Genomic Sciences for Agriculture, Food, and Nutrition

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Summary
From their inception, genomic sciences have been applied to plants, animals, and microbes used in food and agriculture. Genomic sciences are useful for understanding how cells work, how seeds are formed, how nutrition is absorbed by roots, and how plants and animals respond to pests and diseases, extreme weather, and changes in climate. Genomic studies have also discovered the variations in traits occurring in crop and noncrop plants that are used by breeders with DNA-based markers to develop varieties with preferred traits. When useful traits cannot be found, seeds are sometimes altered (mutagenized) to create genetic diversity. Techniques for genetic engineering are also used to direct mutations to specific genes or to introduce genes for desired traits, as is done in genetically modified (GM) crops. Crops and foods developed through genetic modification technologies, now grown in more than 29 countries, have improved productivity and farmer profits while maintaining high food and environmental safety records. Widespread suspicions regarding GM crops are based largely on unsubstantiated fear and mistrust rather than on sound scientific principles. These suspicions have weakened political will by discrediting the science of agriculture at a time when many societies are struggling to meet the demands of growing populations, climate change, and an expanding bioeconomy. Advanced genomic sciences, coupled with good agrological practices and solid science-based policy decisions, will be required to substantially reduce or eliminate global insecurity in food and nutrition and to secure a vibrant global agriculture economy.

Current realities

Food insecurity is an ongoing reality for many people around the globe. Unlike the situation through to the early 1990s, in which there were food surpluses in wealthy, agriculture-rich countries, the world is currently experiencing chronic shortages of commodity grains because of unpredictable changes in weather patterns, poor seed quality, and unsustainable agricultural practices. The Food and Agriculture Organization (FAO), the International Food Policy Research Institute (IFPRI), and other international bodies have predicted that worldwide agriculture production must increase by at least 70% by 2050 to meet the increased demands brought on by global population growth, coupled with increased urbanization and wealth, and a growing demand for animal-based foods. In recent years, uncertainties in production have resulted in the imposition of trade policies that limit export of excess production, further exacerbating global food shortages. In recognizing these challenges, G8 and G20 leaders placed agriculture and food security issues high on the list of priorities in 2011 and 2012. The 2012 FAO report on food security reported encouraging progress through 2008 in meeting the Millennium Development Goal of halving food insecurity by 2015. Unfortunately, food insecurity has increased since 2008. The FAO also noted an important role for agriculture in building rural economies and highlighted reduced poverty in countries where agriculture is encouraged.

Although genetic advances in food and agriculture are rapid, translation to products and impacts is slow. At the same time that debates about achieving sufficiency in food and nutrition are occurring, advanced genomic knowledge is revealing solutions to increase food production, improve the agro-ecology, and improve food safety. Plant breeders have changed their approach to generating new varieties in the hope that they will help to reduce food shortages caused by poor yields. While random selection of natural or induced genetic mutations was the primary source of diversity in the past, genetic information is now regularly used to increase the rate of success in plant breeding and speed up development of new plant varieties. When "induced" or natural genetic diversity is not sufficient, scientists are using genetic engineering to add new genes to derive crop varieties resistant to diseases, insect pests, and heat and drought conditions, among other traits.

While scientific progress in crop improvement during the past decade has been remarkable, there has not been sufficient progress in fundamental research to lead to the increased levels of production that are required to achieve global food security in the near future. The situation has been exacerbated by flat or declining levels of funding for the basic research upon which the food and agriculture sectors rely. Recent studies in the United States and the United Kingdom chronicled the flat or decreasing funding for agriculture sciences in the public sector and suggested that the lack of progress in increasing yields of wheat, barley, soya, and other staple crops are due to reduced research funding.

Unfortunately, the translation of genomic knowledge into consumer and environmental benefits is much slower than necessary, particularly for benefits of crop varieties that are conferred by genetic engineering technologies. From the outset, regulatory agencies took a cautious approach to GM technologies and recommended a complex regulatory pathway for the approval of GM varieties before commercialization. The new pathway established in the U.S. included regulatory oversight to guard against unknown and unpredicted consequences that might be caused by genetic engineering. Other countries imposed regulatory oversight processes different from the U.S., which involved additional reviews that are not synchronized with those conducted in the U.S. These regulatory hurdles significantly inhibit the importation of GM products and the access of farmers and producers in non-adopting countries to genomic advances. When regulatory processes for GM crops were put in place in 1987 it was expected that they would be phased out over time as familiarity with the science and products developed increased; however, the opposite has happened. Existing regulatory structures and asynchrony of approval favor large companies over small innovative companies and university researchers, allowing the development of seeds with high-volume sales over seeds of crops occupying fewer acres (e.g., vegetables and fruits).

Consumer acceptance of crops developed via genetic engineering varies widely between the 29 countries that produce GM crops (on more than 170 million hectares) and those that do not produce them. Even where GM technologies are adopted, vocal anti-GM groups demand that GM technology be halted or that GM products be labeled as such. Seed companies and independent scientists counter with studies that demonstrate both safety and efficacy of the new products in providing benefits to the environment and food that is as safe, if not safer, than older varieties. The impacts of these differences are reflected in current trade negotiations between the U.S. and Europe where GM agriculture products are contentious. While GM products are viewed as safe in the U.S., European leaders have imposed trade restrictions because they are less convinced that the scientific data is sufficient to ensure safety of the foods and the agro-environment. Nonetheless, the European Union has spent more than €300 million on studies that have confirmed safety of GM crops.

Scientific opportunities and challenges

Laboratory researchers use genomic sciences to understand the “whys and hows” of plants and animals. Why do some plants and animals resist certain pests and disease, or drought and heat conditions, while others do not? How do plants make certain beneficial substances, chemicals, and other materials? How do some crops make the nitrogen fertilizer they need while others do not? Why do plants grow better in some soils than others? Answers to these types of questions are as complicated as questions in biomedical sciences and require similar advanced scientific understanding and technologies. Scientists and technologists are applying information gained through genomic sciences to answer such key questions in agriculture.

The application of genomic sciences in agriculture can provide many advantages, including higher yielding crop varieties with increased tolerance against drought and heat, and crops that use chemical fertilizers more efficiently, with resultant environmental advantages. This science makes it possible to develop varieties of crops that are durably resistant to diseases, insects, and parasites. As a consequence, there will be less need for agrichemicals. New varieties will produce higher yields and improve income to the farmer, with lower impacts on the environment and improved food safety for consumers, even in the face of the impacts of climate change. Genomic sciences will make it possible to develop crops with elevated levels of nutrients that improve human health (e.g., vitamins, minerals, and antioxidants); foods will contain healthier oils, fewer allergens, and will contain less cancer-causing mycotoxins. Science will also produce healthier animal-derived foods (e.g., fish, pork) that use less feed and produce lower amounts of greenhouse gases and other pollutants than parent animals. Crop and noncrop plants will be enhanced using synthetic biology to develop plants that produce high levels of natural products that will replace chemicals produced by petroleum-based processes, creating a sustainable bioeconomy that enhances rural economics.

Unfortunately there are major challenges to realizing these and other opportunities. First, there is a severe shortage of financial support in Europe and the U.S. for genomic studies of plants and farm animals. Without fundamental discovery science and translation to innovation, food security and attendant economic growth will be slowed or not achieved. Second, the inability to translate genomic discoveries to products is slow and reliant on complex factors, including (i) an outdated regulatory process that stifles innovation, reduces the participation of entrepreneurs, favors large companies, and limits trade; (ii) a scientifically uninformed and agriculturally illiterate press that often discredits validated science by reporting equally on poor science in this field. Furthermore, scientific truths are not to be equated with philosophical or religious "truths".

Policy issues

- A substantial improvement in food security can only be achieved by accelerating research in the basic agricultural sciences, a goal that can achieved only with increased and sustainable funding, especially for the training of students and professionals.

- Many policies that regulate food and agriculture, including products derived from genomic sciences, are not guided by credible scientific understanding. Recently, many policy makers have become less familiar with agricultural practices (e.g., how seeds, crops, and animals are produced), which has made their decisions vulnerable to views often based on misinformation and mistruths expressed by vocal minorities. Policy decisions concerning food safety and security need to have a foundation in a scientifically based understanding of agriculture.

- Policies and regulation of seeds and foods developed in a GM-adopting country are generally not accepted by an importing country, in contrast to acceptance of nonadvanced foods and seeds. Food and agriculture products must be regulated independently of the method by which they are produced. Regulatory review of products should, as much as possible, be conducted in synchrony with the producing country; regulations must be harmonized based on sound scientific recommendations and be reviewed and revised periodically.

- Since the strong recommendations from scientific advisers and professional academies to use genomic sciences and agricultural biotechnology have generally not been endorsed by political leadership, many consumers have developed a negative view of GM foods. Political leaders, elected and appointed, need to endorse such sound science-based recommendations concerning the food and agriculture sector while acknowledging and facilitating the consumer's right to choose. Without such support, it will be difficult, if not impossible, to provide enough safe and nutritious foods for a growing population in the coming decades.

*** A policy position paper prepared for presentation at the conference on The Genomic Revolution, convened by the Institute on Science for Global Policy in cooperation with the Parliamentary Office of Science and Technology, on September 6, 2013, within the Houses of Parliament, London, U.K.*