thus considered an appropriate model. Results of the OLS for attitudes towards GE food (*ATT_GE*) indicate that objective GM knowledge and subjective GE knowledge both has a positive influence, while the influence of environmental concern was negative (Table 7). No significant results were found for socio-demographic characteristics

(generation, gender, nationality, and educational background) and subjective GM knowledge.

Table 7 Determinants of Attitude towards GE food (OLS estimation).

	(1) ATT_GE	
	Coef.	Std. Err
GEN (1=Millennials, 0=Generation Z)	-0.23	0.13
GENDER (1=female, 0=male)	-0.10	0.12
NATIONALITY (1=NL, 0=Belgium)	0.12	0.12
EDU_BACK (ref=Hard science)		
Soft science	-0.17	0.19
Medical science	0.26	0.19
Other	-0.31	0.16
NEP	-0.59***	0.14
GM_SUBKNOW	0.03	0.17
GE_SUBKNOW	0.35*	0.17
OBJKNOW	1.35***	0.32

Note: ***p<0.01; **p<0.05; * p<0.1. NL, The Netherlands
R^2= 0.30

Model 2 (*GE_LABEL*) explored preferences for labelling policy of GE food (Table 8). Outcomes showed that, relative to a hard-scientific background, having a soft-scientific or other educational background had a positive influence on the demand for GE labelling. No difference was established between those with medical and hard-scientific backgrounds.

A negative, significant effect was found for attitude towards GE. A positive, significant effect was also found for the level of objective knowledge regarding EU policy. The respective effects of generation, nationality, subjective knowledge regarding EU GM policy, and environmental concern were all insignificant however.

Model 3 (*SAME_LABEL*) examined the influence of the consumer preference for a similar labelling policy for GM and GE food products, that is, if consumers preferences are in line with the current EU GM policy. Being Dutch increased the likelihood of preferring a single labelling policy for GM and GE food, that is, in accordance with the current GM/GE regulation in the EU, while having policy-oriented knowledge negatively decreased the preference for a similar label of GM and GE food products. None of the other factors turned out to be significant.

Table 8 Determinants of labeling preferences for GE food (OLM estimation).

	(1) GE_LABEL		(2) SAME_LABEL	
	Coef.	Std. Err.	Coef.	Std. Err.
GEN (1=Millennials, 0=Generation Z)	0.03	0.29	-0.05	0.27
GENDER (1=Female, 0=male)	0.10	0.27	-0.18	0.26
NATIONALITY (1=NL, 0=Belgium)	-0.319	0.28	0.68**	0.27
EDU_BACK (ref=Hard science)				
Soft science	0.99**	0.38	-0.56	0.36
Medical science	0.94	0.59	0.60	0.56
Other	0.94**	0.35	-0.41	0.34
ATT_GE	-1.08***	0.16	-0.14	0.14
NEP	-0.01	0.32	-0.31	0.31
EUPOL_SUBKNOW	-0.014	0.32	0.34	0.31
EUPOL_OBJKNOW	1.01*	0.45	-0.90*	0.44

Note: ***p<0.01; **p<0.05; * p<0.1. NL, The Netherlands
The dependent variable reflects preference of (1) a GE label (GE_LABEL model) or (2) a similar labeling policy as for GM food (SAME_LABEL).
GE_LABEL (1) LR chi2 (10)=72.90, prob>chi2=0.000.
SAME_LABEL (2) LR chi2 (10)=19.62, prob>chi2=0.0330.

3.4 Discussion

This study addresses the need for research on public acceptance of GE food, especially in the EU, in order to provide a better understanding of its potential implementation in the future. The analysis was targeted towards two young generations, i.e. consumers who are expected to increasingly participate in the

public debate and contribute to dietary patterns and food policies.

The first aim of the study was to examine consumer attitudes towards GE food. By comparing statements from two open letters sent to the European Commission, one in favour and one opposed to GE food, we find that consumers are generally in favour of GE food, with support for the pro-GE letter being more pronounced than the rejection of the anti-GE letter. Furthermore, consumers with a hard-scientific or medical background tended to know more about GM and GE techniques, and were less concerned about GE food overall., This may lend support to the importance of prior knowledge, beliefs and familiarity in the domain of agricultural biotechnologies (De Steur *et al.,* 2014; McFadden and Lusk, 2015; Wunderlich and Gatto, 2015). Overall, the young adults in our sample proved to be well-informed about the scientific features of the technology, in line with their own perceived knowledge. Despite this, their specific knowledge of GM policy in the EU was low. This is somewhat surprising, perhaps suggesting the lack of appropriate communication campaigns, particularly in terms of the prevailing EU policy approach.

With respect to the determinants of individual attitude towards GE (Model 1, *ATT_GE*), our results confirmed that knowledgeable consumers were more willing to accept GE food. As far as we know, this study is the first to consider the role of consumer environmental concerns on attitude towards GE food. Because of the environmental benefits that this technology could generate (Adenle *et al.*, 2020), it could be reasonably supposed that consumers that are concerned about the environment would be more likely to accept GE food. Our results do not however support this presumption, as consumers with more negative perceptions of environmental risk were less willing to accept GE food. This could point to the prevailing influence of misleading information on new plant-breeding technologies (Huffmann and McCluskey, 2017). Then, with respect to socio-demographic factors, no significant effects on attitudes towards GE were reported. Despite our interest in the role of generational and national differences, their insignificance may be explained by the fact that both generations are still considered to be younger generations with similar characteristics – and indeed, that our choice to limit representation of Generation Z to those 18 or older means that

we sample a sub-set of this group, and exactly that segment that is closest age to Millennials. A similar explanation might be provided for the lack of difference between the two neighbouring EU regions. Furthermore, contrary to the findings of previous consumer studies (Muringai *et al.*, 2020; Wuepper *et al.*, 2018), we could not identify any gender differences. In this regard, our targeted sample of young consumers may offer an explanation, if for instance the importance of gender is less pronounced than for other generations.

The second aim of this study was to identify consumer preferences for GE labelling policy. While several countries regulate GM differently from GE, the ECJ ruled that, according to current EU legislation (EC Directive 2001/18), GM and GE technologies should be treated equally, and hence the same mandatory labelling policy applies to above. Overall, while consumers expressed interest in labels on GE food, the majority are less supportive of a similar labelling policy being used for GM and GE food products. Results suggest that these breeding techniques are not seen to be the same in consumer eyes (i.e. Muringai et al., 2020; Shew et al., 2018), potentially lending support to a review of the current EU GM labelling approach,

perhaps in a direction similar to the revised policies taking shape in the US, Argentina, Australia, and Japan. These aligns with previous research demonstrating different preferences for different types of GM food labels (Zhan *et al.*, 2020). In view of the current debate surrounding EU policy on GE food, this study also provides insights on consumer attitudes towards GE labelling as such, by assessing the preference for similar or different labelling policies to be used for GE and GM food.

Potential determinants that were considered for GE labelling preferences (model 2, *GE_LABEL)* included socio-demographic characteristics, attitudes towards GE, and knowledge of EU GM policy. Firstly, preferences for labelling of GE food were positively influenced by having an educational background in the soft sciences or something besides the hard and medical sciences. In other words, those with a soft (social) science or another, non-specific educational background were more likely to prefer a GE food label. Secondly, having a more positive attitude towards GE negatively affects the preference for a GE label, while objective knowledge regarding GM policy was found to have a positive effect. Both results are in line with literature on labelling preferences for GM food, where it was

found that those negatively disposed to GM food were more willing to pay for a GM(free) label, and that more educated consumers were less likely to demand such label (DeLong and Grebitus, 2017; Kolodinsky *et al.*, 2018).

Regarding the support for GE-specific labelling approaches vis-à-vis GM food (model 3, *SAME_LABEL*), two factors are found to be significant: objective knowledge and nationality. First, objective knowledge regarding EU GM policy negatively affects the preference for a similar labelling policy for GM and GE food. As this turned out to be the only determinant of GE labelling preferences that remained significant vis-à-vis the preferences for unique GM and GE labels, this finding lends further support to the pivotal importance of objective knowledge, unlike subjective knowledge, as suggested by Fernbach et al. (2019). It is worth noting, however, that attitudes towards GE and preferences for GE labelling are not ultimately correlated, as a more positive attitude towards GE does not imply a rejection of the current EU GM policy. Nonetheless, our results indicate that consumers would generally prefer a different labelling policy for GE. If this results from an awareness that the two are (incorrectly) treated similarly, this

may suggest that information provision of this fact could promote broader support for a different policy approach. If, however, such awareness emerges more as a result of a self-selection process whereby those more interested in this topic tend to have higher levels of knowledge, due to having sought it out, this pattern might not necessarily generalize to the rest of the public. Nevertheless, when knowledge is low, it would be helpful for consumers to gain more awareness, in order to become more empowered to make decisions in food-related context (Bartkowski and Baum 2019). Secondly, we find that being Dutch positively affected the preference for the same labelling policy to for GM and GE food products. This suggests that Dutch young consumers support the current GM EU policy, despite being less aware about EU GM policy than their Belgian counterparts. Even if the study was conducted in two Dutch-speaking regions, campaigners and pressure groups within the two countries might promote different types of arguments and associations, which has the potential to differentially impact consumer preferences. Thirdly, we determine that the level of environmental concern does not influence labelling preferences in any way, which is somewhat

surprising. As suggested by Lusk et al. (2018), it was expected that consumers would prefer the use of a different label for GE, due to its potential for a lower environmental impact. An insignificant result here might therefore suggest that consumers do not have enough information on the potential environmental benefits of NPBTs. In fact, as suggested by other previous studies (Delwaide *et al.*, 2015; Gatica-Arias *et al.*, 2019), providing consumers with information on the environmental benefits of new plant-breeding techniques has the potential to increase acceptance. Future research could thus analyse the impact of information about the environmental impact of GE food production vis-a-vis consumer and public acceptance of this technology.

Several limitations need to be mentioned and may be addressed in future research. Despite the fact that our sample targeted only two young generations of consumers in two EU regions, its size is limited to 234 consumers. Therefore, it is important to interpret the results with caution, and consider the findings as indicative for this target group, rather than generalizable to larger populations or other consumers (cross-regional, cross-generational). Furthermore, we consider only

those young consumers born between 1981 and 2001, i.e. owing to our decision to set a minimum age of 18 to avoid legal issues around parental consent. As a result, the fact that we fail to find any differences between the two generations could be an artefact of our only examining a subset of those individuals from Generation Z, and moreover those closest in age to their Millennial counterparts. Given that age has been shown to be an important indicator of GM acceptance (Kamrath *et al.*, 2019), future research could also consider a comparison between younger (like Millennials and GenZers) and older generations (for example, Boomers). Moreover, an in-depth investigation on the role of knowledge on GE techniques, like CRISPR/Cas9, is warranted given its pivotal importance in our study. To explore the potential for deepening knowledge, future research could examine what type of information should be emphasized by GE communication as well as the proper mode and means for doing so.

Experimental studies on the role of information for consumer acceptance (Frewer *et al.*, 2015) and willingness-to-pay for GMOs (De Steur et al; 2017) could therefore be applied to NPBTs and GE food in particular, with a specific focus on

environment-related (Delwaide *et al.,* 2015) and policy-related information. Finally, more research is needed on the particular determinants of GE labelling policy preferences in the EU. Ongoing debates and discussions of the need for a revised European (labelling) policy scenario demands a better understanding of not only whether or not individual citizens are in favour of such a change, but also how the use of a more transparent and robust approach to communicate the benefits (and risks) of NPBTs might shape public opinion on GE food and help to cultivate a more sustainable food system.

3.5 Conclusion

This study examined attitude towards GE food as well as preferences for GE food labelling among young consumers in two EU neighbouring regions. As one of the first consumer studies on GE food (labelling), this study offers a better understanding of the determinants of attitudes and labelling preferences of this pivotal case of NPBTs, while providing particular insights on the emerging views and relevance of young consumers and their knowledge and evaluation of the current European policy framework.

Findings suggest that Millennials and GenZers generally have a positive attitude towards GE food. Thereby, attitude was positively influenced by objective knowledge and negatively influenced by environmental concern. When it comes to labelling, having a negative attitude towards GE food, as well as having a soft science or non-specific educational background increased consumers preference for a GE food label. Thereby, a policy implication of our study is that young consumers in our sample appear to be more in favour of a different labelling policy for GM and GE food. Key determinants for preferring a labelling scheme that differs from the current EU labelling policy, were objective EU policy-related GM food knowledge (low) and nationality (Dutch).

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Appendix

Figure A1 Scree Plot of ATT_GE (Exploratory factor analysis)

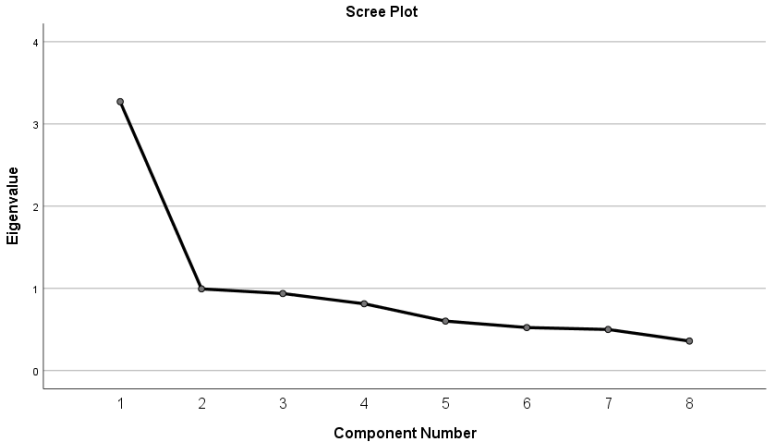

Table A1 Factor Loadings of ATT_GE (Exploratory factor analysis)

	ATT_GE
Item 1	0.770
Item 2	0.633
Item 5	0.437
Item 6	0.820
Item 7	0.528
Item 8	0.703
Item 9	0.413
Item 10	0.687

Table A2 NEP statements (Environmental concern). Mean and standard deviation, per generation

	Millennials		Generation Z		Total	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
We are approaching the limit of the number of people the earth can support.	3.98	1.03	4.10	1.01	4.04	1.02
Humans have the right to modify the natural environment to suit their needs.*	2.91	0.96	2.88	0.95	2.90	0.96
When humans interfere with nature it often produces disastrous consequences.	3.07	1.01	3.04	1.00	3.05	1.01
Human ingenuity will ensure that we do NOT make the earth unlivable.*	3.09	1.06	3.32	0.98	3.20	1.03
Humans are severely abusing the environment.	4.35	0.75	4.12	0.84	4.24	0.80
The earth has plenty of natural resources if we just learn how to develop them.*	3.53	1.11	3.61	1.00	3.57	1.06
Plants and animals have as much right as humans to exist.	4.09	1.08	4.03	1.03	4.06	1.06
The balance of nature is strong enough to cope with the impacts of modern industrial nations.*	1.89	0.83	1.95	0.84	1.92	0.83
Despite our special abilities humans are still subject to the laws of nature.	4.42	0.61	4.19	0.78	4.31	0.71
The so-called "ecological crisis" facing humankind has been greatly exaggerated.*	1.89	1.05	2.04	1.01	1.96	1.03
The earth is like a spaceship with very limited room and resources.	3.81	1.06	3.89	0.92	3.85	1.00
Humans were meant to rule over the rest of nature.*	1.89	0.96	2.04	0.98	1.96	0.97
The balance of nature is very delicate and easily upset.	3.85	0.94	3.73	0.9	3.8	0.92
Humans will eventually learn enough about how nature works to be able to control it.*	2.62	1.19	2.95	1.18	2.78	1.19

If things continue on their present course, we will soon experience a major ecological catastrophe.	4.11	0.87	4.00	0.95	4.05	0.91

Items are measured on a 5-point Likert Scale, from 1 (=strongly disagree) to 5 (=strongly agree).

* indicates that items were reverse-coded.

SD, standard deviation; NEP, New Ecological Paradigm

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Chapter 4

CONCLUDING REMARKS

This thesis includes two research papers with the common objective of analyzing attitude toward GE food. Specifically, the first study was conducted on Italian farmers (rice growers), while the second one was on Flemish and Dutch consumers. The rationale behind these studies is the need of gaining novel insights into stakeholders' attitude in the European context. Both studies were conducted at microlevel and analysis was done on primary data. Data collection was done through the implementation of questions based on Likert scales; thus, the final analysis was mostly conducted using ordered logit to identify significant variables. Results could be helpful to understand the public opinion regarding GE food, in view of a possible revision of the current EU GM policy.

The first research was conducted on Italian farmers to investigate their attitude toward a specific application of gene editing, that is CRISPR/Cas9 rice resistant to blast.

Results suggested that rice growers had an overall positive attitude toward CRISPR rice, and farming prior experience, knowledge and perceived risk played a role in defining their attitude. Surprisingly, even if the locus of control was significant, the present results differed from those of the

existing literature: in fact, findings suggested that having an external locus of control improved attitude toward CRISPR rice. Nevertheless, these results should be seen in accordance with the Italian context, which does not allow the cultivation of modified food.

The second research project analyzed consumer attitude toward GE food and their labelling preferences for these products. The target of the sample included young consumers, who are expected to play a key role in the consumption pattern and policy decisions in the next future. As for farmers, results revealed that consumers generally had a positive attitude toward GE food, and they would prefer a labeling policy for GE food which differs from that of GM food.

In the study conducted on consumers, the vital importance of knowledge has emerged. On such grounds, future research might focus on the role of information provision. Moreover, environmental concern was negatively related to attitude toward GE food. This is surprising, considering the benefits that the cultivation of GE food could bring to the environment. This result was found also in the study conducted on farmers, even if it was insignificant. Summing up, both producers and

consumers of the present samples were open to genetic engineering in food production: on one side, GE products might represent a good with private utility, since farmers might reduce production costs when implying them in their activity; on the other, GE food might be viewed as good with public utility, since its production might be more sustainable for the environment, and this would generate positive externality for the society. Nevertheless, the positive impact that GE food could generate on the environment is only slightly known by the population. In view of this, future research should provide information also on the benefits that the introduction of gene technology in the agriculture could bring to the environment and see how this information could influence attitude and perceptions regarding this technology. Moreover, policies that shown the benefits that these technologies might play on the environment might be planned.

Results of the doctoral work can help researchers to further develop studies on this topic and they might offer valuable insights in view of a possible future revision of the current European policy on genetic engineering on food and feed, as done in other countries like the US, Argentina and Japan..

However, because of the novelty of this topic, more research is needed to confirm the present results and better investigate attitude and acceptance of GE food products. Finally, developing studies on the willingness-to-pay (WTP) for GE feed (among farmers) and GE food (among consumers) might be useful to understand the GE products' market potential.

In conclusion, the results provided important understanding on how public acceptance of GE food and feed could be addressed.

The analyses were not without limitations. Specific limitations for each study were discussed in each respective chapter. The present limitations were common among the two studies. Firstly, both studies were conducted at microlevel (Qaim, 2009). Despite research at macrolevel might offer results that can be easily generalized, this was out of the scope of the present doctoral dissertation. Secondly, data for both studies were collected though convenience sampling, that is a non-random procedure. Convenience sampling was chosen because of time and cost constraints. However, this procedure might suffer from sample bias, thus results should be carefully taken as

representative for the entire population (Etikan et al., 2016). Then, the questionnaires for both studies included several validated Likert scales. Despite this method for data collection is widely used, it is not without critics. Mixed-rated scales might affect the responses given (Hartley & Betts, 2010), and reverse-thinking in presence of reversed-Likert scales might be hard for some respondents, thus their responses might suffer from this (Hartley, 2013).

Overall, the main results suggested that the current EU GM policy should be rethought by policymakers: a revised approach for regulating GE food differently from GM food should be introduced, as well as a revised GM/GE labelling policy in order to meet the request of the population and to address the need of a more sustainable food system.

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Additional Work

CAN NUDGING IMPROVE THE ENVIRONMENTAL IMPACT OF FOOD SUPPLY CHAIN? A SYSTEMATIC REVIEW

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General Overview

In the main context of examining the development of a sustainable food system, a literature review was done. Specifically, the review was performed to see whether nudging techniques can improve the environmental impact of the food supply chain.

Nudges are tools designed by the so-called choice architects that gently push people toward a desired behavior. In this study, the concept of green nudge was considered. Green nudges are policies that are strictly used at protecting the environment, and they are gaining worldwide attention in the environmental policy debate. Specifically, the present work was conducted in view of reviewing how these behavioral interventions affected farmers and consumers behavior when producing and consuming food, respectively.

This paper diverges from the works included in chapter 2 and chapter 3 of the present doctoral dissertation. In fact, the present work is 1) a systematic review 2) focused on green nudges, that is tools from behavioral economics and psychology. Nevertheless, it was conducted in the context of policies developed to address the need of a sustainable food system. Moreover, it examined both farmers and consumers behavior, who are the main subjects of chapter 2 and chapter 3, respectively.

ABSTRACT

Background: According to the prediction of the Food and Agriculture Organization, food supply must increase by almost 70 percent by 2050, with tremendous consequences in terms of land depletion, natural resource use, and greenhouse gas emissions. The current **agri-food system** is incapable to cope with this raising demand meanwhile preserving the environment. There is urgent need to reorient the food system onto a more sustainable trajectory: producers should pursue more conscious and environmentally friendly practices and consumers should account for **sustainability issues** while making their daily food consumption decisions.

Scope and approach: The goal of this **systematic review** is to gather existing evidence on **green nudging** interventions geared at leveraging more environmentally sustainable behaviours among the agents of the food chain, from the producers to the final consumers. An extensive literature search was conducted on Web of Science, Scopus, EconLit, and CAB Abstracts, restricting the selection to the last ten years, and using "nudg*" or "choice architecture" as primary research

strings. Finally, 25 studies were included in the review.

Key finding and conclusions: Almost all studies on farmers as well as on consumers included in this review provide evidence that green nudging can be effective in leveraging more sustainable practices. Overall, we propose that green nudges should not be meant to replace stricter **environmental** and food **policies**, but rather they should be regarded as potential complements to be implemented with the aim of gradually moving society in a direction that might benefit all.

1. Introduction

Feeding the growing world population with less environmental impact is one of the main challenges of the 21st century. According to the Food and Agriculture Organization (FAO) the world's population will increase by 34 percent in 2050 (FAO, 2011), when people will mostly live in urban areas and become wealthier. This will imply a considerable increase of food demand such that, according to FAO predictions, by then food supply must increase by almost 70 percent (FAO, 2009) with tremendous consequences in terms of land depletion, natural resource use, and greenhouse gas (GHG) emissions (Tubiello et al., 2014). Indeed, while the population needs increase, available resources are finite and insufficient to cope with the raising demand. This emerging demand-supply imbalance highlights the overall inadequacy of the current agri-food system, still based on a linear economic concept that is by nature wasteful and polluting (Ellen MacArthur Foundation, 2018). There is need to reorient the food system onto a more sustainable trajectory, with all agents involved to reduce the environmental impact of both the production and consumption of food. Producers should pursue more conscious and

environmentally friendly practices, while consumers could make a substantial contribution by accounting for sustainability issues when making their daily food consumption decisions. With regard to sustainability issues, governments started to take action over the last decade by implementing various food and environmental policies targeting the actors of the food chain at different levels, from stakeholders to consumers. Such policies are be based on the adoption of different policy instruments, namely "*tools used by governments to pursue a desired outcome*" (Cairney, 2015). According to past studies (Cairney, 2015; Galle, 2014; Helmer & Hespanhol, 1997) such instruments can be subdivided into three main categories, that is, command-and-control, economic instruments, and information and education tools. The former (i.e., command-and-control tools) include for instance, permits to pollute (Cox, 2016; Holland & Moore, 2015). Economic instruments comprise taxes, subsidies (like agro-environmental subsidies given to farmers), or incentives; whereas information and education tools include interventions based on information provision at various levels, such as labelling and public awareness campaigns. Policy instruments can also be based on insights from behavioral

economics and psychology (Blumenthal-Barby and Burroughs (2012)). These tools include the so called 'nudges', that is small signals implemented by choice architects aimed a gently push individuals towards a desired behaviour.

This latter instrument represents the focus of the present review. As defined by Thaler and Sunstein, a nudge is "*any aspect of the choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid. Nudges are not mandates. Putting the fruit at eye level counts as a nudge. Banning junk food does not*" (Thaler & Sunstein, 2008). The peculiar characteristic of nudging tools is that they aim at changing people's behaviour acting on their cognitive limitations, instead of enhancing their ability to make rational decisions. This is in contrast with the traditional policy approach that uses instruments based on the underlying assumption that individuals behave rationally (Schubert, 2017;

Thaler & Sunstein, 2008). Nudging is based on the recognition that, most of the times, individuals fail to be rational in the way they think and incur in systematic cognitive biases. Such biases

arise because individuals tend to refer to rules of thumb (also called heuristics) when making judgements, instead of rationally evaluating events and contexts. These rules of thumb are effective and useful in simplifying the decision-making processes, but as a result they lead to systematic cognitive biases that flaw behaviors in quite predictable ways (Tversky & Kahneman, 1974; Thaler & Sunstein, 2008). In such context, by acting on individuals' bounded rationality, nudging-based policies can be surprisingly successful in changing human behaviours through simple and even apparently insignificant changes to the choice architecture (Thaler & Sunstein, 2008). Nudging-based interventions, which are gaining increasing attention in the international policy debate, have been widely applied in the food context over the past years, especially to promote more healthful food consumption patterns (e.g., to lead people consuming more fruit and vegetables -Benson et al., 2018; Betty, 2013; Carroll, Samek, & Zepeda, 2018; Hollands et al., 2018; Stämpfli, Stöckli, & Brunner, 2017; Thaler & Sunstein, 2008; Wilson, Buckley, Buckley, & Bogomolova, 2016). However, evidence about the adoption of nudging tools in

promoting environmentally sustainable practices along the food chain are still relatively sparse.

The goal of this systematic review is to gather existing evidence on nudging interventions geared at leveraging more environmentally sustainable behaviours among the agents of the food chain, from the producers to the final consumers. In detail, we focus on the so called 'green nudges', namely those nudges that aim at encouraging people to voluntarily contribute to environmental protection (Schubert, 2017), which are gaining worldwide increasing attention in the environmental policy debate. The results of the present review will contribute to this field of research by providing an overview of the most effective nudging interventions, thus providing insights that could be relevant for future research and nudging applications, as well as for future policy formulation.

1.1. Nudging tools

Nudging methodologies have been developed since 1970s but the term nudge, or libertarian paternalism, was introduced in 2008 by the economist Richard Thaler and the law Professor

Cass Sunstein in their well-known book *'Nudge: Improving decisions about health, wealth and happiness'* (Thaler & Sunstein, 2008). Nudging-based interventions are aimed at changing people's behaviour by influencing their subconscious or habitual approach to choices, or by modifying the environment in which their decisions usually occur (Wilson et al., 2016). In essence, nudges are aimed at driving people's behaviours by making use of their cognitive limitations, instead of enhancing their ability to make informed, rational and fully conscious decisions (Schubert, 2017). Nudging avoids any imposition or coercive measure and people are gently pushed in a specified direction exclusively by altering the surrounding choice architecture. The choice architect is responsible for creating the nudge environment by recognizing how the options and contexts can interfere with individual decision-making processes. Therefore, nudges stand in contrast to coercive policy tools geared at changing behaviours through mandates or bans. Blumenthal-Barby and Burroughs (2012) identified in their review six principles that can be used to nudge people, namely incentives, defaults, salience and affect, norms and messenger, priming, and commitments and ego (Blumenthal-

Barby & Burroughs, 2012). The former are typically used to either reinforce a positive choice, or to punish a negative one (Blumenthal-Barby & Burroughs, 2012). As underlined by the authors, the use of incentives may be controversial and should be carefully evaluated. Indeed, if the incentives are too high they may work as a coercive measure, that is, as a "shove" instead of a nudge. For this reason, small economic incentives can be categorized as nudging tools, while more sizeable incentives should be regarded as economic policy instruments. The second nudging principle analysed by the authors is based on the evidence that individuals tend to choose preset options (i.e., defaults) to simplify their decision-making process. As such, if defaults are intentionally implemented to drive positive behaviours, people would easily go in that direction. A third way in which people can be nudged is by making use of salience and affect. This type of nudgnig is based on the principle that individuals are commonly influenced by novel, personally relevant, and vivid examples, and that the emotional associations stimulated by these items can be effctive in driving decisions and behaviours in a specifed dierction. Norms and messenger are, instead, used to nudge individuals based on the

principle that they are strongly influenced by the society and by others' behaviours, as well as by the information sources. One of the most popular policy intervention developed using this nudging tool is probably represented by the 'Do not mess with Texas' campaign implemented in the American state to reduce littering along highway roads. Thanks to this intervention, roadside litter decreased by 72 percent over six years (Thaler & Sunstein, 2008).

Priming nudges are based on the principle that people's actions are influenced by subconscious cues that can be used by choice architects as primers to leverage specific behaviours (Blumenthal-Barby & Burroughs, 2012). For instance, to increase the visibility of vegetarian items in restaurants' menu increases the probability that consumers choose these options instead of meat plates (Bacon & Krpan, 2018).

Finally, nudges can make use of commitments and ego principles. These latter are based on the evidence that individuals try to be consistent with their public committments in the way they behave and act in a manner that make they feel better about their selves. These tools are particularly applied with the aim of promoting health-related positive outcomes.

Quite popular examples are represented by websites allowing users to commit themselves to achieving a certain goals, such as losing weight or quitting smoking (Blumenthal-Barby & Burroughs, 2012).

The main advantages of nudging-based interventions are the ease of implementation, the suitability to very diverse situations and contexts, and the limited economic resources needed for their application. For these reasons, nudging tools can be a promising way to formulate and implement effective environmental policies aimed at promoting sustainable behaviors among the agents of the food chain.

2. Approach

2.1. Selection of relevant studies

This review considers only studies that clearly want to nudge proenvironmental behaviours in the agri-food chain. The first search process took place in November 2018 and served as an exploratory phase in order to understand which databases and search terms were more pertinent to the review process. The final research process, took place in May 2019 and consisted in an extensive literature review conducted on four databases,

namely, Web of Science (WOS), Scopus, EconLit, and CAB Abstracts (CAB). As a first step, we used the words "nudg*" OR "choice architecture" as research strings in each database. The literature search was then restricted to English-language research articles and to the past ten years (i.e., 2008–2018), namely considering articles published after Thaler and Sunstein publication (Thaler & Sunstein, 2008). As a second step, the search results were filtered according to the databases' categories that could represent our fields of interest (Table 1). This screening method was not conducted in EconLit, because the specific structure of the database does not allow to select specific categories. In this latter case all records were checked. Moreover, to be included in the review the articles *i)* must report empirical studies on nudging-based interventions involving actors of the food chain at different levels, namely farmers, food processors and/or distributors, and consumers, and *ii)* must be specifically aimed at nudging environmentally sustainable behaviours.

The evaluation process of all titles, abstracts and full-texts was made independently by two researchers, such that the selection procedure was duplicated by two independent coders and their

coding outcomes were compared according to the inter-coder agreement, which assured the validity of the research results (Cohen's Kappa was 98.2%). The remaining differences were resolved through personal consultation between the researchers.

Using the selection criteria and procedure described above, the first search on WOS, Scopus, Econlit and CAB led to the identification of 9975 records. After screening for year of publication and language, the search was restricted to 6041 research articles. After selecting following the database categories, records were limited to 3,071, which were then manually sifted. After title screening, 2912 records were excluded because they did not meet the inclusion criteria and the remaining 159 titles were checked by abstract. Through this process 121 articles were excluded because their abstract content did not meet the inclusion criteria. This screening procedure resulted in 38 articles that were fulltext screened: 15 articles were excluded because they did not meet the established criteria and, finally, 23 articles were selected to be included in the review. As an additional step, we also checked the article references to verify whether it was possible to

retrieve other studies. The search ended up with two additional research papers such that, finally, 25 were included in the systematic review. The flow chart summarizing the whole selection process is illustrated in Fig. 1. Of the selected studies, 13 articles were focused on farmers, while 12 studies were focused on consumers. It is worth highlighting that one of the thirteen studies on farmers, although resulting from the literature research, did not specifically mention the terms 'nudging', 'nudge' or 'choice architecture' (Clot, Grolleau, & Méral, 2017). However, after carefully reading the paper, we decided to include it in the literature review because the experiment explicitly worked as a nudge.

Table 1 Databases categories

Web of Science- categories	Scopus- categories	Cab Abstracts - categories
Agricultural Economics policy	Agricultural and Biological Sciences	Agricultural Economics
Agriculture Dairy Animal Science	Business Management and Accounting	Consumer Economics
Behavioral sciences	Decision Sciences	Crop Produce
Business	Earth and Planetary Sciences	Ecology general

Communication	Economics, Econometrics, Finance	Energy or Plant production
Ecology	Energy	Erosion Soil and Water Conservation
Economics	Environmental Sciences	Food Economics New March 2000
Environmental Sciences	Multidisciplinary	Health Economics New March 2000
Environmental Studies	Psychology	Human Wastes and Refuse
Food Science technology	Social Sciences	Land Resources
Green sustainable science technology		Marketing and Distribution
Health care science services		Meat Produce
Health Policy Services		Milk and Diary Produce
Management		Natural Resource Economics New March 2000
Multidisciplinary sciences		Pesticides and Drugs Control New March 2000
Nutrition Dietetics		Policy and Planning
Political Science		Pollution and Degradation
Psychology		Soil Water Management
Psychology applied		Water Resource
Psychology Experimental		
Psychology multidisciplinary		
Psychology Social		
Public Administration		
Public Environmental occupational Health		

3. Major outcomes

3.1. Overview of the selected studies

Twenty-three articles included in the systematic review reported original primary data, while two articles used secondary data (Brown, 2018; Mills et al., 2017). Most of the selected studies were entirely quantitative, except for three that adopted a qualitative approach (Mills et al., 2017; Torma, Aschemann-Witzel, & Thøgersen, 2018; von Kameke & Fischer, 2018).

The selected studies provided evidence from six European countries (United Kingdom, Germany, Sweden, Denmark, France, and Belgium) and from the US, while only one study was carried out in Africa (Madagascar). Of these, the ones involving farmers were conducted in the US, Madagascar, UK, Germany, France, while those on consumers were conducted in the United Kingdom, Germany, Sweden, France, Denmark, Belgium and the US. Only two articles did not specify where

the experimental data were collected. Moreover, the literature review highlighted that most of the studies were published recently (2016–2018), suggesting that the application of nudging for sustainability-related purposes represents a relatively new field of research, which has gained increasing attention over the last few years. The oldest selected research papers were published in 2011 (Sheeder and Lynne, 2011).

Table 2 summarizes the type of nudges applied in each study, distinguishing between those involving farmers and consumers respectively.

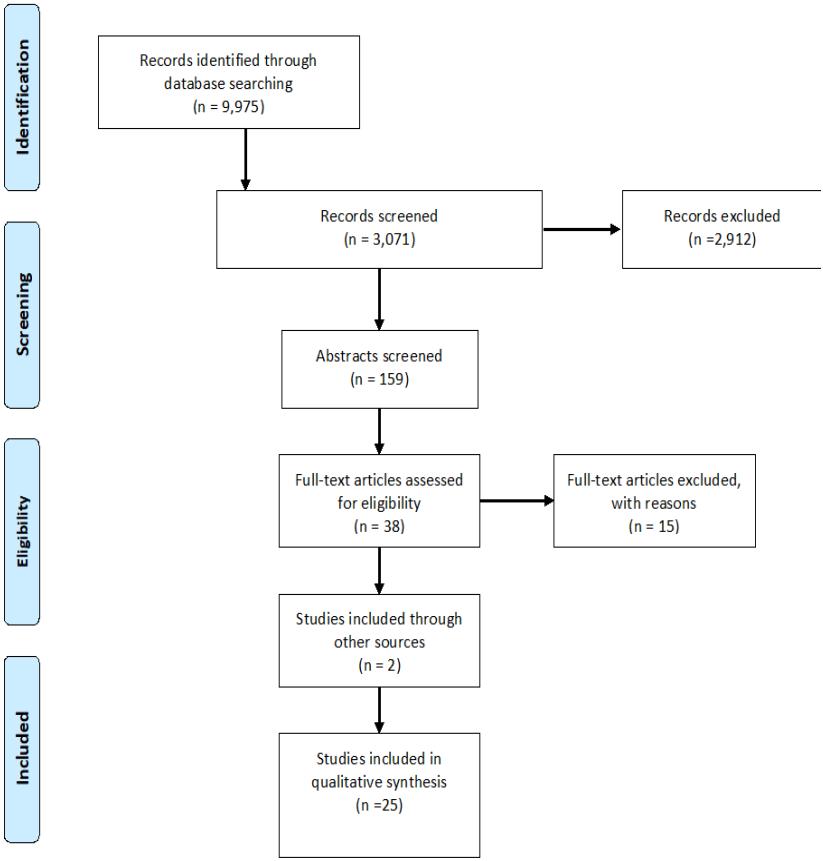

Figure 1 PRISMA flow chart

The most used nudging tools both for farmers and consumers are represented by salience and norms and

messenger, these latter mostly named as social norms and social comparison.

Table 2 Classification of articles based on the type of nudge applied.

Nudge	Farmers	Consumers
Default		(Campbell-Arvai et al., 2014)*; (Kallbekken & Sælen, 2013)*; (Torma et al, 2018); (Vandenbroele et al., 2017)
Salience	(Brown, 2018)*; (Pellegrin et al., 2018); (Czap et al., 2015); (Sheeder & Lynne, 2015); (Czap et al., 2014); (Banerjee, 2018)*;(Clot, Grolleau, & Méral, 2017)*; (Barnes et al., 2013)* .	
Norms and Messages	(Peth et al., 2018); (Banerjee, 2018)*; (Brown, 2018)*; (Mills et al., 2017); (Wallander et al., 2017); (Clot et al., 2017)*; (Kuhfusset al., 2016b); (Barnes et al., 2013)*.(Kuhfuss et al., 2016a)*.	(von Kameke & Fischer, 2018)*; (Linder, et al., 2018); (Kristensson et al., 2017); (Shearer et al., 2017); (Demarque et al., 2015); (Kallbekken & Sælen, 2013)*; (Campbell-Arvai et al., 2014)*; (Filimonau et al., 2017)

Priming		(Bacon & Krpan, 2018); (Kurz, 2018); (von Kameke & Fischer, 2018)*.
Incentive	(Kuhfuss et al., 2016a)*.	

(*) indicates those research papers that used more than one nudge.

3.2. Nudging-based studies on farmers

Overall, thirteen articles were found that nudged farmers to undertake pro-environmental actions (Table 3). These articles were subdivided in three main categories according to their specific aim, that is *i*) nudging practices to improve management of natural resources, *ii*) nudging a responsible use of pesticides, and *iii*) nudging the subscription in pro-environmental schemes. Specifically, four studies focused on implementing best practices in the management of water, one article focused on a better management of the land, while one study was focused both on land and water management. One research paper focused on implementing best practices when using pesticides in order to improve biodiversity conservation

and, finally, six studies nudged the subscription in pro-environmental schemes.

Table 2 Nudging farmers to green practices.

Author/s, year	Aim of the study	Intervention (nudge)	Sample size/country	Data collection	Methodology	Results
(Brown, 2018)	To analyse the effect of a behavioural nudge on farmers' insect resistance management (IRM) practices.	Salience, social norms, social comparison	Data are collected from Monsanto for corn seed sales by Monsanto in North Carolina for 2013–2016- US	Data from Monsanto panel	Difference-in-differences, fractional regression, discrete changes-in-changes. Author focused on estimating the average treatment effect of the program in terms of changes in refuge adoption.	The nudge intervention had a significantly positive effect in the first year following the program.

(Banerjee, 2018)	To promote coordination of land uses among neighbouring farmers.	Social comparison	144 students*-country not specified	Laboratory experiment	Within-subject treatment, information treatment, random effects logistic regressions.	Results shown that having information from another community improves spatial coordination rates in both communities.
(Peth et al., 2018)	To investigate the how nudges affect compliance with the minimum-distance-to-water rule.	Information, social comparison	163 farmers-Germany	Online survey	Multi-period business management game.	Nudging reduced area that is illicitly fertilised and the share of noncompliant participants, but also the total area that is illicitly fertilised. Social comparison is not stronger than information.

(Pellegrin et al., 2018)	To examine whether individual identified victims effect increases farmers' participation in a conservation program.	Salience	328 farmers-France	Mail survey	Quasi-experimental design	Identified victim effect (salience) did not work.
(Wallander et al., 2017)	To investigate whether nudge could improve land owners' willingness to participate into USDA's Conservation Reserve Program.	Information, norms	27,488 farmers-US	Mail survey	Experimental design, two treatments.	Authors found that for the most well-informed group, intervention nudged farmers' participation to the program. Results were not statistically significant for low

						information group.
(Kuhfuss et al., 2016b)	To identify the effect of social norm in driving farmers' decisions to maintain pro-environment practices; to examine whether behaviour of other producers mattered to individual's stated intention.	Norms, social comparison, framing	395 farmers-France	Online survey	Farmers are divided into three treatment groups and one control group.	Social comparison influenced a farmer's stated decision whether to maintain the pro-environment practices. Framing do not influenced decisions.

(Czap et al., 2015)	To explore the effectiveness of implementing an empathy nudge vs a financial incentive in the context of conservation compliance on farming land.	Empathy nudge (salience) vs Financial incentive	400 students*- US	Framed laboratory experiment	Students were grouped in three treatment groups and one control groups. One group was treated with an empathy nudge.	Salience could counterbalance the cut of financial incentives, despite it is less effective. Authors found that applying both empathy nudge and financial incentive was particularly effective in initial cases.
(Clot et al., 2017)	To investigate how words used to describe an environmental program count on individual opinions.	Message	746 students*- Madagascar	Survey	Survey, ordered probit regression.	Wording could influence the perception on environmental conservation programs.

(Barnes et al., 2013)	To explore the voluntary adoption of water quality management techniques.	Social comparison, salience and default vs Regulation	376 farmers- UK	Telephone survey	Likert scale.	Authors reported that shifting from regulation to a nudge could lead to uptake social optimal solutions.
(Mills et al., 2017)	To understand producers' willingness and ability to undertake environmental management schemes.	Personal and social norms	60 farmers- UK	Qualitative questionnaire	Qualitative analysis, data coded into categories.	Personal and social norms affected farmer environmental behaviour.
(Sheeder & Lynne, 2015)	To explore whether empathy counts in deciding if adopting conservation tillage practice.	Salience	498 farmers-US	Mail survey	Logit model.	Farmers with empathy-sympathy interests were more likely to use conservation tillage.

(Czap et al., 2014)	To examine how different genders response to self-interest and empathy stimuli.	Salience	432 students*- US	Framed lab experiment	Author implemented a game to understand how farmers interacted.	Empathy nudging (salience) worked more on female than male when increasing environmentally-friendly behaviour.
(Kuhfuss et al., 2016a)	To explore whether a monetary bonus nudges farmer to enrol land in agro-environmental schemes.	Incentive, social norm	317 farmers- France	Face to face survey	Choice Experiment.	Incentives worked in increasing subscription in pro-environmental schemes and reduced pesticide usage.

Scholars implemented a lab experiment with students to understand how nudging methodologies could work.

3.2.1. Nudging practices to improve management of natural resources

Peth et al. (2018) used nudging to leverage farmers to adopt a more responsible nitrogen fertilization to limit water pollution. Nudges were based on salience and norms. They found an overall positive effect of salience and social comparison in reducing nitrogen pollution when farming, but contrary to what the authors expected, the impact of social comparison and salience together was not stronger than that of salience alone (Peth et al., 2018). Barnes et al. (2013) used social norms to nudge farmers choosing water quality management techniques to reduce nitrate pollution (Barnes et al., 2013). According to the results, changing farmers' behaviour through nudging produced mixed effect. Indeed, because of the different perception that farmers had about the link between water pollution and nitrates presence in water, nudging was not sufficient to shape farmers' behaviour and stronger measures were required. These results suggest that nudging interventions could present some limitations, however authors concluded that a sharing-information approach may be helpful in reaching positive outcomes (Barnes et al., 2013).

Czap et al. (2014) investigated differences in individual response to salience (Czap et al., 2014). The framework of the study was based on agricultural activities but, in this case, the experiment was conducted in a lab with students instead of directly involving farmers. Results indicated that the nudge was more efficient on female than on male in improving environmentally-friendly behaviour (Czap et al., 2014). In a subsequent study, Czap et al. (2015) focused on the use of salience and financial nudges to nudge water conservation and farmers' environmentally conscious behaviour. Also in this case, the authors conducted the experiment in a lab recruiting students. The study demonstrated that salience worked well in promoting water conservation, especially when associated with financial incentives (Czap et al., 2015). Sheeder and Lynne (2011) focused on two important farming activities, that is, water and land management. Specifically, although they did not directly implement nudging interventions, their results highlighted that salience can be effective in pushing the adoption of conservation tillage, which consequently improves the water management (Sheeder and Lynne, 2011). Banerjee (2018) focused his study on land spatial coordination among

neighbouring producers. The authors implemented norm-based nudges and, similar to Czap et al. (2014) and Czap et al. (2015), they conducted the experiment recruiting students in a lab setting. In detail, the experiment mimicked a real-life situation in which farmers had to decide whether to adopt land conservation practices. Students had to identify themselves with farmers and decide about land conservation practices after being informed about their neighbours decisions (Banerjee, 2018). The results provided evidence that this intervention worked in coordinating actions among neighbour farmers, thus improving spatial coordination (Banerjee, 2018).

3.2.2. Nudging a responsible use of pesticides

An article analysed whether nudging tools could promote the subscription in agglomeration bonus (AB) schemes to create refuges for pesticide resistance management among farmers who cultivated Bt-corn (Brown, 2018). The paper empirically analysed secondary data of a social marketing campaign, which adopted a salience-based intervention and social comparison to promote the creation of refuges (Brown, 2018). Nudging interventions worked in improving the subscription to AB

schemes, and the effect was especially positive in the short-run (Brown, 2018).

3.2.3. Nudging the subscription in pro-environmental schemes

Participation in pro-environmental schemes was nudged with norms and salience Wallander et al. (2017) found that the effect of nudging farmers to take part in pro-environmental measures through social norms was strongly affected by farmer's past behaviour. In detail, if farmers had already taken part to such schemes, social norms were effective in nudging them to subscribe again, while the effect was weaker when they had never been part of such programmes (Wallander et al., 2017). Kuhfuss et al. (2016b) examined whether farmers could be pushed to maintain the subscription to environmental management schemes by means of interventions based on social comparison (i.e., by informing them on their peers' behaviour). According to their results, these interventions worked well in maintaining producers enrolled in such schemes in the long-run (Kuhfuss et al., 2016b). Mills et al. (2017) investigated farmers willingness to voluntary adopt pro-environmental practices and to maintain these practices in the long-run. Their findings highlighted that social norms can be

able to influence producers in deciding to manage their activity more sustainably. However, they suggest that farmers may respond to nudges in an heterogeneous manner, based on their specificities (Mills et al., 2017). Kuhfuss et al. (2016a) investigated whether collective bonus given to farmers could increase the total land enrolled in agro-environmental schemes and obtained positive results. Moreover, their results also highlighted that this outcome was reached thanks to the generation of a social comparison mechanism within farmers that influenced each other behaviour (Kuhfuss et al., 2016a). Clot et al. (2017) examined whether using different words (i.e., 'compensation' vs 'payment') could differently affect farmers' behaviour. They implemented a lab experiment with students and provided evidence that the term 'compensation' was more effective than 'payment', thus suggesting that words are not neutral but may exert different responses (Clot et al., 2017). Contrary to the main evidence provided in the above-mentioned studies, Pellegrin et al. (2018) found that salience was not effective in nudging farmers to subscribe in pro-environmental schemes.

3.3. Nudging-based studies on consumers

Overall, the review process identified twelve articles that examined whether nudging interventions could induce consumers to have a more sustainable approach with regard to their eating habits and behaviours (Table 4). These studies mostly focused on nudging consumers in changing consumption habits when *i)* eating out of home *ii*) when purchasing at supermarkets, and *iii*) in improving their food waste management. Specifically, four articles were focused on food consumption choices when eating out, four articles investigated whether nudging could drive food purchasing, and four studies focused on improving food waste management.

Table 3 Nudging consumers to sustainable food habits.
∗ Indicates those research papers that used more than one nudge.

Author/s, year	Aim of the study	Intervention (nudge)	Sample size/country	Data collection	Methodology	Results
(Bacon & Krpan, 2018)	To study if the effectiveness of menu design in nudging pro-environmental food choice depends on the vegetable's habit consumption of consumers (that is, their past behaviour).	Priming	853 students*-UK	Online study	Online scenario. Three different restaurant menu designs as treatments and one control design. Participants were randomly assigned to four different restaurant menu conditions.	Consumers' past behaviour plays an important role in nudging food choices. That means that personalized interventions are needed to achieve sustainable eating habits.

(von Kameke & Fischer, 2018)	To nudge planning behaviour for preventing domestic food waste and to predict the potential effectiveness of a nudging treatment by focusing on consumers' perceptions and evaluations.	Message	101 residents-Germany	Semi-structured questionnaire containing both open-ended and closed questions	Analysis consists in descriptive statistics.	Nudging intervention can contribute to the reduction of household food waste.
(Linder et al., 2018)	To test whether a nudge can be effective in promoting	Social norm, message	474 households-Sweden	Waste was weighted during each collection.	Natural field experiment, difference-in-difference	The increase of the recycled food waste increase in

	recycling of food waste in an urban area.				analysis. Authors studied both the short- and long-term effects of the intervention.	food waste recycled compared to a control group in the research area.
(Kurz, 2018)	To explore if nudging can increase the consumption of vegetarian food to mitigate GHG emissions by reducing meat consumption.	Priming	192 dishes (average)- Sweden	Sales data collected through the restaurants' register.	Field experiment, difference-in-difference analysis.	Consumers adopted a more pro-environmental diet. The change in behaviour is partly persistent.

(Kristensson et al., 2017)	To examine what influences consumer behaviour toward making more environmentally friendly choices.	Message	400 grocery consumers-Sweden	Face-to-face survey	Survey to understand how people perceived the likelihood that consumers in general would change their behaviour.	There is a discrepancy between what consumers think should influence behaviour and what actually does influence behaviour. Nudge intervention increased the choice of environmentally friendly offerings.

(Shearer et al., 2017)	To examine if a sticker prompt would significantly increase the capture of food waste for recycling among households in the long-term.	Message	64,284 households-UK	Waste was monitored and weighted.	Randomized control trial	Authors found a significant increase in recycling food waste in the treatment group. The behaviour persisted in the long-term.
(Torma et al., 2018)	To describe how consumers conceive of their decision to buy organic box ("self-nudging").	Default	10 consumers-Denmark	Face-to-face interview	Phenomenological approach, qualitative research.	Self-nudging worked well on consumers with strong interest in protecting the environment.

(Demarque et al., 2015)	To explore how to promote green consumption through nudging.	Message, social comparison	122 students*-France	Lab experiment	Authors subdivided sample in four groups, one control group, and three treatment groups.	Implemented nudges helped in improving green consumption.
(Kallbekken & Sælen, 2013)	To reduce food waste in hotel restaurant.	Default, message	52 hotel restaurants, 45,000 observations-Norway	Hotels recoded the daily food waste's weight.	Difference-in-difference using a fixed effects panel regression to analyse the treatment effects.	Reducing the plate size by 3 cm reduces food waste by approximately 22percent.
(Filimonau et al., 2017)	To investigate the determinants of consumers choice	Priming	340 consumers-UK	Face to face consumer survey	Field experiment. Authors implemented a menu intervention approach.	Authors found that next to price, food provenance and nutritional

	when dining out and how to nudge people to take more sustainable choices.					value determined consumer choice when dining out.
(Campbell-Arvai et al., 2014)	To explore the role of a nudge in pushing choices with positive environmental outcomes.	Default	316 consumers-US	Focus group and interview	Choice experiment.	Default-based interventions can be important tools in pushing green behaviour also in the long-term.

(Vandenbroele et al., 2017)	To test whether adding smaller portion sizes in supermarkets encouraged consumers to buy smaller portions. Smaller sausage portion sizes generate positive outcomes both on the environment and on health.	Default	1,365 purchasers - Belgium	Changes in purchasing before and after the treatment and between the control and treatment supermarkets.	Field experiment (consumers were not aware that they were involved in the experiment).	52% of sausage sold were small or medium. Thanks to default choice, authors highlighted that 13% less meat (in kg) was sold with regards previous purchasing. During the same period, the treated store sold fewer sausages than the control store.

3.3.1. Nudging consumers when eating out

Consumers' behaviour at the restaurant was usually nudged changing menu designs to test if consumers could be nudged towards more environmentally-friendly choices (Bacon & Krpan, 2018; Filimonau et al., 2017; Kurz, 2018). In detail, these studies tested whether consumers could be nudged to choose vegetable options instead of meat dishes. Taken together, these results highlighted that nudging was effective in increasing the consumption of vegetarian over meat dishes. Kurz (2018) showed that by increasing the saliency of plant-based dishes by modifying their visibility on the menu could lead people to ask for more information. Bacon and Krpan (2018), found that changing the menu design (i.e. increasing the saliency of vegetarian plates or with priming) can be effective to shape food choices, although consumers' likelihood of selecting vegetarian items was strongly dependent on their past behaviour. Furthermore, Filimonau et al. (2017) nudged an environmental-friendly behaviour in a restaurant by inserting information on the menu, like the origin of ingedients and the carbon footprint of the items. Their results did not report strong positive effects in nudging food choices. Campbell-Arvai et al.

(2014) tested how an appealing and an unappealing meat-free menu worked in nudging participants in choosing meat-free options, by examining the effectiveness of different default-based nudges and combinations. Their results suggested that if menus were described in an appealing manner, default and information nudges combined were the most effective interventions, while for the unappealing menus, the default menu was the most chosen option (Campbell-Arvai et al., 2014).

3.3.2. Nudging consumers at supermarkets

Some studies focused on how to promote sustainable behaviours when purchasing food at the supermarket. Kristensson et al. (2017) explored how both verbal and written cues influenced consumers purchasing behaviour, and results highlighted that both nudges encouraged customers to buy more environmentally friendly products, with verbal signs being more effective (Kristensson et al., 2017).

Demarque et al. (2015) conducted a lab experiment with students to test the effectiveness of norms on online grocery shopping behaviour

and found positive effects in terms of increased eco-product purchasing. In a recent study, Torma et al. (2018) explored consumers' ability to nudge themselves in buying organic food by subscribing to 'organic box schemes' consisting in substituting small daily vegetables purchases with larger organic orders delivered at home weekly. The authors considered the subscription to the 'organic box scheme' as 'self-default' nudge. Results reported that such self-nudging concretely helped consumers in acting more sustainably, with effects persisting also in the long-run (Torma et al., 2018). Finally, Vandenbroele et al. (2017) tested the effects of varying (i.e., reducing) food portion sizes sold at supermarkets and found that the availability of smaller portions nudged consumers to opt for these latter, discarding standard sizes. As suggested by the authors, this may also indirectly result in food waste reduction.

3.3.3. Nudging food waste reduction and recycling

Past literature implemented several types of nudges such as default, and social norms to reduce and/or recycle household food waste. All interventions gave positive results and were

useful to reduce food waste or improve food recycling. Specifically, two studies were focused on improving food waste management respectively through the use of visual prompts and information leaflet (Shearer et al., 2017; Linder et al., 2018). Both studies found that these nudges significantly contributed to improve households' food waste management, although Linder et al. (2018) found that the effect decreased in the longer run. von Kameke and Fischer (2018) hypothetically tested the effectiveness of different kind of nudges (for example, tips on shopping planning via email or pictures) in leading the households to shop less in order to reduce food waste. The results showed that the nudges played a significant role in reducing food waste, at least in the hypothetical context of their study (von Kameke & Fischer, 2018). Furthermore, nudging was useful also in reducing food waste in hotel restaurants. Kallbekken and Sælen (2013) decided to provide smaller plates at the buffet (that is, they changed the default) and to show messages that invited hotel guests to take more food from the restaurant's buffet. This controversial combination of signs was aimed at nudging consumers to load less food on their plates when visiting the buffet (Kallbekken & Sælen, 2013). The

experiment results demonstrated that the combination of these nudging interventions was effective in reducing food waste (Kallbekken & Sælen, 2013).

4. Discussion

The present review gathers existing evidence on green nudges applications involving the actors of the food chain with the goal of leveraging more environmentally sustainable practices and behaviours.

Specifically, evidence was collected to examine whether and to what extent the implementation of different type of green nudges could be effective in leading the food chain agents to refashion their behaviours towards more sustainable models, thus voluntarily contributing to environmental preservation.

The first main evidence emerging when analyzing the results of the selected studies is that green nudging can be surprisingly effective in directing people towards the desired direction. Almost all studies on farmers as well as on consumers, indeed, reported significant results, thus strengthening the potential of this tool to be used for environmental policy formulation. Moreover, consistent evidence was obtained in several EU and

extra-EU countries, which suggests that nudging implementation is not particularly affected by cultural or socio-economic specificities. It is also worth noticing that the studies included in this review are all very recent (the oldest dated 2013). This stresses that the use of green nudging in relation to food-related production and consumption is expanding and raising attention. Overall, this documents the increasing significance that behavioural interventions are assuming as possible solutions to be adopted in order to effectively cope with the complexity of environmental problems (Kunreuther & Weber, 2014; van der Linden, Maibach, & Leiserowitz, 2015). Despite the results essentially go in the same direction, differences emerged with regard to the type of nudges used with farmers and with consumers. In the former case, indeed, the review highlighted that the most used nudges were based on norms and messengers, followed by interventions designed to exploit salience. As for consumers, norms and messengers still constitute the most adopted technique, together with priming and default. To investigate the reasons behind the implementation of one nudge or another was out of the scope of this review, but this aspect deserves a more in-depth

investigation. In fact, to understand whether different nudges may act differently on specific food chain agents would make a substantial contribution to successfully develop future environmental policy. Furthermore, no studies were found in which nudges were targeted at the food industry or the distribution sectors. Given the relevant role that both these sectors play in terms of environmental impact, it would be crucial to extend available evidence on nudging effectiveness with studies involving these agents.

This review presents some limitations. As explained in the Approach section, we focused our research on 'nudg*' and 'choice architecture' words. However, there could be some studies that implemented green nudging interventions without mentioning the specific words in the manuscript. If so, they were not included in the review. Indeed, we were able to select an article that did not include the above-mentioned terms, but its intervention worked like a nudge (Clot et al., 2017). In other words, we cannot exclude with certainty that we some pertinent articles were avoided.

Taken together evidence suggest that, from a policy standpoint and contrary to other policy instruments, nudging has at least

two advantageous characteristics. The first is that nudging applications are generally relatively inexpensive, and the second main advantage is the ease of implementation and the possibility to adapt the nudge to various context (Thaler & Sunstein, 2008). As such, this tool may be particularly suitable to be applied in those contexts, such as agriculture, that suffer from geographical or economic specificities that make it difficult to strictly adjust a single policy to all producers. Nudging applications could be helpful to foster pro-environmental practices that could be more in line with the specific needs of the agents involved.

However, in line with the suggestion of Lehner, Mont, and Heiskanen (2016), we claim that nudges should not be meant to replace more strict environmental and food policies, but rather they should be regarded as potential complements to be implemented with the aim of gradually moving society in a direction that might benefit all.

Despite these anticipated benefits and evidence indicating the effectiveness of this tool, there are critical aspects that needs to be acknowledged.

As emerging from the results of this review as well as from previous literature, it is still unclear whether green nudges are able to generate robust and durable behavioural change (Schubert, 2017). Furthermore, nudging use is actually at the core of a lively debate in which opponents argue about the partly manipulative way in which they attempt to shape human behaviours. Indeed, as explained by Thaler and Sunstein (2008) nudges are meant to alter people's behaviour by taking advantage of individual cognitive biases or by responding to them, instead of acting on them to improve their capability to make informed, rational and conscious choices (Grüne-Yanoff, 2015; Schubert, 2017; Thaler & Sunstein, 2008). This has generated concerns regarding the legitimate application of this tool and, although the authors of the libertarian paternalism defend that nudges should shape behaviours in a transparent manner, the boundaries of the underlying manipulations are not so univocal. Hence, while recognizing the significant potential that nudging may have in re-orienting behaviours towards a more sustainable trajectory, future studies should take these

issues into account to provide further knowledge which could be used as guidance for successful policy formulation.

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