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Genome editing and sustainable agriculture

Exploring potential synergies of genome editing with modes of agriculture, such as agroecology, could help food security and environmental integrity.

Food security and the environmental impact of agriculture remain crucial sustainability challenges facing our world today. Genome editing technology has been increasingly applied to address such problems over the past decade. One such method that has seen burgeoning use in the agriculture sector towards crop improvement is the CRISPR system, offering more rapid, efficient and precise ways to edit the genome[1]. It uses programmable site-directed nucleases, which are enzymes that cause targeted breaks in DNA strands that can be thereafter repaired by different cellular pathways. It has enormous potential for providing more calories for a hungry world by introducing genome modifications associated with targeted improvement of traits related to yield, nutritional profile of crops, and tolerance to pests and extreme weather conditions, among many others. This technology can thus help reduce environmental impacts from agriculture by lessening the need for chemical inputs and further agricultural expansion encroaching on biodiverse ecosystems and provide protection against crop losses from pests and an increasingly whimsical climate. Owing to its capacity to introduce genomic modifications in plants without necessarily needing to insert DNA from other species, which conventional genetic modification technologies rely upon, there has been a spate of recent relaxation of regulations concerning its use in agriculture. The United States, India, China and Nigeria are among a growing number of countries following this trend. Additionally, in February 2024, the European Parliament voted to adopt its position in support of a proposal that would allow an easier route to authorize plants produced by such "new genomic techniques" that cannot be easily distinguished from conventionally bred plants, compared with the stricter legislation in place for other cases, including conventional genetic modification technologies[2].

The application of genome editing technology in agriculture is clearly beneficial; however, it also opens doors for a host of associated social and ethical issues, such as intellectual property rights associated with the use of the technology and the question of who benefits from such crops in terms of the stakeholders involved, such as farmers, consumers and multinational corporations. Additionally, it also begs the age-old and thoroughly complex question as to why more efforts are not being spent targeting systemic root causes of such inequalities in food concentration and distribution that can help to address food insecurity.

With the rapid advance of genomic technology and its wider usage in the agricultural sector, it becomes necessary to understand how it relates to sustainable agricultural modalities such as agroecology. At first glance the two approaches might seem at odds with each other, but over the past several years there have been discussions on whether they can be viewed as complementary[3]. Agroecology views the agricultural landscape in a more holistic way, incorporating local and Indigenous knowledge and co-creation of knowledge through participatory processes, and seeks to promote biodiversity and leverage existing species interactions to promote ecosystem services such as pollination and natural pest control, thus reducing the need for external inputs. More recently, Nogué et al. discussed whether genome editing technology such as CRISPR can manifest a transition to agroecology[4]. For example, genome editing technologies could be potentially used to further enhance beneficial mutual associations between plants and soil microorganisms to amplify the provisioning of ecosystem services that they provide, for example, greater efficiency in nutrient availability and uptake, in addition to enhancing beneficial plant–plant interactions. Additionally, it is also providing an easier route for the domestication of orphan crops (also known as underutilized crops), thus increasing the species diversity pool of usable crops in agriculture. For example, certain African rice varieties are underutilized crops that are well adapted to local environmental conditions and endemic pests but lag behind in certain traits that would assist in the crops' ability to be cultivated with more ease. Thus, researchers used genome editing to target traits associated with plant height and seed yield towards this end[5]. Overall, by introducing genome modifications in plants associated with various agroecologically important phenotypes, this technology could thus potentially contribute to important pillars of agroecological principles. Ultimately, however, the success of how genome editing technology and agroecological practices can be complementary might depend on the socio-political context they are embedded in, in terms of who is really benefiting from such practices and whether there is equitable sharing of this knowledge, the degree to which local knowledge is incorporated and whether it creates a culture of dependency rather than self-sufficiency in farming practices.

With a plethora of approaches geared towards the shared goal of agricultural sustainability, the search for new ways to reconcile these different approaches seems inevitable. For example, how do we reconcile genome editing technology with other modes of agriculture that also share similarities and overlap with agroecological principles such as conservation and regenerative agriculture? Can there be a middle ground where the melding of approaches might offer previously unrealized synergies, or does everything have to be mutually exclusive? Perhaps this depends on how holistic an integrated approach is and how equitable the resultant distribution of food and environmental benefits are for society as whole. This calls for a truly interdisciplinary approach incorporating the work of biotechnologists, agronomists, Indigenous scholars and knowledge keepers, local farmers, social scientists and ecologists. Our collective knowledge clearly offers promise for agricultural sustainability. But it also opens the need for greater transparency in how new technologies

are being used, by whom they are being used and who the primary beneficiaries are.

The ongoing debate on the promise of genome editing technology and its associations with other approaches in agriculture towards improving food security and ecosystem and environmental health is interesting and relevant to sustainability. We at *Nature Sustainability* welcome submissions seeking to address how we can use this technology towards addressing sustainability in a holistic way — ensuring enough food for everyone and protecting human, animal and plant health and well-being, and that of the environment.

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