Review

Experience from use of GMOs in Argentinian agriculture, economy and environment

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Argentina is the second largest grower of genetically modified (GM) crops. This high level of adoption of this new agricultural technology is the result of a complex combination of circumstances. We can identify four main causes that led to this: political support (from agriculture officials), ability to solve prevalent farmers' needs, economic and environmental factors and an early implementation of effective regulations. The political willingness to study this new technology and crops as well as the recruitment of sound professionals and scientists to perform the task was crucial. These professionals, with very diverse backgrounds, created the necessary regulatory framework to work with these new crops. Farmers played a decisive role, as adopting this new technology solved some of their agronomic problems, helped them perform more sustainable agronomic practices and provided economic benefits. Nonetheless, all these advancements had not been possible without a rational, science-based and flexible regulatory framework that would make sure that the GM crops were safe for food, feed and processing.

Contents

Introduction

This article describes the situation and the conditions that led Argentina to adopt and develop crops modified through genetic engineering. This is mainly, but not exclusively, a historical perspective. However, some of these conditions and situations may shed some light on the present and may contribute to the development of similar processes elsewhere. The main regulatory guidelines that oriented this process are also included, as these may be useful examples when facing the challenge of adopting the use of GM technology [1,2].

It is important to mention that when Argentina started assessing GM material in 1991, there had been several conditions that had favoured this situation. First, the political situation of the

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country had changed. This was extremely important as the authorities were interested in and willing to give this new technology an opportunity. The former Secretariat of Agriculture promoted the study of these new crops. This in-depth analysis of the new technologies could only have been possible if the necessary human resources were available, the second key element. At that time, sound and committed professionals and scientists with different backgrounds, from the academia and the private sector, became staff of the regulatory body within the (at the time) Secretariat of Agriculture. They faced the challenge before them and created in 1991 the necessary framework to regulate GM crops.

Argentina approved the first GM crop, glyphosate-tolerant soybean (GTS), in 1996, which coincided with the global commercialisation of GM crops. Only six countries were involved in this; Argentina, with the planting of 370,000 ha of GTS, was one of them [3]. The area planted with GM crops has grown since then by more than 50 times (2008/2009 planting data), placing Argentina as the second largest grower of biotech crops in the world, as per 2008/2009 figures. Argentina now grows 21% of the global biotech crop area. Nowadays, areas grown with GM crops, relative to the total planted in the country, are 99% for soybean, 83% for maize, and 94% for cotton. Since 1991, fourteen different GM crops (events) have been approved for commercialisation (Table 1).

Regulators and the regulatory framework

Several factors accompanied the early adoption of GM crops in Argentina. The government was willing to study and implement a regulation for GM crops and the public and the private sectors devoted to studying agricultural biotechnology needed a framework to develop and handle this new technology, which, back then, was at an experimental stage. Consequently, the regulators and the regulations in themselves played a crucial role in this process.

Although the leadership was present in the figure of the Competent Authority (the Secretary of Agriculture at the time), the regulatory capacities were not available yet within the structure of the government. To that end, people from outside the government were recruited. They did not have the typical bureaucratic background, as they were mostly scientists and stakeholders' representatives, who brought a whole range of diverse and solid professional experience. They had the disposition to update their backgrounds according to the new scientific knowledge. Scientists from academia were deeply involved in this process, definitively setting science as the basis of the regulations from the very beginning. The regulatory bodies included government personnel, as well as representatives from the public and the industrial sectors. It was a very productive combination of science, societal interests and field experience. This 'eclectic' background would conform the regulatory bodies (the National Advisory Commission on Agricultural Biotechnology, CONABIA in the Spanish acronym, and the Technical Advisory Committee on GM Organisms Use, CTAUOGM) (http://www.minagri.gob.ar/SAGPyA/areas/biotecnologia/20-CONABIA/creacion_conabia.pdf; http://www.senasa.gov.ar/contenido.php?to=n&in=1079&ino=1079&io=5743).

In a nutshell, the process to approve the trial of a new (in Argentina) GM crop and its eventual commercialisation has remained basically the same since 1991 (http://www.infoleg.gov.ar/infolegInternet/anexos/145000-149999/146801/norma.htm; http://www.minagri.gob.ar/SAGPyA/areas/biotecnologia/60-Solicitudes/Res-39-english.doc). All applications are submitted to the Ministry of Agriculture, as the Minister of Agriculture is the Competent Authority on the matter. The applications are analysed and assessed on a case-by-case basis by the Ministry and its regulatory and advisory bodies and by other areas of the government. At both levels, field trials and commercial approvals, the assessments are science-based and the ultimate aim of the process is to make sure the crop is safe with regard to the agro-ecosystem as well as in all other respects, as food, as feed and processing material. The applications require the applicant to submit information on the engineered crop concerning the phenotypic expression, the description of the agronomic practices, including eventual changes in the geographic zones (if different from the non-GM counterpart), and the molecular genetic characterisation. Up to 2008, a total of 1511 applications for field trials and related regulated activities had been assessed.

Although the processing of the applications has not suffered major changes, the regulations and the regulators have undergone several updates, as more knowledge is available. The early regulations for the biosafety assessment of GM crops in Argentina were similar to those of the European Union and the United States. As time went by, Argentina modified the regulations based on new scientific knowledge and developments and its own understanding of biotechnology and biosafety (http://www.minagri.gob.ar/SAGPyA/areas/biotecnologia/60-Solicitudes/Res-39-english.doc). Argentina was able to do this because its regulatory framework had, and still has, three very important characteristics: it is flexible; it is rational and it is scientific. These key ingredients have helped it 'grow' and adapt to the new technologies, knowledge and resources available. The regulators have had to keep up with it. For example, at the beginning, the number of authorisations for field trials was just a handful whereas at present over two hundred applications are assessed per year.

Applications for field trials may include: (i) several transformed individuals with the same construct but at presumably different genome locations or (ii) transformants obtained with different trait-related constructs, or both. Therefore, the 'development efforts' of the developers, the regulatory framework and the regulators are better depicted by the number of *different events* (not of single applications) tested in field trials. This number has been steadily increasing to reach around two thousands in the past few years. Still a different, qualitative measure of the development efforts in the advance of GM crop technology in Argentina is given by the increasing complexity of the traits, which are currently tested (http://www.minagri.gob.ar/SAGPyA/areas/biotecnologia/50-Evaluaciones/_archivo2/000400-Evaluaciones para liberación experimental.php).

Precommercial tests, that is, extensive sowing, are a good way of seeing the regulations and the regulators in action. These tests, in fact a second phase in the regulatory process after the field trials, are carried out to assess the possible effects on agronomical practices and the environmental impact of GM crops. Also, these precommercial releases are done to perform local-specific tests and to collect material or data for regulatory purposes. In retrospect, an essential criterion for the biosafety review that has helped the further expansion of GM crop technology in Argentina was that agriculture deals with highly managed agro-ecosystems. This was crucial because it gave to the application of agricultural biotechnology in Argentina an initial impetus even under very strict biosafety guidelines.

These sound and strict biosafety guidelines were ‘put under test’ in the European Union’s moratorium. Argentina was trading some GM crops with it, and the EU withheld the import of these products using the Cartagena Protocol on Biosafety to the Convention on Biological Diversity as one of its main arguments. Argentina, together with Canada and the United States, presented a demand before the World Trade Organisation (WTO), because of this unreasonable delay in the imports – hence the name ‘moratorium’. The WTO ruled in favour of Argentina, Canada and the United States, because the products followed all the environmental and food safety standards [4]. The application of the precautionary approach in the assessment of GM crops and in the ultimate granting of a commercialisation permit was crucial in this huge international dispute.

For all these reasons, Argentina and its regulatory framework have gained a good reputation around the world. The underlying principle of the regulations is safety, and with that in mind the assessments only allow for scientific, sound and strict arguments.

The crops and the traits

As stated before, field trials with GM crops started in Argentina in 1991. The first commercial GM crop, GTS, was released in 1996 (http://www.minagri.gob.ar/SAGPyA/areas/biotecnologia/50-Evaluaciones/_archivo2/00http://www.minagri.gob.ar/SAGPyA/areas/biotecnologia/50-Evaluaciones/_archivo2/000200-Eventos con evaluación favorable de la CONABIA y permiso de comercialización.php).

Very favorable combinations of crops and traits were relevant conditions at the beginning of the adoption process. Two cases, linked to the first approved GM crops are analyzed here: GTS and Lepidoteran Resistant maize, which contains an insecticidal toxin from *Bacillus thuringiensis* (Bt).

GT soybean

At the time of the commercial release of GTS, soybean was already an important crop in Argentina. Production was initially pushed by better land use through rotation (with maize), lower production costs [5,6] and by high commodity prices in the mid-1990s. Soybean production came together with glyphosate from the beginning. Pre-sowing application of the herbicide helped to clear the field from weeds (mostly Johnson grass) and cleaned the soil for the further sowing of maize, where these weeds were more difficult to eliminate. Soybean–maize rotation was a very common practice in Argentina. However successful non-GM soybean in Argentine agriculture was, the new GM varieties delivered farmers a significant improvement in the agronomic practices, what stimulated an increased, enthusiastic adoption. Operations were drastically simplified as farmers discontinued the use of complicated mixtures of expensive and more toxic herbicides and switched to a low toxicity, single chemical, friendlier to the environment and to them. Moreover, set-aside land heavily infested with noxious weeds could be brought back to production.

To all these advantages to the farmer, it was also added that the use of GTS has shown a very convenient synergy with no-till farming, which became widely used (Argentina is one of the leading countries in the implementation of low- or no-till farming) [7]. It is well known that low- and no-till farming reduce both soil erosion and emission of greenhouse gases, thereby contributing to agricultural sustainability through a better conservation of soil organic matter and reducing the impact on climate change.

Bt maize

The second important GM crop, also quickly adopted by farmers, was Bt maize (http://www.minagri.gob.ar/SAGPyA/areas/biotecnologia/50-Evaluaciones/_archivo2/00http://www.minagri.gob.ar/SAGPyA/areas/biotecnologia/50-Evaluaciones/_archivo2/000200-Eventos con evaluación favorable de la CONABIA y permiso de comercialización.php). With non-GM maize, insecticide applications were complicated because of the ‘asynchronous’ occurrence of pest attacks. Several, non-standard ‘recipes’ were used, according to pest and variable suggestions given to farmers. With Bt maize, farmers could reduce the use of not only toxic insecticides but also of toxic herbicides if rotating with GTS (see above).

Bt maize brought also very important additional benefits:

(i) better grain quality, which increased farmers’ competitiveness and a healthier product, as mycotoxin levels were consistently well below mandatory regulations [8,9];
(ii) longer sowing/harvest windows, on account of a longer stand of the plants in the field as plants were not damaged by the tunneling caused by maize borers.
(iii) this latter advantage not only increased yield but also allowed harvesting at a higher grain dry matter weight, thereby reducing drying costs and environmental contamination. Again, a significant contribution to sustainability was achieved.

The following chart (Table 1) describes the 14 events currently approved in Argentina (http://www.minagri.gob.ar/SAGPyA/areas/biotecnologia/50-Evaluaciones/_archivo2/00http://www.minagri.gob.ar/SAGPyA/areas/biotecnologia/50-Evaluaciones/_archivo2/

TABLE 1

Commercial approvals for planting, processing, food and feed

Crop	Event	Trait/s	Year
Soybean	40-3-2	HT	1996
Maize	176	IR	1998
Maize	T25	HT	1998
Cotton	MON531	IR	1998
Maize	MON810	IR	1998
Cotton	MON1445	HT	2001
Maize	Bt11	IR	2001
Maize	NK603	HT	2004
Maize	TC1507	HT, IR	2005
Maize	GA21	HT	2005
Maize	NK603 × MON810	HT, IR	2007
Maize	TC1507 × NK603	2HT, IR	2008
Cotton	MON1445 × MON531	HT, IR	2009
Maize	GA21 × Bt11	HT, IR	2009

HT: Herbicide tolerance; IR: insect resistance.

000200-Eventos con evaluación favorable de la CONABIA y permiso de comercialización.php).

Environmental benefits

The benefits that GM crops have brought to the farmers are also reflected in the significant positive effects on the environment. Nonetheless, it must be said that glyphosate does not perform miracles and when misused, it may produce undesired effects on the environment by, for example, generating herbicide resistant weeds [10–12], as will always occur with conventional crops. It should be understood that agricultural biotechnology does not escape the laws of biology and the rules of good agronomic practice.

GTS has brought many benefits to farmers and the environment. First, farmers could turn massively to no-till agriculture. This practice has spread rapidly in Latin America. Argentina is one of the leading countries in the use of no-till farming with 19 million ha cultivated under this system, almost 20% of the global area [13–15]. Conservation tillage systems offer numerous benefits such as fuel savings, reduced soil erosion, wildlife conservation and reduced release of greenhouse gases. The adoption of GTS has changed the pattern of the use of herbicides. Second, even though the number of applications and the amounts per hectare of glyphosate have increased, this did not inevitably involve a negative environmental impact [16]. Indeed, the intensification in the use of glyphosate has caused a reduction in the use of atrazine, a herbicide with high residual effects and environmentally harmful. By contrast, glyphosate has a low toxicity level, has no residual activity and is rapidly decomposed by soil microorganisms. According to the World Health Organization classification [17], glyphosate belongs to Class IV, the 'less toxic' group. A 2005 survey [16] showed that in Argentina glyphosate has completely replaced other herbicides belonging to the more toxic Classes II and III.

In addition, the adoption of insect-resistant (Bt) cotton has resulted in dramatic reductions in insecticide use. On the basis of farm survey data, it was found [18] that the technology reduced application rates of toxic chemicals by 50%.

Overall, the adoption of GM crops has made a positive contribution to the sustainability of the agricultural production. Cotton yields, for example, have increased by 30% in the case of Bt cotton and by 17% in the case of herbicide tolerant varieties [19]. Maize yields increased between 5.5% and 9% in the case of insect-resistant varieties and from 3% to 22% in the case of herbicide-tolerant hybrids, depending on the year and the region.

These yield increases have allowed for the deployment of lesser amounts of land needed for cultivation (an increasingly limiting factor worldwide) and through better conservation of soil and biodiversity [20], which is one of the major contributions of GM crop technology. In addition, no-till practices have had a major beneficial role as it helps to keep soil moisture and to improve water infiltration, what contributes to the conservation of soil structure.

Economic benefits

As regards the economic benefits, many things should be taken into consideration. There are other issues involved in a rather complex way (e.g. high commodity prices, international markets and local economic growth). For these reasons, the economic measurements have estimated that the total gross benefits derived from the adoption of GM crop technology in the 1996–2006 period were of USD 19.7 billion for GTS (1996–2006), USD 482 million for Bt maize (1998–2005) and USD 19.7 million for insect-resistant cotton (1998–2005), making a total of USD 20.2 billion [19]. In the case of soybean for the same period, the cost of re-stocking soil phosphorous consumed by the crop was estimated at USD 2.3 billion, giving a net gain of USD 17.4 billion [21].

Another important estimation is that of the farmers' profit. It has been calculated that the farmers' share of these benefits was 77% for soybean, 43% for maize and 86% for cotton [21]. Other studies [19] estimated that the farmer's income in the 1996–2006 period increased by USD 6.6 billion, and the revenues for 2006 alone were USD 1.3 billion.

Additionally, it was estimated that that the release of GTS has contributed to the creation of almost a million jobs (whole economy-wide), representing 36% of the total increase in employment over the 1996–2006 period [21].

As explained above, GM crop technology has been beneficial in more than one respect. When analysing the whole range of benefits, for the environment and for the economy, that this technological advancement has brought to Argentina, the reasons why this technology was so well received and had such a rapid adoption rate seem quite clear and straightforward.

Concluding remarks

When analysing the conditions that have determined the high rate of adoption of GM crop technology in Argentina, it can be said that it is the result of a complex combination of circumstances. As a first approximation, it is possible to identify four central issues: political support, the early implementation of an effective regulatory framework, the benefits this technology would bring to farmer's prevailing needs, and the positive economic and ecological impact of the GM crops.

The new products allowed farmers to solve important agronomic problems while providing significant and positive environmental benefits. For example, it was possible to achieve a sharp decrease in the use of insecticides in the case of Bt cotton. For GT soybean, there was a shift from toxic, classes II and III herbicides to environmentally friendlier class IV herbicides. To sum up, all these advantages have led to an overall beneficial contribution to sustainability, by the extensive use of no-till practices, and a consistent increase in yields, what allowed for less land deployment.

It was decisive that the Competent Authority rested on agriculture officers, as production concepts largely dictated the approval criteria. Regulations played also a major role, as their early implementation allowed the developers to work in an environment of certainty. Field trials and commercialisation guidelines were science-based, designed by experts with different backgrounds and experiences, who put biosafety of the product first, without jeopardising, or possibly so that they would not jeopardise, the country's exports, one of the strong sources of Argentina's domestic product.

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