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The centennial long and winding road of seeds and crop varieties from 1940 to 2040

The Green Revolution and the development of modern crop varieties refers to a series of research and technology transfer initiatives, using conventional plant breeding methods oc-curring since 1940. These modern crop varieties, basically wheat and rice, were high-yielding and were released initially to farmers in Asia and Latin America, but later in Africa as well. As a direct consequence of the Green Revolution together with the development of hybrid crop varieties in corn and sorghum (lately on sunflower and other species), yields of rice, maize, and wheat increased steadily and the cereal production more than doubled in developing nations between the years 1960 and 1990.

Both the public as well the private sector was equally important for such developments. While the public-sector research was responsible for creating the high-yielding varieties of wheat and rice of the Green Revolution, the private-sector research was responsible for developing the modern hybrid varieties. However, the interaction of both sectors was low.

Entering the nineties, the Biotechnology Revolution, refers to a series of research and tech-nology development and transfer initiatives using DNA recombinant technology which started commercially in 1996. Although Europe and Africa refuse to accept the massive diffusion of biotech crops, the impact of the new transgenic varieties of corn, soybean, cotton, canola and other varieties has been extremely important in several American countries and some countries of Asia.

Again, both the public as well the private sector was equally important for such develop-ments, but, in this case, the interaction of both sectors was high. Public-sector research con-tribution was key to the basic science knowledge which sustain agricultural biotechnology, but the private sector was responsible for

most applied research and almost all commercial development.

In the recent years the rapid pace of advances in molecular biology, functional genomics, big data and computational capabilities, are reshaping the plant breeding in a way in which the borders of the scientific disciplines become diffuse. Plant breeders from public and private sectors has now the possibility to apply genome editing tools -ie. the process of making pre-cise, targeted sequence changes in the DNA or RNA of organisms- to step up genetic pro-gress. But while such developments have created powerful new incentives for private re-search, they are altering once more the structure of the public/private agricultural research with respect to crop improvement. Public researchers no longer wish to be just creators of scientific papers but want to participate in the business. Dozens of new private gene editing companies have been founded by public sector scientists.

There is no doubt that the hybrid crop development, the Green and the Biotechnology Revo-lution can be credited with saving over a billion people from starvation (the gene editing technologies are too new to be a measurable impact). However, such significant crop pro-duction increases depended on applications of fertilizers, pesticides and irrigation to create conditions in which high-yielding modern varieties could succeed, and the dependence on seeds that must be bought rather than saved from year. Such conjunction of factors requires expensive inputs and may exclude many low-income farmers from the benefits of such im-provements.

A number of technological innovations are incorporated soybean

Besides, the widespread use of the modern crop varieties may lead to the loss of traditional varieties and increase vulnerability to pests and diseases. The production ca-pacity of these systems is out of the discussion, but the question is how sustainable they are over time.

The strengthening environment for protecting intellectual property in plant innovations was one of the consequences after all these revolutions. However, the fair coexistence of patent rights on biotechnology inventions and plant breeders' rights on the varieties that contains such inventions are far to be achieved in most countries. And, given that scientific progress is significantly faster than the renewal of legal regulations, some of the new developments derived from gene editing are difficult to protect under the current intellectual property frames.

To achieve sustainable advances and minimize negative side effects, any new revolution must also invest in education, management, information and training. Will this have been done correctly from 1940 to date? Probably the answer is not favorable, and there is no doubt that it is clearly negative in almost all aspects related to plant biotechnology.

The challenges ahead

The public, the ordinary people, are not demanding more food but wants safe food. They are not particularly in favor of modern agriculture but clearly against not sustainable agriculture. They hate to find a worm in the apple they are eating, but they do not want that apple to have been treated with chemical pesticides. They want clean water to drink, not to irrigate crops. They hate multinational companies, but they eat, dress and enjoy all their achievements. And everyone wants more, better and diverse foods.

How to tackle all these issues -in some way contradictory- at once? Without the modern ag-ricultural efforts, the Malthusian predictions of overpopulation resulting in famine may come true. So, more knowledge, more solid ground science and more technological transfer is needed but, probably, all these efforts will be unsuccessful if the social acceptance of the new products and technologies is not increased at the same time.

Advances in maize have a direct impact on sustainability and the fight against hunger

The paradigmatic example is the glyphosate case, the most-used herbicide in the world: four decades of extensive science and public regulatory studies and conclusions worldwide -including the European Commission, and the US Environmental Protection Agency (EPA)-, support the safety of glyphosate-based herbicides. However, the International Agency for Research on Cancer, a branch of the World Health Organization, has classified glyphosate as probable human carcinogen. During 2019, several US state jury ordered Bayer-Monsanto to pay billions of dollars in damages claiming that glyphosate caused cancer. An estimated 13,000 more plaintiffs are suing the company for allegedly causing their cancer. It could be argued that, for the public, it is very difficult to distinguish between good science and junk science, and between causation and probability in product liability cases. However, the cen-tral point is that the rising of anti-business feeling in society coupled with a loss for the scien-tists' credibility has been present.

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In any way the glyphosate case ends, this will affect the entire seed industry and the public institutions working in plant breeding. Probably, the key issue derived from the glyphosate case is to perceive that, for ordinary people, credibility in science is no longer the principal point in their decisions.

The second fact, which emerges from the above, is that the social demand for safe and sus-tainable food is more important than the technological challenge to produce them.

Finally, the complex set of rules, treaties, conventions, protocols, international agreements, and other regional and domestic regulations that rule the seed business has resulted in chal-lenges to make global interpretations, due to overlapping, gaps, ambiguities, contradictions, and lack of consistency. All these frameworks should be revised and be extremely simplified. Otherwise, only the big multinational companies will be the only ones that can navigate in a sea with so many legal difficulties.

The seed industry and public institutions dedicated to the improvement of crops have done an extraordinary job in the last 80 years. Thanks to their efforts and achievements, we have possibilities to feed a world with more than 7,000 million people. But in a few years, we will be many more to feed, in a planet that no longer tolerates more challenges to its sustainability.

The difficulties in the next 20 years will be higher than in the past 80 years. The challenge ahead it is neither just a question to overcome such technological difficulties nor to demonstrate that the new plant varieties have best performance than the previous ones. Working together, the seed industry and the academy, must also convince the public that they can do it, and do it well, attend extremely sensitive social and environment externalities.