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Review
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Ethical and legal implications of gene editing in plant breeding: a systematic literature review

Siti Hafsyah IDRIS[1], Nurzatil Sharleeza MAT JALALUDDIN[2✉], Lee Wei CHANG[3]

[1]*Faculty of Law, Universiti Teknologi MARA, Jalan Sarjana 1/2, Shah Alam 40450, Selangor, Malaysia*
[2]*Centre for Research in Biotechnology for Agriculture (CEBAR), Level 3, Research Management and Innovation Complex, Universiti Malaya, Kuala Lumpur 50603, Malaysia*
[3]*Centre for Civilisational Dialogue, Level 1, High Impact Research Building, Universiti Malaya, Kuala Lumpur 50603, Malaysia*

Abstract: Biotechnology policies and regulations must be revised and updated to reflect the most recent advances in plant-breeding technology. New Plant Breeding Techniques (NPBT) such as gene editing have been applied to address the myriad of challenges in plant breeding, while the use of NPBT as emerging biotechnological tools raises legal and ethical concerns. This study aims to highlight how gene editing is operationalized in the existing literature and examine the critical issues of ethical and legal issues of gene editing for plant breeding. We carried out a systematic literature review (SLR) to provide the current states of ethical and legal discourses surrounding this topic. We also identified critical research priority areas and policy gaps that must be addressed when designing the future governance of gene editing in plant breeding.

Key words: Systematic literature review; Gene editing; Plant breeding; Ethical and legal issues; Consequentialism; Virtue ethics principles

1 Introduction

The global agricultural biotechnology is an important economic sector, with a market revenue valued at USD 40 billion in 2020 and projected to reach approximately USD 110 billion by 2030 (Research and Markets, 2021). Besides being an economically significant industry, agricultural biotechnology provides essential solutions to the accelerating pace of climate change and alleviates its cascading impacts on crop production. In addition, biotechnological tools have the potential to address the challenges of the rapid global population growth and the increasing demand for food crops, threatening food security and safety.

Precision gene-editing techniques are powerful agricultural biotechnological tools that use sequence-specific engineered nucleases, such as clustered regularly interspaced short palindromic repeats (CRISPR)/CRISPR-associated protein 9 (Cas9), transcription activator-like effector nucleases (TALENs), zinc finger nucleases (ZFNs), and meganucleases. These programmable sequence-specific nucleases enable editing or altering parts of the target genomes to achieve desired crop traits (Li et al., 2021). In particular, the CRISPR/Cas9 platform has provided scientists with the capability to simply edit genes in a specific manner, as the guided Cas9 nuclease can target a wide variety of DNA motifs (Boettcher and McManus, 2015). Since the first use of gene editing in plant breeding in 2013 (Zhang et al., 2017), scientists have developed new gene-edited crops with improved tolerance to biotic and abiotic stresses or more robust quality, yield, or traits (reviewed in Jung et al., 2018; Chen et al., 2019). Several gene-edited crops have been trialed in the field, such as rice, tomato, rapeseed, wheat, and maize, with most of these experiments conducted in China, the United States, and Japan (Metje-Sprink et al., 2020). However, only a few of these crops have been successfully approved for commercial use, including the most recent γ-aminobutyric acid (GABA)-enriched tomato in Japan (Stokstad, 2021).

✉ Nurzatil Sharleeza MAT JALALUDDIN, nurzatil@um.edu.my
Nurzatil Sharleeza MAT JALALUDDIN, https://orcid.org/0000-0002-4661-8119

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The potential of gene editing is anticipated to bring in a new Green Revolution (Bain et al., 2020) and complement the vision of the United Nations' Sustainable Development Goals (SDGs), within the framework of "SDG 2: Zero Hunger" and "SDG 13: Climate Action." Depending on the outcomes of gene editing, it may result in different types of New Plant Breeding Techniques (NPBTs) (Hartung and Schiemann, 2014). The use of gene-editing techniques in plant breeding has drawn legal and ethical discourses globally, albeit these may differ depending on the type of gene editing. The initial discourses surrounding gene editing revolved around the necessity to clarify the regulatory mechanisms for this technology, and whether gene-edited crops should be classified as genetically modified organisms (GMOs) or non-GMOs (Whelan and Lema, 2015). Several countries have clarified their regulatory framework on the release of gene-edited crops, resulting in a heterogeneity in national regulatory approaches: the regulations are either stringent, such as in the European Union (EU) and New Zealand, or gene-editing friendly, as in Canada and the United States (Menz et al., 2020). Additionally, other issues such as intellectual property rights, societal acceptance, and farmer's rights are equally important aspects for consideration when drafting a regulation or policy for gene editing in plant breeding. Therefore, this review seeks to provide a comprehensive analysis and summary of ethical and legal discourses relevant to gene editing in plant breeding, as well as identify critical research and policy gaps to be addressed in the future.

2 Ethical and legal discourses

In recent years, advances and development in gene-editing research have triggered ethical and legal discourses on the technology itself. As this body of literature expands, it is timely to analyze emerging themes underlying these discourses, which can provide important critical analysis and highlight research gaps that must be addressed and considered by policymakers. To achieve these objectives, a systematic literature review (SLR) has been carried out in this study. Information selection was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method to select journal articles relevant to ethical and legal issues for gene-edited crops to be included in this SLR (Liberati et al., 2009). Publications for the period 2010–2022 were retrieved from the Web of Science Clarivate database (https://www.webofscience.com). The search task was performed using keywords, asterisks, and Boolean operators to harvest all documents within the TOPIC field. Initial screening was carried out using the query [("Gene* Edit*" OR CRISPR*) AND ("Legal Issue*" OR "Ethical Issue*" OR "Plant Breeding" OR Agriculture)], and the search yielded 852 records. In the next screening round, articles in English language were only considered, while reviews, books, book chapters, or conference proceedings were not considered. As the search strategy is limited by the restriction of including English language articles only, this decision posed a limitation to the SLR. Specifically, because ethical principles, debates, and discussions may be written in other languages than English, these may differ depending on regions, cultures, and beliefs. The initial screening resulted in a total of 431 journal articles, which were further screened by excluding research articles in the Science Citation Indexed Expanded (SCIE). This SLR aims to gauge discourses on ethical and legal issues associated with gene editing for agriculture. Finally, a total of 351 articles were removed from the initial selection, leaving 80 articles that were manually checked for their relevance, and then used in the coding and synthesis process (finally 21 articles, Fig. 1).

The general information of journal articles and their critical descriptions were summarized in a database. The information for each article included the title, journal, author (year), article type, and the country or region (when applicable), in which the field data were gathered or the analysis was conducted. However, for studies that were not grounded based on country or regions, the article was classified as "global." The general features and critical descriptions of each article were summarized in Table 1.

Several themes representing legal and ethical concerns raised in response to the introduction and adoption of gene-edited crops were identified based on the content analysis of the selected articles in this SLR (Table 2).

Among the frequently discussed topics are the societal issue related to the consumer acceptance and public perceptions of gene editing. Evaluations of the

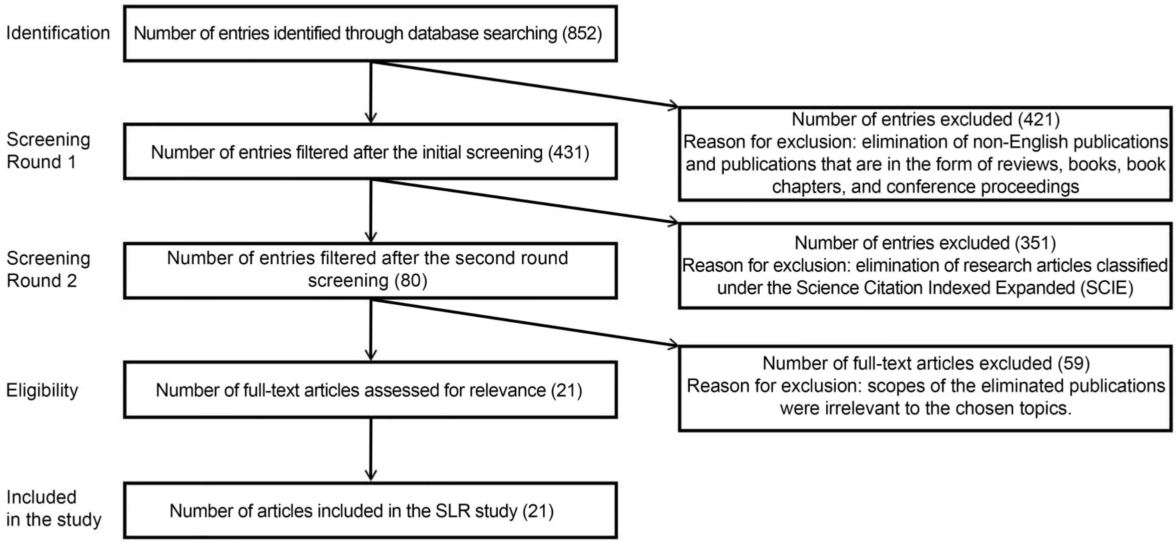

Fig. 1 Selection of journal articles for inclusion in the systematic literature review (SLR) study (method adapted from Liberati et al. (2009)).

Table 1 General features and critical descriptions of articles extracted for the systematic literature review (SLR) study

No.	Title	Journal	Author (year)	Article type	Country/ region
1	Supporters or opponents: will cultural values shape consumer acceptance of gene editing?	*Journal of Food Products Marketing*	Yang and Hobbs (2020)	Online survey	Canada
2	Economic issues to consider for gene drives	*Journal of Responsible Innovation*	Mitchell et al. (2018)	Review	Global
3	NGO perspectives on the social and ethical dimensions of plant genome-editing	*Agriculture and Human Values*	Helliwell et al. (2019)	Secondary data analysis, interview, focus group	UK
4	Genome-edited versus genetically-modified tomatoes: an experiment on people's perceptions and acceptance of food biotechnology in the UK and Switzerland	*Agriculture and Human Values*	Bearth et al. (2022)	Survey	UK & Switzerland
5	Precision technologies for agriculture: digital farming, gene-edited crops, and the politics of sustainability	*Global Environmental Politics*	Clapp and Ruder (2020)	Review	Global
6	Climate solution or corporate co-optation? US and Canadian publics' views on agricultural gene-editing	*PLoS ONE*	Nawaz and Satterfield (2022)	Survey	US & Canada
7	Food system transformation and the role of gene technology: an ethical analysis	*Ethics & International Affairs*	Thompson (2021)	Essay	Global
8	Perceptions of the fourth agricultural revolution: what's in, what's out, and what consequences are anticipated?	*Sociologia Ruralis*	Barrett and Rose (2022)	Content analysis, interview	UK
9	Citizen views on genome editing: effects of species and purpose	*Agriculture and Human Values*	Busch et al. (2022)	Survey	Canada, US, Austria, Germany, Italy

To be continued

Table 1 (continued)

No.	Title	Journal	Author (year)	Article type	Country/ region
10	CRISPR-Cas9 and food in the European Union: an organic solution to an undetectable problem for food business operators	*European Journal of Risk Regulation*	Hughes (2022)	Review	EU
11	The end of the GMO? Genome editing, gene drives and new frontiers of plant technology	*Review of Agrarian Studies*	Hefferon and Herring (2017)	Review	Global
12	Snipping around for food: economic, ethical and policy implications of CRISPR/Cas genome editing	*Geoforum*	Bartkowski et al. (2018)	Content analysis	Global
13	Strategic framing of genome editing in agriculture: an analysis of the debate in Germany in the run-up to the European Court of Justice ruling	*Agriculture and Human Values*	Siebert et al. (2022)	Content analysis	Germany
14	Understanding knowledge and perceptions of genome editing technologies: a textual analysis of major agricultural stakeholder groups	*JCOM, Journal of Science Communication*	Robbins et al. (2021)	Content analysis	US
15	Integrity and agency: negotiating new forms of human-nature relations in biotechnology	*Environmental Ethics*	Preston and Antonsen (2021)	Review	Global
16	Is the patent system the way forward with the CRISPR-Cas 9 technology?	*Science and Technology Studies*	Mali (2020)	Review	Global
17	How regulatory issues surrounding new breeding technologies can impact smallholder farmer breeding: a case study from the Philippines	*Plants, People, Planet*	de Jonge et al. (2022)	Field visit, interview	Philippines
18	The divergent governance of gene editing in agriculture: a comparison of institutional reports from seven EU member states	*Plant Biotechnology Reports*	Meyer and Heimstädt (2019)	Review	Global
19	Tensions at the boundary: rearticulating 'organic' plant breeding in the age of gene editing	*Elementa: Science of the Anthropocene*	Nawaz et al. (2020)	Content analysis	Global
20	How to do what is right, not what is easy: requirements for assessment of genome-edited and genetically modified organisms under ethical guidelines	*Food Ethics*	Antonsen and Dassler (2021)	Review	Norway
21	Governing gene editing in agriculture and food in the United States: tensions, contestations, and realignments	*Elementa: Science of the Anthropocene*	Selfa et al. (2021)	Interview	US

CRISPR-Cas9: clustered regularly interspaced short palindromic repeats (CRISPR)-CRISPR associated protein 9; EU: European Union; GMO: genetically modified organism; NGO: non-governmental organization; UK: the United Kingdom; US: the United States.

public perception of risks and benefits and consumer acceptance are essential to ensure the better success of technological adoption by the general public (Barrett and Rose, 2022). Interestingly, recent surveys evaluating the consumer acceptance of gene-edited food crops found that the public expressed a higher level of acceptance for gene-edited food products than for transgenic products (Yang and Hobbs, 2020; Bearth et al., 2022), with negative attitudes towards gene editing being less firmly entrenched compared to genetic modification, especially in the context of moral acceptability and safety (Yang and Hobbs, 2020). Such findings

Table 2 Overview of societal, legal, and ethical concerns relevant to gene-edited crops

Legal and ethical concerns surrounding gene editing in plant breeding	Number and proportion of articles
Public acceptance, e.g., perceptions of risks and benefits, opposition	5 (24%)
Corporate power and control, e.g., seed market	6 (26%)
Language, metaphors, and terminologies	1 (5%)
Consumer rights to information	2 (10%)
Food choices and transparency, e.g., labeling and tracing	3 (14%)
Environmental risks and uncertainty	3 (14%)
Human health risks and uncertainty	1 (5%)
Integrity of genome, e.g., unnaturalness versus naturalness	2 (10%)
Intellectual property	6 (26%)
Perpetuating industrial agricultural system	2 (10%)
Farmers' livelihood, e.g., dependence on the seed sector	2 (10%)
Integrity and practices for agroecological farming, e.g., organic sector	3 (14%)

illustrated a vast potential for gene-edited products to be more widely accepted than conventional transgenic products.

In addition, two contrasting views were reported for gene editing, with both derived from the two aspects of being an environmental issue and the corporate control of market shares. For the former, proponents viewed gene editing as a "climate smart" technology, since gene-edited crops can withstand severe diseases and environments brought on by climate changes and possess extended durability that can minimize post-harvest waste and carbon footprints. However, the critics questioned the safety of gene editing, especially when the technology is used for gene drives, since off-target effects in gene editing are not fully understood (Clapp and Ruder, 2020). From the aspect of the corporate control over food and farming market shares, proponents believed that the cost of developing gene-edited crops was significantly reduced, as the result of a more relaxed regulation governing the technology, and the barriers to the market entry for non-corporate entities who own the technology have fallen (Hefferon and Herring, 2017). On the other hand, the critics viewed gene editing as a method for agricultural biotech corporations to expand their power and control over industrial agricultural systems, farmers, and consumers. Such claims were made based on the patenting regime that increases the power and authority of industrial corporations (Helliwell et al., 2019).

Furthermore, the language, metaphors, and terminologies used to describe gene editing, such as "precision" and "editing," were argued to have ethical consequences. This is because the semantic use of words was described to exclude the public from expressing their concerns and framing risks while influencing their perception of the technology (Helliwell et al., 2019). Besides, the consumer rights to information and food choices are other critical ethical concerns that should be considered. A more flexible regulatory framework for deregulation of gene-editing techniques, such as the exclusion of labeling and tracing requirements, could potentially lead to the gene-edited products being indistinguishable from non-gene-edited products when sold on the shelves (Helliwell et al., 2019). Agroecological farming communities have also raised concerns that gene editing could prompt the organic sector to reinforce the boundaries between biotechnology and organic breeding to maintain the integrity of the organic industry (Nawaz et al., 2020). As the societal, ethical, and environmental concerns are becoming more complex and dynamic, recent discourses have proposed the inclusion of non-safety assessments to evaluate the ethical, societal, and sustainability impacts of a gene-edited food crop before deregulating gene-edited products (Myskja and Myhr, 2020). The specific ethical and legal discourses are further explained in the following sections.

2.1 Sustainability through gene editing

Sustainability refers to the triad of social, environmental, and economic factors that should be kept in balance to ensure the long-term success of organizations and communities. It involves a holistic approach to making decisions that consider the impact of people, planet, and profits to promote long-term sustainability (United Nations, 1987). On a positive note, gene-edited crops may enhance the crop yield per unit of land, confer disease protection that reduces the over-reliance on synthetic pesticides, as well as provide drought tolerance that decreases the need for the intensive use of irrigation systems. In addition, gene-edited crops may have improved flavors and quality, a longer shelf-life, and better commercial appeal to customers, and provide more nutrition (Bate et al., 2021). By improving the quality attributes and shelf-life of postharvest crops, gene editing can also act as an important means to reduce environmental waste, resulting in a smaller environmental footprint (Shipman et al., 2021).

Faber et al. (2005) discussed the principles of sustainability, with a focus on whether sustainability is sustainable in and of itself. They found that sustainability no longer aims for a perfect state to achieve, but instead is a process of always aiming to make things more sustainable. This dynamic perspective leaves room for discussion and deals with the fact that the world keeps changing. However, biotechnology is presumed to be a profit-driven industry that is heavily invested and predominantly controlled by agri-biotech multinational corporations, and questions remain about how to achieve a balance between the People, Planet, and Profit (3P) goals. The market power that agri-biotech firms hold over industrial agricultural systems, as well as farmers and consumers, may perpetuate and intensify large-scale monocultures and farming systems that could be harmful to the environment, human health, and food accessibility (Helliwell et al., 2019). Corporate control via patenting (Helliwell et al., 2019) and challenges to navigate freedom-to-operate (FTO) issues could indeed potentially increase the power of multinational corporations and fail to support the democratization of technology (Baker, 2019). Arguments for monopolization through the patenting system will be discussed further under social justice (Section 2.3).

To ensure a sustainable future, it is essential to strike a balance between the autonomy and wellbeing of both current and future generations, as well as the survival of planetary ecosystems. Mepham's ethical matrix, for example, is an important tool that emphasizes biota and fairness when evaluating GMOs (Mepham, 2000). However, it fails to capture two other key aspects: social and economic sustainability, and their connection to environmental protection (Dassler and Myhr, 2021). Therefore, the use of this matrix is limited to situations in which environmental protection for future generations is prioritized over increased welfare and economic activity in the present (Dassler and Myhr, 2021). Since research on gene editing and its commercial use is anticipated to expand more rapidly in the near future, it is necessary to incorporate all three dimensions of sustainability and relationships between the dimensions when regulating gene-editing innovations (Wray-Cahen et al., 2022). Hence, for gene-editing technology to be regulated fairly and responsibly, regulatory approaches for the technology must consider essential elements such as conservation, biodiversity, and the intrinsic value of nature, as well as well-being, welfare, choice, and fair trade.

2.2 Biodiversity

Biodiversity conservation is an important goal of sustainable development policies and holds a societal value that covers three system levels: ecology, species diversity, and genetic diversity within species. Modern breeding has unquestionably increased genetic diversity in Europe, particularly in crops such as lettuce, wheat, and tomato, among other organisms (van de Wouw et al., 2010, 2013). Modern molecular breeding techniques, especially gene editing, have also been proposed as a beneficial tool to enhance genetic diversity (Lassoued et al., 2019), and support conservation efforts of threatened and endangered species (Johnson et al., 2016; van de Water et al., 2022). Despite these promising benefits, the global trend of plant breeding has made a profound impact on the selection of domesticated traits, resulting from modern breeding techniques that focus on producing high-yielding crop varieties, thus threatening the diverse genetic base and crop varieties (Tanksley and McCouch, 1997).

Previous work has reported concerns about the possible impacts of modern varieties on biodiversity hotspots, especially the direct effects on non-target species and the risks of transgenes migrating, contaminating landraces and wild relatives (Quist and Chapela, 2001). Various mechanisms and factors, such as genetic drift, the strength of selective advantage, the rate of migration, epistatic effects, and the interaction between genotype and environment, influence the extent of transgene integration in the local gene pool (Gepts and Papa, 2003). Incorporated traits that are recessive and result in a loss of function or adaptation to cultivated environments may have minimal effects on domestication. However, the introduction of transgenic traits, such as insect resistance, may alter natural biodiversity (Gepts and Papa, 2003).

From the perspective of organic farming communities, the extent to which gene-editing applications can interfere with the natural evolutionary processes and the magnitude of these possible impacts remain unknown. For example, gene editing may result in gene drives to change wild-type alleles into drive-type alleles in a drive/wild-type population, linked to RNA interference (RNAi) that causes gene silencing, or used to modify DNA methylation to change gene expression (IFOAM Working Group on New Plant Breeding Techniques, 2017). These arguments support the decision taken by organic farming communities to oppose the use of gene editing for modern agriculture.

2.3 Social justice

In the context of social justice for new innovations, a distinct set of unintended consequences must be foreseen or anticipated either on crops or farmers, and on the environment in which a specific technology is used. Social justice considerations highlight the fair distribution of benefits and opportunities, which also include equal access to knowledge and technologies among different societal groups, generations, or nations. One example of a legal construct under social justice is plant breeders' rights, which operate within the realms of open innovation for commercial plant breeding. Breeders' rights are granted for food crop varieties that physically exist and allow farmers to legally breed protected varieties (Louwaars and Jochemsen, 2021). Plant breeders' rights were first introduced in the US to provide appropriate compensation for breeders' innovation. However, debates were sparked about patentability and specific rights over plant varieties, which eventually led to the establishment of a sui generis system by European countries, prompting the creation of a "limited breeder's exemption" under the Unitary Patent system to restrict the patent holder's exclusive rights (Jiang, 2020).

Under patent laws, "fundamental biological processes" are excluded from the patentability scope. However, the interpretation of this term is narrow since any breeding techniques or processes that involve human intervention and produce varieties can be patented (Blakeney, 2012). Plant varieties that are developed through natural selection and cross-breeding cannot be patented under the patent laws. Furthermore, under the ruling of Article 53 (a) of the Court of Justice of the European Union (CJEU), novel plant varieties are ineligible for patent protection if the patent claims cover more than one particular variety of plant (Lenßen, 2006). However, plant variety rights and patent protection may be granted to new plant varieties that are modified through gene-editing techniques because the technique can be applied across multiple plant varieties (Jiang, 2020). Indeed, gene editing has already led to an exponential rise in the number of patents in recent years (Brinegar et al., 2017), and this trend has raised concerns about potential social costs due to the monopolization of intellectual property that could impact the profit component of achieving sustainability goals.

Therefore, patent laws are only a partial solution to the problem of gene editing, unless mandated by law. Even if the laws include restrictions on local and international licensing, arbitrary restrictions on patentability are slowed down by bureaucracy and subjected to the voluntary nature of ethical licensing (Feeney et al., 2021). Hence, a government-administered patenting system was proposed as a more transparent and legitimate alternative to ethical licensing (Feeney et al., 2021). In this system, technologies are classified into three categories: those eligible for patenting, those requiring compulsory licensing if they are in the public interest, and those excluded from patentability (e.g., atomic weapons) (Feeney et al., 2021). This patenting system would be more comprehensive and formal, and provide better security and greater legitimacy than private ethical licensing. In the authors' opinions, such inadequate flexibility and legitimacy could arguably be improved through amendment of the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS Agreement, 1994) and equipping the World Trade Organization (WTO) with an ethics advisory committee, as proposed by Feeney et al. (2021). The establishment of this committee could serve to provide recommendations to different WTO signatory countries.

2.4 Moral responsibility of breeders and corporates

People connected to the breeder and those who utilize the breeder's products have a moral responsibility that cannot be fulfilled by following regulations alone. It must start with a virtuous course of action that can be accomplished individually or by a sectoral action directive, such as through product labels or commitment to sustainability. Herein, we emphasize the importance of corporate responsibility, which is a concept that covers concerns for both the environment and people. This includes topics such as child labor in less developed countries and providing adequate wages in a particular region. In 2021, the Organisation for Economic Co-operation and Development (OECD) established voluntary principles for the European Commission to abide by. Yet debates continue over whether to abandon the soft-law approach (Gordon, 2001) in favor of at the very least regulating companies' due diligence in performing such responsibilities (Davarnejad, 2011; European Commission, 2019). Therefore, if regulations serve to establish principles, virtue ethics have been supplanted by deontology and the law, as previously stated. For these principles to be consistent, professionals and the organizations and businesses they work with must demonstrate these virtues. It is possible for biotechnological regulations to be morally responsible if they pay attention to the moral principles and virtues embodied in the regulations for organic sectors. For example, chemical crop protection, restriction in the use of chemical fertilizers, and rejection for genetically modified crops, are all examples of regulations that adhere to these moral principles and virtues (Nawaz et al., 2020). Other industry restrictions have also been implemented, partly due to their philosophy applicable for other farming systems, such as biodynamics.

As for breeders, they have a responsibility to be transparent to customers if they are asked about the breeding methods used when creating new plant varieties. However, a breeder will not be able to fulfil such responsibilities if they grow varieties that are derived from parental lines imported from countries where gene-edited seeds are unregulated, or if edits are introduced into natural populations through cross-bred populations (Louwaars and Jochemsen, 2021). Nonetheless, since new varieties are currently being published (and patented), it is unlikely that the issue of edits will be raised extensively, although if breeding editing becomes widespread, the accountability of breeders may be called into question.

Considering that it is impossible to distinguish between traits inherited by gene-edited crops and traits carried by a natural mutant, the detection and evaluation methods for the identification of a gene-edited crop variety would not be able to provide complete assurances (SER, 2020). The breeding methods employed by a breeder, on the other hand, may be required to be made public. As such, breeders and seed suppliers can demonstrate their commitment to transparency through various means throughout the supply chain. Regulators can consider several options when it comes to labeling gene-editing products as GMOs. An obligatory labeling requirement cannot be implemented because gene editing, especially that derived from site-directed nuclease-1 (SDN-1), is most likely undetectable in the final product, and also breeding uses materials from multiple jurisdictions (European Commission, 2021). For consumers to make their own decisions, mechanisms such as organic certification and private labeling will need to be implemented to protect their freedom of choice. In any case, a disclaimer will always be required regardless of the system used.

Following the criticism that preventative measures cannot be rationally justified, the authors argue in favor of "the ethical obligation to take precautionary measures," provided that there is plausible scientific justification for concern about serious harm to human health or the environment. Debates on biotechnological issues that are based on a purely scientific and risk-based approach have been challenged by Jasanoff et al. (2015), who highlighted that this approach has its own set of limitations to resolve conflicts within human and ecological societies. Instead of focusing on risks, Bechtold (2018) argued for a thorough examination of values, which would allow people to make their own decisions about what is important to them in life. Bechtold (2018) further advocated promoting a dialogue about gene editing in agriculture and its products through food labeling and consumer choice.

From the ethical aspect, when new technologies are developed, we must think about not only whether they are safe to use but also the context in which we plan to use them (Harfouche et al., 2021). In addition to scientific knowledge, it is important to consider how a technology will be used practically and what societal objectives it may advance or undermine (Torgersen, 2009; Harfouche et al., 2021). While technological methods and regulatory policies can adequately investigate and address safety concerns, dealing with ethics and other values requires ongoing communication, tolerance, and the potential for coexistence (Bechtold, 2018). As an example, food labeling can effectively manage a reasonable diversity of valid preferences within society, as long as these preferences are not portrayed as threats to one another (Torgersen, 2009). The impending need to label gene-edited products should be viewed as an opportunity to institutionalize a comprehensive debate about agriculturally relevant values by linking technological knowledge, societal objectives, and individual consumption decisions (Torgersen, 2009).

2.5 Regulations for gene editing

Legal discourses on gene editing have been centered on how to regulate agricultural gene-editing applications within the current biosafety framework while ensuring the safety of people, animals, and the environment. New technological developments such as gene editing have intensified the general debate on "product-based" versus "process-based" regulatory triggers, creating new challenges for regulators to align the current regulatory framework with scientific risk analysis for products derived from emerging biotechnology. Gene-editing technologies, for example, enable scientists to create targeted changes with or without having to insert foreign DNA sequences into the specific gene. The proponents of gene editing regarded that the nature of gene editing is similar to mutagenesis, and therefore, gene-edited products that do not contain foreign DNA sequences in the end product should be exempted from biosafety regulations (Macnaghten and Habets, 2020). In certain countries, regulations for gene-edited products have been clarified and continue to be performed on a case-by-case basis, with exemptions applied to products that do not contain inserted transgenes. Product developers, however, must submit dossiers to regulators for an evaluation of the technical, scientific, and potential environmental impacts of the introduced gene-edited products to determine the exemption status (Vieira et al., 2021).

From the legal point of view, legislation imposed by authorizing governments or international organizations is not the only way to regulate gene editing; patent innovations are enabling new forms of (potential) ethical guidance and regulation in this field. Two groups have obtained original CRISPR-Cas9 patents: Jennifer DOUDNA and Emmanuelle CHARPENTIER of the University of California, Berkeley and the University of Vienna—for general use, and Feng ZHANG of the Massachusetts Institute of Technology (MIT)/Harvard/Broad Institute—for use on eukaryotes, including plants and animals (Feeney et al., 2018). Intellectual property rights in CRISPR technology are increasingly used for "ethical licensing," in which companies impose or prohibit specific practices on their customers (Guerrini et al., 2017). This is made possible and encourages adherence to ethical standards by including ethical restrictions in their licensing agreements. Under ethical licenses, for example, tobacco plants, gene drives, or "terminator" seeds are prohibited from being modified using CRISPR-Cas9 technology (Broad Institute, 2022). The use of this method in human germline modification experiments is also expressly prohibited by the licensing policies of the company that manufactures it, among other things. This occurs regardless of whether it is permitted or sanctioned by local laws. In this context, research by Esvelt (2018) aims to strike a balance between the environmental consequences of this contentious technology and widespread community participation, considering the likely impact on all members of a particular society. Using gene drives as an example, we can see how gene editing can make people concerned about their children's future (in which genetic variants are spread through a population at an increased rate of inheritance). Certain countries like Japan, Argentina, and India have prohibited gene drive projects, while other countries have allowed it, such as the United States, Australia, and New Zealand, but have maintained a stronger regulatory burden to commensurate risks (Kelsey et al., 2020; Genetic Literacy Project, 2022).

Regulatory disparities between countries in regard to GMO rulings, such as those pertaining to gene-editing categories as well as the delayed approval of applications for gene-edited plants, could disrupt international trade (Qaim, 2020). Such obstacles eventually will hamper the local adoption of gene-edited innovations. Furthermore, the lack of international harmonization and standardization of market entry requirements, including labeling, traceability, and segregation, can have a detrimental impact on trade flows (Wray-Cahen et al., 2022). For biotech researchers and developers utilizing gene-editing technology, it is compulsory to comply with the most stringent trading partner rules or develop costly product segregation systems to continue to access international markets. In certain countries, non-harmonized regulatory standards may hinder the domestic use of gene-edited applications. For instance, in the EU, all gene-editing applications are regulated under the biosafety GMO framework (Schmidt et al., 2020), making product segregation challenging, particularly if gene-edited crop products are indistinguishable from traditionally-bred ones.

Effective regulatory strategies should be transparent, science-based, risk-proportionate, and appropriate for the intended use. To foster innovation and build public trust in gene-editing technologies, it is essential for regulatory processes to be effective, credible, and defendable. This can be achieved by setting out more transparent regulatory requirements and processes to provide a clear direction for research and development, as well as for commercial use (Kuzma, 2018). Furthermore, these regulations must be implemented with a better predictability of regulatory cost to promote innovations of gene-editing technology (Whelan et al., 2020). Certainly, the widespread use of gene-editing tools in agriculture, especially by farmers and ranchers, depends on future-proof policies that promote innovations deriving from emerging biotechnologies and allow the use of safe products. The implementation of such regulatory requirements plays a crucial role in determining the accessibility and affordability of gene-edited products and ultimately will have a significant impact on people's livelihoods.

3 Conclusions

Ethical debates over gene-editing regulations reflect the social and normative contexts in which molecular breeding technologies can be accepted. Defending the normative principles, and investigating how lifeworld perceptions and various interests influence the implementation of plant gene editing, are both required (Rippe and Willemsen, 2018).

The ethics of gene editing are influenced by various factors depending on the approach taken. Ecological sustainability is expected to gain from the reduced need for chemicals for crop protection and adapting crops to climate change, both from a utilitarian or consequentialist perspective. Nonetheless, there is a growing awareness of the need to avoid overly expensive risk assessments and an unduly restrictive use of the patent system to ensure long-term sustainability and reduce monopoly power. According to virtue ethics, breeders and chain partners have a moral obligation of openness about their practices. This transparency can be conveyed to consumers via quality marks rather than mandatory product labeling. Meanwhile, both above scenarios necessitate that the limitations imposed by available technology are considered when developing future governance for gene-edited plants.

The regulation of gene-edited products is rapidly evolving, with many countries performing evaluations based on their novel characteristics rather than the processes used to create them. Several countries have approved the commercial use of gene-edited food products, while others are expected to follow suit. With the fast-paced technological development for gene editing and the need to ensure the safety of gene-edited products before they reach the market, as well as the importance to promote innovation that can benefit all stakeholders in current agricultural systems, especially farmers and plant breeders, implementing future-proof biosafety regulations becomes a crucial aspect.

Additionally, we propose that the current discourses on gene-editing technology should incorporate animal welfare in their analysis by comparing the use of gene-editing technologies in a proportionate and subsidiary manner and conducting further research into the various issues raised by the public. By taking a proactive and cross-disciplinary approach, this would allow us to move beyond speculations and fears, and develop a more contextualized and realistic understanding on the ethics of gene editing in our everyday lives (Lucivero, 2016; Jongsma et al., 2018).

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Author contributions

Siti Hafsyah IDRIS: conceptualization, formal analysis, validation, writing – original draft, and writing – review & editing. Nurzatil Sharleeza MAT JALALUDDIN: conceptualization, data curation, formal analysis, funding acquisition, methodology, project administration, validation, writing – original draft, and writing – review & editing. Lee Wei CHANG: formal analysis, validation, writing – original draft, and writing – review & editing. All authors have read and approved the final manuscript.

Compliance with ethics guidelines

Siti Hafsyah IDRIS, Nurzatil Sharleeza MAT JALALUDDIN, and Lee Wei CHANG declare that they have no conflict of interest.

This review does not contain any studies with human or animal subjects performed by any of the authors.

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