BIOHACKING THE FOOD CHAIN: USING CRISPR TO COMBAT THE GLOBAL FOOD CRISIS

To feed an ever-growing population in an increasingly volatile climate, new technologies are required; is CRISPR the key to reducing food waste and creating climate change-proof crops?

We are now facing an unprecedented global food crisis. Spurred by conflict, COVID-19 and climate change, the number of individuals facing famine has soared and an estimated 828 million people go to bed hungry each night [1]. Conflict is the primary contributor to world hunger – with 60% of the world's hungry living in areas of war or violence [1] – and compounding this is the impact of climate change; floods, droughts and extreme storms destroy crops and livestock, leaving many without food. However, it is not only extreme weather patterns that threaten to leave millions hungry, should global temperatures rise by 2°C from pre-industrial levels, an additional 189 million people worldwide face hunger – a number that could rise to 1.8 billion if temperatures rise by 4°C [2].

Under all of this, the world's population continues to rise – albeit at a slower rate than in previous years [3]. In order to feed an ever-growing population in a volatile global climate, new techniques for growing food are required. Traditional methods for increasing crop yield – such as intensive agriculture, fertilizers and pesticides – have improved food production rates, but to the detriment of both human and ecosystem health [4].

Enter CRISPR – the ubiquitous 'molecular scissors' used to change the genetic code of an organism. Compared with its use in animal cells, CRISPR–Cas9 editing in plants remains in its infancy, yet it has already been used to modify the genes of a wide range of plant species [5,6]. CRISPR experiments in plants have developed virus-resistant cucumbers [7], citrus trees immune to disease [8] and rice lines with enhanced crop yield [9].

Recent advances have served to improve the efficiency of CRISPR editing in plants, such as enabling the editing of multiple genes at a time. Named CRISPR-Combo, one new tool allows researchers to add combinations of edits that work together to boost functionality and improve breeding of crops [10, 11]. Publishing in Nature Plants, the team behind the tool demonstrated its applications on the flowing plant Arabidopsis thaliana, simultaneously making the plant resistant to herbicides and shortening its life cycle to increase time to seed production [11].

The potential uses for CRISPR are ever increasing, and its applications in agriculture present new opportunities for addressing the global food crisis. With gene editing it is possible to create crops that can adapt to the changing conditions, that are resistant to common diseases, and that have a longer shelf life [12-14] – all of which help to increase the amount food that makes it from the field to the table.

ADAPTING TO A CHANGING PLANET

Agriculture and crop production as we know it is interlinked with the seasonal changes in weather and environmental conditions that promote plant growth. Globally, these conditions are changing and the landscape of land suitable for farming is shifting; regions previously well suited to crop growth now have too little rainfall, are too hot or have unsuitable soil conditions [12]. While this also means that new, previously unfarmable regions are now optimal for farming, many who have relied on their land for food for decades will now go hungry, and it is the communities who have contributed least to the climate crisis that are bearing the brunt of its impacts [2].

CRISPR offers an environmentally friendly way to help plants adapt to their changing ecosystems, without compromising yield. Indeed, by disrupting a plant's genome, researchers have been able to develop crops that are resistant to harsh or stressful environmental conditions, including tolerance to drought [15], salt stress [16], or extreme heat [17]. One study used CRISPR editing techniques to create a dwarf version of the tomato plant, allowing it to withstand strong winds and storms that could damage or break its full-sized counterpart [18].

In science, the time for research to make its way from the lab to the real world can be lengthy, yet given the pressing timeline and increased occurrence of extreme weather, artificially adapted foods may be on the table sooner than expected; India is likely to see CRISPR-edited drought-resistant rice as soon as 2026 [19].

REDUCING FOOD WASTE

Globally, an estimated 2.5 billion tons – close to 40% of all food produced – is wasted each year [20]. Approximately 1.2 billion tons of that is lost before ever leaving the farm, usually during, around or after the harvest. Not only does this loss result in less food available for consumption, it also increases the impact of agriculture on the climate; farm-stage food waste has an estimated carbon footprint of 2.2 gigatons of CO2 equivalent [20].

Drivers of food waste can include poor infrastructure or harvesting practices, environmental stresses – such as those covered previously – or pests and disease. While such factors are often beyond the control of the farmer, techniques to limit any damage can help to vastly reduce the amount of food lost [20]. In attempts to cut down food waste, CRISPR could play a staring role. From bananas to potatoes, a variety of crops have been developed that are resistant to common diseases or infection, which could all help to cut waste and prevent any supply chain disruptions from low crop yields [14].

Once out of the farm, further food is wasted due to poor storage, damage during transportation or cosmetic irregularities. Each year, 3.6 billion lbs. of potato is wasted due to poor storage and shelf life – costing up to US$1.7 billion in losses [21]. To combat this, in 2018 agricultural firm Simplot (ID, USA) acquired a license to develop a new type of potato using CRISPR technology [21]. They are working with the technology to develop potatoes that have reduced browning and blackspot bruising – foods that resist browning keep their color longer when sliced, which lengthens their shelf life. The company expects to launch their CRISPR-edited potatoes next year [14].

Professor Yinong Yang, a plant pathologist at Pennsylvania State University (PA, USA), has performed similar work in fungi, developing a CRISPR-edited mushroom that is engineered to resist browning. By targeting the family of genes that encode polyphenol oxidase – an enzyme that causes browning – and knocking out one of the six PPO genes, Yang was able to reduce the enzyme's activity by 30% [22]. This CRISPR-edited mushroom was the first CRISPR-edited organism to receive approval from the US government when, in 2016, the US Department of Agriculture (DC, USA) announced they would not regulate the fungi, meaning it can be cultivated and sold without passing through a regulatory process [22].

REGULATIONS, RESTRICTIONS AND A NEGATIVE PUBLIC OPINION

Yang's mushrooms flew under the radar of US regulators as they do not contain any foreign DNA [22]. Indeed, this is where CRISPR editing differs from conventional genetically modified organisms (GMOs), which typically involve the introduction of DNA from a second species with the desired characteristic [14].

Many regulatory frameworks for GMOs were developed decades ago, when the addition of material from a second organism was necessary. In the US, regulators state that because CRISPR-edited crops do not contain DNA from another source they are not considered genetically modified and are thus exempt from regulation. However, the EU took the opposite stance and any genetically edited organism will be subject to the same regulations and monitoring as a GMO [14].

This global disconnect caused concern amongst researchers and in September 2022, a Policy Forum article in Science called for a new approach to the regulation of genetically engineered crops [23]. The authors proposed that, rather than focusing on the creation of the crop, all newly developed plants would be examined with an omics-based approach that focuses on the core characteristics of the crop. Once a molecular fingerprint has been developed, it can then be used to determine if the new crop variety is 'substantially equivalent' to an existing product. Only those found to have new or different characteristics that could have health or environmental effects would undergo additional safety testing [23].

Once passed regulations, CRISPR-edited foods face an additional hurdle before gaining widespread acceptance at the dinner table. Despite genetic manipulation not being new to plants – many of the fruits and vegetables we know today are the result of decades of selective breeding, their original form now being unrecognisable – GMO foods have long had a bad reputation in the public eye. One 2018 survey found that almost half of Americans believed GMOs to be worse for one's health than foods with no genetically modified ingredients [24].

When it comes to genetically edited foods, there is a degree of uncertainty; "*Right now, there are a lot of people in the middle. They have not fully made up their mind about gene-edited foods, but as they learn more about the technologies and products, they will likely move to one side of the issue*" commented Dr. Christopher Cummings, co-author of a recent study investigating public perception of genetically edited foods [25]. Published in Frontiers in Food Science and Technology, the study found that an individual's wiliness to eat modified food is driven by their existing social values and institutional trust [26].

It is clear that, for CRISPR-edited foods to be adopted, transparent and open communication is needed to highlight the benefits this could have for society's most pressing challenges. With climate change, sustainability requirements and increasing world hunger, there is too much at stake to get this wrong.

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REFERENCES

1. World Food Programme. A global food crisis. www.wfp.org/global-hunger-crisis
2. World Food Programme. Climate action. www.wfp.org/climate-action
3. Our World in Data. World Population Growth. https://ourworldindata.org/world-population-growth
4. UN Environment Programme. Environmental and health impacts of pesticides and fertilizers and ways of minimizing them. https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/34463/JSUNEPPF.pdf?sequence=13
5. Manghwar H, Lindsey K, Zhang X, Jin S. CRISPR/Cas system: recent advances and future prospects for genome editing. *Trends Plant Sci.* 24(12), 1102–1125 (2019).
6. Gaillochet C, Develtere W, Jacobs TB. CRISPR screens in plants: approaches, guidelines, and future prospects. *Plant Cell.* 33(4), 794–813 (2021).
7. Chandrasekaran J, Brumin M, Wolf D, *et al.* Development of broad virus resistance in non-transgenic cucumber using CRISPR/Cas9 technology. *Mol. Plant Pathol.* 17(7), 1140–1153 (2016).
8. Peng A, Chen S, Lei T, *et al.* Engineering canker-resistant plants through CRISPR/Cas9-targeted editing of the susceptibility gene CsLOB1 promoter in citrus. *Plant Biotechnol. J.* 15(12), 1509–1519 (2017).

9. Zhou H, He M, Li J, *et al.* Development of commercial thermo-sensitive genic male sterile rice accelerates hybrid rice breeding using the CRISPR/Cas9-mediated TMS5 editing system. *Sci. Rep.* 6, 37395 (2016).
10. University of Maryland College of Agriculture and Natural Resources. New CRISPR-Combo boosts genome editing power in plants. https://agnr.umd.edu/news/new-crispr-combo-boosts-genome-editing-power-plants
11. Pan C, Li G, Malzahn AA, *et al.* Boosting plant genome editing with a versatile CRISPR-Combo system. *Nat. Plants* 8, 513–525 (2022).
12. Raza A, Razzaq A, Mehmood SS, *et al.* Impact of climate change on crops adaptation and strategies to tackle its outcome: a review. *Plants (Basel)* 8(2), 34 (2019).
13. Abdelrahman M, Al-Sadi AM, Pour-Aboughadareh A, Burritt DJ, Tran LP. Genome editing using CRISPR/Cas9-targeted mutagenesis: An opportunity for yield improvements of crop plants grown under environmental stresses. *Plant Physiol. Biochem.* 131, 31–36 (2018).
14. WIRED. These super crops can save us from climate disaster. www.wired.co.uk/article/farm-food-waste-genetics
15. Shi J, Gao H, Wang H, *et al.* ARGOS8 variants generated by CRISPR-Cas9 improve maize grain yield under field drought stress conditions. *Plant Biotechnol. J.* 15(2), 207–216 (2017).
16. Farhat S, Jain N, Singh N, *et al.* CRISPR-Cas9 directed genome engineering for enhancing salt stress tolerance in rice. *Semin. Cell Dev. Biol.* 96, 91–99 (2019).
17. Yu W, Wang L, Zhao R, *et al.* Knockout of SlMAPK3 enhances tolerance to heat stress involving ROS homeostasis in tomato plants. *BMC Plant Biol.* 19, 354 (2019).
18. Tomlinson L, Yang Y, Emenecker R, *et al.* Using CRISPR/Cas9 genome editing in tomato to create a gibberellin-responsive dominant dwarf DELLA allele. *Plant Biotechnol. J.* 17(1), 132–140 (2019).
19. Financial Express. Das S. Drought-resistant & genome edited rice variety likely to be released to farmers by 2026: Agriculture minister Narendra Singh Tomar. www.financialexpress.com/market/commodities/drought-resistant-genome-edited-rice-variety-likely-to-be-released-to-farmers-by-2026-agriculture-minister-narendra-singh-tomar/2600615/
20. WWF. Driven to waste: The global impact of food loss and waste on farms. wwfint.awsassets.panda.org/downloads/wwf_uk__driven_to_waste___the_global_impact_of_food_loss_and_waste_on_farms.pdf
21. Simplot. Simplot Company Secures Agricultural Research & Commercial License from Corteva Agriscience™, Broad Institute of MIT & Harvard (2018). www.simplot.com/company/news/simplot-secures-license-from-corteva-agriscience-mit-harvard
22. Waltz E. Gene-edited CRISPR mushroom escapes US regulation. *Nature* 532, 293 (2016).
23. Gould F, Amasino RM, Brossard D, *et al.* Toward product-based regulation of crops. *Science* 377(6610), 1051–1053 (2022).
24. Funk C, Kennedy B, Hefferon M. Public perspectives on food risks. Pew Research Center, DC, USA (2018). www.pewresearch.org/science/2018/11/19/public-perspectives-on-food-risks/
25. Iowa State University. Who trusts gene-edited foods? New study gauges public acceptance. www.news.iastate.edu/news/2022/06/28/gene-editing-foods
26. Cummings C, Peters DJ. Who trusts in gene-edited foods? Analysis of a representative survey study predicting willingness to eat- and purposeful avoidance of gene edited foods in the United States. *Front. Food Sci. Technol.* 2, 858277 (2022).