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Attitude and application: Judge a crop on its potential and not breeding technology

In comparison with technological advancements in other fields, applications of biotechnology in agriculture elicit strong, divisive opinions. The polarizing debate over genetically modified organisms (GMOs), or transgenic crops, has spanned decades. Opponents have focused heavily on a single trait: herbicide tolerance. Public concern regarding the impacts of herbicides on human health and the environment has overshadowed other applications of genetic engineering, such as pest resistance, biofortification, and non-browning fruit (Abdallah et al., 2015). We argue that newly developed crops should be judged based on their potential, rather than tainted based on association with unpopular applications.

THE CHALLENGE OF FEEDING THE WORLD

Advances in new breeding technologies (NBTs), such as gene editing, have opened new avenues of crop research over the past decades. Current and future applications of biotechnology could provide solutions to critical global agricultural challenges. In 2020, more than 690 million people were estimated to suffer from hunger, with most of these living in developing countries (FAO et al., 2020). Ending malnutrition, achieving food security, and promoting sustainable agriculture make up the second goal of the United Nations 2030 Agenda for Sustainable Development (United Nations, 2015). Achieving this will require a coordinated effort from scientists, growers, policy makers, and the public. With the global population predicted to reach 9.7 billion by 2050, agronomists and growers are challenged to improve yields while coping with biotic stress from emerging pests and pathogens (Haque et al., 2018; Savary et al., 2019). At the same time, the looming threat of climate change will demand that agriculture adapts to increasing levels of abiotic stress (Godfray et al., 2010; Joshi et al., 2020). The regulatory landscape for agricultural biotechnology is changing as methods have evolved from the transgenic crops of the 1990s to the transgene-free gene-edited crops of today. As new methods are developed and applied to a greater range of crops, the dialogue between scientists, policymakers, and the public must also expand to encompass the potential of these new applications. Public understanding and acceptance are critical for the adoption of crops created through traditional technologies as well as NBTs. The objection to all applications of genetic engineering in agriculture, due to concern over herbicides applied to herbicide-tolerant crops alone, ignores a growing list of applications that are not associated with the application of herbicide or pesticide. These traits could improve the health and well-being of millions of people around the world. The question is whether the public can overlook the negative associations and consider each new application based on its own merit and potential impact.

EMERGING TECHNOLOGIES ARE CHANGING THE REGULATORY LANDSCAPE

The latter part of the twentieth century saw increases in agricultural productivity, with grain yields more than doubling, as a result of the Green Revolution. This was largely due to mechanical advances, the development of new chemical treatments, and conventional breeding programs (Godfray et al., 2010). Despite these successes, growers today face a constant battle with weeds, pests, and pathogens (Savary et al., 2019). In addition, the benefits of the Green Revolution have been unevenly distributed around the world (Godfray et al., 2010). Domestication, selective breeding, and conventional breeding (including random, chemical-, or UV-mediated mutagenesis) have given rise to the desired traits in crops consumed today. Public opinion is that GMO crops are those that differ from their ancestral species in both appearance (phenotype) and DNA (genotype). Following this logic, selectively bred and domesticated crops are GMOs. The regulatory viewpoint in the United States is that a genetically engineered or transgenic crop is one containing foreign DNA, not created through classic breeding methods, such as hybrids. There are, however, many crops that are "naturally" transgenic. Sweet potato, a classic example, contains foreign DNA as the result of horizontal gene transfer mediated by soil-dwelling *Agrobacterium tumefaciens*, a bacterium utilized in the laboratory for decades (Matveeva and Otten, 2019). NBTs can result in the same outcome as conventional breeding or natural development: the edited crops do not contain foreign DNA. They are thus not transgenic, and regulatory bodies in the United States have aligned with science-based policies, with other countries following in the same direction. Although this presents the opportunity for new crops to be developed to address some of the key challenges in agriculture, public opinion is still focused on controversial past applications of genetic engineering. Time and cost restricted access to biotechnology in the past.

Due to the exorbitant costs and decade-long time commitment required to develop new products, economically important crops such as maize, rice, and soybean have been the focus for industry or academic-industry collaborations. Biotechnological advancements over the past three decades have therefore predominantly focused on the needs of growers and producers, introducing traits such as herbicide tolerance, and pest and disease resistance (Figure 1). Pests and pathogens are

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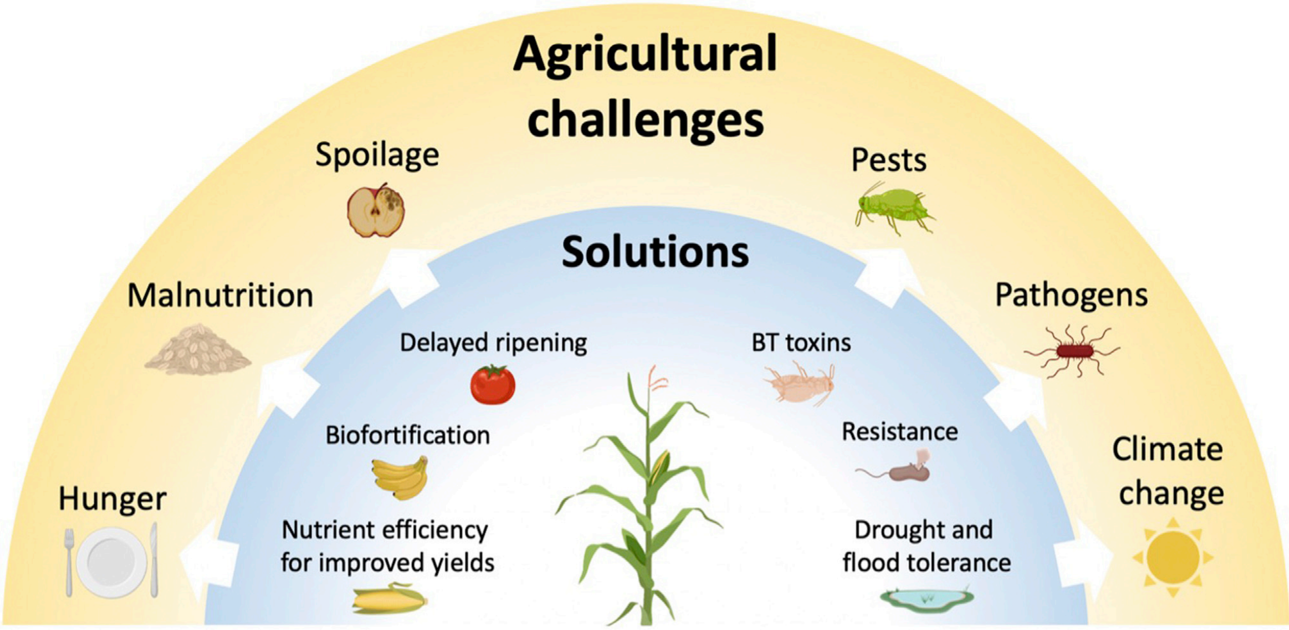

Figure 1. Global agricultural challenges and potential solutions.
Agriculture faces a wide range of challenges. Biotechnology offers potential solutions to many of these global issues. To have any chance of impact, society should try to consider each crop independently based on its potential, rather than immediately disregard due to the method associated with other applications.

estimated to account for global yield losses between 17.1% and 30% for major crops like potato and rice, and developing countries are likely to lose even higher proportions (Savary et al., 2019). The bacterium *Bacillus thuringiensis* (BT) naturally produces toxins that harm insects and pose little or no risk to human health. Transgenic plants engineered to produce BT toxins reduce the need for potentially environmentally harmful external pesticide applications. Since 1985, many BT varieties have been generated in response to specific pests, such as the European corn borer (Abbas, 2018). Gene-edited solutions to bacterial, fungal, and viral pathogens have been developed (Andolfo et al., 2016). Importantly, multiple resistance genes can be targeted during crop development, providing several layers of defense for the plant. Engineered or edited crops that are resistant to pests and pathogens could require lower chemical inputs than those developed through conventional breeding. In contrast to the public view of engineered crops, this could make cultivation less environmentally damaging.

GENE EDITING AS A TOOL FOR ADDRESSING THE NEEDS OF THE CONSUMER

Due to the new regulatory practices for gene-edited crops, a new era of accessible and affordable biotechnology can address the needs of the consumer and improve the quality of subsistence crops (Abdallah et al., 2015; He and Creasey Krainer, 2021). All methods will need to be utilized to combat food insecurity and climate change (Figure 1), while keeping pace with population growth. An estimated increase in food production between 70% and 100% is needed to feed the global population by 2050 (Godfray et al., 2010). Transgenic rice lines have been engineered to photosynthesize more efficiently, resulting in grain yields up to 27% higher than control plants (Shen et al., 2019). NBTs have been applied to increase grain size in important commercial crops like rice, wheat, and maize. Early studies indicate that the system will prove equally valuable when applied to subsistence crops like banana and cassava (Haque et al., 2018). Bioengineering improvements in nutrient uptake efficiency also allow for yield increases and provide the potential for sustainable farming and less environmentally damaging practices. Globally, over one-third of food is wasted, due in part to early ripening and spoilage. This figure is likely to be higher in tropical regions, which constitute some of the lowest-income areas of the world. A wide range of methods have been successfully applied to slow ripening in fruits, such as tomato, and improve the storage life of foods such as potato (Abdallah et al., 2015). Malnutrition affects two billion people, predominantly in developing countries (FAO et al., 2020). Biofortification offers a targeted approach to increase the content of specific nutrients in crops through both transgenic and gene-edited approaches. Vitamin A deficiency is linked to 6% of the deaths of children under the age of 5 years in Africa (Paul et al., 2017). Biofortified crops such as transgenic "golden" rice and bananas over-expressing beta-carotene could offer a solution, if adopted by society (Paul et al., 2017). An equally important agricultural issue is to ensure food safety by reducing crop toxicity, such as cyanogenic glucosides in cassava (Abdallah et al., 2015). Unfortunately, crops developed to address specific humanitarian issues continue to be discriminated against and receive negative attention due to the methods utilized in their development.

DEVELOPING NEW CROPS FOR AN UNCERTAIN FUTURE

Improving crop tolerance to unfavorable environmental conditions, such as flooding and drought, will be an important component of agriculture's adaptation to climate change (FAO et al., 2020). Environmental stress promotes complex responses in plants. As a result, traditional breeding is poorly suited to tackle these problems while maintaining yields (Joshi et al., 2020). Drought is a leading cause of yield loss in developing countries. NBTs have been developed to edit drought tolerance (Joshi et al., 2020). Similar approaches could be applied to other stresses associated with climate change, such as flooding (Xu et al., 2006). Acceptance of such solutions will be reliant on public opinion of emerging technology. The benefits of embracing biotechnology to solve global agricultural problems are undeniable. However, for the application to have impact, scientists and farmers must also collaborate with society to provide the world with safe, nutritious, and sustainable food sources that are meeting a need. Allowing the longstanding debate over herbicide tolerance to overshadow any other aspect of biotechnology prevents a broader conversation about the tangible environmental and agronomic benefits of agricultural biotechnology. The current inequalities in medicine and food accessibility are slated to be exacerbated in coming years (Godfray et al., 2010). Tackling these global problems will require that every tool available is applied to its full potential. Consideration must be given to each application of agricultural biotechnology based on the need for the trait and impact of its application. Those who are already food secure should no longer be deciding the fate of biotechnology in countries that are not.

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