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GENOMIC EDITING AND ITS STRATEGIC INTEREST FOR UKRAINE: OPPORTUNITIES OFFERED BY NEW GENOMIC TECHNIQUES IN THE CONTEXT OF CLIMATE CHANGE, ENVIRONMENTAL CHALLENGES, AND GEOPOLITICAL TENSIONS

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The adoption by the European Union, on June 17, 2026, of a regulatory framework authorizing New Genomic Techniques (NGTs), and in particular CRISPR/Cas9-based approaches, marks a decisive turning point in the history of plant breeding. After nearly a decade of scientific debates, legal battles, and political negotiations, European legislators finally recognized that certain categories of genomic editing are fundamentally different from conventional transgenesis and deserve a distinct, more flexible regulatory treatment. This historic decision opens a new era not only for European agriculture but also, and perhaps above all, for countries that are closely associated with or aspire to integrate the European agricultural and scientific space, foremost among them Ukraine. As one of the world's leading producers and exporters of cereals, and as a nation engaged in an existential war that has deeply disrupted its agricultural sector, Ukraine stands at a crossroads where scientific innovation, food sovereignty, and geopolitical strategy converge. This article examines the nature and mechanisms of New Genomic Techniques, their technical advantages over conventional GMOs, their specific applications in cereal breeding, and the strategic imperative for Ukraine to adopt and develop these technologies as a matter of national priority.

***Key words*:** New Genomic Techniques, CRISPR/Cas9, genomic editing, cereal breeding, Ukraine, food security, climate change, geopolitical resilience.

A Historic Regulatory Turning Point

On June 17, 2026, the European Union achieved what had seemed, for many years, a near-impossible political and regulatory feat: the formal adoption of a comprehensive legal framework governing New Genomic Techniques (NGTs) in plant breeding [1]. This legislation, the culmination of a process initiated by the European Commission's landmark report of

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April 2021 and followed by a legislative proposal in July 2023, established a two-tier system distinguishing between plants that could have been obtained through conventional breeding (NGT Category 1) and plants carrying more complex modifications (NGT Category 2), each subject to proportionate levels of oversight and authorization [2].

The road to this legislative milestone had been extraordinarily tortuous. Since the European Court of Justice's ruling of July 25, 2018 [3], which controversially classified all organisms obtained through mutagenesis techniques, including the most precise forms of directed mutagenesis, under the scope of the GMO Directive 2001/18/EC, the European scientific community, the agri-food industry, and numerous member states had been pressing for regulatory reform. The 2018 ruling had created a profound paradox: organisms whose genomes had been modified in ways that were indistinguishable from natural mutations or from the results of conventional breeding were subjected to the same lengthy, expensive, and politically fraught authorization process as transgenic organisms carrying foreign genes. Critics argued, compellingly, that this approach was scientifically incoherent, economically damaging, and strategically shortsighted at a time when climate change, biodiversity loss, and food security challenges were demanding accelerated innovation in agriculture.

The years between 2018 and 2026 were marked by intense scientific lobbying, numerous reports from advisory bodies including the European Food Safety Authority (EFSA), the French High Council on Biotechnologies (HCB), and the German Leopoldina Academy of Sciences, as well as sustained pressure from agricultural organizations and plant breeders across the continent. Several member states, led by Sweden, the Netherlands, and Germany, pushed aggressively for regulatory modernization, while others, particularly Hungary and Austria, maintained strong reservations rooted in the precautionary principle and consumer perception concerns. The European Parliament, after multiple readings, amendments, and negotiations in trilogue with the Council and the Commission, eventually reached a compromise that, while imperfect in the eyes of some scientific actors, represented an undeniable step forward.

The significance of June 17, 2026, therefore, cannot be overstated. It signals that the world's largest single market and most stringent regulatory environment has acknowledged the scientific reality: that tools like CRISPR/Cas9 represent a qualitative leap in precision, speed, and accessibility compared to earlier generations of biotechnology. This recognition carries immediate implications for European plant breeders and farmers, but it also sends a powerful signal to the rest of the world, including, crucially, to Ukraine.

Ukraine's situation in 2026 is characterized by a unique and painful combination of challenges. The full-scale war launched by the Russian Federation in February 2022 and its continued prosecution have caused enormous destruction to Ukrainian agricultural infrastructure, displaced millions of farmers and agricultural workers, contaminated vast areas of land with mines and unexploded ordnance, and disrupted the logistical chains that had made Ukraine one of the world's most important granaries. At the same time, Ukraine's agricultural sector has demonstrated remarkable resilience, continuing to produce and export significant quan-

tities of wheat, corn, barley, sunflower, and other crops even under wartime conditions. Ukraine's candidacy for European Union membership, formalized in June 2022 and progressing through various stages of negotiation, adds yet another dimension: the gradual alignment of Ukrainian legislation and agricultural practice with European standards, including the new NGT framework.

This article argues that the adoption of genomic editing technologies, and CRISPR/Cas9 in particular, is not merely a scientific opportunity for Ukraine but a strategic necessity. In the sections that follow, we examine what New Genomic Techniques are and how they work; why they represent a fundamentally different and superior approach compared to conventional GMOs; what specific advantages they offer in the context of cereal breeding under conditions of climate stress, environmental constraint, and geopolitical pressure; and why Ukraine, in its specific historical, agricultural, and geopolitical context, must treat the development of genomic editing capabilities as a national priority of the first order.

1. New Genomic Techniques and CRISPR/Cas9: Nature, Mechanisms, and Taxonomy

1.1. Defining New Genomic Techniques. The term «New Genomic Techniques» (NGTs) refers to a family of molecular biology tools that have emerged or been significantly refined since the adoption of the European GMO regulatory framework in the early 2000s. These techniques share a common characteristic: they enable scientists to make precise, targeted modifications to the genome of a living organism — including plants, with a degree of accuracy, predictability, and efficiency that was previously unattainable. The European Commission, in its 2021 study, identified and characterized a range of such techniques, including site-directed nucleases (SDNs) of various types, cisgenesis, intragenesis, RNA-dependent DNA methylation (RdDM), grafting with a genetically modified rootstock, reverse breeding, agro-infiltration, synthetic genomics, and others [2].

Among these, the most scientifically significant, technologically mature, and commercially relevant are the site-directed nucleases, molecular tools that can be programmed to cut DNA at a specific, predetermined location within the genome. The three main families of site-directed nucleases are Zinc Finger Nucleases (ZFNs), Transcription Activator-Like Effector Nucleases (TALENs), and Clustered Regularly Interspaced Short Palindromic Repeats associated with the Cas9 protein (CRISPR/Cas9) [4]. Of these, CRISPR/Cas9 has emerged, since 2012—2013, as the dominant platform, combining unprecedented precision with extraordinary ease of use, versatility, and affordability. It is for this reason that CRISPR/Cas9 has rapidly become synonymous, in both scientific and public discourse, with the broader concept of genomic editing.

The European regulatory framework distinguishes, within the category of site-directed nuclease applications, three sub-categories.

1) *SDN-1* — modifications that introduce small insertions, deletions, or substitutions (indels) at a targeted genomic location, without the introduction of any exogenous DNA. The result is functionally equivalent to what could be achieved by natural mutation or by conventional mutagen-

esis techniques such as chemical mutagenesis or irradiation, but in a vastly more targeted and predictable manner.

2) *SDN-2* — modifications that introduce small, specific changes (typically point mutations or small insertions) guided by a short DNA template, again without the integration of any foreign genetic material. The modifications introduced fall within the natural range of allelic diversity that exists or could exist within the species.

3) *SDN-3* — modifications that involve the insertion of a large exogenous DNA sequence at a targeted location. This category is considered closer to conventional transgenesis and is subject, in the 2026 European framework, to a regulatory pathway broadly similar to that applicable to conventional GMOs.

For the purposes of this article, and consistent with the primary focus of the 2026 European legislation on NGT Category 1 plants, we will concentrate primarily on SDN-1 and SDN-2 application — those that do not involve the integration of foreign DNA and whose products are, or could be, indistinguishable from the results of natural evolutionary processes or conventional breeding.

1.2. The CRISPR/Cas9 System: Biological Origins and Molecular Mechanism. The CRISPR/Cas9 system did not originate in a laboratory. It is, in its essence, a component of the adaptive immune system that bacteria and archaea use to defend themselves against viral infections. When a bacterium survives an infection by a bacteriophage (a virus that infects bacteria), it can retain short fragments of the viral DNA in specific regions of its own genome called Clustered Regularly Interspaced Short Palindromic Repeats — the CRISPRs. These stored sequences serve as a molecular memory. If the same virus attacks again, the bacterium transcribes RNA molecules from these stored sequences, called CRISPR RNAs (crRNAs) — which, in combination with a scaffold RNA (the trans-activating crRNA, or tracrRNA), guide a Cas (CRISPR-associated) protein to recognize and cut the viral DNA, neutralizing the threat.

The critical insight that transformed this bacterial immune mechanism into a universal genome editing tool came from the work of Jennifer Doudna and Emmanuelle Charpentier, published in the journal *Science* in August 2012 [5], and was rapidly extended to eukaryotic cells, including plant and animal cells, by multiple research groups in early 2013 [6, 7]. Doudna and Charpentier [8] were awarded the Nobel Prize in Chemistry in 2020 for this discovery, a recognition that reflected the profound and transformative impact of CRISPR/Cas9 on biology and medicine.

The operational mechanism of CRISPR/Cas9 in a plant cell can be described in the following steps.

Step 1 — Design of the guide RNA: The researcher identifies the specific DNA sequence within the plant genome that is to be targeted. A short RNA molecule, called the single guide RNA (sgRNA), is designed to be complementary to this target sequence. The sgRNA is, typically, 20 nucleotides long and is flanked, in the genome, by a short motif called the Protospacer Adjacent Motif (PAM), which is recognized by the Cas9 protein. For the most commonly used Cas9 from *Streptococcus pyogenes*, the PAM sequence is NGG (where N is any nucleotide).

*Step 2 — Delivery into the plant cell***:** The sgRNA and the gene encoding the Cas9 protein (or, alternatively, the pre-assembled sgRNA-Cas9 ribonucleoprotein complex) are introduced into the plant cell. Various delivery methods are used in plant systems, including *Agrobacterium tumefaciens*-mediated transformation, biolistic bombardment (gene gun), protoplast transfection, and, more recently, virus-based delivery systems. A critical advantage for regulatory purposes is that, in SDN-1 and SDN-2 applications, the CRISPR/Cas9 components can be introduced transiently and then eliminated from the plant genome through segregation in subsequent generations, leaving no trace of the editing machinery in the final product.

Step 3 — Target recognition and DNA cleavage: Once inside the nucleus, the Cas9 protein, guided by the sgRNA, scans the genome for the complementary target sequence. When it finds a match, it binds to the DNA and introduces a double-strand break (DSB), a cut through both strands of the DNA double helix, at the target location.

Step 4 — Cellular repair and the introduction of the desired modification: The plant cell's own DNA repair machinery then acts to repair the break. Two main repair pathways exist:

1) *Non-Homologous End Joining (NHEJ)* — this error-prone pathway ligates the broken ends of the DNA back together, but frequently introduces small insertions or deletions (indels) at the cut site. These indels can disrupt the reading frame of a gene, effectively knocking it out, inactivating it. This is the mechanism used in SDN-1 applications when the goal is to silence or disable a specific gene.

2) *Homology-Directed Repair (HDR***)** — if a repair template — a short DNA sequence homologous to the region surrounding the cut site but carrying the desired modification, is provided along with the CRISPR/Cas9 components, the cell can use it as a template to repair the break with precision, introducing the exact sequence change specified by the researcher. This mechanism is used in SDN-2 applications.

Step 5 — Regeneration and selection: Edited cells are cultured and regenerated into whole plants. The plants are then screened using molecular techniques (sequencing, PCR) to identify those that carry the desired modification, and unmodified or incorrectly modified plants are discarded. The selected plants are then used in conventional breeding programs to develop improved varieties.

1.3. The Family of CRISPR Tools: Beyond CRISPR/Cas9. It is important to note that CRISPR/Cas9, while the best known and most widely used, is merely the first of what has become a rapidly expanding family of CRISPR-based editing tools. Scientists have identified and engineered numerous Cas proteins with different properties, targeting ranges, and editing capabilities. Particularly noteworthy developments include:

1) *CRISPR/Cas12a (Cpf1)* — an alternative nuclease that produces staggered cuts (rather than the blunt cuts made by Cas9), recognizes a different PAM sequence (TTTV), and can process its own guide RNAs, making it useful for multiplex editing.

2) *Base editors* — these tools, pioneered by David Liu's laboratory at Harvard, combine a catalytically impaired Cas9 (a «nickase» that cuts only one DNA strand) with a deaminase enzyme, enabling the direct chemical

conversion of one DNA base to another (e.g., cytosine to thymine, or adenine to guanine) without introducing double-strand breaks. This greatly reduces the risk of unintended indel formation.

3) *Prime editing* — also developed by Liu's group, prime editing uses a reverse transcriptase fused to a Cas9 nickase and a specialized guide RNA (the pegRNA) to write new genetic information directly into a specified genomic site, with even greater precision and versatility than base editing.

4) *CRISPR interference (CRISPRi) and CRISPR activation (CRISPRa)* — these systems use catalytically dead Cas9 (dCas9) fused to transcriptional repressors or activators to modulate, rather than mutate, gene expression, offering powerful tools for functional genomics research. The availability of this expanding toolkit gives plant breeders an unprecedented range of options for modifying plant genomes in precise, predictable, and reversible ways.

2. Technical Superiority of CRISPR/Cas9 and NGTs Over Conventional GMOs: Precision, Speed, and Cost

2.1. The Limitations of Conventional GMO Technology. To understand why CRISPR/Cas9 and NGTs represent a qualitative leap over conventional GMO technology, it is necessary to briefly review the principles and limitations of the latter. The term «GMO» (Genetically Modified Organism), in its most widely used sense, refers to organisms produced through transgenesis, the introduction and stable integration of one or more genes from another organism (often from an unrelated species) into the genome of the host organism. The canonical example in plant science is the insertion of the gene encoding the Cry protein from *Bacillus thuringiensis* into the genome of corn or cotton, conferring insect resistance, or the insertion of the CP4 EPSPS gene from *Agrobacterium* into soybean, conferring herbicide tolerance.

The technical process of creating a transgenic plant involves:

1) Identifying the gene of interest in the donor organism.

2) Isolating and cloning the gene, typically with a strong promoter and other regulatory sequences from various sources.

3) Constructing a transformation vector, typically based on the Ti plasmid of *Agrobacterium tumefaciens* or a physical bombardment approach.

4) Transforming plant cells and selecting transformed cells using a selectable marker gene (typically an antibiotic resistance gene).

5) Regenerating whole plants from transformed cells.

6) Screening for stable integration of the transgene.

7) Extensive backcrossing to introduce the transgene into elite cultivar backgrounds while eliminating unwanted background mutations.

This process has several fundamental limitations:

Random insertion — the transgene integrates into the plant genome at a random location. This randomness can have unpredictable consequences: the transgene may insert into or near other genes, disrupting their function; it may insert into genomic regions that result in silencing of the transgene; or it may result in position effects that alter its expression level. To find plants with a satisfactory insertion site, researchers must generate and screen hundreds or thousands of independent transformation events.

Foreign DNA — transgenic plants, by definition, carry genetic material from other organisms — sometimes from very distant taxonomic groups. This is the biological basis for regulatory concerns about horizontal gene transfer and unintended ecological effects, and it is the primary driver of consumer and public perception concerns about GMOs in many countries.

Regulatory burden — the regulatory approval process for transgenic crops is extraordinarily lengthy and expensive. A study by the consultancy Cropnosis, widely cited in the literature, estimated that the average cost of bringing a transgenic trait from discovery to regulatory approval was approximately 130 to 150 million US $, with a timeline of 13 years or more. More recent estimates suggest these figures may be even higher. This level of investment is accessible only to the largest multinational agrichemical corporations, effectively excluding public research institutions, national breeding programs, and small and medium enterprises from the development of transgenic crop varieties.

Variety-specificity — because each transformation event is unique (different insertion site, different integration context), regulatory approvals for GMO traits are typically event-specific, meaning that the same trait cannot simply be transferred from one approved variety to another without repeating the entire transformation and regulatory process. This makes GMO technology particularly ill-suited to the highly fragmented, diversity-rich world of national and regional crop breeding programs.

2.2. The Precision Advantage of CRISPR/Cas9. The most fundamental advantage of CRISPR/Cas9 over conventional transgenesis is its precision, the ability to make a specific, predetermined modification at a specific, predetermined location in the genome. Rather than randomly inserting a foreign DNA construct somewhere in the genome and hoping for an acceptable result, CRISPR/Cas9 goes directly to the target, like a molecular GPS compared to the random walk of conventional transgenesis [9, 10].

This precision has several important dimensions:

Sequence specificity — the sgRNA is designed to be complementary to a specific 20-nucleotide sequence in the genome, which, combined with the PAM requirement, defines a unique address in the genome. The probability of an identical 20-nucleotide sequence occurring elsewhere in the genome (off-target sites) is theoretically very low, and has been further reduced by advances in sgRNA design algorithms, high-fidelity Cas9 variants, and the use of paired nickases. Multiple studies have confirmed that, when properly designed, CRISPR/Cas9 edits in plants show very low rates of off-target modifications: rates that are, importantly, lower than the off-target mutation rates routinely induced by conventional mutagenesis techniques such as EMS (ethyl methanesulfonate) or gamma irradiation, which have been used in plant breeding for decades without triggering GMO-equivalent regulatory requirements.

Reproducibility — because the target site is defined by the sequence of the sgRNA, the same editing outcome can be achieved reproducibly, in different plant genotypes, in different laboratories, and at different times — provided the target sequence is present and accessible. This reproducibility is in stark contrast to the stochastic variability of conventional transformation.

Multiplexing — CRISPR/Cas9 can be used to edit multiple genes simultaneously by delivering multiple sgRNAs targeting different loci in the same experiment. This is particularly valuable in plant breeding, where complex agronomic traits are typically controlled by multiple genes (polygenic traits), and where simultaneous modification of several genes in the same metabolic pathway may be required to achieve the desired phenotypic outcome.

2.3. The Speed Advantage. Conventional plant breeding, even without any biotechnological intervention, is a slow process. Developing a new wheat variety through traditional cross-breeding typically requires 10 to 15 years from the initial cross to commercial release: multiple generations of selection, evaluation of agronomic performance across multiple environments and years, disease resistance testing, quality assessment, and variety registration trials. Even accelerated breeding approaches, such as doubled haploid technology or speed breeding under continuous light, can only compress this timeline to a limited extent.

The introduction of a new trait through conventional transgenesis adds further delay: the transformation and selection process, the regulatory approval process (which, as noted, can take 13 years or more in the most demanding jurisdictions), and the event-specific nature of the approval, which may require additional backcrossing into elite genetic backgrounds.

CRISPR/Cas9 dramatically accelerates this timeline in several ways:

Speed of modification — the design of a sgRNA targeting a specific gene can be accomplished in days using bioinformatics tools. The construction of the CRISPR/Cas9 delivery vector typically requires a few weeks. Plant transformation, regeneration, and initial screening can be accomplished in a few months for species with well-established transformation protocols, such as wheat, barley, or tomato. The entire process from target identification to the first edited plants can, in many cases, be accomplished in 6 to 18 months.

No regulatory delay (for NGT Category 1) — under the 2026 European framework, NGT Category 1 plants, those carrying modifications that are equivalent to what could have occurred through natural mutation or conventional breeding, are not subject to the GMO authorization process. They are treated, for regulatory purposes, essentially like conventionally bred varieties. This eliminates the 10—15 year regulatory delay that has been the principal bottleneck for GMO technology.

Compatibility with modern breeding pipelines — CRISPR/Cas9 edits, once verified, can be introgressed into different elite genetic backgrounds through conventional crossing, just like any other natural allele. The edited allele segregates in a Mendelian fashion and can be tracked using simple molecular markers. This makes NGT-derived traits fully compatible with the sophisticated genomic selection and speed breeding pipelines that progressive plant breeding programs are already using.

Accelerating the breeding cycle — CRISPR/Cas9 can be combined with speed breeding protocols, growing plants under continuous or extended light to reduce generation time to as little as 8—10 weeks for wheat and barley, compared to the typical 20—24 weeks under field conditions, to further compress the timeline from edited plant to registered variety. In combination with doubled haploid technology, this approach could allow

elite wheat varieties carrying novel CRISPR-introduced traits to be developed and ready for registration within 5 to 7 years of the initial editing event — roughly twice as fast as conventional breeding without biotechnology.

2.4. The Cost Advantage. The cost differential between conventional GMO technology and CRISPR/Cas9-based editing is enormous and has profound implications for the accessibility of the technology.

As noted, the average cost of developing and obtaining regulatory approval for a new GMO trait has been estimated at 130—150 million US dollars or more. This figure reflects the cost of the regulatory process itself — generating the extensive safety data required for dossier submission — rather than primarily the cost of the underlying science. This level of investment means that conventional GMO technology has been, in practice, accessible only to a handful of multinational corporations with the financial resources to navigate a decade-long regulatory process [9].

By contrast, the direct costs of CRISPR/Cas9 editing in plants are dramatically lower. The reagents for constructing a CRISPR/Cas9 editing system targeting a specific gene can be procured for a few hundred to a few thousand US $. The full cost of a plant editing project, from target identification through regeneration and screening of edited plants, in a well-equipped public research laboratory typically ranges from 10,000 to 100,000 US $, depending on the complexity of the project and the species involved. Even accounting for the additional costs of variety development, performance evaluation, and registration (which are required for any new variety, regardless of how it was developed), the total development cost for an NGT-derived crop variety is estimated to be one to two orders of magnitude lower than for a transgenic crop.

This cost democratization is potentially transformative for plant breeding in medium-income agricultural countries like Ukraine. It means that public research institutes, national plant breeding companies, and university laboratories can afford to use CRISPR/Cas9 as part of their routine breeding toolkit, without needing to partner with, or cede intellectual property to, large multinational corporations.

Furthermore, the intellectual property landscape around CRISPR/Cas9, while still contested and complex (particularly regarding the foundational patents held by the Broad Institute and the University of California), has evolved in ways that are increasingly favorable for plant breeding applications in non-commercial and public sector contexts. Several major patent holders have made commitments to license CRISPR technology for humanitarian or food security applications at no cost or minimal cost.

3. Advantages of Genomic Editing for Cereal Breeding in the Current Global Context

3.1. The Urgency of Breeding Innovation in a Changing World. The global context in which plant breeders must operate in 2026 is one of compounding and interconnected crises. Climate change is altering precipitation patterns, increasing the frequency and severity of drought, heat waves, and flooding, shifting the geographic ranges of pests and diseases, and reducing the predictability of growing seasons. Environmental constraints —

primarily the imperative to reduce the agricultural sector's contributions to greenhouse gas emissions, to protect soil health and biodiversity, and to reduce dependence on synthetic inputs — are demanding that crop varieties perform efficiently with less water, less fertilizer, and fewer pesticides. And geopolitical instability — exemplified most dramatically by the Russian war against Ukraine but also manifest in trade disruptions, sanctions, and the weaponization of food supply chains — has underscored the critical importance of food security and agricultural self-sufficiency.

Conventional plant breeding, even augmented by genomic selection and high-throughput phenotyping, may not be sufficient to meet these converging challenges at the pace required. The rate of genetic gain — the improvement in yield, quality, or stress tolerance achieved per unit of time — achieved through conventional breeding is real but gradual. Given the speed with which climate conditions are changing and the urgency of adapting cereal varieties to new environmental realities, there is a compelling argument that all available tool, including the most modern and precise biotechnological ones, must be mobilized [10].

3.2. Drought Tolerance: Adapting Cereals to Water Stress. Water scarcity is one of the most pressing threats to cereal production globally and in Ukraine specifically. The Black Sea region, including much of southern and eastern Ukraine, is already experiencing increased drought frequency and severity as a consequence of climate change, and projections suggest that these trends will intensify in the coming decades. Drought is the single most important abiotic stress factor limiting wheat and corn yields in Ukraine.

CRISPR/Cas9 offers multiple avenues for improving drought tolerance in cereals:

Stomatal regulation — stomata are the pores in leaf surfaces through which plants exchange gases with the atmosphere and through which most water loss (transpiration) occurs. Plants regulate stomatal aperture through a signaling cascade involving the phytohormone abscisic acid (ABA) and guard cell potassium channels. CRISPR/Cas9 has been used to edit genes encoding negative regulators of ABA signaling, such as the *SlMPK12* gene in tomato or *TaSnRK2* genes in wheat, to enhance stomatal closure under drought conditions, reducing water loss while maintaining photosynthetic capacity. Similarly, editing of the *HvERA1* gene (Enhanced Response to ABA 1) in barley has been shown to improve drought tolerance in field conditions.

Root architecture modification — deeper and more extensive root systems enable plants to access water from deeper soil layers. CRISPR/Cas9 editing of genes controlling root angle and root elongation, such as members of the *DRO* (Deep Rooting 1) gene family, first characterized in rice, can produce cereal varieties with superior water extraction capacity under drought conditions.

Osmotic adjustment — many drought-tolerant plants accumulate compatible solutes (small organic molecules such as proline, glycine betaine, or trehalose) that maintain cell turgor under water deficit. CRISPR/Cas9 can be used to upregulate genes in the biosynthetic pathways for these molecules, or to downregulate competing pathways, enhancing osmotic adjustment capacity.

Waxy starch modification — in wheat, the editing of genes encoding waxy proteins (granule-bound starch synthases, *GBSS*) to produce waxy or partial-waxy endosperm phenotypes has been shown to improve water use efficiency and to alter grain quality in ways relevant to specific market applications. This is one of the earliest examples of CRISPR/Cas9 application in wheat, achieved by Zhang et al. [11, 12] by simultaneous editing of three *TaGW2* orthologs in the hexaploid wheat genome.

3.3. Heat Tolerance: Protecting Grain Setting Under Temperature Stress. Heat stress during the critical period of grain filling, typically occurring in May and June in the Ukrainian steppe zone, is increasingly recognized as a major constraint on wheat yields. Rising spring temperatures and the increasing frequency of heat waves are causing pollen sterility, reduced grain number, and accelerated grain filling with consequent reduction in grain weight and quality.

CRISPR/Cas9 approaches for improving heat tolerance in cereals include:

Editing of thermosensitive genes — several genes involved in flowering time and pollen development are particularly sensitive to high temperatures. The *TaRHL1* gene in wheat, for example, has been identified as a thermosensitive regulator of the pollen developmental pathway; editing of this gene can modify the thermal response threshold.

Heat shock protein regulation — heat shock proteins (HSPs) are molecular chaperones that protect proteins from heat-induced denaturation. CRISPR-based upregulation of HSP genes or editing of negative regulators of HSP expression can improve thermotolerance.

Membrane lipid composition — the fluidity of biological membranes at high temperatures is a critical determinant of cellular heat tolerance. CRISPR/Cas9 editing of genes encoding fatty acid desaturases can alter the degree of unsaturation of membrane lipids, modifying membrane properties at elevated temperatures.

3.4. Disease Resistance: Protecting Yields Against Fungal and Other Pathogens. Fungal diseases represent a major threat to cereal production in Ukraine. Fusarium head blight (scab), caused primarily by *Fusarium graminearum*, is a devastating disease of wheat that reduces yields and contaminates grain with mycotoxins (deoxynivalenol, zearalenone) that render it unfit for human consumption or animal feed. Stripe rust (caused by *Puccinia striiformis f. sp. tritici*), leaf rust (*P. triticina*), and powdery mildew (*Blumeria graminis f. sp. tritici*) are endemic in Ukrainian wheat production zones and require intensive fungicide applications to control.

One of the most elegant and widely demonstrated applications of CRISPR/Cas9 in cereal disease resistance involves the modification of susceptibility genes (*S-genes*) — genes that encode plant proteins that pathogens exploit to establish infection. By disrupting these genes with CRISPR/Cas9, it is possible to make plants resistant to the pathogen without introducing foreign resistance genes and without the «gene-for-gene» specificity that makes conventional resistance genes vulnerable to rapid pathogen evolution [13].

The most prominent example is the MLO gene system in powdery mildew resistance. The *Mlo* gene, originally discovered in barley, encodes a membrane protein that serves as an entry point for the powdery mildew

fungus *Blumeria graminis*. Loss-of-function mutations in *Mlo* confer broad-spectrum, durable resistance to powdery mildew. Wang et al. [14] used CRISPR/Cas9 to simultaneously knock out all three homoeologs of *TaMlo* in hexaploid wheat, producing plants with strong, broad-spectrum powdery mildew resistance, a landmark achievement that demonstrated the power of CRISPR/Cas9 for editing the complex polyploid wheat genome.

Similarly, editing of eIF4E (eukaryotic translation initiation factor 4E) genes in wheat, barley, and other cereals has been shown to confer resistance to potyviruses. Editing of TaNFXL1 genes has been associated with improved *Fusarium* tolerance. And CRISPR/Cas9-mediated modification of genes in the jasmonate signaling pathway can enhance the expression of systemic acquired resistance against a range of pathogens.

The importance of these approaches for Ukrainian wheat production cannot be overstated. The annual cost of fungal diseases in Ukrainian cereal production (in terms of direct yield losses, quality downgrading, fungicide costs, and soil contamination) amounts to hundreds of millions of euros. CRISPR/Cas9-derived disease resistance could dramatically reduce these costs while also reducing the environmental footprint of cereal production.

3.5. Nutritional and Quality Improvement: Adding Value to Ukrainian Grain. Ukraine's competitive position in global cereal markets depends not only on the quantity of grain it can produce but also on its quality. CRISPR/Cas9 offers powerful tools for improving the nutritional profile and processing quality of Ukrainian cereals:

Gluten protein modification for reduced allergenicity — wheat gluten proteins (gliadins and glutenins) are responsible for the unique viscoelastic properties of wheat dough and are essential for breadmaking quality. However, certain gliadin fractions (particularly alpha-gliadins) contain immunodominant epitopes that trigger celiac disease in susceptible individuals. CRISPR/Cas9 has been used to edit the complex alpha-gliadin gene family in wheat, producing experimental lines with dramatically reduced celiac disease immunoreactivity while maintaining acceptable baking quality [15]. Such low-gluten wheat could open premium market segments for Ukrainian grain.

Resistant starch enhancement — modification of the amylose/amylopectin ratio in wheat and barley starch through CRISPR/Cas9 editing of starch biosynthetic genes (including *GBSS* and *SSIIa*) can produce high-amylose grains with increased resistant starch content, a dietary component associated with improved glycemic control, gut health, and reduced risk of colorectal cancer. High-amylose grains command significant price premiums in functional food markets.

Reduced acrylamide formation — asparagine is an amino acid that reacts with reducing sugars at high temperatures to form acrylamide, a potentially carcinogenic compound formed during baking and other high-temperature food processing. CRISPR/Cas9 editing of genes encoding asparagine synthetases in wheat can reduce free asparagine levels in grain, thereby reducing acrylamide formation in baked products, a significant food safety benefit with commercial implications in European markets.

Improved nutritional value of barley — CRISPR/Cas9 editing of genes controlling beta-glucan content in barley can produce varieties with elevated levels of this soluble fiber, which has well-documented cholesterol-lowering and blood sugar-regulating properties. Beta-glucan enriched barley products are increasingly sought by the health food industry.

3.6. Herbicide Tolerance: Reducing Dependency on Specific Chemical Inputs. Herbicide-tolerant crop varieties allow farmers to use specific herbicides to control weeds without damaging the crop, potentially simplifying weed management and reducing the total amount of herbicide applied. CRISPR/Cas9 can be used to introduce specific, targeted mutations in plant genes encoding the target proteins of herbicides, mutations that reduce herbicide binding while maintaining the protein's normal biological function.

The most widely explored example in cereals involves the acetyl-CoA carboxylase (ACCase) gene and the acetolactate synthase (ALS) gene, which are respectively the targets of aryloxyphenoxypropionate (APP) and cyclohexanedione (CHD) herbicides, and of sulfonylurea and imidazolinone herbicides [16, 17]. Specific point mutations in these genes, which occur naturally in some weed populations (conferring herbicide resistance in weeds), can be introduced into cereal crops by CRISPR/Cas9 to create varieties that tolerate these herbicides. Under the 2026 European framework, such modifications, being point mutations equivalent to what can occur naturally, qualify as NGT Category 1 and do not require GMO-level authorization.

This approach is particularly relevant for Ukraine, where weed management in cereals is a significant agronomic and economic challenge, and where the availability of safe, effective herbicide tolerance traits in nationally developed varieties could reduce input costs and increase flexibility for farmers.

4. Why Genomic Editing Is Essential for Ukraine: Strategic, Agricultural, and Geopolitical Imperatives

4.1. Ukraine as a Global Agricultural Power: Stakes and Vulnerabilities. Ukraine's agricultural significance in the global food system is well established but deserves restating in the current context. In the years immediately preceding the full-scale Russian invasion, Ukraine was the world's fifth-largest wheat exporter (exporting typically 20—25 million tonnes per year), the world's largest sunflower oil exporter (accounting for approximately 46 % of global sunflower oil exports), one of the top four global corn exporters (with exports of 25—30 million tonnes per year), a major barley exporter, and a significant exporter of rapeseed, soybeans, and other agricultural commodities. The food security of numerous countries in the Middle East, North Africa, and Sub-Saharan Africa was substantially dependent on access to affordable Ukrainian grain and oilseeds. The disruption of Ukrainian agricultural exports following the Russian invasion in February 2022 contributed directly to food price spikes and food insecurity in multiple vulnerable countries — a stark demonstration of Ukraine's systemic importance to global food supply.

This importance is both an asset and a responsibility. Ukraine has a moral and strategic interest in maintaining and enhancing its agricultural productivity and export capacity not only for its own economic recovery and reconstruction but for the food security of the global community. This imperative makes investment in cutting-edge plant breeding technology not a luxury but a strategic necessity.

4.2. The Specific Impact of the War on Ukrainian Agriculture. The Russian aggression, now in its fifth year, has inflicted extraordinary damage on Ukrainian agriculture. The direct impacts include:

Land contamination and inaccessibility — according to estimates from Ukrainian government sources and international organizations, by mid-2026, between 3 and 4 million hectares of Ukrainian agricultural land are contaminated with anti-personnel and anti-tank mines, unexploded ordnance, and other remnants of war. Additional areas in frontline regions are inaccessible or unsafe for agricultural operations. This represents a permanent or long-term reduction in cultivable area that requires compensatory increases in productivity on the remaining accessible land.

Infrastructure destruction — Russian missile and drone attacks have systematically targeted Ukrainian grain storage facilities, port infrastructure, agricultural machinery, and rural energy supply systems. The destruction of the Kakhovka dam in June 2023, a deliberate act of military sabotage, eliminated irrigation infrastructure serving hundreds of thousands of hectares in southern Ukraine, fundamentally altering the agricultural geography of the region, and making varieties tolerant of unirrigated, dryland farming conditions far more critical than before.

Labor disruption — the mobilization of millions of men of working age into military service, combined with the displacement of millions of civilians, has created acute labor shortages in the agricultural sector. This reinforces the economic desirability of simplified, lower-input farming systems, including varieties that require fewer applications of pesticides and fungicides.

Seed supply disruption — the destruction of seed processing and storage facilities, the disruption of seed multiplication contracts, and the loss of experienced agricultural personnel have created challenges for the maintenance and distribution of improved seed in many regions.

In this context, the development of NGT-derived cereal varieties that offer higher and more stable yields with lower input requirements, better adaptation to local soil and climate conditions, and enhanced resistance to the diseases and pests that are proliferating in disrupted agricultural landscapes is not an abstract scientific ambition. It is a concrete response to immediate agricultural needs.

4.3. The Comparative Advantage Argument: Ukraine vs. Russia in Agricultural Technology. Perhaps the most strategically compelling argument for Ukraine's adoption of genomic editing technology is the comparative advantage argument: in the ongoing economic and agricultural competition with Russia, Ukraine can and should use technological superiority as a strategic lever.

Russia is one of the world's largest wheat exporters, having dramatically increased its agricultural production and export capacity over the past two decades. Russian wheat production has benefited from improved

agronomy, large-scale investment in agricultural infrastructure, and access to modern foreign-sourced agricultural inputs, inputs that are now progressively cut off by international sanctions. Russia has also pursued, under its current government, a strategy of aggressive agricultural expansion, driven partly by a desire to use food exports as a geopolitical instrument.

However, Russia's agricultural research and biotechnology sector is in a paradoxical position. The Soviet-era legacy of agricultural science, rooted in the infamous Lysenkoist episode that devastated Soviet genetics for decades, continues to cast a shadow. While Russia has significant plant breeding capacity and genetic resources (including the Vavilov Institute of Plant Industry in Saint Petersburg, one of the world's largest seed banks), its regulatory framework for biotechnology has been inconsistent and restrictive. Russia has been deeply resistant to the adoption of GMO crops in its domestic agriculture. Why? Partly for ideological and populist reasons, and partly as a marketing strategy positioning Russian grain as «GMO-free» in international markets. This stance has, in effect, also constrained Russian interest in and adoption of NGTs.

The 2026 European regulatory decision creates a specific and important opportunity for Ukraine. By adopting the European NGT framework as part of its EU accession process, or by adopting a compatible national framework ahead of accession, Ukraine can position its agricultural exports as technologically advanced, climate-adapted, and produced under the most rigorous safety standards in the world. Ukrainian grain carrying CRISPR-derived disease resistance or drought tolerance traits, certified under the European NGT framework, will be welcomed in European markets. Russian grain, produced under opaque regulatory conditions and without access to the most advanced breeding technologies, will face growing competition and scrutiny.

Moreover, the democratization of NGT technology — specially its much lower cost compared to conventional GMOs — means that Ukrainian public research institutions, national plant breeding companies, and even medium-sized private breeding enterprises can develop their own NGT-derived varieties, without dependence on large foreign corporations. This is qualitatively different from the GMO model, where the cost and complexity of trait development effectively forced national programs to license technology from Bayer, Corteva, or Syngenta. NGTs offer Ukraine the prospect of genuine technological sovereignty in plant breeding: the ability to develop and own the intellectual property for varieties adapted to specifically Ukrainian conditions.

4.4. NGTs and Ukrainian Food Sovereignty. The concept of food sovereignty (the right of a nation to define its own food and agriculture policies, to produce food adapted to its own ecological and cultural conditions, and to maintain control over its own agricultural genetic resources) has particular resonance for Ukraine in the current geopolitical context. A nation engaged in an existential struggle to defend its territorial and political sovereignty has every reason to prioritize its agricultural sovereignty as well.

Ukraine possesses exceptional genetic resources for cereal breeding. The territory of modern Ukraine encompasses the Vavilov centers of origin for several important crop species and harbors extraordinary diversity in

landraces, wild relatives, and elite germplasm. The National Center for Plant Genetic Resources of Ukraine (NCPGRU), housed at the V.Ya. Yuriev Plant Production Institute in Kharkiv, itself damaged by Russian bombardment and partially relocated, maintains collections of wheat, barley, corn, sunflower, and numerous other crops that represent irreplaceable scientific and agricultural heritage. CRISPR/Cas9 technology provides the tools to mine this genetic diversity efficiently, to identify the genes and alleles responsible for valuable traits in Ukrainian landraces and wild relatives, and to rapidly introduce these alleles into elite modern varieties.

This approach using genomic editing to accelerate the exploitation of native genetic resources is directly aligned with Ukraine's food sovereignty interests. It is the opposite of technological dependence: it is the use of cutting-edge tools to give new power and relevance to Ukraine's own biological heritage.

4.5. The EU Accession Imperative and Regulatory Harmonization. Ukraine's path to EU membership necessarily involves the progressive alignment of its legislation and regulatory frameworks with the European acquis communautaire. The 2026 EU NGT Regulation will form part of this acquis and will need to be transposed into Ukrainian law as part of the accession process. However, there is a strong argument that Ukraine should not merely transpose this regulation passively and belatedly, but should proactively develop national NGT capacity and regulatory infrastructure as part of its accession preparation.

The development of a national NGT regulatory framework, building on the European model but adapted to Ukrainian institutional realities, would serve multiple purposes: it would demonstrate Ukraine's seriousness as a future EU member state; it would provide the legal clarity needed to attract investment in Ukrainian plant biotechnology; it would establish the institutional expertise needed to evaluate and authorize NGT products; and it would position Ukraine as a proactive rather than reactive player in the emerging European genomic innovation ecosystem.

Several Central and Eastern European countries that joined the EU in the 2004 and 2007 waves of enlargement (Poland, Czech Republic, Romania) developed significant plant biotechnology research and regulatory capacity as part of their accession process and have since become important players in the European agricultural science community. Ukraine, with its far larger agricultural sector, its deep scientific tradition, and its pressing need for agricultural innovation, has every reason and every capacity to aspire to a leading role.

4.6. International Scientific Cooperation and Capacity Building. The development of NGT capacity in Ukraine requires not only regulatory reform and political will but also investment in scientific infrastructure and human capital. Ukrainian agricultural science has suffered from decades of underfunding, from the brain drain associated with emigration (dramatically accelerated by the war), and from institutional challenges inherited from the Soviet system. However, Ukraine also retains significant human capital (experienced plant breeders, molecular biologists, geneticists, and bioinformaticians) and has strong institutional foundations in its agricultural universities and research institutes.

The current period, paradoxically, offers an opportunity. Ukraine's international scientific partners (the EU, the USA, Canada, Australia) have demonstrated remarkable willingness to support Ukrainian science during the war, through emergency funding mechanisms, hosting of displaced scientists, equipment donations, and collaborative research programs. Several EU-funded projects have specifically targeted the development of climate-adapted varieties for Ukrainian conditions. The 2026 NGT framework creates a new rationale and a new framework for EU—Ukrainian scientific cooperation in plant breeding; cooperation that can contribute both to Ukrainian agricultural reconstruction and to the development of NGT varieties of interest to the broader European market.

Specific priority areas for international scientific cooperation in Ukrainian NGT development should include:

- Establishment of CRISPR/Cas9 transformation protocols for elite Ukrainian wheat and barley varieties (many of which have proven recalcitrant to transformation using existing protocols optimized for Western European genotypes).
- Development of bioinformatics capacity for guide RNA design and off-target analysis in polyploid genomes.
- Building of regulatory science capacity — the ability to characterize NGT plants according to the criteria of the 2026 EU regulation and to prepare regulatory submissions.
- Training of a new generation of plant breeders fluent in both conventional breeding and molecular editing technologies.
- Development of efficient intellectual property management frameworks that protect Ukrainian public investment while enabling the free exchange of scientific knowledge.

4.7. A Specific Strategic Program for Ukrainian Genomic Editing in Cereals. Based on the analysis presented in the preceding sections, we propose the following framework for a national strategic program for genomic editing in Ukrainian cereal breeding:

Priority 1 — Wheat drought and heat tolerance. Given the projected increase in drought and heat stress in Ukrainian wheat production zones, CRISPR/Cas9 editing of genes controlling stomatal behavior, root architecture, ABA signaling, and heat shock response in elite Ukrainian winter wheat varieties should be established as a national priority. Target varieties should include the most widely grown Ukrainian winter wheat cultivars, with the objective of improving performance under the temperature and precipitation conditions projected for 2040—2060.

Priority 2 — Wheat and barley disease resistance. CRISPR/Cas9-mediated disruption of susceptibility genes for powdery mildew (*TaMlo* homoeologs), Fusarium head blight (candidate *S-genes* in the jasmonate signaling pathway), and stripe rust in elite Ukrainian wheat and barley varieties. The objective is to develop varieties with durable, broad-spectrum disease resistance that reduce dependence on fungicide applications.

Priority 3 — Corn drought and aluminum tolerance. Southern and eastern Ukraine's soils include significant areas of acid soils where aluminum toxicity limits corn production. CRISPR/Cas9 editing of *AltSB*-type aluminum tolerance genes, combined with drought tolerance improvements, could significantly extend the productive corn belt of Ukraine.

Priority 4 — Sunflower Sclerotinia resistance. Sunflower remains one of Ukraine's most important export crops. CRISPR/Cas9 offers potential approaches to improving resistance to Sclerotinia stem rot, the most important fungal disease of sunflower globally, through editing of genes in the jasmonate and salicylic acid defense signaling pathways.

Priority 5 — Grain quality improvement for European markets. Development of low-gluten wheat varieties for the European health food market, high-amylose wheat and barley for the functional foods market, and low-acrylamide potential wheat for the baked goods market, all through CRISPR/Cas9 editing of genes in the relevant starch and protein biosynthetic pathways.

Conclusion: A Strategic Imperative for Ukrainian Agriculture

The adoption of the European Union's New Genomic Techniques regulation on June 17, 2026, marks the beginning of a new chapter in the history of plant breeding, one in which the extraordinary precision, speed, and affordability of CRISPR/Cas9 and related tools can be fully deployed in the service of agriculture, without the regulatory constraints that have until now impeded their application. For Ukraine, this regulatory breakthrough arrives at a moment of acute and converging challenges: a devastating war that has disrupted agricultural production, displaced farmers, and destroyed infrastructure; accelerating climate change that is intensifying drought, heat stress, and disease pressure; and a global food security context in which Ukraine's role as a major grain exporter carries both economic importance and moral weight.

This article has argued that genomic editing, and CRISPR/Cas9-based plant breeding in particular, is not merely one option among many for Ukrainian agriculture. It is a strategic imperative, for several interconnected reasons.

First, the technical superiority of CRISPR/Cas9 over both conventional breeding and conventional GMO technology is unambiguous. Its precision, speed, and cost-effectiveness make it uniquely suited to the urgent task of adapting Ukrainian cereal varieties to rapidly changing conditions — whether those changes originate in the climate, in the epidemiology of pathogens, in the disruption of established agricultural systems by war, or in the evolving demands of European and global markets.

Second, the democratic accessibility of CRISPR/Cas9 technology, its much lower cost compared to conventional transgenesis; means that Ukrainian public institutions can develop and own their own NGT-derived varieties. This is a matter of technological sovereignty that goes to the heart of Ukraine's capacity to define and pursue its own agricultural future, free from dependence on foreign corporate technology providers.

Third, the geopolitical dimension is inescapable. Ukraine is in competition — agricultural, economic, and civilizational — with Russia. Russia's agricultural sector, while significant, is increasingly constrained by sanctions, by its ideological resistance to modern biotechnology, and by the progressive isolation of its scientific community from the global research network. Ukraine, by contrast, is deepening its integration with European science and with the global innovation ecosystem. Adopting and develop-

ing genomic editing technology is one concrete way in which Ukraine can turn this integration into a durable competitive advantage in the agricultural domain.

Fourth, the European accession context transforms the adoption of the NGT framework from a choice to a necessity. As Ukraine aligns its legislation with the European acquis, it will need to transpose the 2026 NGT regulation. The question is not whether Ukraine will have an NGT regulatory framework but whether it will be a passive importer of that framework or a proactive developer of national NGT capacity that can shape and contribute to the European genomic innovation ecosystem.

Fifth, and perhaps most profoundly, the development of genomic editing capacity in Ukrainian agriculture is an investment in hope. In a country that has endured extraordinary suffering, that has seen its fields mined and its granaries bombed, that has watched its farmers mobilize as soldiers and its agricultural workers flee as refugees, the development of new tools for growing more, better, and more sustainably on the land that remains is an act of reconstruction and affirmation. Ukrainian wheat has fed the world for millennia. CRISPR/Cas9-improved Ukrainian wheat, adapted to the climate of the mid-21st century, disease-resistant, drought-tolerant, nutritionally enhanced, and certified under the world's most rigorous safety standards, can continue to do so.

The call to action for the National Academy of Agrarian Sciences of Ukraine, for Ukrainian research institutions, for the Ministry of Agrarian Policy, and for Ukraine's international partners is therefore clear: invest now in the development of genomic editing capacity; develop a national strategic program for CRISPR/Cas9 application in cereal breeding aligned with Ukrainian agricultural priorities; establish the regulatory framework, in harmony with European legislation, needed to allow NGT-derived varieties to move from laboratory to field to market without unnecessary delay; and build the human capital — the next generation of Ukrainian plant breeders fluent in molecular biology and bioinformatics as well as in agronomy and genetics — who will carry this work forward.

Ukraine's fields can be among the most productive and technologically advanced in the world. The tools are available. The need is urgent. The moment is now.

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РЕДАГУВАННЯ ГЕНОМУ ТА ЙОГО СТРАТЕГІЧНЕ ЗНАЧЕННЯ ДЛЯ УКРАЇНИ: МОЖЛИВОСТІ, ЯКІ ПРОПОНУЮТЬ НОВІ ГЕНОМНІ ТЕХНОЛОГІЇ В КОНТЕКСТІ ЗМІНИ КЛІМАТУ, ЕКОЛОГІЧНИХ ПРОБЛЕМ ТА ГЕОПОЛІТИЧНОЇ НАПРУЖЕНОСТІ

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Прийняття Європейським Союзом 17 червня 2026 року регуляторної бази, що дозволяє нові геномні методи (НГТ), зокрема підходи на основі CRISPR/Cas9, знаменує собою вирішальний поворотний момент в історії селекції рослин. Після майже десятиліття наукових дебатів, юридичних баталій та політичних переговорів європейські законодавці нарешті визнали, що певні категорії геномного редагування принципово відрізняються від звичайного трансгенезу та заслуговують на окремий, гнучкіший регуляторний режим. Це історичне рішення відкриває нову еру не лише для європейського сільського господарства, а й, можливо, насамперед для країн, які тісно пов'язані з європейським сільськогосподарським та науковим простором або прагнуть інтегруватися в нього, передусім для України. Як один з провідних світових виробників та експортерів зернових культур, а також як країна, що бере участь в екзистенційній війні, яка глибоко порушила її сільськогосподарський сектор, Україна стоїть на роздоріжжі, де сходяться наукові інновації, продовольчий суверенітет і геополітична стратегія. У цій статті розглядається природа та механізми нових геномних методів, їхні технічні переваги над традиційними ГМО, їх конкретне застосування в селекції зернових культур, а також стратегічна необхідність для України впроваджувати й розвивати ці технології як національний пріоритет.

Ключові слова: нові геномні методи, CRISPR/Cas9, геномне редагування, селекція зернових культур, Україна, продовольча безпека, зміна клімату, геополітична стійкість.

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