CHAPTER 10

Bio-innovations
Genome-Edited Crops for Climate-Smart Food Systems

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KEY MESSAGES

- New genome-editing (GEd) technologies, including CRISPR-based tools designed to edit genes, will play a critical role in addressing climate change adaptation and mitigation in agriculture. GEd allows researchers to rapidly develop climate-resilient and climate-adaptable crop varieties tailored to low- and middle-income countries (LMICs).
- Pursuing pragmatic approaches that enable convergence of GEd applications with ecologically and environmentally sustainable production systems is a prudent and valuable approach.
- Public and private sectors in LMICs both have a role to play in developing GEd products to address climate change but will need a robust enabling environment to support this development.
- Functional and streamlined regulatory frameworks are an important component of any robust enabling environment to create and support incentives for product development and deployment. Lessons learned from earlier technologies will be critical to successfully advancing GEd products through the process of approval, transfer, and adoption.
- Transparency across GEd research and development (R&D), regulation, and deployment will be essential to ensure social "buy-in" from a broad range of stakeholders. Achieving buy-in will require more comprehensive assessment methods to build evidence on GEd tools, as well as the prioritization of strategic communication and outreach.
- Start-ups and small and medium enterprises (SMEs) can help drive the democratization of GEd in LMICs, as they have been more agile in implementing GEd R&D processes. Partnerships that enable technology transfers or even generate spin-offs or SMEs are a promising strategy to rapidly deliver new climate-resilient applications for LMICs.

- GEd crops can help small farmers — including women and youth farmers, indigenous people, and other vulnerable groups — to increase farm productivity and adapt to climate change. Understanding the needs and preferences of farmers, including gendered needs, for different crop traits, delivery methods, and extension services is essential to the successful development and deployment of GEd products.

As growing populations, changing diets, and climate change affect growing conditions for crops, our agriculture and food systems must increase production and productivity to ensure access to healthy and diverse diets for all. The expanding demands on agriculture and food systems must be met without increasing pressure on the environment, and while accomplishing other development goals and objectives. Addressing this complex problem requires the identification of game-changing interventions that can drive sustainable, equitable agriculture for food system transformation. "Bio-innovations" will be one key set of interventions. Bio-innovations encompass biotechnology-based tools and product innovations, as well as innovations in their governance, regulation, and social and business contexts. They hold potential to contribute to food system transformation by accelerating productivity growth and reducing agriculture's environmental footprint, as well as contributing to climate change adaptation and mitigation.[1]

Within the portfolio of potential bio-innovations, this chapter focuses on second-generation biotechnologies, specifically genome-editing (GEd) tools and the products developed through their use. We group GEd tools and products together under the term "GEd applications," which includes newer genome-editing tools among other applications (Box 1). To date, however, the global experience with bio-innovation tools has almost exclusively been with first-generation applications, including genetically modified organisms (GMOs). This experience will likely offer lessons for newer GEd applications that are soon to enter the market and can inform the present discussion around their innovations and their commercialization, governance, and social acceptance. Our discussion focuses exclusively on crops, although it is also relevant for genome-edited animals, microorganisms, and industrial and pharmaceutical applications.

GEd is a revolutionary and disruptive technology for crop improvement.[2] Its applications can effectively unlock existing genetic value by introducing new traits into crops, while reducing the time necessary to develop new varieties. In the case of maize, time needed to deliver hybrids can be cut by as much as half, assuming that regulatory scrutiny is streamlined (for example, CIMMYT's maize lethal necrosis–resistant project using GEd[3]). Furthermore, this technology enables researchers to improve crops that have been difficult to enhance with conventional tools, including crops of interest to low- and middle-income countries (LMICs) like cassava, bananas, and sweet potatoes.

GEd applications can be particularly important for climate change mitigation and adaptation. These crops can be engineered to increase productivity, thereby reducing the amount of land needed for agriculture and thus reducing GHG emissions. Introduced traits can also improve crop resilience and nutrition, reduce pesticide and fertilizer runoff and leaching, and enhance soil health, all contributing to climate change mitigation.[4] GEd crop applications can also support adaptation to unexpected changes in environmental factors, including precipitation, temperature, extreme climatic events, and increased pest and disease

BOX 1 DEFINITIONS

The two distinct terms "gene editing" and "genome editing" are currently used almost interchangeably in the regulatory and popular science literature, with the supposition that they mean the same thing. In molecular biology, however, these two concepts have very different definitions, denoting distinct and increasingly complex levels of genetic structure in an organism. There are three genetic structure levels: gene, genome, and epigenome.

The **gene** is a basic unit of genetic information. The **genome** is the complete set of genetic information, including all genes present in an organism, which provides all the information that the organism requires to function. This includes regulatory sequences that operate like "on" or "off" switches. The **epigenome** is an even higher level of genetic structure or expression, which involves chemical modifications to the DNA and proteins that regulate the expression of genes within the genome. The three genetic structure levels give rise to gene, genome, and epigenomic editing processes. Gene and genome editing are now entering the product pipeline, and epigenomic editing will enter this pipeline soon.

The first-generation tools of genetic engineering randomly insert genetic material or genes from different or the same species into a host genome, resulting in **transgenic** or **cisgenic** organisms, respectively. These are also known as **genetically modified organisms** (GMOs). In contrast, second-generation tools such as CRISPR allow a more precise type of genetic engineering in which a gene or regulatory sequence can be identified and located at a specific site of an organism's genome. This gene or regulatory sequence can be silenced, deleted, modified, or replaced. These techniques are also known in some places as **new plant breeding techniques** (NPBTs) or **precision genetic technologies**.

Note: For formal definitions of gene, genome, and epigenome, see P. Portin and A. Wilkins, "The Evolving Definition of the Term 'Gene,'" *Genetics* 205, 4 (2017): 1353–1364; D. Goldman and L.F. Landweber, "What Is a Genome?" *PLoS Genetics* 12, 7 (2016): e1006181; and M. Ridley, *Genome* (New York: Harper Perennial, 2006).

incidence. Examples of GEd plants include drought- or salt-resistant crops, which result in fewer crop losses and less yield deterioration.[5]

As a result of their greater precision, ease of use, efficiency, and productivity,[6] these applications are the most promising bio-innovation available to foster food system transformation that addresses climate change, food security, nutrition, and livelihoods in LMICs. From the standpoint of achieving several goals and objectives, pragmatic approaches that use multiple approaches and applications – combining sustainable ecological approaches with genetically improved seeds – can be effective.[7] Applying such approaches to GEd in a broader context appears to be prudent.

In addition to the R&D investments necessary to use GEd tools and create new products (see Chapter 4), context-appropriate policies, regulatory frameworks, and programs will also be needed to create an enabling environment for the creation, assessment, and adoption of GEd applications.[8] This enabling environment will be particularly critical for the inclusion of vulnerable groups, particularly smallholders, women farmers, and other marginalized populations in LMICs, who often have limited access to new agricultural technologies and related knowledge.[9] Policy, regulatory, and other governance actions must facilitate widespread adoption and ensure equitable access to appropriate, beneficial, and safe GEd applications.

Agricultural innovations and technology adoption are not without cost. There can be “winners” and “losers” among both technology “adopters” and “non-adopters.” However, technology use or consumption outcomes may be hard to predict.[10] Adoption processes can have unintended outcomes and their temporal and dynamic nature may induce both positive and negative impacts, creating unforeseen trade-offs.

To address this uncertainty, researchers have proposed an approach for proactively identifying potential exclusionary and other negative effects emerging from the adoption of transformational technology applications.[11] This approach includes promoting alternatives to mitigate negative effects, while ensuring compliance with responsible innovation pathways as much as possible. All potential outcomes are considered, such as the impact of farmers not having access to a technology that could address food security and environmental impacts from climate change. Furthermore, as GEd technologies become easier and cheaper to use, and democratized through widespread use for everyone, the dependence on multinational companies for seeds and pesticides will decline significantly, and risks related to climate change and production can be addressed with safer GEd products.

Within the scientific and regulatory community, consensus is growing that, in principle, newer GEd applications are safer for use than first-generation bio-innovations and even conventional plant breeding.[12] This consensus is based on evidence from GEd products that contain only small genetic changes, which are indistinguishable from changes that could be found in nature or created through conventional breeding methods. Compared with first-generation techniques, all second-generation GEd tools allow for targeted changes and greater control over where these changes occur in the genome. This improved precision suggests that new GEd tools are now safer, as they pose less risk of generating unintended changes in the genome[13] – and therefore are likely to require less regulatory scrutiny.

The enabling environment for GEd applications continues to evolve. Regulatory processes have focused only on gene-editing tools as yet, while the situation for other genome-editing applications remains unclear everywhere. To date, no GEd crop products have been commercially released in LMICs and very few in high-income countries.[14] This may change soon, as several GEd products (specifically those based on gene-editing tools) in the R&D and regulatory pipeline are poised to enter the marketplace (Table 1).

PRIVATE AND PUBLIC SECTOR ENGAGEMENT

The public sector has taken a strong leadership role in developing GEd applications. Of the approximately 1,400 families of GEd-related patents and patent applications in agriculture, most have been submitted by public sector entities, primarily state-sponsored research institutes in China and public universities and research centers in the United States.[15] In LMICs, public sector entities such as CGIAR and its Centers are showing increasing interest in GEd applications (Table 1), and regional and national research organizations are now conducting R&D for GEd applications, including research on maize, sorghum, rice, beans, cassava, and fonio.

Public sector initiatives increasingly aim to develop public–private and international collaborations that enable the management of R&D, technology transfer, and product stewardship capacities necessary to deliver GEd applications to producers. Recent advances have improved access to and availability of funds that prioritize regional or multilateral collaboration and integration of private or public–private entities. For example, in Latin America, initiatives from FONTAGRO and the Inter-American Development Bank (IDB) are funding capacity building in GEd for public research institutions, with South–South support from public research institutes in Argentina, Brazil, and Chile.[16] However, the donor landscape is mixed. Some donors have supported GMO application development, including Australia's CSIRO, Japan's JIRCA, the Bill & Melinda Gates Foundation, and the US Agency for International Development, providing limited investments in GEd. Other donors, especially in the European Union, have either decreased investments in GMO applications or have not invested in GEd development at all.[17]

In the private sector, nimble start-ups are taking the lead in advancing GEd applications.[18] Multinational corporations have attempted to keep up with the rapid growth of GEd applications and to overcome lags in capacity building by gradually acquiring start-ups that have developed commercially viable applications. The market potential of such acquisitions is attractive to multinational corporations, but their market access may be hampered by slow-moving regulatory processes, high costs of regulatory compliance, and their lack of experience in negotiating complex GEd-related regulatory processes across different jurisdictions.[19] Where time and cost considerations are a serious constraint, multinationals and other private sector developers are likely to push forward only those GEd applications with potential to become commercial blockbusters.

Given the focus of GEd investments on commercially profitable applications, shifting attention to agro-climatic- and region-specific varieties of LMIC-appropriate crops is a challenge for public sector farmer-led plant improvement communities and for some smaller private sector developers.[20] Private financing for such R&D will likely remain limited because varieties tailored to LMIC agro-environments often lack the economies of scale needed to generate an attractive return for private investors. The emergence of local start-ups using GEd technologies for LMIC crops also continues to lag due to the high initial investments required in specialized R&D infrastructure and other capacities. As a result, the development process in LMICs typically depends upon public systems that also face significant financial and resource constraints for deployment acceleration, marketing, and product stewardship.[21]

TABLE 1 CGIAR genome-editing bio-innovations to increase resilience to climate change impacts

TRAIT	In the R&D pipeline	Potential projects
Disease and insect resistance	bananas, cassava, rice, maize, wheat, potato	cassava
Enhanced heat tolerance		potatoes
Enhanced input use and reduced GHG emissions	rice	
Enhanced nutrition and quality and safety traits	cassava, cacao	beans, wheat, maize
Weed resistance		sorghum
Reduced postharvest loss		wheat

Source: Based on K. V. Pixley, J.B. Falck-Zepeda, R. Paarlberg, P.B. Phillips, I. Slamet-Loedin, K. Dhugga, H. Campos, and N. Gutterson, "Genome Edited Crops for Improved Food Security of Smallholder Farmers," Nature Genetics, forthcoming.

Note: Potential projects refer to those that are feasible with the current state of knowledge, application advancement, demand, and an appropriate funding level.

POLICY, REGULATORY, AND SOCIAL LICENSE FRAMEWORKS

Science-based regulations and transparent regulatory processes offer investment security for companies and public sector entities developing GEd technologies and can help deliver valuable and safe technologies to producers in LMICs. GEd crops are likely to face some of the same issues experienced by genetically modified (GM) crops in the approval, transfer, and adoption processes, and in securing "social license," that is, public acceptance of these processes and products.

Although safety and economic assessments and regulatory decisions on GM crops have demonstrated a history of safe and productive use for society,[22] existing biosafety regulatory processes continue to pursue a strict interpretation of the precautionary approach embedded in the 2003 Cartagena Protocol on Biosafety and the 1992 Convention on Biological Diversity. This approach makes these processes both costly and time-consuming. Such financial and time costs may be prohibitive for small and medium enterprises (SMEs) and the public sector.[23] In sum, these national measures would likely hamper the deployment of GEd technologies and crops.[24]

Regulatory frameworks for GEd crops are gradually being developed through a mix of approaches.[25] Countries with ample R&D and regulatory experience with GM technologies — including Argentina, Brazil, Chile, Colombia, Honduras, Paraguay, Uruguay, Australia, Canada, and the United States — will likely regulate GEd crops that have no permanent presence of foreign DNA (that is, DNA coming from other species) in the same way they regulate conventional crops. China's position on regulation remains a bit unclear, although it has invested heavily in developing GEd applications[26] and has recently announced new GEd regulatory guidelines.[27] The United Kingdom and Japan have signaled their intent to consider regulating GEd crops with different safety assessment processes than those required for GM crops under the 2003 Cartagena Protocol. The European Union and New Zealand have indicated in principle that GEd applications will be regulated as GM. This regulatory landscape is in flux and can be expected to change over time.

The success of GEd applications depends not only on science, R&D, and regulatory processes, but also on societal "buy-in" by a broad set of actors.[28] Establishing social license will require securing political support for innovation, ensuring and enhancing public participation and transparency, and making communication and outreach an integral part of the decision-making process. Some concerns can be resolved by responding to consumer and special interest groups' questions about new technologies, but certain segments of society may always remain opposed to GEd products.

Nevertheless, building transparency, using the best available evidence to address concerns, and communicating complex scientific concepts clearly to the public can help build the credibility of regulatory and decision-making processes and systems. Several comprehensive studies and reviews look at willingness to pay or consume GM products, and others discuss the role of science communications and actors.[29] This literature can help identify avenues to address and secure social license. It should be noted, however, that the ability of scientific and regulatory communities to respond to some societal concerns in a robust manner may be constrained by the limitations of available assessment methods.[30]

USING GEd TECHNOLOGIES TO ADDRESS CLIMATE CHANGE AND FOOD INSECURITY

A portfolio of policy actions has the potential to create an enabling environment for the development and deployment of safe, effective GEd applications that benefit producers and consumers in LMICs. Providing impetus for GEd applications will require: 1) enhancing innovation through capacity building, partnerships and networking, and improved regulatory processes, and 2) enhancing participation and inclusion through farm-level adoption, the use of evidence and transparency to address concerns, and the consideration of women's knowledge and needs in designing programs and selecting crops and traits.

ENHANCING INNOVATION AND TECHNOLOGY DEVELOPMENT

INCREASE CAPACITY FOR AGRICULTURAL R&D AND ENTREPRENEURSHIP. Current R&D efforts must expand beyond crop productivity improvements to include the development of stress-tolerant and climate-resilient crops, which are critical for LMIC farmers, including smallholders and women farmers, to safeguard and improve food and nutrition security. Both public and private sectors have a role to play in accomplishing this goal, but capacity building and an enabling environment will also be required. By working together, public and private sector actors can support the efficiency, inclusiveness, innovation, resilience, and sustainability of GEd applications.

Investing in **human and infrastructure capacities** can expand access to GEd applications while also addressing the economies-of-scale effects that have constrained work on LMIC crops.[31] To ensure that high regulatory costs do not impede the work of public organizations or private SMEs and start-ups, support should be targeted to developing partnerships between public and private institutions and entities with existing technical, legal, management, and regulatory skills to address GEd issues. Partnerships that foster broader public–private sector engagements can also contribute to an enabling environment that broadly promotes the development, transfer, and adoption of GEd crops.

The process of "democratizing" GEd tools — that is, making them available to SMEs and small organizations to create products that will be delivered to producers — could be accelerated through the development of "bio-foundries" and technology **incubators** that provide infrastructure and support in the early stages of product development.[32] By reducing initial investment requirements and accelerating R&D processes, these incubators could launch a new generation of bio-entrepreneurs offering differentiated and tailored products to targeted LMIC markets.

Capacity building or strengthening is also needed in both the public and private sectors to support the development of **strategic approaches** and policy design of regulatory, intellectual property, and product stewardship frameworks. Capacity building can facilitate commercial success by reducing barriers and thus securing economic benefits, especially for new companies and the public sector.[33]

Developing policies and management procedures for **intellectual property** rights and benefit sharing for public and small private research institutions is also critical, as well as investment in capacities to improve all aspects of intellectual property management. Building new partnerships can help to ensure firms and organizations have the capacity to negotiate intellectual property rights and licenses for operating and deploying technologies to farmers.[34]

PROMOTE INNOVATION THROUGH PARTNERSHIPS AND R&D NETWORKING. The development and deployment of GEd applications will benefit from an R&D ecosystem that fosters inclusive and innovative R&D approaches, linkages, and networking, as well as intercountry regulatory coordination and convergence in LMICs. For example, start-ups are increasingly focusing their R&D efforts on fruit and vegetable products of interest to LMICs.[35] To ensure GEd applications are approved in the countries where they are needed, developers — especially start-ups and the public sector — require support for regulatory compliance. These actors can use GEd networks to draw on the substantial experience accumulated by organizations and countries related to regulatory issues and compliance, intellectual property, licensing, and preparation of data necessary for assessment. For example, GEd developers have been attracted to regulatory processes in countries like Colombia, Guatemala, and Honduras that allow them to conduct safety assessment activities, such as field and performance trials. The data generated can then be used in submissions to regulatory authorities in other countries, which may open new markets in these countries for GEd applications.

SUPPORT STREAMLINED AND INNOVATIVE REGULATORY PROCESSES. Functional and streamlined biosafety review processes have been proposed and used in several countries for GEd applications. These allow the regulatory authority to undertake an initial technical review of a proposed gene-edited product to determine how it should be evaluated. If a full biosafety regulatory assessment is not deemed necessary based on the lack of a permanent presence of foreign DNA, then the product proceeds through the standard national regulatory and registration processes for conventional varieties.[36] If the initial technical review determines that the product is subject to a full assessment, then it follows GMO regulations.

This feasible and streamlined regulatory approach has led to significant progress in R&D and deployment of GEd applications. In some countries, clear and precise regulations have allowed researchers from universities and public research centers to develop GEd applications. Since Argentina approved the use of a feasible and streamlined regulatory approach in 2015, crops generated by the public sector and research centers using gene-editing have represented 59 percent of all applications using GEd tools, while only 8 percent have been for older approaches such as GM.[37]

The case of bananas resistant to Fusarium tropical race 4 (TR4), an important fungal disease, demonstrates the need for streamlined approaches and for capacity building and collaboration. The Fusarium TR4 fungus is most common in LMICs that have little capacity to develop or evaluate GEd applications to address the disease. Bananas resistant to TR4 have been produced in developed countries where streamlined approval processes have been adopted, but where the disease is not present. Finding ways to connect capacity and needs across countries and regions is the logical next step for protecting banana crops and for introducing other new GEd crops in LMICs.

ENHANCING PARTICIPATION AND INCLUSION

PROMOTE FARM-LEVEL ADOPTION OF GEd PRODUCTS. Public policies, regulations, standards, and investments must support improved availability, access, and affordability of high-quality seeds and traits for smallholder farmers, especially women farmers, given the role they play in guaranteeing household food security.[38] Creating inclusive seed systems will require pragmatic reforms and investments in seed policy harmonization, common standards, and certification requirements to ensure their suitability to local social, economic, and environmental contexts. Seed system reforms and investments must also consider strategic interventions that support scalable, climate-smart practices to achieve climate resilience and increase productivity, as well as gender and social equity. Women farmers, for instance, often have limited access to quality seeds and planting material. Thus, a gender lens is needed to understand women's often informal access to seeds and their preferences for different crop traits. Women tend to adopt improved varieties of crops that are central to household food security in quality and quantity, whereas men tend to favor cash crops directed to the market. However, women often cannot access these crops and planting materials due to their lack of purchasing power and access to information. This behavior has been shown for different crops in many regions, including improved cassava in the Caribbean and maize in Central America and Mexico, among other places.[39]

ADDRESS CONSUMER AND OTHER STAKEHOLDER CONCERNS. Achieving social license, or "buy-in," for GEd applications from relevant stakeholders including producers, consumers, decision-makers, and other stakeholders will require both better evidence and more strategic communication. More robust knowledge is needed about GEd applications themselves and their potential societal impacts, as well as evidence on "what works" regarding policies, incentives, property rights, and governance. To generate this evidence, **integrated assessments** will be needed across multiple scales, including local, national, regional, and global levels, and gaps in the impact assessment capability of LMICs must be addressed. Versatile, robust, and easy-to-use analytical tools and big data can help identify constraints to adopting new technologies and distributing benefits. These tools can also improve the understanding and inclusion of broader societal concerns such as gender, institutions, and rights in technical and social change processes.

Strategic **outreach and communication** efforts are also necessary for local and national buy-in, both to address consumer and other stakeholders' concerns and interests and to develop implementation and delivery capacities to support country-led participatory and collaborative efforts for use of GEd applications.[40] As part of this, decision-makers must consider the diverse interests of various stakeholders in their assessments of regulatory frameworks for GEd applications.[41] Effective communication also depends on the transparency of R&D, regulatory frameworks, and technology transfer processes. This **increased transparency** can be achieved by helping build up actors' empowerment and knowledge as relevant stakeholders in broader efforts for building value chains. Furthermore, capacity for assessing evidence on GEd applications must be increased. Both transparency and capacity will help with strategic efforts to share knowledge and communicate through multiple channels and media, which are crucial to facilitating GEd uptake.[42]

PROMOTE INCLUSION. Improving technologies to meet the needs of smallholders, including women farmers and other vulnerable groups, and increasing their access to GEd applications will build resilience to climate change impacts and contribute to food security and improved nutrition. All farmers should have access to better GEd crop **information and extension** that is tailored to their needs. Extension activities need to consider local conditions, be accessible to differing levels of literacy (for example, by using pictures), use local languages, and emphasize farmers' local knowledge. Messages should be realistic and present concrete examples of how GEd applications can perform and solve real on-farm problems that are not easily addressed through conventional plant breeding or pest control methods, such as integrated pest management.

Participatory methodologies will be essential to making GEd applications accessible and contextually appropriate for smallholder farmers.[43] GEd applications developed using participatory methods, especially those that seek to maximize agro-biodiversity and match valuable seed use to specific contexts, can support the diversification of poor people's livelihoods. This approach is important to pursue in LMICs, as seed suitability must be ensured for highly diverse preferences and supply systems. Well-known approaches such as farmer field schools and farmer-to-farmer initiatives that include a variety of stakeholders can also help breeders learn about drivers of adoption and trait selection.[44] The choice of GEd applications for specific contexts will need to be carefully considered and developed through robust research evaluations. Using local knowledge and networks will allow farmers to access appropriate strategies that meet their needs and thus help ensure socially beneficial outcomes.

INCLUDE WOMEN'S VOICES. Extension for GEd applications can facilitate the inclusion of women farmers. Women are more likely to farm on marginal plots and have less access to inputs such as fertilizers, quality seeds, and irrigation schemes. They are also more likely to lack financing and information, which constrains their adoption of GEd crops. For example, providing packages with small quantities of seeds has been shown to stimulate the adoption of improved varieties by women farmers in Africa[45] and could be effective in encouraging women to adopt GEd seeds. This strategy may be attractive to the public sector, local seed companies, and nongovernmental organizations to stimulate demand for GEd seeds and to increase farmers' access by making the technology affordable.

Women's voices should also be heard in the **selection of GEd applications**, that is crops and crop traits. Women are most likely responsible for raising crops for home consumption and sale in local markets. Often, women's time and labor constraints prevent them from choosing the most profitable crop options, such as cash crops including grains.[46] Instead, the crops that women often prioritize as quality home food sources are otherwise neglected and underutilized. Enhancing the capacity of public and private research institutions to focus on these crops can increase access to nutritionally rich food sources, foster dietary diversity,[47] and reduce micronutrient deficiencies, especially among lactating women and young children.[48]

Women farmers must also be able to **participate in adopting GEd applications**. To ensure their inclusion, it will be important to reflect on women farmers' leadership and issues that enhance or hinder rural women's access to new technologies. Using a gender lens can improve the "menu" of crops to be improved and contribute to a more inclusive redesign of the commercial agenda for both public and private sectors. To improve understanding of how GEd crops can boost food security and incomes, women must be empowered to access information about these crops through advisory services, experiential learning strategies, and women-centered extension education strategies. More broadly, there is a need to focus on the development and adoption of gender-responsive GEd applications. To do this, women must also be included in exploring how genome editing is developed and regulated within research institutions and political structures.

CONCLUDING REMARKS

As GEd applications become more routine, we can expect increased standardization of R&D tools and procedures, expanded use of core development tools, and growth in crop-specific development platforms to introduce valuable traits, even in crops with little commercial promise. These developments, coupled with an acceleration of gene discovery processes and improvement in genomic mapping techniques, should speed the identification and deployment of valuable crop traits. Expanding the use of GEd tools will increase the need to adopt practical, effective assessment and regulatory frameworks, foster social acceptance of GEd technologies, and provide appropriate crop traits, extension, and support for all farmers. Putting GEd applications to work will also require broader economic, legal, and policy reforms for agrifood value chains, many of which are discussed in other chapters of this report. Most importantly, both public and private sectors must work together to develop an enabling environment that will allow bio-innovation to flourish and contribute to well-being, resilience, and climate change mitigation and adaptation. Systematic GEd landscape evaluations anticipate an increased interest in GEd crops that are resistant to intractable diseases (fungi, bacteria, viruses), and less interest in management of insect pests and weeds, especially in Latin America. Therefore, during this transition period, existing technologies and production practices that can address environmental and food security concerns related to pest and weeds will still play a role. This includes first-generation bio-innovations, such as GMOs, and other products that have a proven record of safety and value when developed and used responsibly.