BIOTECHNOLOGY

New plant breeding technologies for food security

Improved crops can contribute to a world without hunger, if properly managed

By **Syed Shan-e-Ali Zaidi[1,2], Hervé Vanderschuren[1], Matin Qaim[3], Magdy M. Mahfouz[4], Ajay Kohli[5], Shahid Mansoor[2], Mark Tester[4]**

A world without hunger is possible but only if food production is sustainably increased and distributed and extreme poverty is eliminated. Globally, most of the poor and undernourished people live in rural areas of developing countries, where they depend on agriculture as a source of food, income, and employment. International data show a clear association between low agricultural productivity and high rates of undernourishment (*1*). Global studies have also shown that rapid reduction of extreme poverty is only possible when the incomes of smallholder farmers are increased (*2*). Therefore, sustained improvement in agricultural productivity is central to socioeconomic development. Here, we argue that with careful deployment and scientifically informed regulation, new plant breeding technologies (NPBTs) such as genome editing will be able to contribute substantially to global food security.

Previously, conventional plant breeding through cross- and self-pollination strategies played a major role in improving agricultural productivity. Moreover, the adoption of genetically modified (GM) crops by smallholder farmers has led to higher yields, lower pesticide use, poverty reduction, and improved nutrition (*2*). Nevertheless, so far only a few developing and emerging economies—such as China, India, Pakistan, Bangladesh, and South Africa—have embraced GM crops. Even though three decades of research show that GM crops are no more risky than conventional crops (*3*), many countries in Africa and Asia are hesitant to promote the use of GM crops, largely because of erroneously perceived risks and fears of losing export markets to Europe.

In the meantime, NPBTs have emerged. These technologies may allay fears associated with GM crops. For example, recent advances in genome editing allow the alteration of endogenous genes to improve traits in crops without transferring transgenes across species boundaries. In particular, CRISPR-Cas has emerged as one of the foremost systems with which to edit the crop genome, with rapidly increasing agricultural applications in major cereals such as rice, wheat, and maize and other food security crops such as banana and cassava (*4*). Because of its low cost, genome editing can also be used to improve orphan crops such as local fruits, vegetables, and staple crops that can play an important role for healthy diets. The use of foreign DNA in transgenic GM crops is the main reason for their heavy regulation. Hence, the absence of transgenes in genome-edited crops could lower the costs of the regulatory procedures and thus speed up innovation, increase competition in the seed industry, and make improved seeds more affordable for farmers in developing countries (*2*). The lack of technical, regulatory, and communication capacities to handle transgenic GM technologies locally has contributed to limited public acceptance and adoption (*5*). Scientific and sociopolitical developments are not always a continuum, which is true in developed and developing countries alike. Therefore, a renewed effort and strategy is necessary to facilitate the use and adoption of genome-edited crops and other NPBTs that have much potential to contribute to sustainable development. Learning lessons from the past, the strategy should be based on transparent communication, training of researchers and other stakeholders in the innovation system, and efficient, informed regulation (see the box).

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Public-private partnership has been perceived by many as one way to promote and implement NPBTs (*6*). Such partnership is especially promising in more advanced developing countries that are still home to a large number of people in poverty but are already in a position of economic strength to negotiate mutual benefits with private agribusiness companies. Plant produce and seeds from these more advanced developing countries could also be delivered regionally to neighboring less-developed countries, which would otherwise have limited access to NPBTs or would have to pay much higher prices. An existing intergovernmental initiative for rice seeds without borders is a major step in this direction, which allows for seed sharing between a number of South and Southeast Asian countries (*7*).

Such intergovernmental initiatives could be taken to a new level through companies working with Asian and African regional development and cooperation bodies such as the Association of Southeast Asian Nations (ASEAN) or the New Partnership for Africa's Development (NEPAD). Opportunities exist to capitalize on previous success stories of public-private partnership, such as the development and commercial release of transgenic insect-resistant eggplant in Bangladesh. The recent public declaration of the Bangladesh minister of agriculture in support of biotech and the initiatives of field-testing three additional transgenic GM crops position Bangladesh as a global model for addressing hunger and malnutrition through modern technology (*8*). Another example is the Water Efficient Maize for Africa (WEMA) project, in which drought-tolerant varieties are being developed with the intention to make these available royalty-free to smallholder farmers through African seed companies (*9*). A concerted development plan for priority traits in food crops, including orphan crops, should be elaborated, which would help to demonstrate more broadly the large potential of new breeding technologies for food security in developing countries (table S1).

The toolbox of plant breeders is expanding in exciting ways. Rapid generation advance (RGA) and single-seed descent minimize crop life cycle for research on breeding, selection, and fixing of useful genes (*10*). This approach is already contributing to the improvement of several grain crops, building on the slower and less accurate pedigree selection methodologies that characterized the Green Revolution.

[1]Plant Genetics, TERRA Teaching and Research Center, Gembloux Agro-Bio Tech, University of Liège, 5030 Gembloux, Belgium. [2]National Institute for Biotechnology and Genetic Engineering, 38000 Faisalabad, Pakistan. [3]Department of Agricultural Economics and Rural Development, University of Goettingen, 37073 Goettingen, Germany. [4]Biological and Environmental Science and Engineering Division (BESE), King Abdullah University of Science and Technology (KAUST), 23955-6900 Thuwal, Saudi Arabia. [5]Strategic Innovation Platform, International Rice Research Institute, DAPO 7777, Makati, Philippines. Email: shahidmansoor7@gmail.com; mark.tester@kaust.edu.sa; herve.vanderschuren@uliege.be

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Along with these, genomic selection, which uses genotyping and imputation as a strategy to predict the value of phenotypically uncharacterized plants in a population, is also becoming popular. Current limitations in breeding methods can also be partially addressed by the recent emergence of the CRISPR-Cas systems that provide an effective suite of applications and molecular tools to precisely and efficiently alter the genome in a user-defined manner. CRISPR-Cas9–mediated gene knockout is widely used for a variety of applications in crop improvement—for example, high-yield rice, disease-resistant bread wheat, and flavor-enhanced tomato. Other possible modalities include precise DNA sequence editing, gene replacement, and simultaneous enhancement of multiple traits (stacking), as well as promoter and regulatory element engineering for altered gene expression patterns (*11*). Additionally, CRISPR genome-wide screens can be used to identify previously unknown valuable crop plant traits. However, the utility of CRISPR technologies to improve quantitative traits—including drought and salinity tolerance—remains to be tested in several crop species. We anticipate that CRISPR-Cas technologies, in combination with modern breeding methods, will play an important role in future crop improvement programs, but other technologies for genomic prediction and selection will also remain important.

Several interesting applications of genome editing may become available in the next 5 years. For instance, multiple food security crops could immediately benefit from the new genome-editing technologies to address major pest and disease problems, reduce the need for chemical pesticides, and make plants more resilient to climate stress (table S1). Successful public or public-private development of related crop varieties could serve as a clear example to build trust and demonstrate local capacities to use genome editing for local benefits. The target genes for improvement are now more easily identified by the increasing number of high-quality crop genomes and the allelic comparisons in crop and plant diversity panels. The availability of such diversity in public databases is being recognized by the private sector, which could foster mutually beneficial public-private partnerships. The publicly funded Consultative Group on International Agricultural Research (CGIAR) has a mandate for most of the major food security crops and unites regional organizations engaged in research for a food-secure future (*12*). Most CGIAR centers support crop-specific gene banks that can be assessed for genome-edited improvements, in collaboration with regional and national institutes. Previous efforts of the CGIAR to provide plant genetic material to developing countries made it easier for breeders to develop new crop varieties. Given their presence in different local environments, the CGIAR centers could be a neutral coordinator of a network of field research facilities for the development and testing of genome-edited crops.

Improving plants with new technologies

Responsible and effective development and use of new plant breeding technologies (NPBTs) in developing countries requires efficient regulation, objective communication, and capacity building.

Regulation and commercialization

Regulation of crop varieties/products falling under evidence-based regulation

Coordinated field testing in national and international platforms

Delivery by public or public-private partnerships

Availability to smallholder farmers royalty-free

Communication

Raise awareness of global food security and how NPBTs can help

Raise awareness of safety of NPBTs and their advantages to society

Marketing with carefully designed strategies for NPBTs

Capacity building

Training scientists/biosafety regulators from developing countries

Incentives to relocate trained staff to laboratories in developing countries

Establishing local facilities for product development and stewardship

Global opposition to transgenic GM crops explains why there are currently limited applications of these crops. European attitudes and policy approaches are particularly important in this respect. Given their longstanding trade connections with Europe, African and Asian nations also logically fear that adoption of transgenic crops could lead to the loss of export opportunities to Europe, where opposition to genetically modified organisms (GMOs) is now deeply ingrained (*13*). Genome editing could represent a renewed opportunity to harness the potentials of modern biotechnology for food security. However, the recent European Court of Justice ruling to regulate genome-edited crops in the same way as GMOs (*14*) is disappointing and could stifle international progress in applying genome-editing technologies for crop improvement. Nevertheless, the rulings by the United States (*15*) and Japan on relaxation of rules toward genome-edited crops are expected to set the ground for a new paradigm that could lead to more efficient regulation internationally. More than 30 years of experience with GM crops show that regulatory procedures influence public attitudes and that negative public attitudes in Europe can have a considerable effect on public perceptions and policy in developing countries (*2*). A less-restrictive regulation of genome-edited crops in the EU could therefore send a positive signal to developing countries in need of agricultural technologies for food security.

Achieving global food security will require a framework based on the lessons learned from the past: Innovation is essential, and thus an environment facilitating innovation is also essential. In order to fully exploit the potentials of NPBTs, a multipronged approach is needed, taking into consideration all components involved in technology development, dissemination, adoption, and social acceptance (see the figure). NPBTs should not be misunderstood as a panacea. Many other technologies and approaches are needed as well, including improvements in postharvest management, market infrastructure, and social services. However, genome editing is predicted to be a powerful addition in the fight against hunger and poverty. The global community should seize this opportunity by developing conducive regulatory frameworks and support mechanisms. ■

REFERENCES AND NOTES

1. Food and Agriculture Organization of the United Nations (FAO), *State of Food Security and Nutrition in the World* (FAO, 2018).
2. M. Qaim, *Genetically Modified Crops and Agricultural Development* (Palgrave Macmillan, 2016).
3. A. Nicolia, A. Manzo, F. Veronesi, D. Rosellini, *Crit. Rev. Biotechnol.* **34**, 77 (2014).
4. S. E. Bull *et al.*, *Sci. Adv.* **4**, eaat6086 (2018).
5. O. C. Ezezika *et al.*, *Nat. Biotechnol.* **30**, 38 (2012).
6. H. Vanderschuren, *Nat. Biotechnol.* **30**, 1170 (2012).
7. International Rice Research Institute (IRRI); www.fareasternagriculture.com/crops/agriculture/asian-countries-sign-agreement-on-seed-sharing (2018).
8. B. Owens, *Nat. Biotechnol.* **36**, 559 (2018).
9. S. Oikeh *et al.*, in *Convergence of Food Security, Energy Security and Sustainable Agriculture*, D. D. Songstad, J. Hatfield, D. T. Tomes, Eds. (Springer, 2014), pp. 317–329.
10. G. N. Atlin, J. E. Cairns, B. Das, *Glob. Food Secur.* **12**, 31 (2017).
11. S. Svitashev *et al.*, *Plant Physiol.* **169**, 931 (2015).
12. M. Renkow, D. Byerlee, *Food Policy* **35**, 391 (2010).
13. S. J. Smyth, W. A. Kerr, P. W. B. Phillips, *Plant Biotechnol. J.* **11**, 527 (2013).
14. E. Callaway, *Nature* **560**, 16 (2018).
15. E. Waltz, *Nat. Biotechnol.* **36**, 6 (2018).

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