Trends in
Plant Science

CellPress

Special issue: Climate change and sustainability II

Forum

Interactive database of genome editing applications in crops and future policy making in the European Union

Oana Dima,[1,2,3,@]
Yana Heyvaert,[1,2,3] and
Dirk Inzé[1,2,*,@]

European R&D in plant breeding is lagging behind, bound by strict genetically modified organism (GMO) regulations, applied to all crop varieties obtained with genome editing techniques. We developed an online database of worldwide genome editing applications in crops to support conclusions and to facilitate science-based policy making for this plant breeding innovation.

Current EU legislation is outdated and hinders agricultural innovation

The transition to sustainability as outlined in the 'European Green Deal' and the 'Farm to Fork' strategy aims to make food and agricultural systems fair, healthy, and environmentally friendly[i,ii]. Over the past 20 years, new plant breeding techniques have become available for which the general term 'new genomic techniques' (NGTs) is now widely being used. According to the EU Commission, NGTs are defined as techniques that are capable of altering the genetic material of an organism and that have emerged or have been developed since 2001, when the current legislation on genetically modified plants in the EU was adopted[iii].

In recent years, NGTs, including the Nobel prize winning CRISPR-Cas genome editing technique, have been adopted worldwide in research and breeding activities because they are much more specific, efficient, and time-saving in the genetic improvement of plants through targeted genetic changes that result in the desired trait compared with other plant breeding techniques[iv]. There are many published studies that demonstrate the potential of genome editing to improve crop yield and quality, as well as to render agriculture more sustainable and climate resilient. Many applications are at precommercial stage in the R&D pipeline but could reach the market in the short term, depending on the regulatory framework [1].

Under the current EU legislation, all crop varieties obtained by using NGTs are subject to strict GMO regulations, which *de facto* prevents the EU from using and cultivating these crops because of the political indecisiveness in the authorisation process [2]. In April 2021, the EU Commission published its study on NGTs and concluded that the current legal framework governing NGTs, including genome-edited crops, is no longer fit for purpose[iii]. Furthermore, the EU Commission proposed to initiate a targeted policy action on plants obtained from certain NGTs, specifically 'targeted mutagenesis' and 'cisgenesis'.

The EU legislation is in strong contrast to the global legislative landscape for genome-edited crops [3,4]. Today, several countries, including Argentina, Japan, the USA, and Australia, have adapted legislations or released guidelines enabling the applications of genome editing techniques and international harmonisation of their policies, while in other countries, such as the UK and China, policy discussions are still ongoing. It has become clear that EU legislation is outdated and needs to be adapted in the light of the current state of scientific knowledge and applications because it blocks agricultural innovation in the EU. Future policy discussions in Europe will involve an impact assessment, including a public consultation on NGTs and their applications[v].

Genome editing is used in a wide variety of crops with benefits for producers and consumers

Decision-making requires a careful balance between scientific evidence and other aspects, such as societal considerations. Therefore, it is of utmost importance to provide up-to-date information about the progress of genome editing applications in plants. To facilitate a more comprehensive understanding of the current and future applications of genome editing in crops, we developed an interactive, publicly accessible online database (https://www.eu-sage.eu/genome-search) of genome-edited model plants and crops for market-oriented agricultural production.

The aim of the database is to inform interested stakeholder communities, including civil society, in a transparent manner about the available state-of-the-art evidence about genome editing applications in crops. Different elements, including the plant species, traits, techniques, and applications, can be filtered in the database, which will help to address specific questions and to support conclusions relevant in future policy discussions about this plant breeding innovation. The categories for each of these elements can be filtered in the database, which is accessible online.

In the mapping period between January 1996 and March 2022, more than 500 genome editing applications were compiled. Interestingly, NGTs have been used in 63 different crops, with the vast majority in rice (*Oryza sativa*), tomato (*Solanum lycopersicum*), maize (*Zea mays*), soybean (*Glycine max*), and wheat (*Triticum aestivum*) (Figure 1). The applications in the database revealed as well that genome editing has been used to improve minor and even orphan crops as well as a broad range of

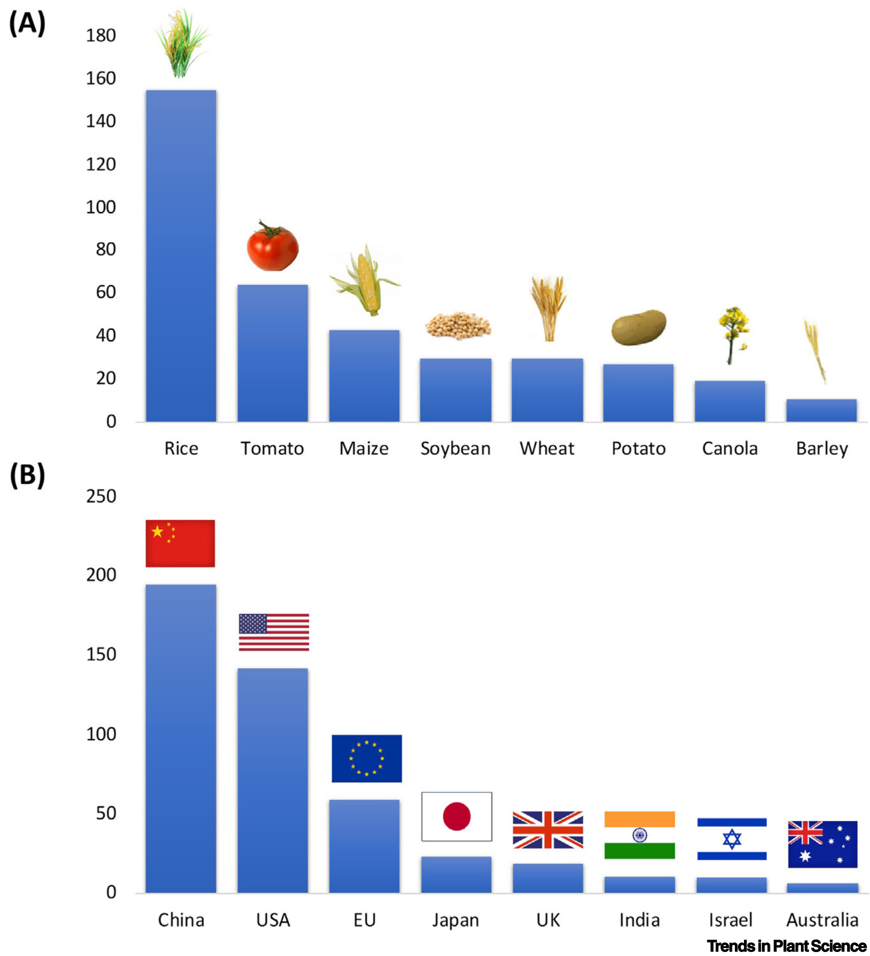

Figure 1. Distribution of genome editing applications according to crops (A) and to the country of origin (B) in the period 1996–2021. The country of origin is deduced from the country where the developer was affiliated.

a small genetic change to the insertion of large pieces of genetic material, such as a complete gene[vi]. Genetic changes resulting from a genome editing technique are grouped into three different categories, which are being referred to as site-directed nuclease (SDN) 1–3 types [5]. Most of the genome-edited crops contain specific, small genetic changes that belong to the SDN1 category and are referred to by the EU Commission as 'targeted mutagenesis'[iii]. These targeted genetic changes do not differ from the changes that can occur spontaneously in nature or as a result of conventional breeding techniques[vii].

vegetables. Most of the genome-edited crops have been developed in China and the USA, however, R&D using genome editing techniques occurs worldwide (Figure 1). In the EU, the highest number of applications originate from Germany and France.

The majority of traits constitute three categories: (i) improved quality of the plants for food and feed production; (ii) improved agronomic traits that relate to plant yield and growth in order to improve productivity, or avoid preharvest losses; and (iii) improved resistance against diseases, which will reduce the need to apply plant protection products in agricultural production (Table 1). In addition, important traits for industrial applications, such as biofuel production and nitrogen use efficiency, have been introduced in crops as well.

Most of the genome editing applications have been developed with the use of CRISPR-Cas because it is more versatile compared with other genome editing techniques and can be very easily customised to introduce specific, small genetic changes in plants. Depending on the genome editing technique, the change in the genetic material of the plant can vary in proportion from

Science-based policy making: the way forward

Genome editing techniques are promising tools in plant breeding and are of particular relevance to researchers, breeders, and farmers but also to policy makers taking into account the broader agricultural policies and future challenges. Policy makers depend on the provision of a reliable body of scientific evidence to draw and support conclusions about genome editing applications. An interactive, publicly accessible, and updated database can help to provide an overview of the available evidence and to facilitate objective debates by informing interested stakeholders in a transparent manner about the status and progress of research.

The genome editing applications compiled in the database revealed the rapid adoption of genome editing in research activities and plant breeding by the considerable number of market-oriented applications across the world. Genome editing was already applied in 63 different crops. Diverse market-oriented applications were identified in a wide range of species, resulting in crops with improved traits ranging from disease resistance to storage performance and food or feed quality. Nearly 90% of the genome editing applications are crops improved with the CRISPR-Cas genome editing technique. The majority of genome

Table 1. Distribution of genome editing applications according to different trait categories in the period 1996–2021

Trait categories	Description	%
Improved food/feed quality	Modified composition of components such as vitamins, toxic substances, starch, oil, proteins, fibres, allergens, etc. to improve nutritional value.	25
Plant yield and growth	Increased yield related to photosynthetic efficiency, to fruit size or weight, or to increased number of flowers, seeds, and fruits. Improved plant architecture, for example, plant height and shape, growth pattern, and fruit shapes.	22
Biotic stress tolerance	Resistance to plant diseases caused by bacteria, viruses, fungi, pests, pathogens, or nematodes.	18
Industrial utilisation	Applications of industrial interest such as breeding tools, biofuel production, nitrogen use efficiency, etc.	14
Herbicide tolerance	Tolerance of plants to various types of herbicides.	8
Abiotic stress tolerance	Resistance to abiotic stress factors such as drought, heat, cold, salt, water excess, and UV radiation.	5
Product flavour/colour	Modified flavour or colour.	5
Storage performance	Improvement of storage characteristics such as increased shelf-life, altered storage requirements, non-browning properties, and reduced black spots.	3

editing applications are crops with targeted, small genetic changes.

The many applications in the database demonstrate that genome editing can contribute to the 'EU Green Deal' and the 'Farm to Fork' strategy by enabling the possibility of reaching diverse sustainability breeding goals in a much more targeted and efficient manner. However, R&D in Europe is lagging behind compared with China and the USA, mainly due to current EU legislation, which determines that all crop varieties obtained by using NGTs are subject to strict GMO regulations. It has become clear that the EU legislation needs to be updated in the light of the current state of scientific knowledge and applications because it prevents agricultural innovation in the EU. A consistent and legally effective framework, as already is in place in many other areas of the world, will foster the development of genome-edited crops for the EU market by universities, academic research centres, and the plant breeding sector.

Declaration of interests

No interests are declared.

Resources

[i]https://ec.europa.eu/food/farm2fork_en

[ii]https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[iii]https://ec.europa.eu/food/plant/gmo/modern_biotech/new-genomic-techniques_en

[iv]www.nobelprize.org/prizes/chemistry/2020/summary/

[v]https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13119-Legislation-for-plants-produced-by-certain-new-genomic-techniques_en

[vi]www.biosafety.be/content/targeted-genome-editing

[vii]https://gmo-crl.jrc.ec.europa.eu/doc/JRC116289-GE-report-ENGL.pdf

[1]Department of Plant Biotechnology and Bioinformatics, Ghent University, (Technologiepark 71), 9052 Ghent, Belgium
[2]VIB Center for Plant Systems Biology, (Technologiepark 71), 9052 Ghent, Belgium
[3]These authors contributed equally to this work.

*Correspondence:
dirk.inze@psb.vib-ugent.be (D. Inzé).
[@]Twitter: @Oana__Dima (O. Dima) and @InzeDirk (D. Inzé).

https://doi.org/10.1016/j.tplants.2022.05.002

References

1. Parisi, C. and Rodriguez Cerezo, E. (2021) *Current and Future Market Applications of New Genomic Techniques*, Publications Office of the European Union
2. Purnhagen, K. and Wesseler, J. (2021) EU regulation of new plant breeding technologies and their possible economic implications for the EU and beyond. *Appl. Econ. Perspect. Policy* 43, 1621–1637
3. Schiemann, J. *et al.* (2021) Policies and governance for plant genome editing. In *Plant Biotechnology* (Ricroch, A. *et al.*, eds), Springer
4. Dima, O. and Inzé, D. (2021) The role of scientists in policy making for more sustainable agriculture. *Curr. Biol.* 31, R218–R220
5. Podevin, N. *et al.* (2013) Site-directed nucleases: a paradigm shift in predictable, knowledge-based plant breeding. *Trends Biotechnol.* 31, 375–383