Gene editing is a transformative innovative technology which offers great potential in agriculture to sustain productivity and ensure nutritional security. This technology will help in mitigating the effects of climate change and global warming by creating climate resilient crops. India has taken lead in harnessing the potential of this technique by releasing two genome-edited rice varieties – DRR Rice 100 (Kamla) and Pusa DST Rice 1 which is a staple food of majority population in the world. The technology will help the farmers with better returns without any further stress on land.

Gene Editing Technology
Transforming Agriculture

Dr. Harender Raj Gautam

Gene or genome editing is a transformative innovative technology which has huge potential in the field of bio-sciences including agriculture. In agriculture, it offers great potential to customise crops with desirable traits for increased productivity and quality; increased resistance to pests and diseases and making plants resilient to stresses being imposed by climate change. The word 'genome' refers to the hereditary material of an organism. While genes determine heritable characteristics, but it is the genome that determines the organism. Gene editing technologies, including the most precise CRISPR (clustered regularly interspaced short palindromic repeats) is one of the latest advances in genetics and its application to plant and animal breeding will transform the agriculture in the coming decades. Specifically, CRISPR-Cas has its origin in a bacterial immune system where these are widely distributed and have an important role in the defence against viral pathogens that attack the bacteria. This system was studied in detail by Spanish scientist Francis Mojica in the 1990s which later paved the way to adapt this system into an efficient genome editing tool. But, ultimately it

The author is Former Professor and Head, Dr. Y. S. Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh. Email: hrg_mpp@yahoo.com

was in 2012 that Jennifer A. Doudna and Emmanuelle Charpentier took the work of Mojica further and discovered the 'CRISPR/Cas9' genetic scissors which is one of the precision tools of gene technology. By using this technique, researchers can make precise changes in the DNA of human beings, animals, plants and other microorganisms to have desired changes. Keeping in view the vast potential of this technology, these scientists were awarded the Nobel Prize in Chemistry in 2020. In agriculture, this technology will enable precise modifications in the genetic makeup of crops, accelerating the production of new high yielding crop varieties with better nutrition and allowing for the development of varieties that can better withstand the environmental stresses posed by climate change. Gene editing uses site directed nucleases (SDNs) to make changes such as a small deletion, a substitution or the addition of a number of nucleotides. Such targeted edits in the genomes of the different crop varieties results in new and desired characteristics. Now, researchers from the University of Maryland, USA have further refined the technology by developing a comprehensive all-in-one CRISPR toolbox which is able to do large-scale CRISPR screens in plants both in monocots (rice) and also in dicot (tomato) plants. Genome editing is now being applied to more than 40 crops to improve food and feed quality or stress tolerance in more than 25 countries, but only six genome-edited crops for different traits have been approved for commercialisation in the US and in Japan.

Gene Edited Crops: Sustaining Food and Nutritional Security

Staple crops such as rice, wheat, maize, and soybeans are the backbone of global food security, providing the primary source of calories for a large portion of the world's population. Just three of them, rice, maize and wheat, provide 60 percent of the world's food energy intake and are also the staples of over 4,000 million people worldwide. Gene editing technology CRISPR/Cas offers new opportunities to enhance crop yield by directly targeting genes that regulate plant growth and development. For example, editing the *OsAPL* gene which is involved in nutrient transport has been shown to increase yield in rice. Photosynthetic efficiency of the plants can be enhanced by targeting genes involved in chlorophyll synthesis and light capture and this has been done in rice by targeting the gene *OsSXK1* which improved photosynthetic rates and increased grain yield. In rice, the technology has also been employed to enhance aromatic qualities by editing the *OsBADH2* gene, leading to increased production of 2-acetyl-1-pyrroline (2-AP), a compound that imparts a desirable fragrance, thereby catering to consumer preferences. Until now, more than 55 rice genes have been subjected to editing in rice only, using the CRISPR-Cas approach for various traits such as abiotic and biotic stress tolerance, plant architecture, and grain yield. This technology has also played pivotal role in addressing nutritional deficiencies through crop biofortification. Biofortification aims to increase the content of essential nutrients in crops, thereby improving their nutritional value. The development of 'Golden Rice,' which contains higher levels of beta-carotene, was accomplished

Wheat is an important crop of our food basket and genome editing efforts in this crop are being pursued with an aim to enhance its nutritional profile by modifying the levels of amylose and gliadin. Gliadin is a key component of gluten and is known to be a trigger for celiac disease, an autoimmune disorder, in genetically susceptible individuals.

by modifying genes involved in pro-vitamin A biosynthesis. Scientists have used this technology for an enhanced per-plant accumulation of micronutrient zinc (Zn) in the rice grain and the increased Zn content in genome edited rice lines holds significant potential to support global initiatives toward nutritional security as Zn is an essential micronutrient in human diets. In rice and wheat, genes such as *OsNAS* have been edited to increase iron and zinc levels, addressing the micronutrient deficiencies that often lead to anaemia and also impaired immune functions in the vast population of consumers. Similarly, in maize, this technology has boosted the biosynthesis of pro-vitamin A, resulting in the creation of 'Golden Maize.'

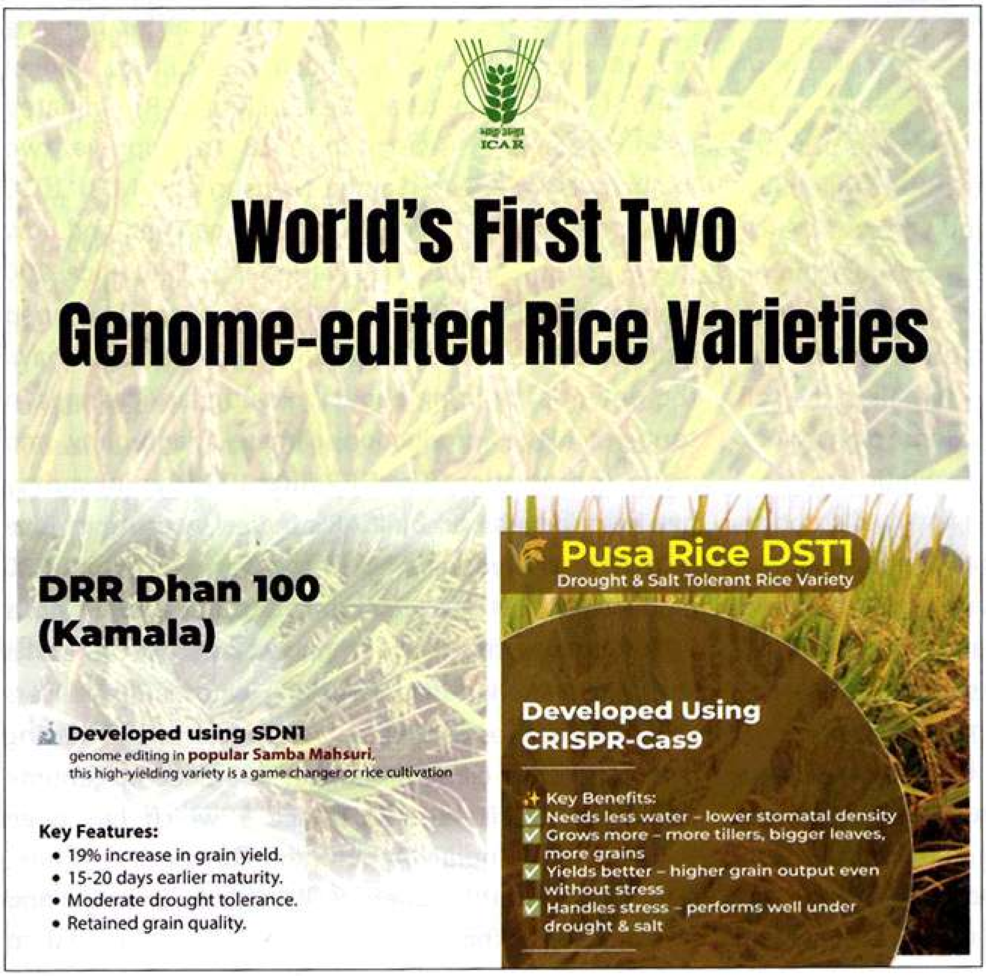
Agricultural biotechnology in India is advancing rapidly through innovations in genomics, transgenics, and gene editing under the Department of Biotechnology's Agriculture Biotechnology programme. Biotechnology Industry Research Assistance Council (BIRAC), operating under the Department of Biotechnology has played a pivotal role in nurturing emerging biotech companies through funding, infrastructure, and mentorship.

Wheat is another important crop of our food basket and genome editing efforts in this crop are being pursued with an aim to enhance its nutritional profile by modifying the levels of amylose and gliadin. Gliadin is a key component of gluten and is known to be a trigger for celiac disease, an autoimmune disorder, in genetically susceptible individuals. Wheat is mostly used in baking industry, including bread making and that require high temperatures during preparation. Baking of wheat at high temperatures converts the small endogenous molecule asparagine into acrylamide, which is known to be associated with increased cancer risks. The genes encoding the asparagine biosynthesis pathway were first identified and now with genetic knockout of the 'asparagine synthetase gene' in wheat, near complete reduction in levels of asparagine has been achieved. In this way, nutritional profile of wheat has been greatly improved. In maize, genes involved in lysine biosynthesis were edited which has resulted in increased lysine content, thus addressing a common deficiency in cereal grains. In potatoes, with the use of CRISPR/Cas9, the *gbss* gene responsible for granule-bound starch synthase has been modified, resulting in amylose-free starch that provides a smoother texture, which is highly valued in both culinary applications and industrial processes. This technology has been used to reduce antinutritional factors such as phytic acid in soybean, thus enhancing the bioavailability of iron and zinc and thereby improving the overall nutritional quality of the soybean. In addition, soybean has also been customised with this technology for improving traits like oil content and protein quality. Genes in potato has also been tinkered to enhance traits, such as tuber quality and reduced acrylamide formation. Similarly, in horticultural plants, such as apple and tomato, gene editing has been utilised to augment traits like fruit ripening and shelf life. With concerted global efforts in application of this technology, genome edited crops such as waxy corn, high-oleic soybeans, γ-aminobutyric acid-rich tomatoes, wheat, maize, potato and now rice varieties are already commercially available. Gene edited plant products such as browning-resistant mushrooms, high-amylopectin waxy corn and false flax (*Camelina sativa*) with enhanced omega-3 oil, have been approved by the US Department of Agriculture. The first gene-edited tomato, 'Sicilian Rouge High GABA' (GABA-enriched tomato) from Sanatech Seed (Tsukuba, Japan) is now available to the consumers in Japan. Further, two genome edited fish 'Madai' red sea bream and '22-seiki fugu' tiger puffer have also been approved for commercial sale in Japan and both of these grow bigger than their conventional counterparts.

Technology to Manage Biotic and Abiotic Stresses

All foodgrain crops are vulnerable to water scarcity, which poses a major challenge to food security. Gene editing with CRISPR/Cas technology allows precise genetic modifications to improve drought tolerance by targeting genes that regulate water use efficiency and osmotic balance. A notable breakthrough in this area is the modification of the *ZmHDT103* gene, which has been shown to improve drought tolerance in maize by enhancing the plant's ability to withstand water scarcity without compromising growth and yield under non-stress conditions. Another promising application of this technology has been to combat drought stress by engineering the *TaRPK1* gene in wheat to enhance water absorption and develop plants with deeper root systems which are capable of accessing water from deeper soil layers.

Genome editing is increasingly being used to protect plants against pests and diseases. Pests and pathogens use 'S genes' of the hosts for successful nutrition, infection, establishment, and proliferation and knockout of 'S genes' is a straightforward way to develop disease resistance in plants against a specific pathogen. In crops like wheat and maize, this technology has been employed to introduce the traits including herbicide resistance and disease resistance. Rice blast disease caused by *Magnaporthe oryzae* reduces rice yields worldwide and knocking out a susceptibility gene (OsERF922) in rice has been shown to significantly improve resistance to blast disease. Further, mutations induced in the *ethylene responsive factors* gene using CRISPR tool have been shown to enhance rice blast resistance. Furthermore, disruption of the 'subunit of the exocyst complex' (SEC3A) with gene editing has also been linked to enhanced resistance against rice blast disease. This disruption leads to an increase in salicylic acid synthesis, a key signalling molecule involved in plant defence responses against pathogens. Bacterial blight caused by *Xanthomonas oryzae* pv. *oryzae* is another major disease of rice with considerable impact on yields and here also the bacteria can be prevented from infecting the plant by editing the specific genes which are crucial for bacterial blight infection. In citrus, modifying the promoter of the *'lateral organ border'* (LOB) gene can increase resistance to citrus canker in grapefruit and oranges. Application of CRISPR/Cas technology to target the *'downy mildew resistance'* (DMR) gene has helped to control serious Xanthomonas wilt disease in banana. Genome editing techniques offer promising avenues for controlling insect pests by targeting crucial developmental genes. CRISPR/Cas9-mediated knockout of vitellogenin, a precursor for egg yolk essential for insect egg maturation and embryonic development, has resulted in incomplete embryo development in diamondback moth (*Plutella xylostella*), which is a major pest of cabbage, cauliflower, broccoli, and other members of the Brassicaceae family. Similarly, knockout of the 'abdominal-A homeotic' gene induces severe abdominal morphological defects in *Plutella xylostella* and *Spodoptera frugiperda* (fall armyworm) which are major pests of wide variety of crops, especially maize, rice, sorghum, and other economically important cultivated grasses.



Gene Editing Technology in Climate Change Mitigation

Gene editing technology-CRISPR could play an important role in mitigating the effects of climate change and global warming. Creator of CRISPR technology-Doudna while highlighting the potential of combination of artificial intelligence and CRISPR, emphasised that creating a methane-free cow in future is possible in our quest to reduce the generation of greenhouse gases in animal husbandry which contribute significantly in

New Eel Species Identified!

ICAR-National Bureau of Fish Genetic Resources scientists have discovered a **new eel species — *Facciolella smithi* —** from **260–460m** deep in the **Arabian Sea** off the **Kerala coast!**

Identified through advanced **morphological, radiographic & genetic analyses**, this **slender eel** with a **duckbill-like snout** belongs to the ***Nettastomatidae family*** and is named in honour of **Dr. David G. Smith**, renowned **ichthyologist**.

exacerbating climate change. Drought stress is one of the imminent effects of climate change which make serious dent on crop productivity and is the primary cause of productivity loss in agriculture globally. Scientists are now able to create crop varieties which are well adapted to various abiotic stresses including drought and crop lodging in floods. Other abiotic stresses including salinity, temperature fluctuations (high/low) and the presence of heavy metals in the soil can also be dealt with this technology. Some plant genes enhance the deleterious effects of abiotic stresses, known as sensitivity genes (Se genes) and by disrupting these 'Se genes', stress tolerance has been created in several plant species, including grain, vegetable, and fruit crops. Climate change can increase the severity and likelihood of plant diseases and to counter the threat of such pest resurgence, scientists have been working on conferring disease resistance in livestock and food crops without the use of pesticides and fungicides. This will help to make significant reduction in the pesticide usage in agriculture as evidenced in the case of Bt cotton. In banana, banana streak virus is activated under stress conditions such as drought and extreme heat prevalent in Africa, particularly in the areas where bananas are widely cultivated as an important food crop. To counter the problem, researchers from the International Institute of Tropical Agriculture in Nairobi, Kenya, made the use of CRISPR gene editing technology to deactivate banana streak virus in plantains. In general, gene-edited plants can play a crucial role in carbon sequestration, capturing and storing atmospheric CO_2 more efficiently.

Application of Gene Editing Technology in Agriculture

India has become the first country in the world to develop genome edited rice varieties and these varieties hold the potential for bringing revolutionary changes in Indian agriculture. Indian Council of Agricultural Research (ICAR) initiated genome-editing research in 2018 to improve two major rice varieties – Samba Mahsuri and MTU 1010 under the National Agricultural Science Fund and now these genome-edited rice varieties – DRR Rice 100 (Kamla) and Pusa DST Rice 1 have been developed and released on May 4, 2025. These varieties have the potential to bring about revolutionary changes in terms of higher production, climate adaptability, and water conservation. The DRR Rice 100 (Kamla) variety has been developed by ICAR's Indian Institute of Rice Research, at Hyderabad and this variety matures 20 days earlier and can yield up to 9 tonnes/ha which is 20 per cent higher than the parent variety. Due to its shorter duration, it helps in saving water and fertilisers and also reduces methane gas emissions thus having less impact on climate change. The second genome edited variety is Pusa DST Rice 1 which has been developed by Indian Agricultural Research Institute, New Delhi and this variety is also suited to saline and alkaline soils. These varieties have the potential to have 19% increase in yield with saving of 7,500 million cubic meters of irrigation water, 20% reduction in greenhouse gas emissions and improved tolerance to drought, salinity, and climate stresses. The seeds will be made available to the farmers in the next 3-4 years, after more field performance trials. Another, good example is the development of mustard (*Brassica juncea*) seeds with reduced glucosinolate content by Delhi University by editing of the plant's glucosinolate transporter (GTR) family genes. This modified variety is less pungent and more resistant to pests and diseases, helping potential growers to reduce usage of chemical pesticides and promoting sustainable farming practices. Similarly, researchers at the Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, led by Dr. Riyaz A. Shah, have successfully developed India's first gene-edited sheep in a ICAR sponsored project, marking a historic breakthrough in animal biotechnology. The gene-edited lamb has been modified by disrupting the 'myostatin gene', which regulates muscle growth. In this case, the lamb's muscle mass has been enhanced by nearly 30%, a trait naturally absent in Indian sheep breeds but present in select European breeds, such as the Texel. This gene-edited lamb will be heavier and will give more meat than a non-edited one. Apart from ICAR, Council of Scientific & Industrial Research governed institutes like National Botanical Research Institute, Lucknow are also working to develop plant varieties with improved yield and nutrition through genome editing in crops like tomato, cotton, chickpea, rice, and *Brassica* species. India is currently working on the use of gene editing technology on 24 field crops and 15 horticulture crops. In the 2023-24 budget, the Government of India allocated ₹500 crores for genome editing in agricultural crops. ICAR has further widened the horizons of genome-editing research for several crops, including oilseeds and pulses. But we need to widen the horizons of our research to our major crops which constitute our food basket.

The agriculture Genomics with gene editing as major component has huge potential in areas like Gene Editing, DNA Sequencing, and Molecular Breeding to improve food crops and animal yields; incorporating pest and disease resistance and making plants resilient to withstand drought and flood lodging tolerance to face the challenges of climate change. The onus now lies on both the Government and private funded institutions to apply the technology in all the potential areas of agriculture for higher productivity and quality traits.

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Simplified Regulatory Framework

Use of genome editing technology based on CRISPR-Cas, makes precise changes in the organism's genetic material without adding any foreign DNA. Hence, these are not genetically modified crops because no foreign DNA has been added to the original genome of the crops thus making them safe in comparison to genetically modified (GM) crops where foreign DNA is added which raises some questions about GM crops. Organisms naturally perform such programmed, targeted and adaptive rearrangements of their own DNA sequences and notable examples include the vertebrates which employ programmed and targeted DNA rearrangements to enhance their immune responses and natural CRISPR spacer arrays in bacteria, which recognise and cleave foreign DNA of invading viruses. Thus, the genetic changes that are introduced by CRISPR-Cas technology do not differ from the changes that can occur naturally or result from conventional breeding. This scientific reasoning of no possible adverse consequences of the technology made it possible for its commercial launch and consumer acceptance. Globally, about 30 countries have accepted genome edited crops as equivalent to conventionally bred crops and hence are not regulated as Genetically Modified Organisms for which there are apprehensions of health and environmental concerns. In 2022, Government of India exempted certain types of genome-edited crops from the stringent bio-safety regulations applicable to genetically-modified (GM) crops. The 'Guidelines for Safety Assessment of Genome Edited Plants, 2022' issued by the Department of Biotechnology exempt researchers who use gene editing like CRISPR-Cas technology by employing site directed nuclease (SDN) 1 and 2 genomes from rules 7-11 of the Environment Protection Act and seeking approvals from the Genetic Engineering Appraisal Committee (GEAC). However, an Institutional Biosafety Committee (IBSC) will oversee the progress of the crops and will certify that gene-edited crops are free of foreign DNA before their commercial release. Cultivation and commercialising gene-edited crops in India necessitates authorisation from India's Ministry of Agriculture and Farmers Welfare. Additionally, approval from the Food Safety and Standards Authority of India (FSSAI) is necessary to ensure that gene edited crops intended for human consumption meets the safety standards. This will ensure wider use of this technology and will also accelerate genetic improvement of crops in the country.

Potential for Commercial Gains

Gene editing technology with CRISPR has emerged as potent vehicle to make desired changes in crops of our interest to ensure future crop yield sustainability and nutritional security. The agriculture Genomics with gene editing as major component has huge potential in areas like Gene Editing, DNA Sequencing, and Molecular Breeding to improve food crops and animal yields; incorporating pest and disease resistance and making plants resilient to withstand drought and flood lodging tolerance to face the challenges of climate change. The onus now lies on both the Government and private funded institutions to apply the technology in all the potential areas of agriculture for higher productivity and quality traits. There are 954 Agriculture Biotechnology startups engaged in such type of work which include Syngenta, Benson Hill, Cibus, Advanta, and Mahyco. United States leads with highest number of companies in Agriculture Biotechnology (302), followed by India (209), and then Israel (47). Globally, Agriculture Genomics accounted for market size of USD 4.32 billion in 2024 and it is expected to reach USD 10.32 billion by 2035. In India, Genomics Market size was USD 2.2 billion in 2024 but it included all fields including the health sector. Gene editing technology has created great avenues for the global seed market which is presently at USD 88.82 billion and is expected to grow to 99.94 billion by 2030. India being the second largest producer of food grains, fruits and vegetables was having a seed market size of USD 3.61 billion in 2024 which is expected to reach $5.01 billion by 2030 according to the Federation of Seed Industry in India. As private agribusiness entrepreneur has more than 65 percent share in the seed industry in India, many companies have made huge investments in gene editing technology. Agribusiness giant Bayer is collaborating with G+FLAS, a South Korean biotech company in the development of a genome-edited variety of tomato biofortified with vitamin D3. It will a great intervention to check malnutrition among people as it is estimated that at least one billion people are affected by vitamin D deficiency worldwide.

Though gene editing technology has potential to enhance food and nutritional security but there are also concerns about off-target effects, unintended consequences, and ethical implications of germline editing. Risks from the introgression of genes from genetically modified crops into wild relatives is an area of concern for both GM, gene-edited crops, conventionally bred varieties and varieties bred using mutagenesis. Generally, gene flow can reduce the differences between populations and decrease diversity within a population, thus broadly impacting biodiversity. Gene introgression into wild relatives may also pose more direct risks, depending on the introduced trait.

As this technology has potentiality to achieve food and nutritional security with the almost stagnant or decreasing cultivated area, the associated risks should also be in focus for their possible solutions. The quest for high yield and quality traits in crops will continue to keep pace with surging demand and population. But we need to always remember the words of the 'Father of Green Revolution' and Nobel Laureate Dr. Norman Ernest Borlaug that 'the revolution in plant genetics is the only way to significantly increase the food production to meet the needs of the growing population in the coming decades.' Gene editing is certainly a revolution in plant genetics with CRISPR/Cas9 as an innovative tool. ❑