Article

CRISPR in Wheat: Patents, Breeding Advances, and Emerging Challenges

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Abstract: CRISPR and its derivatives, such as prime editing and base editing, have a significant potential for precision biology in plant breeding, particularly in wheat. This technology can help develop climate-resilient wheat varieties, improve stress tolerance, enhance nutrient use efficiency, and increase yield potential. However, the concentration of CRISPR patents in a few academic institutions and corporations in the Global North creates a "Genome Editing Divide," impacting innovation pathways, research incentives, economic power in the seed value chain, and global food sovereignty. This study explores the implications of this divide on wheat innovation systems in the Global South and argues that the current intellectual property (IP) landscape favors privatization and profit-maximization over public good-oriented research, potentially undermining food security and sustainable development goals. Alternative governance models and licensing frameworks are proposed to ensure equitable access to CRISPR technology for wheat breeding, aiming to safeguard global food security and reduce inequalities in agricultural innovation. The analysis shows a concentration of research output in the Global North, particularly in countries like Switzerland and UK. This indicates a form of digital colonialism, restricting the Global South's ability to develop locally adapted, climate-resilient wheat varieties. The patent network reveals a concentration of power among key institutions, limiting access to essential technologies for wheat improvement and reinforcing the "Genome Editing Divide.

Keywords: CRISPR patents; wheat breeding; genome editing; intellectual property

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1. Introduction

Wheat (*Triticum aestivum* L.) is one of the three globally dominant cereal crops and a cultural and nutritional-economic foundation that provides approximately 20% of worldwide calorie and protein intake. Besides being an agricultural crop, wheat is an archaeological artifact of human domestication, a driving factor of geopolitical stability, and an indispensable pillar of global food security (Shewry and Sandra J. Hey 2015). The projected harvest losses due to the climate changes, the growing scarcity and degradation of water resources, the evolution of high-virulence pathogen strains, and soil erosion are key challenges to the global wheat production architecture (IPCC 2022). Conventional phenotype-based selection, despite the integration of molecular markers (Marker-Assisted Selection, MAS), has biological limits and temporal bottlenecks and cant yield the demanded traits.

CRISPR technology with the original ethos of democratizing genome editing is a comparatively cost-effective, highly precise, and – in its forms classified as SDN-1 and SDN-2 (Site-Directed Nuclease 1&2) – for precise mutagenesis for a broad spectrum of actors (Jinek, Krzysztof Chylinski, and Ines Fonfara et al. 2012). CRISPR has accelerated development of climate-resilient varieties with improved drought and heat stress tolerance, the establishment of broad-spectrum and durable resistance against emerging pathogen strains (such as the Ug99 stem rust lineage, Puccinia graminis f. sp. tritici), the optimization of nutrient use efficiency (nitrogen, phosphorus), and the enhancement of yield potential under marginal agro-ecological conditions.

However, its benefits have not neem explored properly due to the structural reality of an intensive, capital-driven patent dynamics. Current study unfolds the control architecture through relevant, multi-layered patent landscape and its licensing logics highlighting the immediate socio-economic, research-practical, and development-political impacts of this control architecture on the wheat innovation systems of the Global South. CRISPR as a strategic asset and instrument of national and regional power projection in the global agricultural competition has also been discussed. Critical discussion of counter-models and reform pathways, before a synthesizing conclusion consolidates the central findings, highlights the overarching implications, and ventures a normative outlook on the necessary redesign of innovation governance.

2. CRISPR Patents as Control Architecture

Proprietary control over CRISPR technologies is not a monolithic block but rather a highly complex, dynamic, and multi-layered network of fundamental composition, improvement, and application patents. Their detailed analysis will help understand the actual levers of economic and innovative power (Sherkow 2017).

2.1 The Fundamental Patent Families and the "CRISPR War"

Two primary legal entities dominate the fundamental patent landscape and were involved in a years-long, highly publicized conflict (Cohen 2017). The patent family held by the University of California, Berkeley, the University of Vienna, and their licensee Caribou Biosciences is based on the seminal work of Jennifer Doudna and Emmanuelle Charpentier on the in vitro functionality of the CRISPR-Cas9 system (Jinek Krzysztof Chylinski, and Ines Fonfara et al. 2012). The competing family is held by the Broad Institute, the Massachusetts Institute of Technology (MIT), and Harvard University, derived from Feng Zhang's work on the first demonstration of functionality in eukaryotic cells (Cong Ann Ran, David Cox, Shuailiang Lin, and Robert Barretto et al. 2013).

The intense patent dispute, the "CRISPR War," revolved primarily around the question of priority and scope of the invention for applications in eukaryotic cells – the relevant cell type for plants, animals, and humans. While the United States Patent and Trademark Office (USPTO) in several interference proceedings largely decided in favor of the Broad Institute, awarding it the priority patents for eukaryotic applications, the European Patent Office (EPO) and other important jurisdictions such as China and the United Kingdom ruled in favor of the Doudna/Charpentier camp, granting them broad patents (Sherkow 2021). Partial resolution of conflicts through comprehensive cross-licensing agreements between the core institutions themselves – for example, between Broad and Caribou did not eliminate this uncertainty for external third parties. Rather, it increased access barriers for outsiders, as licenses from both camps may now potentially be required to achieve global Freedom-to-Operate (FTO).

2.2 The Second and Third Wave of CRISPR Patents

Beyond the basic patents, a highly dynamic race to improve, specialize, and circumvent the original technology has emerged, creating several new, strategically significant layers of proprietary rights. The discovery and development of alternative CRISPR systems (e.g., Cas12a/Cpf1, with different PAM sequences; Cas13 for RNA targeting; or smaller Cas variants such as CasΦ for better delivery into plant cells) has opened new spaces not covered by the basic patents. Leading patents in this area are held by institutions such as the Broad Institute, Caribou Biosciences, Rutgers University, or specialized biotech start-ups (Zetsche Jonathan S. Gootenberg, Omar O. Abudayyeh, Ian M. Slaymaker, and Kira S. Makarova et al. 2015). These "circumvention patents" are of enormous strategic value. These more precise second- and third-generation technologies enable targeted point mutations (C-to-T, A-to-G) or small insertions/deletions without generating double-strand breaks, which can increase efficiency and reduce unwanted off-target effects (Anzalone Peyton B. Randolph, and Jessie R. Davis, et al. 2019). They are particularly of decisive interest for the precise correction or modification of polyploid genomes such as that of hexaploid wheat. The leading patents in this area are concentrated at the Broad Institute (Base Editing) and Prime Medicine (Prime Editing).

Composition patents ("Trait Patents") is the fastest-growing layer. It encompasses patents on the editing of specific gene loci or genomic regions associated with agronomically valuable traits. Examples include genes for disease resistance (the Sr, Lr, Yr genes for stem, leaf, and yellow rust), drought tolerance (e.g., genes of the DREB family), nitrogen efficiency, or baking quality (gliadin/glutenin genes). These patents are increasingly filed by the major integrated agricultural companies such as Bayer (after acquiring Monsanto), Syngenta (ChemChina), Corteva Agriscience, and BASF, thereby securing exclusive "Freedom-to-Operate" (FTO) for specific, commercial pipeline products and excluding competitors (Lusser Claudia Parisi, Diego Plan, and Emilio Rodríguez-Cerezo 2012).

2.3 Licensing, "FTO Trap," and the Costs of Uncertainty

The licensing regime follows no uniform, transparent logic, thereby reinforcing the market power of established actors. While the major "Big Ag" corporations through comprehensive, bilateral cross-licensing agreements, grant each other access to their entire patent portfolios creating internal FTO, all external actors. However, public universities, small and medium-sized enterprises (SMEs), and research institutes in developing countries face an opaque, costly, and legally risky jungle (Graff, David Zilberman, and Alan B. Bennett 2019).

For a public breeding institute in Kenya (e.g., the Kenya Agricultural and Livestock Research Organization, KALRO) or Pakistan (e.g., the Wheat Research Institute, Ayub Agricultural Research Institute) seeking to develop a drought-tolerant wheat variety using CRISPR, the FTO analysis is a legal, administrative, and financial nightmare. It must be clarified whether the specific Cas variant used (e.g., SpCas9, Cas12a), the specific transfection or transformation procedure for wheat protoplasts or immature embryos, the promoter sequence used to express the CRISPR components, and the target gene locus itself are claimed by still-valid third-party patents. The costs for a comprehensive, legally binding FTO analysis by specialized patent law firms and subsequent license negotiations often far exceed the entire annual research budget of such programs. This is a de facto barrier that effectively stifles innovation at its inception, even before it can practically begin in the laboratory (Louwaars, and Bram De Jonge, et al 2022).

3. Wheat-CRISPR Research Landscape (2021–2025)

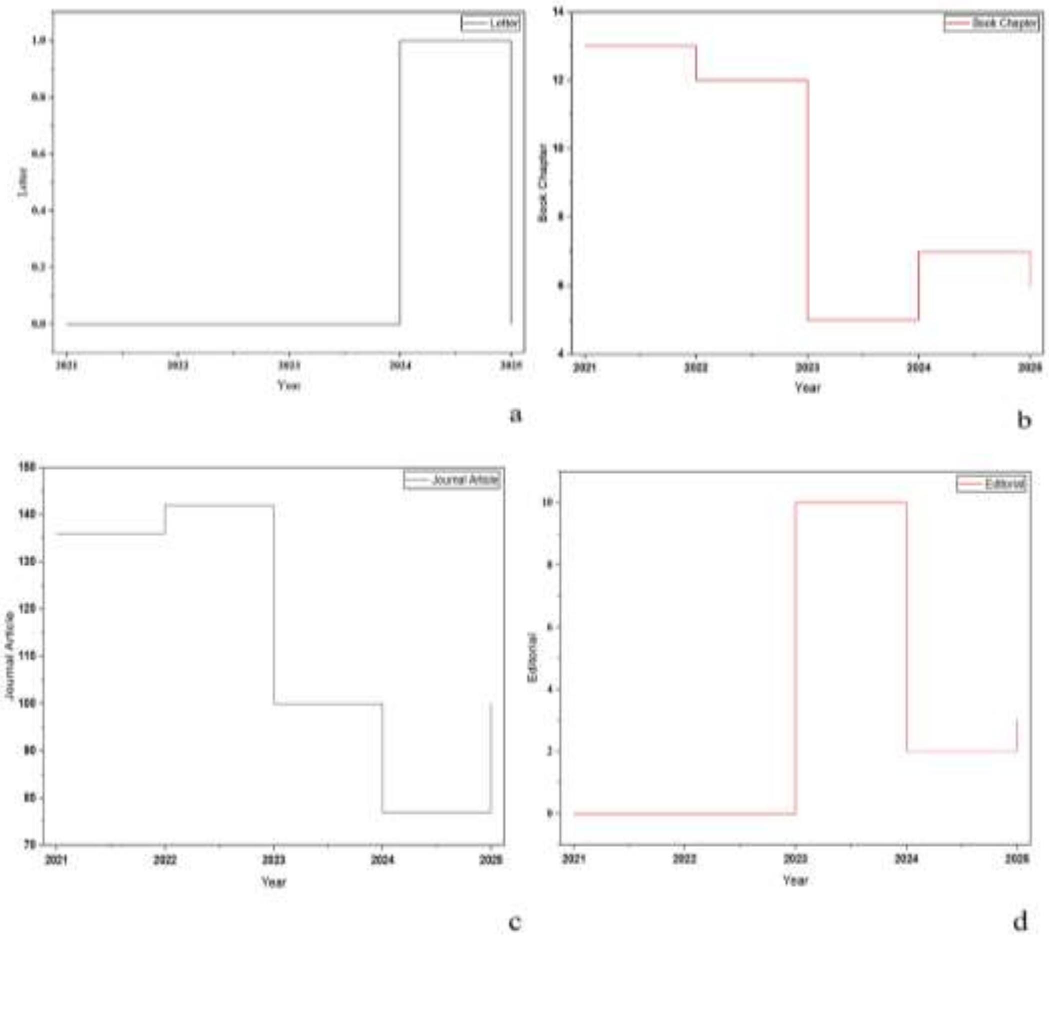
Bibliometric and tech-mining analysis were employed to systematically organize the current knowledge in this field. Data was gathered from lens.org, a database containing scholarly records and patents, using the Python-based graphical application Tech-Miner. Lens.org provides robust text analysis, keyword support, and studies on thematic evolution. Specific keywords such as Wheat

AND Triticum aestivum AND food AND agri-food AND genome-editing AND CRISPR AND CRISPR/Cas9 were used for systematic literature retrieval, limited to publications from 2021 to 2025. Data cleaning and author disambiguation were conducted in TechMiner to eliminate duplicates, address variations, and standardize metadata. Basic analysis included frequency distribution of countries, patents, journals, citation counts calculations, keyword clustering, mapping network of citing countries, and identification of emerging trends to track thematic evolution over the study period (2021 to 2025) (Velasquez 2023). Technical life cycle analysis was performed using S-curve method to predict the trends of technology evolution. The S-curved method employed in this study is Logistic curve method:

$$P(t) = \frac{k}{1+e^{-\alpha(l-\beta)}} \qquad (1)$$

3.1 Journal Publications Analysis

The bibliometric analysis reveals that the publication volume is dominated by journal articles, peaking at 142 publications in 2022, and remained the primary medium for high-impact innovation until 2025 (Figure 1a to 1i). This dominance is also evident in the heatmap with dendrogram, where journal articles are depicted as high performers (green color), while preprints and book chapters are shown as low impact (red color) (Figure 2). Geographical analysis reveals a high concentration of research output in the Global North, particularly in countries like Switzerland and the United Kingdom, with significant publication counts reaching up to 84 and 35 publications in peak years. In contrast, wheat-dependent countries in the Global South, such as Egypt, Nigeria, and Bangladesh, have minimal output. This data indicates that transformative precision biology research is primarily limited to specific geographic regions. This concentration is a form of colonialism, where the tools essential for global food security are controlled by a few powerful regions, restricting the ability of the Global South to develop locally adapted, climate-resilient wheat varieties (Figure 4). The journal article network indicates that China and the United States are the primary drivers of wheat CRISPR editing research. The US is the scientific origin, while China is the production powerhouse with a large number of application-based articles. The UK, Australia, and Germany act as knowledge bridges, connecting research groups and facilitating the transfer of CRISPR protocols across different regions of the world. The peripheral position of the Global South, such as India, highlights the divide in genome editing and institutional connectivity (Figure 4). Keyword analysis indicates a thematic evolution and a shift towards the Anthropocene (2021-2025). The field has progressed from basic methodology to climate-responsive treatments. The heatmap with dendrogram illustrates this transition. The core term CRISPR and genome editing remain highly significant and intense. Recent years have seen a focus on abiotic stress, salt tolerance, and food fortification, signaling a shift towards climate-resilient varieties. However, the low intensity of orphan traits and food system-related keywords suggests a global research agenda that prioritizes commercial traits over the needs of smallholder farmers (Figure 5).



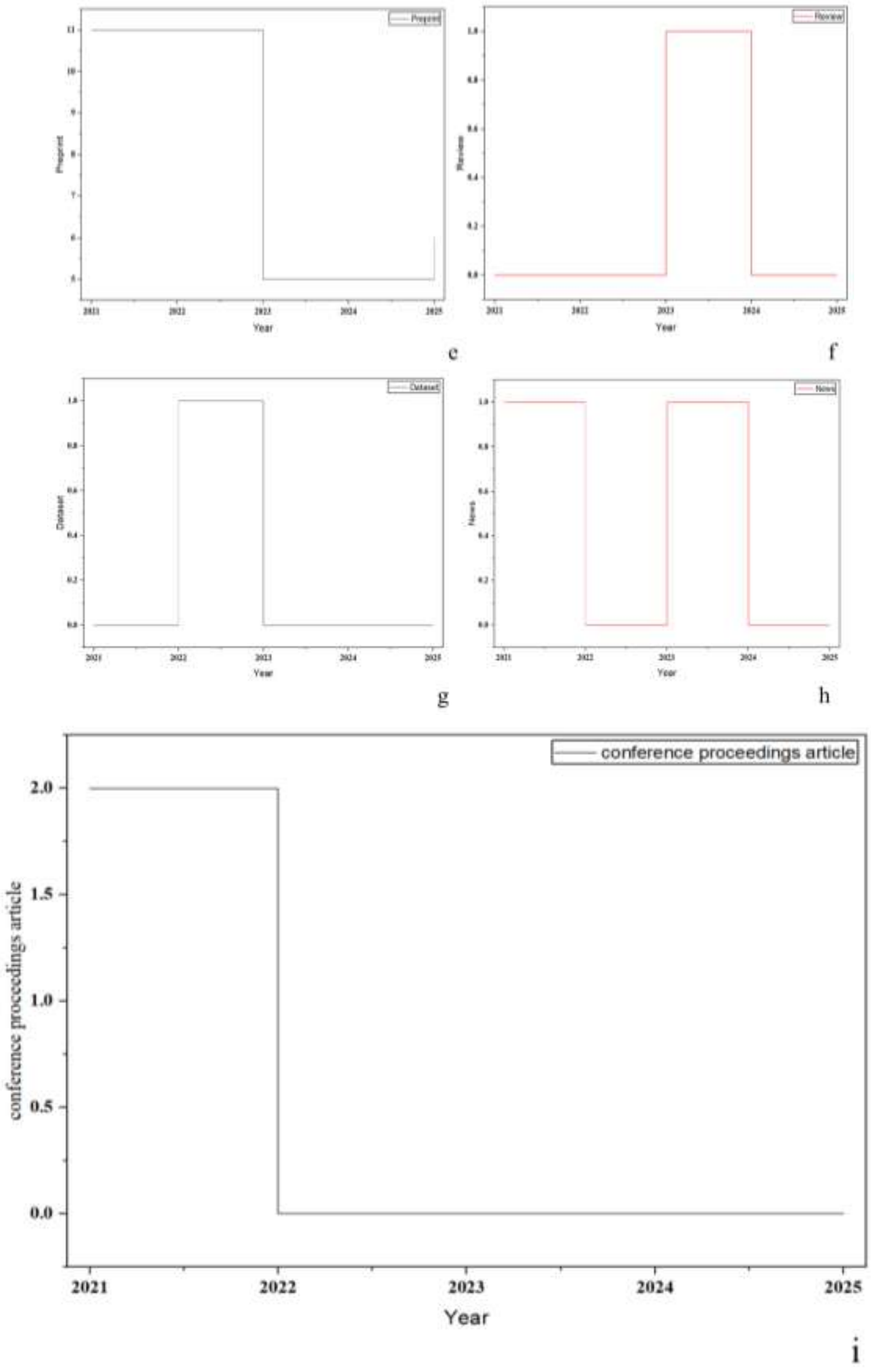


Figure 1. Bibliometric analysis showing volume a) letter b) book chapter c) journal article d) editorial e) preprint f) review g) datasets h) news and i) conference proceedings articles (2021-2025).

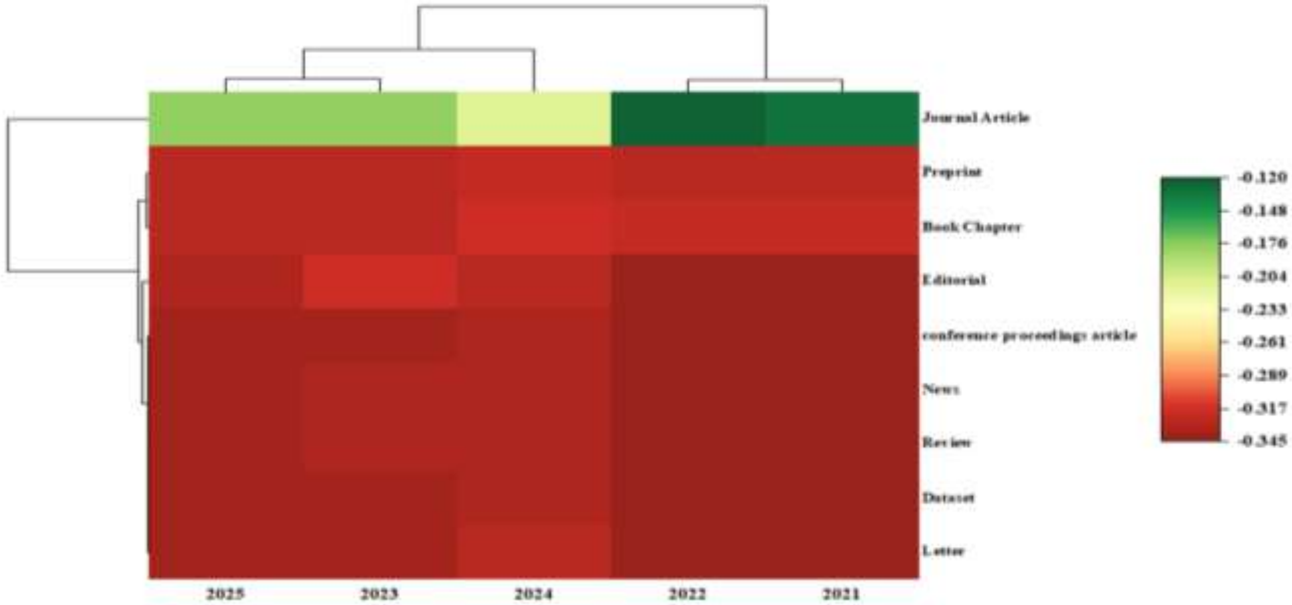


Figure 2. Publication performance matrix (2021-2025).

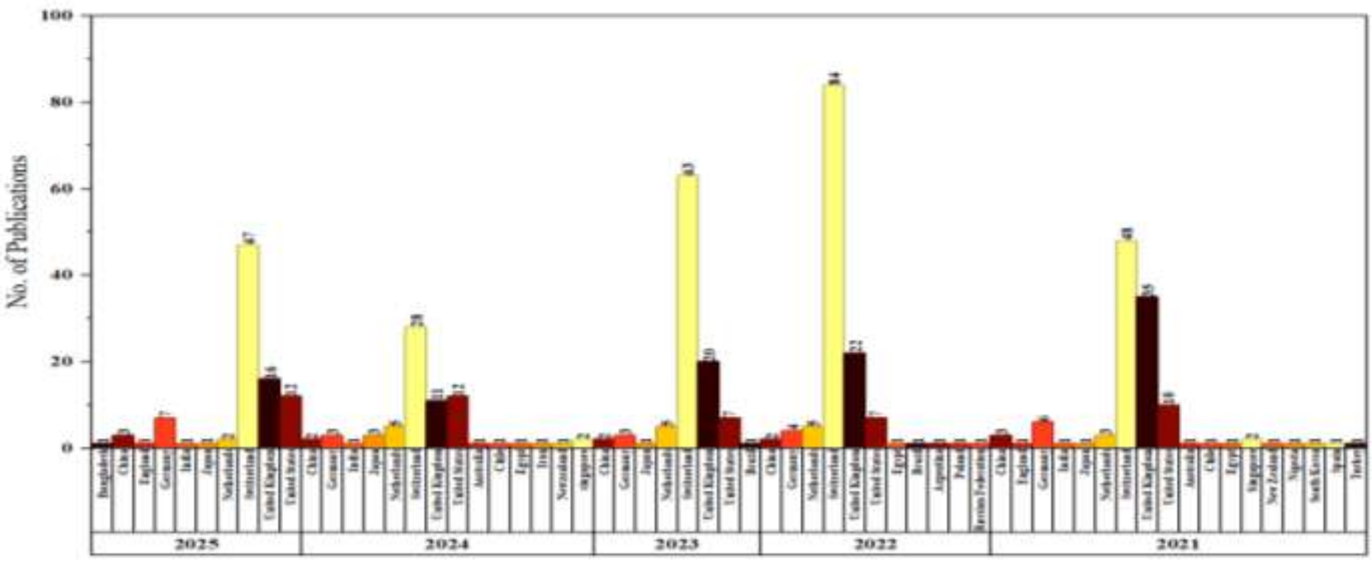


Figure 3. Annual Publication Trend (2021-2025).

3.2 Patents Analysis

The annual trend data for patent publications confirms the genome editing divide by the geographical and institutional isolation of patents. Annual patents increased from 128 in 2021 to 189 in 2025 (Figure 6 and 7), with the majority still originating from the Global North. This is further emphasized by the limited participation of wheat-dependent nations in the Global South, which are also excluded from patent cycle. The annual patent publication trend for CRISPR-Wheat shows peak in 2022 indicating an aggressive acquisition of intellectual property (IP) for manipulating the hexaploidy genome, leading to a second wave of innovation focused on climate-resilient traits and alternative enzymatic systems. This resurgence is geographically and institutionally isolated, with journal articles dominating over secondary literature. This suggests that high-value patent priority claims are still being validated within an elite scholarly circle. This indicates that the rights to the second green revolution are controlled by actors in the Global North, while the Global South remains passive consumer (Figure 8 and 9). The patent bibliometric network provides a visual representation of the legal landscape of wheat CRISPR research, illustrating how collaborative research findings from journal articles have evolved into a structure of control characterized by proprietary exclusion. The scientific article network demonstrates widespread knowledge diffusion and global co-authorship, while the patent network reveals a concentration of power among a few key institutions, notably the Broad Institute and MIT, who control foundational tools through extensive patent portfolios, including 416 filings for CRISPR-related patents. This network analysis highlights a "genome editing divide," with the United States holding a dominant position with 118 patents in 2025, creating barriers for other nations to access essential technologies and potentially leading to costly freedom-to-operate (FTO) challenges. Table 1 highlights the concentrated control of CRISPR technology by elite institutes such as the Broad Institute, MIT, and Harvard. These institutes dominate key patent clusters, limiting access to essential tools for wheat improvement. Companies like Pioneer Hi-Bred (301) and KWS Saat (299) control specialized modifications, creating barriers for global researchers. This dominance creates challenges for public breeding programs in the Global South.

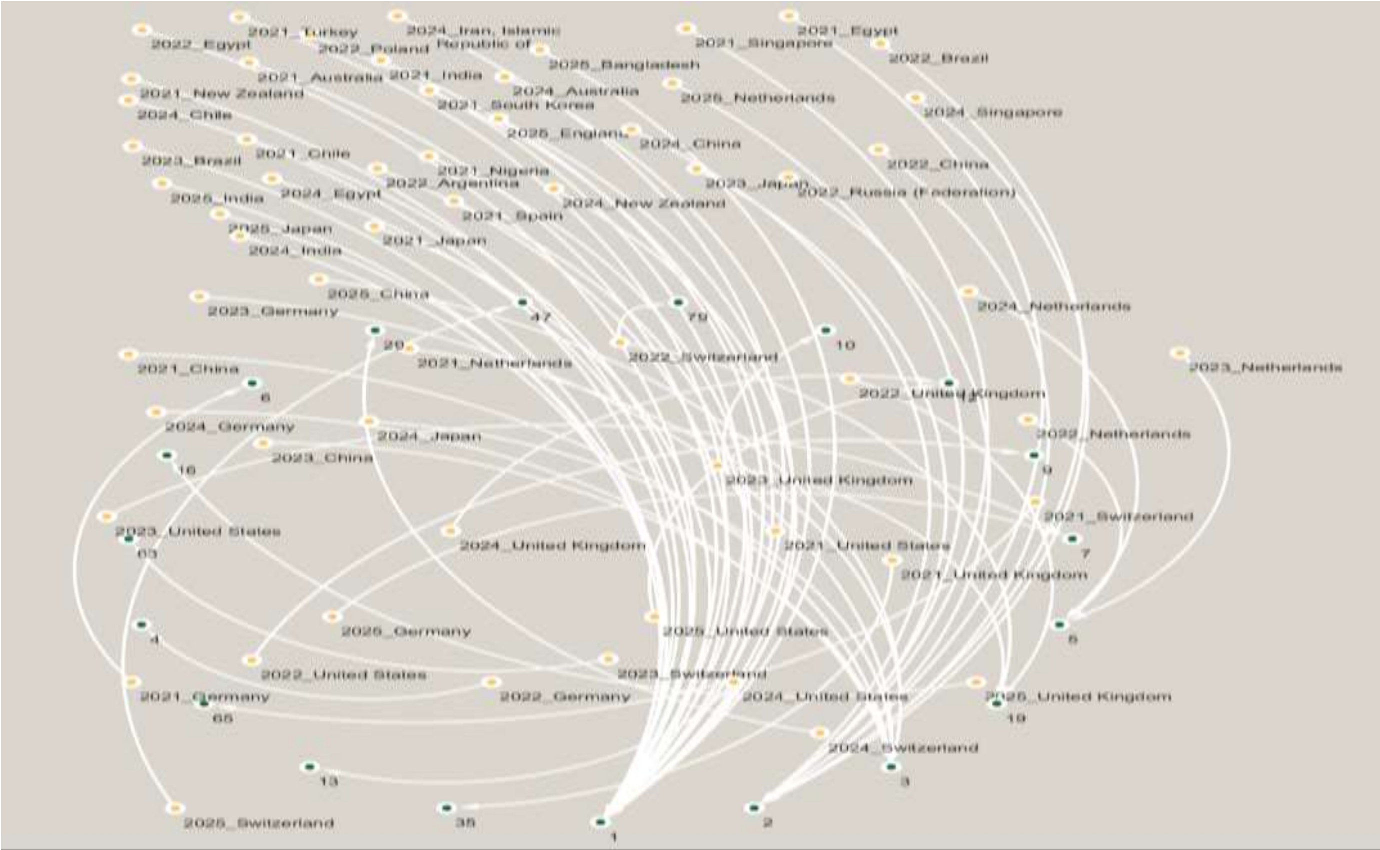


Figure 4. Bibliometric network analysis of global CRISPR-wheat research from the past five years (2021- 2025). Node size indicates the number of scientific publications per country, edge thickness indicates the strength of co-authorship.

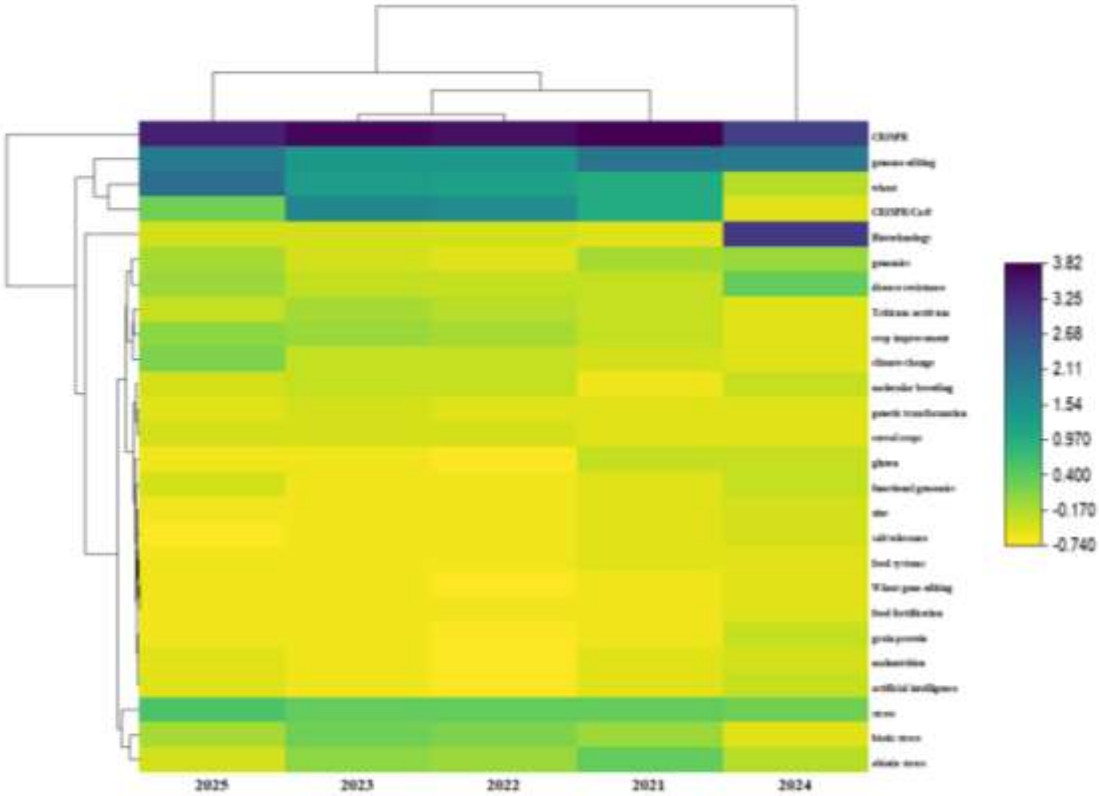


Figure 5. Keyword intensification and emergent clusters (2021-2025).

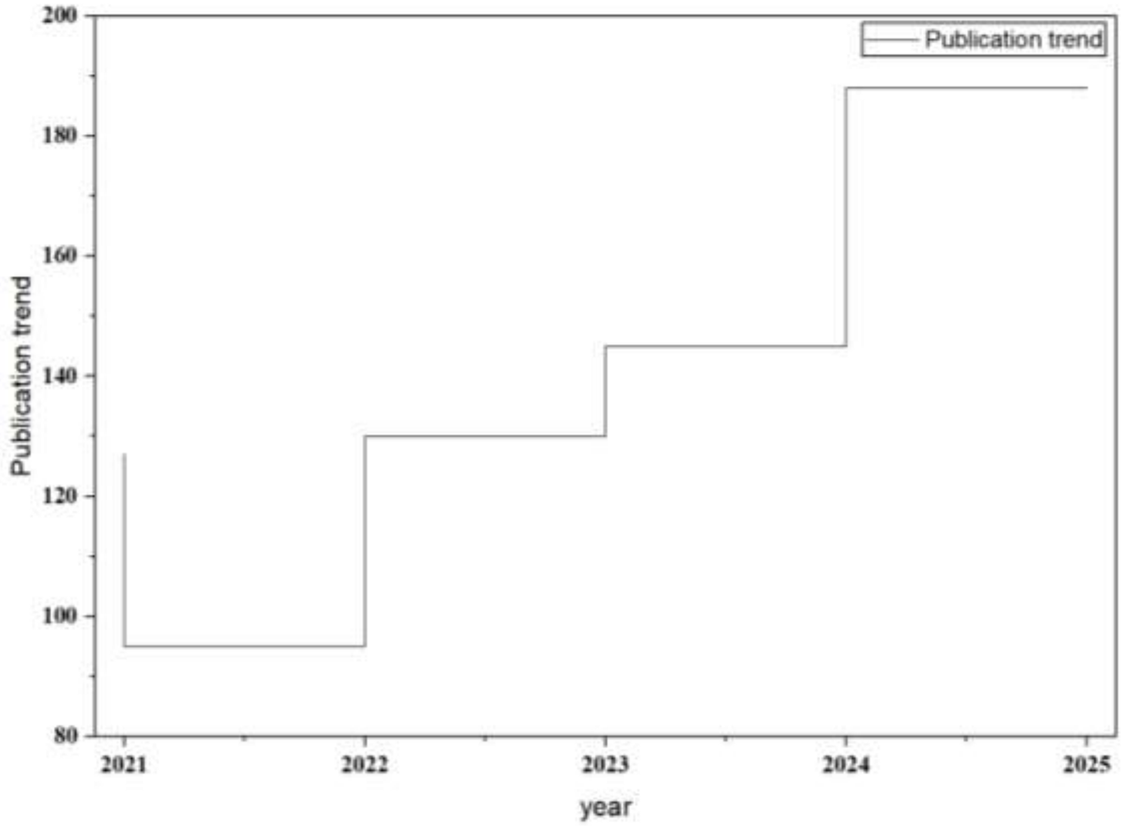


Figure 6. Annual Patent publication trend on Wheat-CRISPR (2021- 2025).

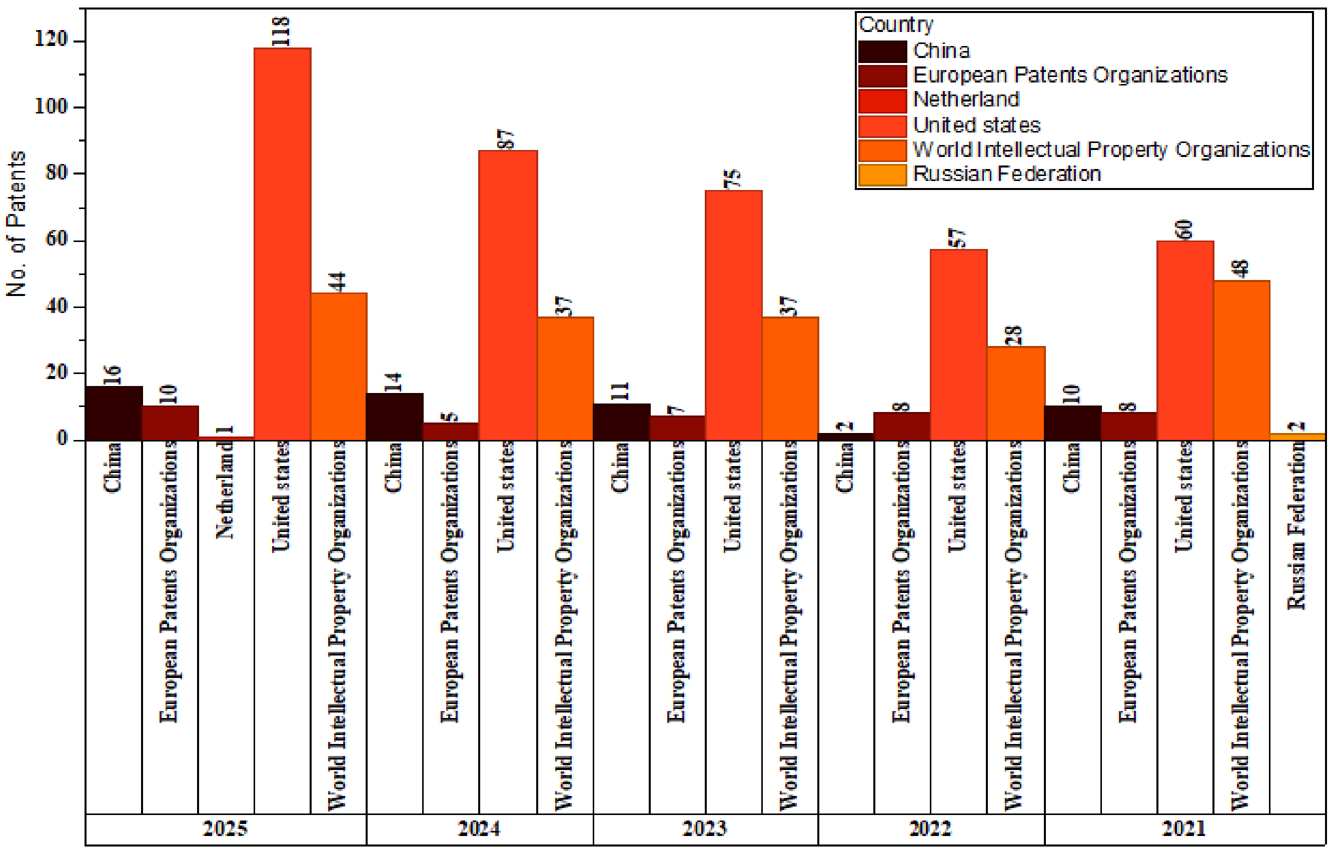


Figure 7. Global Annual Patent publication trend of Wheat-CRISPR (2021- 2025).

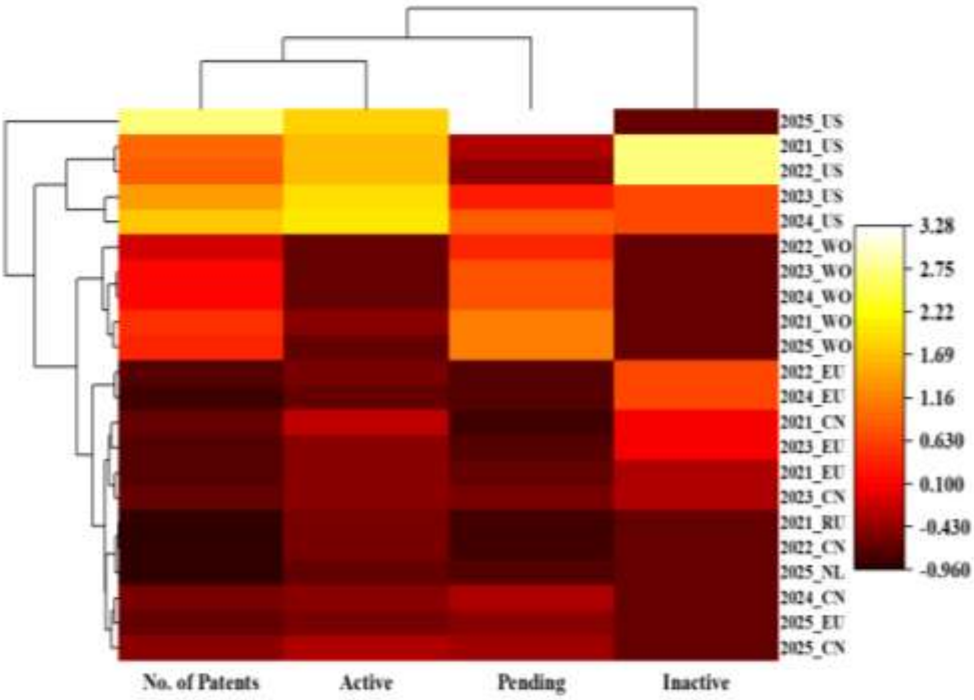


Figure 7. Worldwide distribution of Wheat CRISPR patents (2021- 2025).CN: China; EU: European Patents Organizations; NL: Netherlands; US: United states; WO: World Intellectual Property Organizations; RU: Russian Federation.

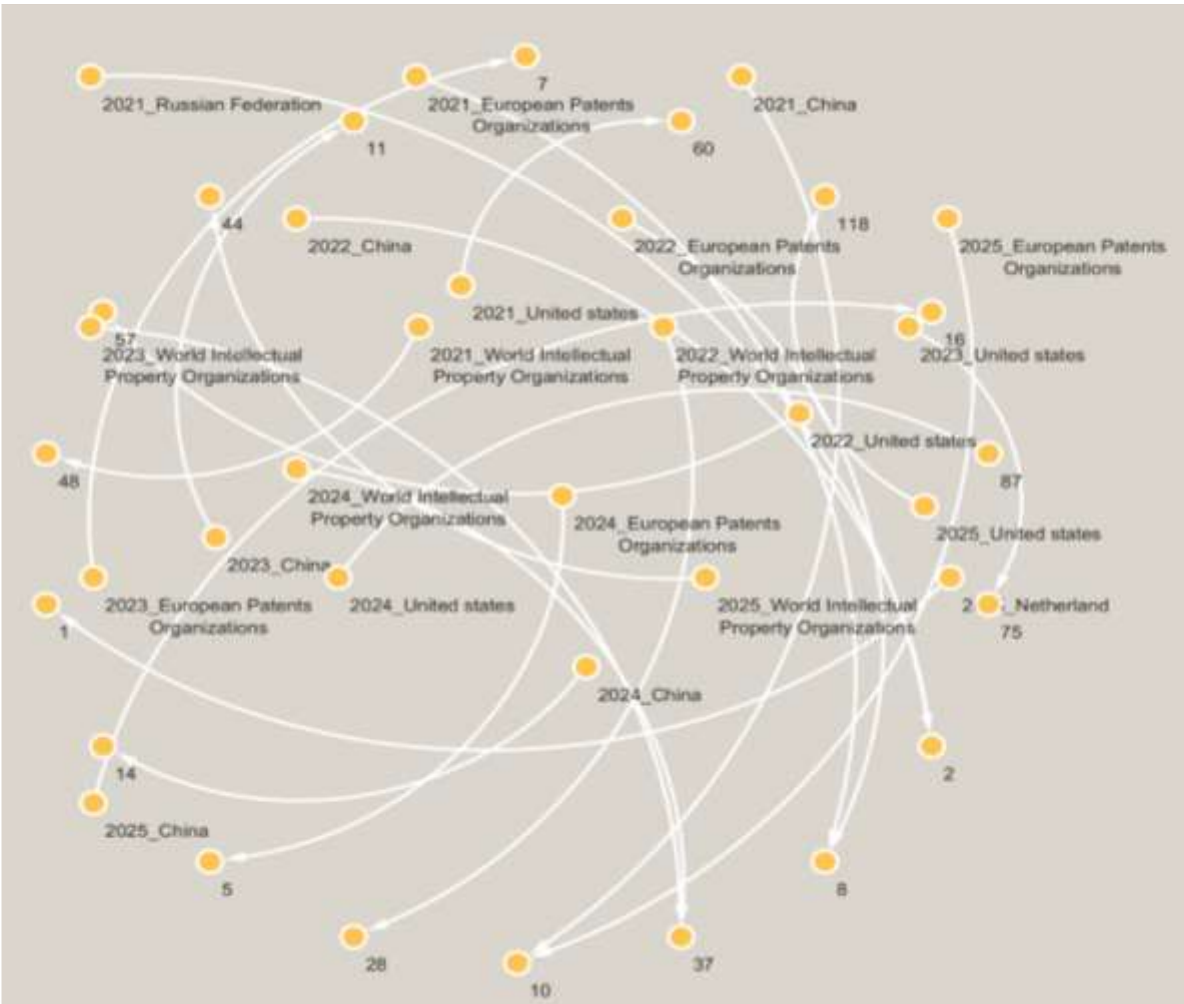


Figure 8. Patent bibliometric network analysis of global CRISPR-wheat research from the past five years (2021-2025). The nodes represent patent assignees, and the edges represent citation relationships.

Table 1. Top 10 High-Impact Patent Clusters.

Title	Assignees	Number
CRISPR-associated mu transposase systems.	Broad Inst Inc; Massachusetts Inst Technology (WIPO).	416
Systematic screening and mapping of regulatory elements in non-coding genomic regions, methods, compositions, and applications thereof.	Broad Inst Inc; Harvard College; Massachusetts Inst Technology (US).	398
Non-class I multi-component nucleic acid targeting systems.	Broad Inst Inc; Brigham & Womens Hospital Inc; The Brigham And Womens Hospital Inc (US).	362
Random CRISPR-Cas deletion mutant.	Broad Inst Inc; Dana Farber Cancer Inst Inc (US).	352
dead guides for CRISPR transcription factors.	Pioneer Hi Bred Int (US).	301
Methods and compositions for RNA-directed target DNA modification and for RNA-directed modulation of transcription.	Kws Saat Se & Co Kgaa; Univ Leicester (European Patents Office).	299
Escorted and functionalized guides for CRISPR-Cas Systems.	Broad Inst Inc; Massachusetts Inst Technology; Harvard College (US).	282
degradation domain modifications for spatio-temporal control of RNA-guided nucleases.	Broad Inst Inc; Massachusetts Inst Technology (US).	277
Methods and compositions for optochemical control of CRISPR-CAS9.	Kovarik Joseph E; Kovarik Katherine Rose; Seed Health Inc (US)	259
DNA damage response signature guided rational design of CRISPR-based systems and therapies.	Broad Inst Inc; Massachusetts Inst Technology; Harvard College (US).	256

3.3 Technical life cycle analysis (LCA)

A significant transformation in wheat research was observed through logistic growth analysis from 2021 to 2025 (Table 2). The analysis revealed that CRISPR and genome editing have transitioned from an emerging phase to a dominant growth stage, with a high growth rate (r=1.2) and an estimated saturation point (k=250), indicating that genome editing is driving modern wheat innovation and reducing reliance on traditional practices. Contrarily, fields such as breeding and agronomy have reached maturity or saturation, as evidenced by a post-peak decline and erratic growth due to technological stagnation. Additionally, disease resistance is undergoing a renewed growth phase, with an inflection point observed at the end of 2024, suggesting that the scientific community is leveraging CRISPR tools to address emerging diseases. The decline in stress tolerance studies reflects the integration of molecular editing frameworks into broader climate adaptation research.

Table 2. Logistic growth analysis of wheat research based on annual journal articles (2021 to 2025).

a) Technical focus areas of wheat research/

Technical Focus area	2025	2024	2023	2022	2021
CRISPR, Genome editing	228	47	60	90	88
Stress tolerance	1	8	15	35	18
Disease resistance	77	12	10	15	11
Agronomy	29	30	35	55	7
Breeding	40	3	7	23	13

b) Logistic growth analysis of wheat research.

Technical focus areas	K (saturation)	r (growth rate)	t_0 (inflection year)	S-Curve Phase
CRISPR, Genome editing	250	1.2	2024.2	Growth
Stress tolerance	2	-0.5	No growth	Decline
Disease resistance	100	1	2024.5	Renewed growth
Agronomy	60	2	2022	Post-peak decline
Breeding	45	0.5	2023.5	Cyclic or erratic

Wheat patent data of the last five years (2021-2025) shows a logistic growth pattern. The field's control architecture has strategically consolidated, with key technologies reaching a mature stage, leading to significant growth in functional applications. The CRISPR-Cas System Architecture and Guide RNA strategies have matured, with a high value of k (30) and an early inflection point in 2022, indicating well-established proprietary scissors dominating high-volume filings in US and WIPO patents. Gene regulation and transcription control are the dominant frontier, showing the highest growth rate (r=0.8) and a recent inflection point in late 2024, signaling a shift towards precise orchestration of gene expression beyond simple DNA cutting. China plays a crucial role in this evolving landscape. Molecular composition and screening platforms exhibit slow growth, suggesting untapped potential for future development in the patent landscape's nascent edges where technical complexity and low patent volume hint at significant future growth opportunities (Table 3).

Table 3. Logistic growth analysis of wheat research based on annual patents (2021 to 2025).

a) Technical focus areas of wheat research patent.

Technical Focus Areas	No. of Patents	Patent Office			
		WIPO	**USPTO**	**CNIPA**	**EPO**
CRISPR-Cas system architecture	10	High	High	moderate	moderate
Guide RNA and targeting strategies	7	High	High	control	low
Gene regulation and transcription control	6	High	low	High	low
Molecular compositions and constructs	3	low	low	High	High
Screening and functional genomics platforms	1	High	low	low	low

b) Logistic growth analysis of heat research patent.

Technical focus areas	K (saturation)	r (growth rate)	t_0 (inflection year)	S-Curve Phase
CRISPR-Cas system architecture	30	0.2	2022.5	Mature
Guide RNA and targeting strategies	12	0.3	2022	Mature
Gene regulation and transcription control	10	0.8	2024.5	Growth
Molecular compositions and constructs	3	0.1	2025.5	Very slow growth
Screening and functional genomics platforms	2	No growth	No growth	Pre-growth

4. Socio-Economic Impacts on Wheat Innovation Systems

The abstract, legal concentration of patents leads to socio-economic distortions and scientific impediments that systematically deepen and solidify the already existing structural inequality in the global agricultural research system (Byerlee and Harvey Jesse Dubin 2010).

Wheat breeding has been characterized as public good. Institutions such as the International Maize and Wheat Improvement Center (CIMMYT), based in Mexico, function as central "Global Public Good" producers, distributing genetic material (gene bank accessions), advanced breeding lines, pre-competitive knowledge, and capacity building free of charge or at marginal cost to national agricultural research programs (NARs) in the Global South – a model institutionalized through the International Wheat Improvement Network (IWIN) (Pardey Julian M. Alston, and Connie Chan-Kang 2016). This model, based on open exchange and accelerated dissemination, is now under massive, existential pressure from the IP-based CRISPR technology. Even so-called "humanitarian," "academic," or "non-profit" licenses, e.g., those offered by Corteva (for their Cas12a technology under the designation "Inclusive Innovation") or in certain fields by the Broad Institute – are not without significant conditions and hidden costs. They often include complex reporting, monitoring, and administrative obligations, limit commercial use (frequently to "low" income countries), and regularly prohibit in their clauses the crucial transfer of edited plant material to third parties for their further breeding work (Kahl and Aashish R. Arora 2021). These "no-transfer" clauses undermine the core business and raison d'être of CIMMYT and similar centers, which consists of freely and rapidly disseminating improved genetic material as a global public good, thereby enabling a "multiplication and adaptation effect" in national programs.

National agricultural research organizations (NARs) in key wheat-producing countries such as India (ICAR), Egypt (ARC), or Brazil (Embrapa) face an impossible dilemma. Either they acquire expensive and restrictive licenses for the most efficient CRISPR tools (diverting budget resources), or they must forgo their use and fall behind technologically. Both paths shift innovation capacity and control to the Global North patent holders instead of sustainably strengthening local scientific and regulatory capacities and building endogenous innovation power (Scoones and John Thompson 2011).

Patent protection follows the logic of the market and capital return. For private patent holders and their licensees, investments in CRISPR editing of wheat traits are only attractive if they can be monetized in large, lucrative, and legally protected markets where seed prices are high and replanting can be prevented (e.g., through hybrid wheat technologies or strict contract farming agreements). This economic rationality leads to systematic neglect of so-called "orphan traits" – those agronomic characteristics that are of existential importance for marginal, poverty-affected, or smallholder production systems in the Global South but promise no significant commercial potential in global mass markets (Nelson, Rebecca, Daniel de la Torre, and Maricelis Acevedo, et al et al. 2019). These particularly include tolerance to locally specific abiotic stress factors (soil salinity, aluminum toxicity in acidic soils, micro-droughts), resistance against regionally limited or economically "unimportant" pests and diseases and qualitative improvements such as biofortification with micronutrients (iron, zinc, vitamin A) for local populations with specific malnutrition deficiencies.

Public wheat research, which traditionally filled precisely this gap and dedicated itself to these "pro-poor" traits, is now hindered or excluded by high patent and licensing barriers precisely in this area critical to food security for vulnerable populations. The global innovation pipeline for wheat is thus structurally distorted in favor of traits primarily relevant to capital-intensive, industrial agriculture in the North (e.g., herbicide tolerances, uniform maturation for mechanical harvesting, storage stability), while the urgent needs of smallholder farmers are neglected (Glover, James Sumberg, and Jens A. Anderson 2019).

The unique biological challenge of hexaploid bread wheat (with AABBDD genome sets) acts as an additional amplifier as reflected in the patent landscape. For a desired phenotypic effect, all three homeologous alleles of a gene on the different genomes often must be successfully and simultaneously edited. This requirement makes highly efficient, multiplexed editing strategies (simultaneous targeting of multiple genome sites) not only desirable but often necessary (Zhang et al. 2017). Patents on specific methods for efficient multiple editing in polyploid genomes (e.g., through several specifically arranged gRNAs on one construct) or on the use of certain optimized tissue culture systems for wheat (highly efficient in vitro culture of microspores as a transformation route) can thus become strategically crucial "bottleneck patents" or "gatekeeper technologies." The owners of these patents control access to CRISPR-based wheat breeding overall – a control that currently lies almost exclusively with North American and European institutions and their exclusive private partners.

5. CRISPR as a Strategic Asset

The controlling parts of the innovation chain (basic tools, patents, bioinformatic design, commercial varieties) remain in the Global North (and increasingly in China), while the Global South is the user of proprietary technologies, supplier of valuable genetic resources (for the discovery of useful genes via phenotyping and sequencing), and sales market for finished seed products (Tilghman et al. 2021). Control over a dual-use key technology such as CRISPR has long since evolved into a central element of national innovation, economic, and security strategies that extend far beyond immediate corporate business interests and shape new geopolitics of biotechnology (Fukuyama 2021).

The European Union hosts world-leading public research institutions (such as the Max Planck Institute, ETH Zurich, or Wageningen University) and is the origin of one of the two major patent camps (Doudna/Charpentier). Its regulatory landscape for genome-edited organisms, which were effectively equated with transgenic GMOs under the strict Directive 2001/18/EC by the controversial ruling of the European Court of Justice (ECJ) in 2018 (Case C-528/16), is among the most restrictive in the world (Court of Justice of the European Union 2018). This regulatory hurdle acts as an innovation brake, even for technology developed on its own soil. European CRISPR patents can be economically valuable abroad (USA, Latin America), while the commercial application of the technology they protect is nearly impossible and politically toxic in their own internal market. This undermines the competitiveness of European plant biotech companies and public research programs in the global race and significantly weakens their negotiating position in international forums and vis-à-vis powerful partners such as the USA and China (Eriksson K. B. Kutschera, Jonas B. Jonasson, and Nils Rostoks, et al. 2020).

China since the mid-2010s responded with an unprecedented, centrally directed, and massively capitalized offensive. Through massive state funding programs within the framework of its "National Key Research and Development Programs" and the "Strategic Priority Initiatives" of the Chinese Academy of Sciences (CAS), China has achieved a leading position in basic research on CRISPR and its derivatives and built its own dense and rapidly growing network of patents on alternative enzymes, systemic improvements, and specific applications (Cohen and Amy Maxmen 2019). Chinese Academy of Agricultural Sciences (CAAS) and companies like BGI (Beijing Genomics Institute) pursue a sophisticated dual strategy of accessing essential patents through licensing agreements where necessary for market access. In parallel, they invest massively in developing their own patented technology pathways (e.g., around Cas12f, an extremely small enzyme) and application fields to circumvent FTO barriers, serve their own export markets, and achieve an independent, strong negotiating position in the long-term global technological competition.

For most countries in Africa, Latin America, and Asia (except for a few emerging economies such as India or Brazil), the financial, scientific, and administrative resources for an independent, offensive patent or circumvention strategy following the Chinese model are lacking. Their position is therefore fundamentally precarious and dependent on external dynamics; they are largely "price takers" in the global IP system (Ouma 2020). Their reactive strategies therefore focus on a mixture of selective use of flexible licensing models (where available and accessible), formation of regional alliances and political blocs to strengthen a collective negotiating position and develop common regulatory approaches, and investment in alternative CRISPR-free or patent-free breeding capacities (e.g., high-throughput phenotyping, genome selection with open bioinformatics tools) as a strategic fallback option and to strengthen their own autonomy. Similarly, they demand for Special and Differential Treatment (SDT) within the framework of existing international agreements, particularly the Convention on Biological Diversity (CBD), the Nagoya Protocol on Access and Benefit Sharing (ABS), and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). They argue that CRISPR components should be considered "Digital Sequence Information" (DSI), the use of which should also be subject to fair and equitable benefit sharing-a highly controversial debate (Welch, Fabiana Fonseca, and Flavia de Andrade 2017).

6. Alternative Pathways and Reform Models

Below models and instruments can be explored each exhibiting specific strengths, practical limitations, and political implementation hurdles (Van Der Meer and Manju Bhardwaj 2022).

6.1 Humanitarian and Academic Licensing Frameworks

Initiatives for voluntary licensing for humanitarian purposes, such as the "OpenCRISPR" license of individual patent holders or the specific "Humanitarian Use" model of the Broad Institute, are to be welcomed as political signals and initial pragmatic steps, but their impact remains limited and structurally insufficient (Broad Institute 2023). They enable non-commercial research and limited, defined commercial use in low-income countries. They significantly lower the initial financial and legal entry barrier for public research institutions in these countries.

These models are often restrictive in their geographic and thematic definition of "humanitarian" (frequently excluding middle-income countries, where a large proportion of the poor and undernourished population lives). They prohibit the crucial transfer and exchange of edited plant material between research institutes, which destroys the core of the cooperative, public breeding model. They are also voluntary, unilaterally designed, and can be changed or terminated by licensors with relatively short notice. Finally, they do not address the complex problems of FTO for improved second-generation enzymes or for third-party application patents ("trait patents") that are also needed for successful commercialization (Kahl and Aashish R. Arora 2021).

6.2 Patent Pools and Collective Licensing Agreements

A successful historical model is the Golden Rice Patent Pool, managed by the public-private partnership "Humanitarian Board" to manage the complexity of over 70 patents for the development of vitamin A-enriched rice (Kryder, and Stanley P. Kowalski at al. 2000). A CRISPR pool for wheat can be structured similarly. Patent holders make their rights available to a neutral management entity (e.g., an independent foundation), which then issues standardized licenses to breeders, particularly in the Global South. The revenues would be distributed proportionally to the patent holders.

Creating such a pool requires the cooperative willingness and consent of all essential patent holders—a difficult undertaking given their antitrust-sensitive positions, different commercial interests, and partially ongoing legal disputes. Management would have to be carried out by an internationally recognized, absolutely neutral, and technically competent entity that enjoys the trust of all parties involved (potential candidates would be a specialized organization under the umbrella of the Food and Agriculture Organization of the United Nations (FAO), the World Intellectual Property Organization (WIPO), or the CGIAR system). Defining the "essential" patents and setting fair licensing fees would be extremely complex negotiation processes (Van Overwalle 2006).

6.3 Heritage Strengthening of Public-Private Partnerships (PPPs)

Public-private partnerships must go beyond simple project-based research funding and specifically prioritize sustainable technology transfer, capacity building, and the creation of "freedom to operate." International initiatives such as the "Wheat Initiative" (a global coordination platform) or the "Excellence in Breeding (EiB)" platform of CGIAR can be strengthened to conduct and provide central, regularly updated FTO landscape maps and analyses for priority breeding goals (e.g., rust resistance, heat tolerance).It can act as a collective negotiating partner and "single window" for licenses on behalf of consortia of public institutions in the Global South to strengthen their negotiating position and reduce transaction costs. Trainings can be provided in the areas of molecular breeding, IP management, and regulatory requirements for edited plants. Open-source-based CRISPR tools can be developed promoting platforms that are deliberately developed outside the proprietary patent system (e.g., through the use of non-patented enzyme variants or open vector systems) (Deibel 2022).

6.4 International Law, Regulatory, and Trade Policy Interventions

New norms of international law or creative adaptation of existing agreements may be necessary to counterbalance the proprietary logic. International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) with its Multilateral System (MLS) for access to plant genetic resources and benefit sharing could be extended by a protocol or annex that also regulates access to "critical Digital Sequence Information (DSI)" and associated technologies (such as CRISPR components) for food security purposes—analogous to access to physical seed material in the MLS (Halewood Isabel López Noriega, and Selim Louafi, et al. 2018). This is one of the central and most controversial debates in international biodiversity governance. A worldwide convergence and harmonization of regulation for SDN-1 and SDN-2 edited plants (which could be classified as "convention-equivalent" and thus "non-GMO") would drastically reduce market entry costs and regulatory uncertainties. This would particularly help public and small actors with limited resources. The progressive, product-based regulatory approaches of countries such as Argentina, the USA (USDA-SECURE rule), Japan, or Kenya can serve as models for evidence-based policy and be supported through international agreements (Entine, Maria Sueli S. Felipe, and Jan-Hendrik Groenewald, et al. 2021). Global South can negotiate special clauses in bilateral or regional trade agreements that bindingly establish technology transfer and capacity building in precision breeding or provide exceptions from strict IP rules for technologies for food security (like TRIPS flexibilities in the pharmaceutical sector).

7. Conclusions

Current analysis has demonstrated that the question "Who will feed the world?" in the context of the CRISPR revolution is not purely agronomic, technical, or business-related. It has transformed into a central question of political economy, global distributive justice, technological sovereignty, and democratic governance of future and key technologies in the Anthropocene. The extreme concentration of patent rights on CRISPR technologies systematically impedes and drains the innovative capacity of precisely those institutions that are historically and mandatorily responsible for feeding the poorest, most vulnerable, and climate-threatened populations of the world. If unchecked, CRISPR patents can distorts the global research agenda for a key food crop in favor of narrowly defined profit and market logics, thereby criminally neglecting the development of "orphan traits"-the survival characteristics for marginal agriculture. This patent war threatens the historically successful model of public wheat breeding based on global public goods and open exchange-indispensable for food security-and pushes it to the edge of incapacity to act. The counter-models and reform pathways discussed-from multilateral patent pools to public interest-oriented and strengthened PPPs to bold international law initiatives-are not merely technical or administrative quick fixes. Rather, they require clear political will, the courage to question established economic power interests and the dogma of unrestricted, strong patent protection in sensitive sectors, as well as the willingness for multilateral cooperation beyond geopolitical rivalries. At its core, it is about nothing less than negotiating a new social contract for agricultural innovation in the 21st century. This new contract must institutionally anchor spaces for open cooperation, public interest-oriented licensing models, and the protection of public innovation systems. The future of wheat must be shaped and fought for in the fields of farmers, in the participatory laboratories of public and public interest-oriented researchers, and at the negotiating tables of inclusive global governance institutions.

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