

# CRISPR beyond Editing: Innovative Applications in Medicine and Agriculture

**Ghafran walled Awad Aliwi**

Al Qasim Green University Collage of biotechnology Department of medical biotechnology

**Israa Mohammed Karim Lazim**

University of Baghdad College of science Department of Biotechnology

**Ahmed wleed sadiq farhan**

University of Fallujah College of applied sciences Department of Biotechnology

**Zahraa Hafde Fadhel Jeber**

University of Baghdad College of Science Department of Biotechnology

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**Annotation:** CRISPR is a versatile technology for editing genes originally discovered in bacteria as a component of their immune system. In a very short period, it has gone through numerous advancements and is presently applied not only in editing genes but also in many other innovative applications in the fields of agriculture and medicine.

## 1. Introduction

This approach is acquiring recognition for its ability to modify not only somatic but also germline DNA to cure various genetic disorders in humans. In agriculture, it has been widely utilized in developing crops with optimal growth and nutrition, with improved resistance to various kinds of pathogens and tolerance to environmental stress. Recently, various new techniques have been applied within this technology to accelerate the rate of developing pathogen and drought-resistant crops, which would certainly contribute greatly to the global food requirements. This increasing pace of research and development in CRISPR technology demands a nuanced understanding of marketing, regulatory, and ethical challenges for the stakeholders in medicine and agriculture. Thus, this review will act as a catalyst to foster knowledge about the fundamentals of CRISPR, its working mechanisms, its various applications, including gene editing, diagnostics and therapeutics,

programmed gene drives, biosensing, and its diversification potential, along with the current ethical considerations and future directions of CRISPR.[1]

## 2. Fundamentals of CRISPR Technology

With the novelty of genetic engineering, explorers have been actively dealing with the genomic sequence. Recently, the healthcare and agriculture sectors have experienced revolutionary technology. Due to its precise, accurate, and low-cost nano-resolution editing, this technology has brought a remarkable transformation in these two regions of the world. It has versatile applications in the biological sector, achieving a boost during the generation of standalone gene-edited crops and also modifying the genome of human beings. Now, it serves as a broader, mature, and popular systematic editing tool to manipulate the genome with more accuracy. The functionality of this technology is explained and used in cells, plants, animals, and humans.

This technology means 'Clustered Regularly Interspaced Short Palindromic Repeats', which is named based on the structure of the prokaryotic genome. The mutation of the genome can be established either at the genetic level of the organism or at the heritable genomic level. 'Genome editing' is the process of targeting a specific gene and making alterations like mutations, insertions, and deletions. Continuous research has been performed, leading to different versions, each possessing its unique mechanism of function in the coupled system. Each of the proteins is utilized by specialized RNA, such as CRISPR RNA or single guide RNA, mostly in mammalian cells, for the binding of edited DNA, hence deleting that particular sequence and leaving an unedited DNA behind. This can be used to create a knockout model integrated with an eye to read out the phenotypic change in the next generation. In ribonucleoprotein systems, the siRNA targets the silencing of the desired genes in a variety of cultured cell lines. Each class has a different classification for some species of bacteria and has been widely used across global regions. [2][3][4]

### 2.1. Mechanism of CRISPR-Cas9 System

Designed with the precision of a highly skilled tailor, the most illustrious molecular biology invention of the 21st century has revolutionized gene editing. The magnificent intricacy of the system is its operational mechanism, and the diversity of its applications. The enzyme has two functional cores – an HNH domain and a RuvC domain. An enzyme that can easily climb the helix of DNA, it cleaves both strands of the DNA, which further expedites the opening of the DNA double helix. All these functionalities, when coupled with a guide RNA, enable it to make a double-strand break in the DNA.

Fundamentally, the guiding RNA coordinates with the enzyme. Integrating with the system, cells have in-built repair systems that are instrumental in the implementation of the aftermath of double-strand breaks. Double-strand breaks activate error-prone Non-Homologous End-Joining or the comparatively rare error-free Homologous-Recombination Repair pathway. These processes speedily rewrite the DNA by erasing, inserting, or replacing the faulty gene. Such extraordinary precision has made its applications paramount in modern medicine and agriculture, being effectively recognized as a therapy for the creation of remarkable knockouts of oncogenes or organ-specific gene insertion. This management of cells has amplified the scope of translational biology research. Although challenges exist, the applications of precise gene editing and development are no longer unconquerable. Understanding these innovations is of great importance in minimizing off-target effects, potentially increasing the chances of wider application. [5][6]

### 2.2. Key Components of CRISPR Technology

CRISPR consists of three main components. Guide RNA has a partial sequence complementary to the target DNA and is capable of recognizing the target sequence. CRISPR-associated protein (Cas), specifically the Cas9 protein, functions to cut the double-stranded DNA, and this protein is guided by guide RNA to do its duty. When people want to insert new DNA in a particular place or to replace defective DNA with normal DNA, they usually add the new DNA they want to insert or the new DNA that will replace the existing defective DNA.

The CRISPR system relies heavily on the guide RNA component. This guide RNA has at least three main components, namely the gRNA scaffold attached to the stem loop. One component is a direct repeat that is important as a variable RNA fragment. The last component is the CRISPR RNA fragment, to which crRNA is attached. The spacer is a short RNA represented by a fragment of sequence-based DNA in organisms. This spacer plays a role in guiding the Cas proteins to the target DNA sequence. This guide RNA cuts the double-stranded DNA in a sequence-specific manner with the help of the Cas protein. The target DNA is recognized by complementary surfaces between the guide RNA and the spacer, called the protospacer. This enzyme can cut DNA in a variety of sequences using a protospacer-like adjacent motif. You can improve the properties of guide RNA to increase the efficiency and accuracy of CRISPR. Researchers also design to engineer the CRISPR system to make it more programmable and versatile, one of which is by modifying the guide RNA. These modifications are used as tools to broaden the scope of CRISPR applications in genetic and genomic studies. Moreover, the use of the CRISPR system for site-specific genome editing in basic and applied research is becoming increasingly popular. Using CRISPR technology to introduce a mutation that causes a disease in a specific type of cell, then growing the cells in the laboratory and testing the molecular compounds being developed, especially likely to be used in drug and nutrition research. Other ongoing research is to modify genetically plants and animals and automate food processing equipment. These modifications could help meet the nutritional needs of a rapidly growing world population. [7][8]

### 3. Medical Applications

The explosion in CRISPR research makes it a biological tool transformative of society. Initially, it was described as a method of genome editing, but soon expansions on its use began. The focus was on correcting a hereditary mutation that cannot be solved by conventional medicine, such as Huntington's disease or hemophilia, creating a gene therapy. In 2016, the first human embryonic modifications developed outside of the mother's womb were made, associated with three third-party reproductive gene therapies aimed at preventing deafness or sickle cell anemia. Recently, applications in cancer have been shown as immunotherapy. With the information of the genes involved, CRISPR is used to reproduce immune cells to be injected to destroy the tumor. Although it is still being investigated, it promises that the current idea of medicine will change.

Within its application, it is the creation of personalized drugs, whose characteristics will be marked by the genes and the environment where the individual was raised, being more successful in reducing side effects. If we use CRISPR to treat certain tissues in a person of age, these cells will evaporate when the individual dies, so the therapy will not be transferred to their descendants. Although dossiers go through the "gene demos justice" for each use, those who work in this field say that they have passed the judges. Despite the enormous potential that CRISPR has to transform clinical situations radically, it is still in the experimental stage, and everything must be supported by scientific evidence within clinical trials. There are still many challenges to be faced before saying that this is a revolution in medical practice. [9][10]

#### 3.1. Gene Therapy

The focus on CRISPR in gene therapy for its ability to cure genetic disorders should not shortchange the interdisciplinary connections currently happening in molecular and cellular biology, physiology, genetics, ethics, and society. The "gene therapy" heading needs better focus on medical applications for tampering with the human genetic code.

CRISPR can edit defective genes and turn them back to the wild-type form to restore normal cellular function. This has already been explored clinically in multiple genetic disorders such as cystic fibrosis and Duchenne muscular dystrophy. The delivery of the different components of CRISPR into the patient's cells for the editing to happen has posed both challenges and opportunities. Viruses known as viral vectors have been traditionally used to deliver clinical gene therapy and have advanced timelines for the clinic. However, viruses can still cause unwanted gene edits in other parts of the genome. There has been no clear evidence to date of this happening, but regulators have

thus far still carefully weighed this possibility.

However, the growing understanding of how to deliver a large payload genetically into the cells using a virus has also opened the door for CRISPR to be delivered into the cells. Part of this success has also come from the ongoing progress of gene editing within the cell. In the human species, CRISPR has greatly transformed basic and applied research, most notably in gene and embryonic editing. Future research on how to dial up the accuracy and reduce off-target gene effects for CRISPR, versus that of a natural new virus exposure, may also contribute to wider CRISPR technology adoption in the future.

### **3.2. Cancer Treatment Innovations**

A targeted approach is at the heart of the CRISPR genetic editing tool, an innovation that changes the cells of people, animals, and plants. In addition to being able to potentially identify and kill only cancer cells, CRISPR is helping in the fight against tumors by being used in immunotherapy to make immune cells that the body naturally produces more effective in destroying cancer cells. Researchers are working on developing experimental therapies for cancer. Human clinical trials are underway at various cancer centers and other locations.

These researchers are altering the genes of a person's T-cells, a key actor in the fight against cancer and infectious diseases, with CRISPR. This therapy is already the first treatment used that changes the actual DNA in the body as part of a course of treatment. Companies are also jumping into CRISPR as a capacity to treat cancer. Investigators studied a version of CRISPR that removes genes permanently. This approach is for cancer patients suffering from blood disorders. CRISPR is currently being used to treat types of cancer, such as leukemia, as part of an experimental therapy that has been tested in people. Ethical concerns are raised about creating germline cells whose altered genes can be transmitted, which is prohibited in many countries and raises ethical concerns. Overall, CRISPR therapy holds promise for enhancing existing therapies and developing new ways to treat cancer. [11][12]

### **4. Agricultural Applications**

In agriculture, it is hoped that the CRISPR technique will lead to the development of crops and livestock that are better equipped to support the growing global population. Through this technology, we have the potential to create crops that are resistant to pests. It therefore has the potential to improve food security and reduce food spoilage caused by pests and diseases. Climate change problems, such as periods of drought, can also be tackled as it offers the possibility of developing plants with higher water use efficiency. This would enable production on marginal land and increase the diversity of available crops. For farmers, early maturing and higher crop yields would result from reducing the number of breeding cycles, as well as protein and nutrition enhancement.

CRISPR may also be used as a tool for crop trait optimization in precision agriculture. Among other things, the technology will improve livestock productivity by enhancing disease resistance, growth rate, and the quantity and quality of animal products. Furthermore, livestock are major consumers of the water and food resources, eating a significant portion of the world's agricultural land. Using gene editing, we can design livestock with high yields, which will help in achieving global food and nutrition safety over the next 20-30 years. There are many challenges contributing to the development of the rural sector and society, and gene editing can overcome those, help achieve long-term sustainability objectives, reduce dependence on external sources, and develop promising rural areas. The developed society is changing the sync that is needed to overcome the challenges of individuals, in particular, with sufficient food, material, energy, and all other ecosystem services. The integration of gene editing, nanotechnology, and biotechnology is now able to unlock significant pathways to rural development and human health. Scientists are confirming this innovative tool in global research, innovation, and regulatory reporting around the world in agriculture, healthcare, and daily lives. There are some strong motivating factors around the world

for transforming gene editing crops and animals. The first motivating factor and potentially the most compelling to society is the ability to develop crops that are resistant to pests, diseases, and environmental stress. The technology has the potential to not only improve food security but also reduce the economic losses due to pests and pathogens and reduce food spoilage. [13][14]

#### **4.1. Crop Improvement**

To feed the 9 billion people projected to inhabit Earth by 2050, we will need to increase food production by 70%. New tools are required as many strategies currently in use worldwide pose risks to the environment and raise ethical concerns. Indeed, these classical strategies often involve the use of transgenic plants with potentially harmful genes. One alternative, with the potential to meet such projections, is the use of CRISPR. Notably, this has been demonstrated by the fact that CRISPR is widely used now to rapidly breed elite crops, reducing the R&D process by several years. Apart from improving yield, CRISPR has been used to protect cereals from pests attacking the underground or above-ground parts of plants. The papaya ringspot virus is a severe constraint on papaya production, and producing transgenic plants resistant to the virus was costly, time-consuming, and faced many social acceptance problems. CRISPR is being used to address a similar approach of resistance by renaturing the gene of papaya, rendering it resistant to the ringspot virus, thus solving a 30-year-old problem of resistance to the ringspot virus in papaya. The plummeting interest of the young generation in changing climate and rapid urbanization, as well as massive adoption of healthy lifestyles—with an increasing preference for vegetarianism or veganism—has led developed countries to explore molecular farming. CRISPR was used to reprogram cauliflowerer sidelines by increasing the level of a broccoli gene that codes for a health-protective protein preventing the formation of cancer. Edits developed specifically for plant secondary metabolism were used with the aim of commercializing orange lilies producing extended periods of blooming time, with the goal of indoor beautification. The production of apple trees producing apples that do not oxidize in air has been developed, breaking a paradigm of not using CRISPR in expanding the profitability of fresh-cut apple nurture. It is estimated that this apple tree obtained without the use of transgenes will penetrate the pared market in the next five years. Indeed, apples are extremely prone to browning, as every injury to the fruit, even by the smallest impact, accelerates the browning process, limiting the areas where they can be packed and requiring costly sprays of anti-browning products. Expensive dusts containing ascorbic acid and citric acid, or antioxidants and secondary metabolites, must be applied to the apple's surface to keep the packaging of apple cuts prolonged. The ability to extend the shelf life of the apple is an innovation that has led to a harvest of over USD 20 million. However, gene silencing control in any processing tumor area is already used, typically in the USA. [15][16][17]

#### **4.2. Enhancing Livestock Wellbeing**

Some of the most innovative applications of CRISPR can be expected in the domain of agriculture, particularly with dairy and beef industries seeing an uptake of biotechnologies for better food safety profiling, breeding management, or animal identification. Genetic modifications in livestock can involve disease resistance, general animal welfare, as well as the sex of the offspring. Recent focus is very much on breeding robust farm stock with greater native immunity, reducing the reliance on using antibiotics. Several animal breeds have had their DNA modified using genome editing, showing immunity to deadly viruses resulting in 100% survival during laboratory challenges. Broiler chicken breeds have also been enhanced via a CRISPR knockout of a specific protein; these birds laid eggs with a resilience trait, and subsequent progeny were resistant to the progression of the influenza virus.

One logical step in CRISPR research is to go beyond generic disease resistance traits. Reference points from the pig industry indicate that an array of phenotype traits could also be genetically modified, for example, coat color, fat deposition, lean muscle growth, and skeletal sturdiness. Easy-to-breed traits or genes which also affect fitness (such as general health, litter size, or feed conversion efficiency) would likely leave a more enduring impact and where breeding may be

profitable. Encouraging a clandestine approach to CRISPR safety studies in animal agriculture lacks transparency at a time when the drive for corporate responsibility and confirming gene capital of livestock are key buying considerations. The transition for some of the first genetically modified non-commodity species seems to be a breeding approach rather than being motivated by academia. The possible negative aspects of genetic traits towards welfare or stress resilience present a complication, as picturing problems that don't yet exist could pose an unintended threat that triggers anti-genome editing sentiments. The welfare sensitivities of some of these traits will likely spark a broader fear in the public, with genetic modification as a breeding practice becoming unwelcome. Indeed, relevant authorities have already been in consultation with the broiler chicken genome editing trials where alternative horned genetics are seeking approval for sale and consumption. The controlled studies are hoping to evaluate the consumers' attitudes to CRISPR edited animals. The numerous untouched fields require the implementation of time to generate suitable data within the dairy and beef CRISPR field, and research where the risk can be mainly focused will aid disposition in the future. [18][19]

## **5. Ethical Implications and Regulatory Framework**

The possibilities of gene editing that rise to the fore with CRISPR-Cas9 bring a new set of ethical questions. Consent is a major concern across both medicine and agriculture. Questions arise regarding the selective use of gene editing, the level of control and surveillance that is feasible, concern for the long-term implications of alterations, and whether equality would indeed be achieved, because while some may be able to afford such treatments, others may not. Risks can range from unintended consequences or off-target effects to damaging ecological impacts of gene-edited crops. Responsible research and innovation frameworks are under development to help guide researchers, policymakers, and other stakeholders in deciding how new technologies should and could be put into practice. In more practical terms: how the development of both medical and agricultural gene editing therapies can be managed will be a matter of regulation. Development will also be contingent upon the accumulation of adequate safety and efficacy data, as governed by existing regulations enforced by national and regional health services. These will determine if, how, and when CRISPR therapies can be made available to patients. In the field of agriculture, crops and other GM products must satisfy regulations concerning safety and efficacy and demonstrate they offer a quantifiable advantage before they can be commercialized. The trajectories of medical and agricultural gene editing vary by country. These differences offer unique opportunities to learn and develop insights into how best to guide the upcoming application of CRISPR and gene editing in our various contexts. It could also be necessary to develop global responses to a number of the challenges presented by gene editing in a range of domains. Discussions with patients and the wider public about their attitudes toward CRISPR and gene editing, whether medical or agricultural, are vital as the field continues to develop. There is a real need for conversation about the best ways forward.

## **6. Vision for the Future and Final Thoughts**

As we have examined and speculated about the applications of CRISPR in medicine and agriculture, we have envisioned ADAR base editors to correct RNA transcripts for non-invasive gene editing; dual-gene drive systems to block disease transmission by suppressing vector populations; single-molecule CRISPR diagnostics for home or field use; and combination approaches of sustainable allele editing and constitutional gene editing to provide for a more diverse and plentiful food supply. We imagine many innovative uses for CRISPR in the creation of new crops, such as the synthesis of nutrients like vitamin A to make 'Golden Rice 2.0' or the production of allergen-free peanuts. CRISPR can extend well beyond DNA modifications and be harnessed for other cutting-edge fields like synthetic biology and neurobiology to advance cell-based therapies for cancer and toolkits to cure brain disease. Today, we are seeing the beginning of applications for CRISPR in conservation, with potential to reverse species decline and build ecological resilience. Future work will also reassess and recalibrate our research horizon as we discover new ways to edit and regulate genes, akin to the days of recombinant DNA and Dolly the sheep.

The global community is continually modernizing with advanced information technologies and greater connectedness, accelerating the speed at which CRISPR applications are developed. We must remain astute and engage in ongoing research and reflection about how to guide the generation of new CRISPR technologies, responsibly incorporating the perspectives of ethicists, society, and policymakers. Continuous reevaluation of risks and oversight for CRISPR technology is also a must. It should be made clear, however, that risks should not be a barrier to responsible research and application. At the same time, there needs to be public engagement and regulatory contexts that govern such technologies. As CRISPR advances and becomes more accepted, careful public education will convince individuals to take up transformative technologies that may help bridge disparities in health based on wealth, sex, geography, education, disability, or other inequalities. The societal implications of gene editing technology on both food and medicine vary, but have the power to transform the global standard of living through upgraded crops and enhanced medical care. It is also clear that this technology should be pursued with caution and should not supplant careful political or regulatory work. [20][21]

## 7. Conclusion

In conclusion, CRISPR gene editing technology is a potentially transformative power in agriculture and human health. In medicine, researchers are working on developing a host of new drug delivery mechanisms and treatment methods. Overall, a primary application of CRISPR in medicine is gene therapy. There are promising and innovative results from first-stage trials in cancer, with a longer range aim of using CRISPR for potentially treating sickle-cell anaemia and beta-thalassemia, HIV, and diseases such as severe combined immunodeficiencies and chronic granulomatous disease, as well as accelerating analgesic recovery and stem cell development. In agriculture, CRISPR technology is driving novel guided crops that will unambiguously engage with regulatory consideration. CRISPR biotechnology will form the core of potential post-transgene and edited cultivars, both with increased sustainability and requiring additional ethical reflection to assess and justify their potential uses. In line with these innovative applications, multiple reports raise the need to draft globally acceptable ethical walls such as the importance of involving the public and to enforce existing regulation in line with evolving biotechnology.

As high-throughput DNA and RNA sequencing expand in capabilities and reach, the ability for researchers, doctors, and even enthusiasts to modify genes is growing much more quickly than before. CRISPR genome editing technology offers new potential for modern biological analysis and biotechnical application, but also confronts ethicists, policymakers, and the scientific community with a growing number of ethical considerations and conversations. In the coming years, it will fall to all three sectors, and many others, to answer unprecedented questions about the potential risks and rewards of gene editing, and to develop regulatory procedures at the national and international level to accompany the rapid technological advances. The ethical considerations and regulatory boundaries developed as CRISPR gene editing development tools extend our human capacities to heal and feed the world in a safe, effective and responsible way that is both aware of the dynamics of progress and nurtures the capital with which society—now, and for future purposes. The exponential pace of biotechnology and information technology has advanced in the 21st century, requiring interdisciplinary and global responses to cultural change in the management of innovation and the governance of cutting-edge knowledge. A gaze into the future of science is mandatory as it should engage in dialogue and awareness with the public on new applications and possibilities for genetic editing. As biotechnology continues to advance, bringing with it new complexities, ethical questions, and regulations, we must ensure that CRISPR technology is used in a responsible manner and provides a social and societal benefit. Working hand in hand, genetics and society can address the global challenges awaiting us in the coming years, from antibiotic resistance to mass migrations of people, interspecies infections through agriculture to spy satellites, and many more. A global multidisciplinary conversation is already taking place to ensure that a consensus is found on how to use custom genetic editors like CRISPR in a way that is safe, responsible and feasible for the future of the earth.

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