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GMOs: A Good but Battered Means for Sustainable Production Intensification

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This paper expresses the views of the author, who alone is responsible for its contents. The paper does not reflect the official position of the author's employer, FAO.

Abstract
FAO promotes Sustainable Production Intensification (SPI), which consists of a technology menu for optimizing crop production per unit area, taking into consideration the range of sustainability aspects including potential and/or real social, political, economic and environmental impacts. The author suggests that Genetically Modified Organism (GMO) cropping is not only well aligned to SPI but also that this technology is a way to maximize the SPI principles. GMO crops cover about 13 percent of the world's cropped land. More than three quarters of this area is within the three countries that also lead the production and export of the major food and feed commodities: USA, Brazil and Argentina. The remaining area is spread across about 29 countries, mostly developing countries and a few industrialised countries. Four crops account for the majority of land under GMO crops: corn, soybean, cotton, and canola. About 90 percent of the soybean and 80 percent of the corn that is traded in the world market is genetically engineered. Consequently a very large part of the world population likely eats every day food that either contains GMOs or GMO derivatives or animal products derived from GMO fed animals. It has been the fastest adopted agricultural technology, rising to its current level over only twenty years. Further increases in production will mainly occur in developing and low-income countries. In the EU, a large majority of the member states have chosen to rule against GMO cultivation. It is essentially a 'marketing' strategy. Nevertheless, GMOs land on European tables daily in one way or another. The developing world and its low income countries are gradually improving their policy, institutional and administrative environments towards the adoption of modern biotech rules. The technology is simple, has been thoroughly tested and through extensive scientific research and testing has been shown to be as safe as crops bred and developed by other techniques. The advantages in terms of higher crop productivity and lower production costs are substantial and widely proven. GMOs are also substantially eco-friendly but more research and development is required to improve herbicide management. Only a small fraction of the GM achievements, and opportunities, are being widely exploited. Other tested discoveries, which offer valuable strategies to address the challenges of climate change, productivity concerns and human health plagues/malnutrition that are widespread in low income countries, are yet to be adopted on a meaningful scale. There is no credible evidence that GMOs constitute a threat to human health. International rules and regulatory frameworks exist and are acknowledged. Cultural, which at times appear to be ideological, barriers more often of the developed world, are hindering rational technological advancement and food security and adequacy. In order to feed the growing world population, heading towards 9 billion or more by 2050, there is the need to increase food production by 60-70 percent, and to double it in the developing world where the highest demographic growth will occur. A safe and sustainable technology exists that can contribute substantially towards this target and humanitarian responsibility.

Keywords: GMOs, FAO , Sustainable Production Intensification

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Introduction

"The need to feed a growing population is a constant pressure on crop production, as is coping with an increasingly degraded environment and uncertainties resulting from climate change - and the need to adapt farming systems to these."[1] In this light, FAO promotes Sustainable Production Intensification (SPI), which consists of a "menu" for optimizing crop production per unit area, taking into consideration the range of sustainability aspects including potential and/or real social, political, economic and environmental impacts. SPI is anchored around seven key principles that include: a) integrated cropping systems; b) ecosystem services in agricultural production; c) sustainable mechanization strategies and conservation agriculture; d) integrated weed management; e) integrated pest management; f) rehabilitation and management of drylands and grasslands; and g) soil health.

We suggest that Genetically Modified Organism (GMO) cropping is not only well aligned to SPI but also that this technology is a way to maximize the SPI principles. Effectively, GMO crops are predominantly grown to produce feed for livestock; the technology has the potential to enhance ecosystem services' resilience and for adaptation to the climate change imposed stresses; the coupling of conservation agriculture/no till and GMO technologies is successfully evident in many areas of the world (e.g. USA, Canada, Brazil, Argentina, etc.); the application of biotechnology to agriculture since its onset and until now is overwhelmingly meant to address weed and pest issues of crop productivity while reducing use of agro- chemicals and the related costs of production; there is growing evidence that GMO cropping, in particular when it is associated to other SPI principles (e.g. conservation agriculture), is a means to enhance soil health. Relatedly, a very recent work of the Joint Research Centre of the European Soil Data Centre[2] maps the potential threats to three categories of soil biodiversity (namely soil microorganisms, fauna and biological functions), and gives guidelines for identifying soils that are potentially at risk. According to the JRC metadata analysis, the use of genetically modified organisms in agriculture was considered as the threat with least potential, while the potential impact of climate change showed the highest uncertainty.

Unfortunately, as explained in this study, the GMO technology is practiced in large part of the developed and is advancing fast in the developing world, but at the same time it is also one which is least available to smallholders in low income countries. In contrast, this is where hunger and suffering are the highest and where this technology has the chief potential to address production and productivity issues and to become a terrific tool to combat the vagaries of climate change. Population growth will increase exponentially in the low and middle income countries. This is where SPI will need to advance speedily.

This paper is based on available knowledge, information, and current scientific evidence on GMOs. It is a snapshot of what is known as of December 2015. The objective of this paper is to review the topic and to be a "living document" that can be updated as and when important new evidence is published. It is hoped the review contributes to a greater understanding of the impact of GMO technology. The major concerns and controversies that directly or indirectly refer to the GM technology have been taken into consideration.

1. FAO

2. http://esdac.jrc.ec.europa.eu/content/potential-threats-soil-biodiversity-europe Ranking the threats to soil biodiversity is based on the knowledge of 107 soil experts from 21 countries, the study found the potential risk to soil biodiversity to be remarkably high. JRC developed normalized indices of potential risk to soil biodiversity based on assessments of the threat associated to 13 possible stressors: climate change, land use change, habitat fragmentation, intensive human exploitation, soil organic matter decline, industrial pollution, nuclear pollution, soil compaction, soil erosion, soil sealing, soil salinization, the use of GMOs in agriculture and invasive species.

Context and trends: Key facts and numbers

Genetically engineered (GE)[1] crops are currently grown in more than 180 million hectares, globally: a significant 13 percent of the overall arable lands in the world. Although the main part of GE crops are produced in only a small number of countries, these same countries are overwhelmingly important in terms of agricultural production and in ensuring global food security, and are leaders in their uptake. It is striking that 77 percent of the world Genetically Modified Organisms (GMO) cropped areas belongs to three countries only (USA, Brazil and Argentina).

Interestingly, eight countries have invested heavily in this technology to the extent that between 1/5 (South Africa) and almost 3/4 (Paraguay) of their total arable area is devoted to GE crops (Table1, Fig. 1). The bulk of the GMO area worldwide is made of only four crops: corn, soybean, cotton, and canola (Figure 2). A small remaining area (1%) is comprised of alfa-alfa, sugar beet, papaya, squash, and eggplant GE crops. A number of other GMO crops, that have been released and that might have food/feed safety regulatory boards' approvals, are actually not grown or are grown to a miniscule extent.

Table 1. GE crops' planted area and share of the arable land area (2014).

	Country	GMO area (1000 ha)	GMO area as % of arable land area (%)
1	USA	73100	47.13
2	Brazil	42200	58.12
3	Argentina	24300	57.23
4	Canada	11600	23.01
5	India	11600	0.77
6	China	3900	1.70
7	Paraguay	3900	70.75
8	Pakistan	2900	13.69
9	South Africa	2700	22.50
10	Uruguay	1600	55.69
11	Bolivia	1000	26.10
12	Philippines	800	14.43
13	Australia	500	1.02
14	Burkina Faso	500	8.33
15	Myanmar	300	2.77
16	Mexico	200	0.86
17	Colombia	100	6.31
18	Spain	100	0.66
19	Sudan	100	0.53
20	Others	100	
	Global area	181,500	13.01

Data source: Own elaboration and data from the International Service for the Acquisition of Agro-Biotech Applications (ISAAA[2]), 2014

1. In this paper the terminology related to biotechnology products such as crops that are genetically engineered (GE), genetically modified (GM), that are biotech or are understood as genetically modified organisms (GMO) is, when convenient, used interchangeably.
2. ISAAA is a non-profit international network that is co-sponsored by public and private sector entities (http://www.isaaa.org/inbrief/donors/default.asp). ISAAA is also the single-source available for comprehensive global statistics on GMO cropped area. Occasionally and for very specific countries which have more limited area under GMO crops, ISAAA statistical data has been disputed.

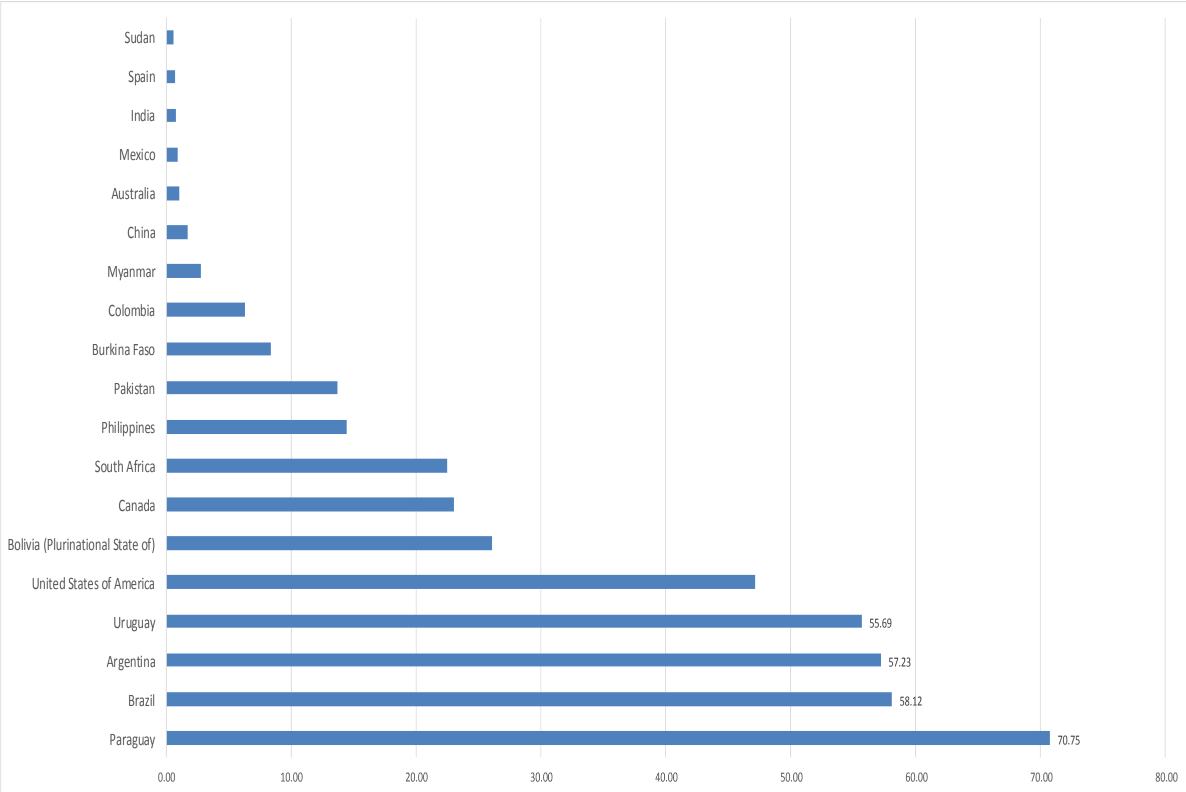

Fig. 1. GMO area as % of arable land area (2014).
Source: Own elaboration and data from the ISAAA, 2014

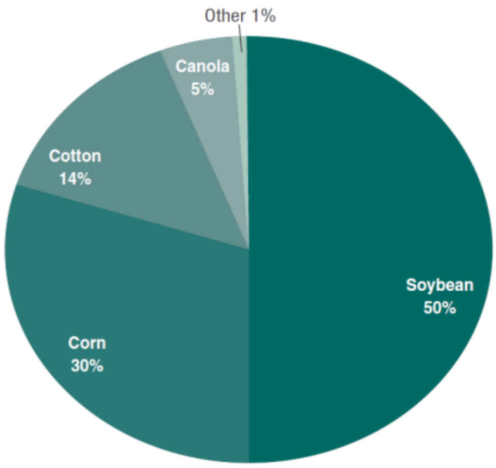

Fig. 2. Share of major GMO crops (cropped area, percent)
Source: Canadian Biotechnology Action Network based on ISAAA data, 2015 ("*Where in the world are GM crops and foods?*" 2015)

About 90 percent of the corn and virtually all the soybean produced in the USA is GE[1], and the U.S. produces 46% of the world's corn and 33% of the world's soybeans (2014). The U.S. exports of corn amounted to about 47 million tons in 2014 (13% of its production, and 36% of world

1. In 2012, U.S. GE cotton accounted for 94 percent of all cotton planted, GE soybeans accounted for 93 percent of planted soybeans, and GE corn accounted for 88 percent of planted corn.

trade) and that of soybean was equal to 48 million tons (12% of its production, and about 40% of world trade)[1]. The three champion countries – the United States, Brazil and Argentina export about 90% of the soybeans and 80% of the corn that is traded in the world market[2], which is practically all GE.

As a result, Genetically Modified (GM) corn, soybean and canola, and cottonseed oil are easily found (while not necessarily recognized) in our food system as e.g. ingredients in processed food and in animal feed[3]. Consequently a very large part of the world population likely eats every day food that is GMO-inclusive along some part of its production chain, and has done so for a long time.

Consequently, it appears that GE is the fastest adopted agricultural technology in recent history. It is also undeniable that in the countries where the technology has picked up most, it has actually been a farmer-led process and not a biotech-industry pushed initiative. Nonetheless, given the concentration in a small number of countries and the high proportion of available land already devoted to GMO crops in those countries, any further sustained advancement of the planting of biotech crops in the next future will have to occur in other developing and in low-income countries.

A significant expansion of GM crop cultivation in the EU is unlikely in the short and medium term due to the continued anti-GMO *battage*, a public opinion that is/or has been induced to be hyper-wary and ideologically motivated about biotechnology, and policy makers that are very attentive in obtaining/maintaining consensus. In effect, the European parliament has recently set free the governments of the EU member countries to legislate pro- or against GMO crop cultivation at their national levels. Nineteen EU countries on October 3rd, 2015 have decided and legislated against[4], all other EU states that have not decided by this deadline will continue to have (e.g. Spain) or may introduce[5] in the future GMO cultivations. In Europe the few 'institutional' supporters for a pragmatic and science-based position on biotech crops are – almost exclusively - among the academia[6].

1. Production and export data are sourced from the USDA database.
2. About 85 percent of the world's soybeans are processed-crushed annually into soybean meal and oil. Approximately 98 percent of the soybean meal that is crushed is further processed into animal feed with the balance used to make soy flour and proteins. Of the oil fraction, 95 percent is consumed as edible oil; the rest is used for industrial products such as fatty acids, soaps and biodiesel (http://www.soyatech.com/soy_facts.htm). Most of the corn that is traded is used for feed; smaller amounts are traded for industrial and food uses. The U.S. share of world corn exports averaged 60 percent during 2003/04-2007/08. Since then, U.S. exports have rebounded to account for about 40 percent of world corn trade. Global population increases and consumer demand for meat products will continue to support expanding feed grain exports in the long term (http://www.ers.usda.gov/topics/crops/corn/trade.aspx).
3. The overwhelming majority of GM crops is available as animal feed. As reported in A.L. Van Eenennaam's (and A.E. Young) paper "Prevalence and impacts of genetically engineered feedstuff on livestock populations", 2014 : United States animal agriculture produces over 9 billion food- producing animals annually, and more than 95% of these animals consume feed containing GE ingredients.
4. Austria, Belgium (Wallonia only), Bulgaria, Cyprus, Croatia, Denmark, France, Germany (allowing only scientific research), Greece, Italy, Latvia, Lithuania, Luxemburg, Malta, the Netherlands, Poland, United Kingdom (only Scotland, Wales, and North Ireland), Slovenia, and Hungary.
5. Actually, it will be possible to legislate in disfavor of GMO cultivation in the future but undergoing more complex procedures
6. See e.g. (in Italian): http://www.nextquotidiano.it/elena-cattaneo-ogm-fermiamo-linganno-anti-scientifico/

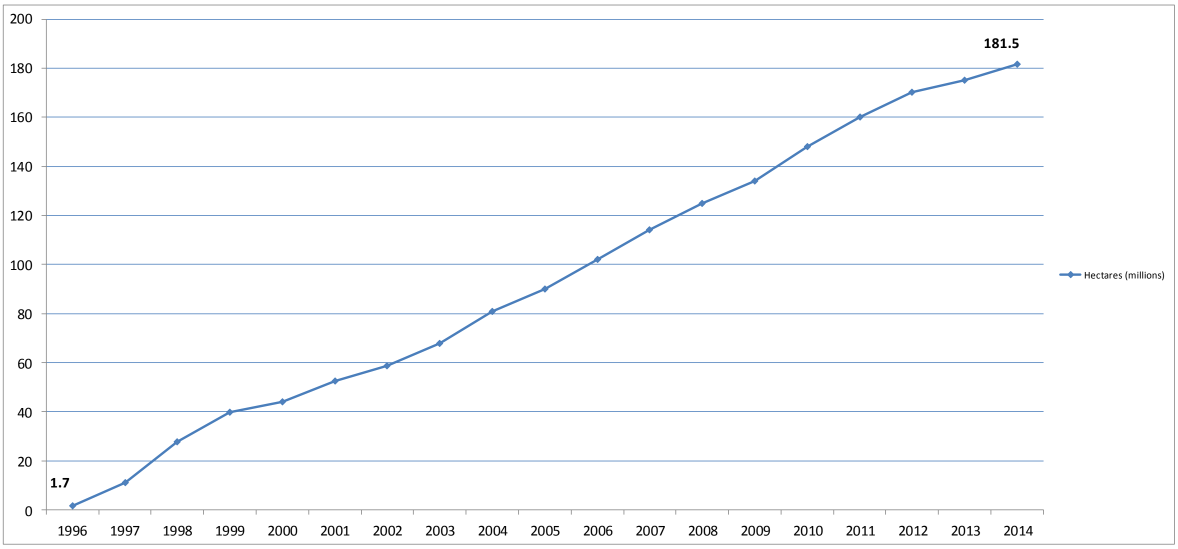

Fig. 3. Progress of Bio-tech Crops' Global Area, 1996-2014
Source: ISAAA, 2014

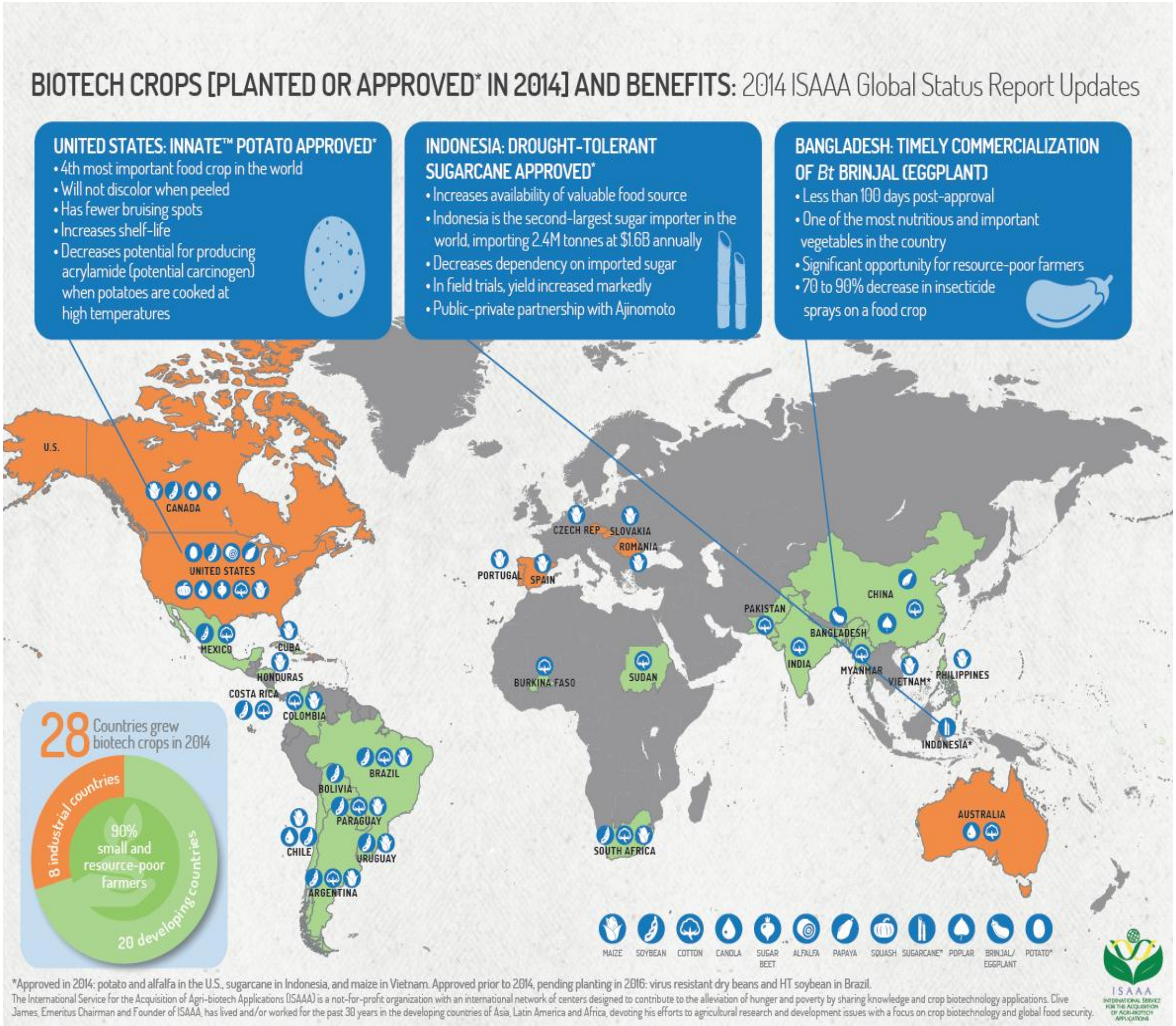

Fig. 4. Biotech Crops in the World (2014);
Source: ISAAA

The situation is quite different in the developing and low income countries that bear a technology-divide, are essentially dependent on the technology promoted by the biotech industry, and where however agriculture intensification and food security are a major concern and issue. Increasingly, new countries in Africa (e.g. Uganda, Nigeria) and Asia (e.g. Bangladesh, Indonesia) are providing regulatory frameworks, and institutional and administrative mechanisms in the application of modern biotech. In such countries producers and their associations have been instrumental in advocating for a risk proportionate and science- based policy environment.

India and China are becoming showcases in Asia because in these countries the biotech experience is one involving smallholders combined with some indigenous development of GMvarieties to address specific needs of local farmers. In India, in particular, it is also evident that GMO cropping is capable of bringing many advantages to the farmers and to the domestic economies but also that safeguard policies and crop failure risk-adverse measures are required, especially during the initial phases of technology introduction.

GMOs: What are they and what are we exactly talking about?

By an internationally acknowledged definition GMOs are: organisms that have been modified by the application of genetic engineering including the recombinant DNA technology, a technique used for altering a living organism's genetic material.

Recombinant DNA technologies are procedures used to join together DNA sequences in a cell- free system. A DNA sequence is the relative order of base pairs, whether in a fragment of DNA, a gene, a chromosome, or an entire genome.

All such definitions and terminologies are true and correct from a scientific-language viewpoint but also, and unavoidably, remain too broad in order to encompass the wide range of genetic engineering technology options. Nonetheless, they are also complex or "greyish" for those who do not have any molecular- and biology-science educational background.

In actual terms however, the vast majority if not the totality of GM crops commonly grown in the world are engineered with one, or both of just *two traits* that aim at herbicide tolerance (HT) and insect resistance (IR). There are numerous other achievements (e.g. traits for drought tolerance, virus resistance, ripening retardants, vitamin promoters, etc.) which have been scrutinized for food safety but have hither to not received usage acceptance. Hence the derived crop varieties are not commercially grown.

> Herbicide-tolerant crops are engineered to survive applications of particular herbicides, which would otherwise kill the crop plants. This means that the herbicide can be applied on an entire field, killing the weeds but leaving the GM crop standing.
> Insect-resistant crops are engineered with a gene from the bacteria *Bacillus thuringiensis* (Bt), which is toxic to some insects. GM Bt plants are engineered to synthesize Bt endotoxin in their cells, making the entire plant toxic to some above- and/ or below-ground insects.

GMOs are such because a single gene is accurately attached to existing DNA sequences to form a modified chromosome. The gene is nothing else than a feature-specific (e.g. tolerance to an herbicide) DNA sequence that in turn, codes for a bunch of amino-acids (protein components). At the end of the day, it's all about proteins.

Yet we are still striving to ensure food security to all. Today some 2.3 billion people live in countries with under 2,500 kcal, and some 0.5 billion in countries with less than 2,000 kcal, while at the other extreme some 1.9 billion are in countries consuming more than 3,000 kcal. The UN-set Sustainable Development Goal n.2 and FAO's Strategic Objective n.1 are both aligned to eradicate hunger by 2030.

It is factual to state that both nature and humankind have been genetically modifying agricultural crops for at least the last 10,000 years through conventional breeding and selection of natural variability. None of the crops we grow and eat every day is 'natural', while the natural ancestors of such crops are by and large inedible by modern standards or have agronomic deficiencies and limitations.

An interesting example of natural recombinant DNA and thus a GMO crop, is the sweet potato, which has naturally incorporated *Agrobacterium* T-DNA[1]. This has enabled the swelling of the tuber making it a useful human food crop. Conventional breeding has allowed the development of crops that produce higher yields, are pest-resistant, are drought tolerant, have more nutritional value, taste better, are more appealing etc. This has taken time and we have done a good job ensuring good and nutritious food of the right quantity is available to most of the current world population.

But the world population is projected to reach 9 billion and more people by 2050. The food that is produced today will not suffice to feed us all. FAO reports that some 70 to 80 percent higher crop yields will be needed. Doubled agricultural productivity will be especially needed in the low income countries, where the highest demographic growth will occur[2]. We do not have many years ahead before this happens. Technology other than or additional to conventional breeding is needed if we want to meet our targets.

The most common GMO technology, recombinant DNA, works by inserting genes into a plant's cells via bacteria or specialized delivery tools, but it involves some trial and error until the desired sequence is found. A new method called gene editing uses enzymes to isolate a specific bit of DNA to either delete it or replace it. This allows for more precise changes to a plant's genome. However, current GMO methods leave a trace behind—for example, a bit of the DNA from bacterium used to insert new genes. The enzymes used in gene editing don't leave such a fingerprint, so future gene edited plants will be harder, or impossible, to detect with laboratory tests.

Among the biotechnologies, GE through cis-(closely related) and trans-(less related) genes is the 'simplest' and safest available, as it causes very specific and tracked genetic variations. Random mutagenesis induced by chemicals or radiations (e.g. gamma-ray) are other techniques that cause numerous and unknown genetic variations into a crop genome. Yet although such latter techniques are permitted and have been widely used, the crops derived from these techniques do not require the regulatory scrutiny that applies to GMO crops.

1. Ghent University. 2015. Horizontal gene transfer: Sweet potato naturally 'genetically modified. http://www.sciencedaily.com/releases/2015/04/150421084204.htm
2. Every 12 years a new china is added to the world's population. That is 3000 million extra meals every day. If a meal is taken as being half a liter in volume, that is 1.5 million cubic meters of extra food a day. Placed end to end that would be 1.5 thousand kilometers a day or from the earth to the moon in a year and part way back again. If food production cannot be increased locally the transport requirements alone for such a vast amount of food will stretch economies and CO2 reduction targets.

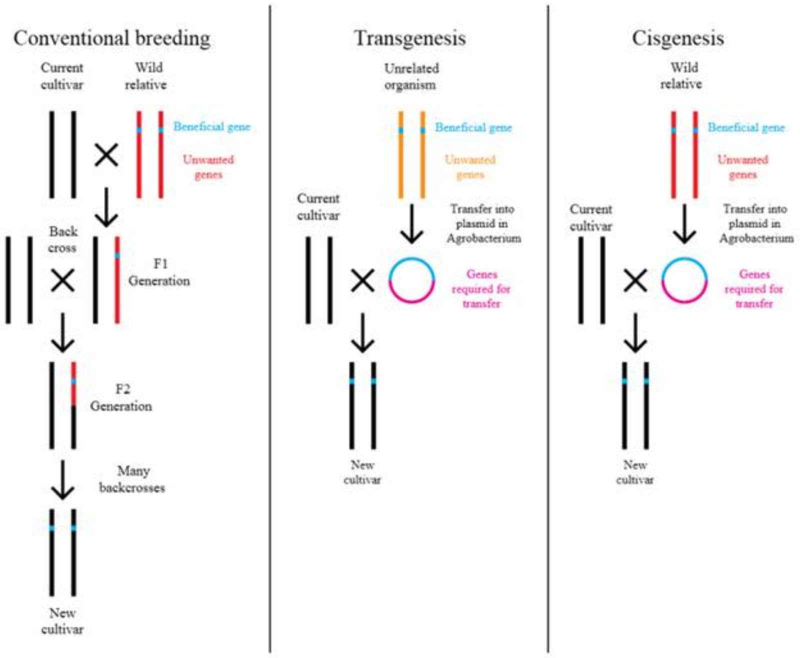

Fig. 5. Schematic comparison of conventional and genetic engineered breeding
Source: https://en.wikipedia.org/wiki/Cisgenesis

Myths and truths

"GMOs are unsafe for human food consumption, they can carry toxic agents, they can cause allergies, they can be carcinogenic."

"GMOs are enemies and killers of bio-diversity."

"GMOs are an environmental doom by creating super-weeds and super pests."

Such statements either separately or at times altogether, are continuously found on the media and at times on 'technical' publications. When those against GM technology run out of arguments, you can still find the following:

"We don't know enough." Or "There are a multitude of credible scientific studies that clearly demonstrate why GMOs should not be consumed, and more are emerging every year. There are also a number of scientists all around the world that oppose them."

The truth is that there is no credible science-based evidence that supports such statements. The truth is that all the so called credible scientific studies are flawed, have not been peer-reviewed, and/or are referred to very limited or biased contexts. The truth is that there has never been a case of allergy, or toxicity[1] that can be reasonably attributed to consumption of GMO/GMO-inclusive food, and even more so, not a single case of human death or disease caused by GMO foods has been recorded.

The biotech industry performs allergy and toxicity testing on GMO crops. Otherwise, extensive research on GMOs, co-funded by the European Commission[2] over the last two decades, provides equal assurance of the safety of these foods compared to conventional counterparts, provided these GM products have been approved by the EU and the national food safety evaluation procedures. A team of Italian scientists catalogued and analyzed

1. "With GMOs, we know the genetic information we are using, we know where it goes in the genome, and we can see if it is near an allergen or a toxin or if it is going to turn [another gene] off," says Peggy G. Lemaux, a plant biologist at the University of California, Berkeley. "That is not true when you cross widely different varieties in traditional breeding."
2. A decade of EU-funded GMO research. European Commission Directorate-General for Research Communication Unit. 2001-2010. http://ec.europa.eu/research/biosociety/pdf/a_decade_of_eu-funded_gmo_research.pdf

1783 studies about the safety and environmental impacts of GMO foods, concluding that the scientific research conducted so far has not detected any significant hazard directly connected with the use of GM crops[1]. A great deal of the studies deal with the environmental impact on the crop-level, farm- level and landscape-level. A study by Van Eennemaan argues that in animal production, weight gain for a given weight of food and reproductive performance are critical production parameters determining the economic performance of the farm. Sick animals gain less weight and do not reproduce efficiently. The fact that 95% of the 9 billion food animals raised in the US each year are fed safely with GM feed is a very strong, perhaps the strongest, evidence that GM food is entirely safe[2].

The cited Italian team found “little to no evidence” that GM crops have a negative environmental impact on their surroundings. Another study by IUCN on environmental impacts of GMO crops reports in its conclusions an earlier remark made by *Nature* (Anon, 2003): “*Amid all the fuss about GM crops, there’s been little acknowledgement that similar questions about biodiversity and gene flow must be asked about conventionally bred varieties*”.

In contrast, the emergence of ‘super weeds’ and ‘super bugs’ in GE technology - terms which should be appropriately reworded with herbicide-(one, glyphosate) resistance and insecticide- (one, Bt) resistance - has some evidence although note exclusively related to the technology itself[3]. Glyphosate-resistant weeds have now been found in 18 countries worldwide, including those with wide coverage of GMO crops. Also, but to a lesser extent, failures with some Bt- engineered crops are being reported. At the same time, herbicide and insecticide resistance is and has been a problem for farmers since cropping has become a business, regardless of whether they grow GM crops. This is inevitable. It means we need to continue to do our homework and work hard on technology innovation. A USDA reporting[4] concludes saying that “*Farmers will continue to use GE seeds as long as these seeds benefit them. However, it is not clear that first-generation GE seeds will benefit farmers indefinitely. Best management practices can help delay the evolution of resistance and sustain the efficacy of HT* (and IT) *crops.”*

There has been an increase of herbicide use in the USA over the 1996-2014 period, which corresponds to the GE technology lifetime. It is also factually acknowledged that over the same period there has been a significant decrease of insecticide use. True in both cases, numbers are numbers. However, should the increase in use of herbicide be a major environmental concern?

The fact is that there has been a usage shift from Category II and III (moderately and slightly toxic) towards Category IV (practically non-toxic) pesticides during the same time. Very recently the European Food Safety Authority has finalized the re-assessment of glyphosate[5], a chemical that is used widely. The report concludes that glyphosate is unlikely to pose a carcinogenic hazard to humans.

All the direct and indirect benefits to the environment are less considered and certainly not sufficiently reported. Effectively, modern agricultural technology including GE cropping and conservation agriculture/no till techniques (which are often coupled), all allow production of more food on less land,

1. http://www.geneticliteracyproject.org/wp -content/ uploads/ 2013/10/Nicolia-20131.pdf
2. See note 6.
3. Actually, herbicide resistance occurred even prior to GM crops and is not directly due to the technology but rather to the overuse of a single herbicide gradually selecting for resistance. I.e. not due to horizontal gene flow.
4. USDA. http://www.ers.usda.gov/media/1282246/err162.pdf
5. http://www.efsa.europa.eu/en/press/news/151112

wasting less fuel and water, and helping to prevent runoff and soil erosion.

Prejudicial positions and ideological opposition to science-based technological innovations are founded in ignorance and selfish self-indulgence potentially at the expense of the worlds most disadvantaged and vulnerable populations and are therefore ethically unacceptable. It is a fact that humankind has progressed considerably and that technology has highly contributed to its progress. It is also a fact that life expectancy has improved everywhere in the world, including during the last twenty years, and including in those countries that make high use of GE technology.

Table 2. Life expectancy rates (1990-2011) in selected countries

	Country	GMO area as % of arable land area (%)	Life expectancy, years (2011)	Life expectancy, years (1990)
1	Paraguay	70.75	74.5	68.1
2	Brazil	58.12	74.3	66.6
3	Argentina	57.23	75.8	71.7
4	Uruguay	55.69	76.6	72.6
5	United States of America	47.13	78.6	75.2
6	Bolivia	26.10	67.2	58.9
7	Canada	23.01	81.5	77.4

Source: Own elaboration and data from http://www.worldlifeexpectancy.com/

Public opinion

According to a US-based assessment of the Pew Research Centre[1], a minority of adults (37%) say that eating GM foods is generally safe, while 57% say they believe it is unsafe. And, most are skeptical about the scientific understanding of the effects of genetically modified organisms (GMOs) on health. Two-thirds (67%) of adults say scientists do not clearly understand the health effects of GM crops; 28% say scientists have a clear understanding of this. About half of the U.S. adults report that they always (25%) or sometimes (25%) look to see if products are genetically modified when they are shopping food. Some 31% say they never look for such labels and 17% say they do not often look. Fewer women (28%) than men (47%) believe eating GM foods is safe. Opinions also tend to vary by race and ethnicity with fewer blacks (24%) and Hispanics (32%) than whites (41%) saying that GM foods are safe to eat. Views about GMOs are roughly the same among both younger (ages 18 to 49) and older (50 and older) adults. Those with postgraduate degree say that GM foods are generally safe or unsafe by a margin of 57% to 38%. This is the only education group with a majority saying such foods are generally safe. Those with more knowledge about science in general are closely divided about the safety of eating GM foods (48% safe to 47% unsafe). Those with less knowledge about science are more likely to see GM foods as unsafe to eat (26% safe to 66% unsafe). There are no statistically significant differences on the safety of eating GM foods between Republicans as compared with Democrats.

What about Europe? A common platitude is that Europeans are overwhelmingly against GMOs. But when one looks at the polls, and the questions that are asked, it becomes evident that the questions are skewed in order to obtain a pre-desired result on the so called “general opinion”. This is because most of the surveys are sponsored by anti-GMO activists. Otherwise, according to Eurobarometer 2010[2] on food related risks (commissioned by the European Food Safety Authority), only 8% of Europeans spontaneously say they are worried

1. http://www.pewresearch.org/

2. http://www.efsa.europa.eu/en/riskcommunication/riskperception

about GM in food. People are more worried about: 1) chemical products, 2) food poisoning, 3) diet-related diseases, 4) obesity, 5) lack of freshness, and 6) food additives, colours and preservatives. Although there is concern about GM and biotechnology, consumers report a low level of knowledge about GM food. When a consumer has no direct experience or verifiable evidence to support concerns, he or she takes a much more cautious approach. In one recent survey, 34% of Europeans found a clear deficit of information on GMOs; as a result, many have yet to form their final opinion on the subject.

And in Africa (Cooke and Downie, 2010)? Well, the paucity of home-made science and technology in Africa (with the exception of South Africa) has paved the way to widespread skepticism over biotechnology in general. Non-African voices of two-fold origin have been loudest: the US-based biotech industries have claimed GMOs to be the panacea of all endemic issues of the continent. On the other side, well organized European NGOs have made claims about the health and environmental risks of GMOs and their implications for trade and dependence on Western corporate interests. As a result, most African governments adopted over-restrictive policies and public research in Africa has come to a halt. Currently, only three African nations produce biotech crops - South Africa, Egypt, and Burkina Faso. Only the first two grow GM food crops, and only South Africa grows them in significant quantities. Africans have yet to conduct a serious debate among themselves on the pros and cons of GM crops. Yet, encouraging signals are emerging among African scientists such as the messages delivered by Segenet Kelemu, the director general and CEO of the International Centre of Insect Physiology and Ecology's in Nairobi, Kenya, who recently (3 November 2015) at Trieste[1] urged the scientific community to rethink future agricultural scenarios by addressing biotechnology for sustainable food production.

In Asia, production and opinions vary from one country to another with regards to any health effects or benefits of GM foods. While some areas have experienced rapid growth of the GM market over the last decade, others still have yet to adopt GM crops (see Table 1). In Bangladesh, consent is growing and public research is advancing; the Philippines government supports commercial production of GM corn; Japanese are wary but the government is using an open-minded approach; China has strict rules on GM crops and public opinions on GM crops are polarized, with a great number of people holding suspicions toward GM products but in reality the GE cropped area is increasing; the other giant Asian country, India, once against is now opening its doors to GMOs and has almost 12 million hectares under GM cropping (however less than 1 percent of its total arable area). India is also home to one of the world’s strongest opponents to GMOs: Vandana Shiva. The infamous farmers’ suicides issue attributed by some activists to Bt cotton cropping in India has been disputed and is generally considered as unrelated (Gruère et al., 2008).

A factual issue is that researchers and technologists do not adequately consider in advance public opinion prior to release of a crop innovation. Respect and consideration are always due when people are to take informed decisions. Researchers and technologists must embrace such concepts and informative communication must be part and parcel of the Biotech Industry’s routine activity. While it is difficult to shift entrenched ideological or religious beliefs it is still possible to argue the case and get a buy-in on broader philosophical issues such as food security, food adequacy and alleviation of poverty and disadvantage. There is much to learn from the health industry. In effect, in the medical innovation almost anything goes. If my life and health is dependent on a GE vaccine, medicine or drug, I can still decide on ideological or

1. http://twas.org/article/redesigning-modern-agriculture

religious grounds not to take it, but it is very likely that my life-preserving philosophical considerations will eventually prevail. Quality communication becomes even more important when it is food at stake, considering that in the developed world food is available in excess both in terms of variety and quantity and people are adequately free to choose what to eat and what not to.

More work needs to be done to prove, show and persuade the rich and healthy public opinion that the vitamin-A carrying Golden Rice can be the cure to blindness for millions of children of low income developed countries; that GE drought tolerant varieties can be an important Climate Smart Agriculture means in water scarce countries; that food crop (and not weed) yields need to be higher and pests need to be defeated with more sustainable techniques in every country in the world. Technological innovations must be an option for the entire humanity, not just for some of us.

Advantages and disadvantages

A matrix is used presenting the principal pros and cons that are widely argued on GMO crops and food. This is far from being exhaustive and many other cons (and pros) can be listed and discussed. There is an enormous quantity of literature and debate that is available on the internet, which can be easily accessed. A meta-analysis (Klümper and Qaim, 2014) of the agronomic and economic impacts of GM crops was made, which provided results showing that GM technology adoption has reduced chemical pesticide use by 37%, increased crop yields by 22%, and increased farmer profits by 68%. Yield gains and pesticide reductions are larger for insect-resistant crops than for herbicide-tolerant crops. Yield and profit gains are higher in developing countries than in developed countries.

Final judgment is to be made by any reader who wants to form his/her own independent opinion.Advantages	***Comments***	**Disadvantages**	***Comments***
GM crops are more productive and have a larger yield. GM crops are an answer to feeding growing world populations.	*Wide evidence. Access to GM seed needs to improve. Biotechnology needs to be coupled with other sound and sustainable technologies (Conservation Agriculture, Climate Smart Agriculture, etc.) to obtain the highest productivity gains.*	**Ending world hunger with GM food is a false claim. World hunger is not caused by shortage of food production.**	*World production may be adequate but local production deficient. Food access must be achieved at all times. Food shortage will become an issue with a growing world population in the absence of sustainable productivity increases.*
GE can be a useful Climate Smart Agriculture tool.	*Access to drought-tolerant varieties must be made available. GMO crop growing is conveniently tied with CA/no till practice in many countries.*	**GE is a technology designed only for intensive and large scale agriculture.**	*GM technology can equally be applied to small scale cropping for specific communities but that is prevented by the cost of regulatory compliance. In Asia many countries are developing specific niche crops for isolated or disadvantaged communities. GE can be used conveniently at all scales, as per wide evidence (India, China, and Bangladesh).*
GM foods are safe, controlled and regulated.	*Food safety authorities' acknowledged protocols are applied.*	**We cannot prove that there are no risks.**	*Of course, and this is true for any technology (including conventional breeding) but not a good reason to cease*

			innovations. In all cases, studies have proven that risk is even below negligible levels (see note n. 6 and many other)
GE crops have inbuilt resistance to pests, weeds and diseases.	*Sustained work is required. R&D continues and is showing that GE technology may be the response to several hitherto unaddressed diseases (e.g. Citrus Greening).*	**An outcome of GMO crops are Super-weeds and super-pests that would need newer, stronger chemicals to destroy them.**	*Innovation will need to continue to tackle these and other issues. The fact that GM global crop adoption levels have not fallen in recent years suggests that farmers must be continuing to derive important benefits from using the technology.*
Capable of thriving in regions with poor soil or adverse climates.	*R&D is making major achievements in this direction; barriers to wide access need to be removed.*	**The GM technology companies patent their crops and also engineer crops so that harvested grain germs are incapable of developing. Farmers, who cannot save seeds for replanting have to buy expensive seeds every time.**	*True, but access to High-Yielding-Varieties including GM seeds must improve in order to improve productivity and income of smallholders. Even non GM seeds can and are patented. Farmers' preference is to buy seed rather than plant save seed because the hybrid vigour increases yield more than compensating for the increased cost.*
More environment friendly as they require less pesticides, and are more efficient land and water users.	*Sustained work is required.*	**GM food will end food and agro-diversity. GM crops could cross-pollinate with nearby non-GM plants and create ecological problems. Too much focus on GMOs, why not focus more on improving organic agricultural practices.**	*GM crops are very limited and mainly regard few crops. Improved technology and crop management techniques are available to avoid 'contamination'. Focus needs to be on all sustainable and profitable (for the farmers) practices.*
An option to eliminate allergy-causing properties in some foods.	*R&D is making major achievements in this direction; barriers to wide access need to be removed.*	**Genes don't work in isolation, changing a few could change the whole picture, with unpredictable and different effects under different circumstances.**	*Twenty years of experience has shown no evidence of undesired effects that are unmatched.*
Foods are more resistant and stay ripe for longer so they can be shipped long distances or kept on shop shelves for longer periods.	*R&D is making major achievements in this direction; barriers to wide access need to be removed.*	**GE is about meddling with nature.**	*Humankind has been doing this since its existence. Where we stand today is the result of the progress made. Nature also meddles with nature. Plant genome is highly plastic and wide scale mutation and gene movement is the norm.*
Offer more nutritional value and better flavor.	*R&D is making major achievements in this direction; barriers to wide access need to be removed. (e.g. for Golden Rice, rich of Vitamin A)*	**Some people have moral or religious objections.**	*Transparency is undisputable; people must choose what they grow and what they eat.*

At the end of the day, all depends on one's perspective and values.

"All of creation is an expression of the divine. At its most basic level, that is what the GMO question is about: the destruction of life, but also the commodification of life. The only sustainable farming is farming of rotation and seasonality. It's as perennial as the ocean, forest, and prairie, because it is doing everything that those ecosystems

are doing in terms of nutrient cycling." Vandana Shiva[1] (Physicist, Environmental activist).

"We need more investments in agriculture and we must stop looking at agriculture as a donkey's profession. We need sophisticated scientific technology to boost our production. There is no evidence to indicate that biotechnology is dangerous. After all, Mother Nature has been doing this kind of thing for God knows how long. Mother Nature has crossed species barriers, and sometimes nature crosses barriers between genera. Take the case of wheat."

Norman Borlaug[2] (Father of the Green Revolution, Noble Peace Prize, 1970).

The regulatory frameworks

The international principles for risk assessment of GMOs are set out by the Codex Alimentarius[3]. As of today 180 countries are members of the Codex Alimentarius.

The *Cartagena Protocol on Biosafety to the Convention on Biological Diversity*[4] is an international treaty governing the movements of living modified organisms (LMOs) resulting from modern biotechnology from one country to another. It was adopted on 29th of January 2000 as a supplementary agreement to the Convention on Biological Diversity and entered into force on 11th of September 2003. The protocol establishes an advance informed agreement (AIA) procedure for ensuring that countries are provided with the information necessary to make informed decisions before agreeing to the import of such organisms into their territory. The Protocol contains reference to a precautionary approach and reaffirms the precaution language in Principle 15 of the Rio Declaration on Environment and Development.

At the WTO[5] level, the basic rules of the General Agreement on Tariffs and Trade (GATT) apply also to GM products, including the discipline of the Sanitary and Phytosanitary Measures (SPS agreement)[6]. These rules are, *inter alia*, that the importing country cannot give to a product of a particular supplier, if from a WTO member country, less favorable treatment than it affords to the "like" product from other suppliers. The imported product should also not be treated, once on the market, in a way that is more onerous than a domestic "like" product. GM trade matters need to be looked at in the SPS agreement, which specifically applies to regulations designed "to protect human or animal life and health from risks arising from additives, contaminants, toxins or disease-causing organisms in imports of food, beverages and feed stuffs" as well as "to prevent or limit other damage from the entry, establishment or spread of pests".

All EU countries are members of the Codex Alimentarius Commission. In 2003, the EU itself also joined, sharing competence with EU countries depending on the level of harmonization of the respective legislation. The EU is also a party of the Cartagena Protocol. The European Union (EU) has established a legal framework to ensure that the development of modern biotechnology, and more specifically of GMOs, takes place in safe conditions. The aim is to protect human and animal health and the environment by introducing a safety assessment of the highest possible standards at EU level before any GMO is placed on the market; put in place harmonized procedures for risk assessment

1. On GMO et alia check: https://www.youtube.com/watch?v=vbIQF72IDuw
2. On Norman Borlaug check: https://www.youtube.com/watch?v=m2TmEdiXTvc and: https://www.youtube.com/watch?v=SmmJ29pGba8
3. FAO
4. https://bch.cbd.int/protocol
5. The widespread commercialization of GM products dates back to 1996, two years after the establishment of the WTO. Accordingly the trade rules agreed in the Uruguay Round (1986-1994) did not specifically refer to such products.
6. https://www.wto.org/english/tratop_e/sps_e/spsagr_e.htm

and authorization of GMOs that are efficient, time- limited and transparent; ensure clear labeling of GMOs placed on the market in order to enable consumers as well as professionals (e.g. farmers, and food feed chain operators) to make an informed choice; and ensure the traceability of GMOs placed on the market. A number[1] of directives and regulations rule the GMO affairs in the EU. The European Food Safety Authority (EFSA) is in charge of EU risk assessment regarding food and feed safety. In close collaboration with national authorities and in open consultation with its stakeholders, EFSA provides independent scientific advice and clear communication on existing and emerging risks. Cultivation of GMO crops and marketing of GMO food and feed is only for authorized GE products. An EU register for GM food and feed exists. The EC Directorate-general for agriculture and rural development states that the regulations concerning the import and sale of GMOs for human and animal consumption grown outside the EU provide freedom of choice to farmers and consumers. All food (including processed food) or feed which contains greater than 0.9% of approved GMOs must be labeled. As of 2010 GMOs unapproved by the EC had been found twice and returned to their port of origin. In October 2015, the EU member states have been set free to legislate for or against GE crop cultivation[2].

The U.S. is a member of the Codex Alimentarius but not a party to the Cartagena Protocol on Biosafety. In the U.S., the rules on GE crops and food are regulated by the Food and Drugs Administration (FDA)[3], using a science-based approach. FDA works in conjunction with the U.S. Department of Agriculture (USDA) - to make sure that all new GE plant varieties pose no pest risk to other plants - and the Environmental Protection Agency (EPA) - to make sure that pesticides are safe for human and animal consumption and do not pose unreasonable risks of harm to human health or the environment. Although consultations between the GMO developer and FDA are voluntary, the developers find these instrumental to validate the assessment that they however need to make. The developer produces a safety assessment, which includes the identification of distinguishing attributes of new genetic traits, whether any new material in food made from the GE plant could be toxic or allergenic when eaten, and a comparison of the levels of nutrients in the GE plant to traditionally bred plants. FDA scientists evaluate the safety assessment and also review relevant data and information that are publicly available in published scientific literature and the agency's own records. FDA's priority is to ensure that all foods, including those derived from GE plants, are safe and otherwise in compliance with the Federal Food, Drug, and Cosmetic Act and applicable regulations. Food manufacturers may indicate through voluntary labeling whether foods have or have not been developed through genetic engineering, provided that such labeling is truthful and not misleading. Following consumers' petitions that are requesting the agency to reconsider its position on labeling, FDA is reviewing such requests. Compared to other countries, regulation of GMOs in the US is relatively favorable to their development. GMOs are an economically important component of the biotechnology industry, which now plays a significant role in the US economy.

Brazil introduced in 2005 a comprehensive GMO regulatory system[4]. The law also created the Internal Biosafety

1. GMO legislation. European Communication. http://ec.europa.eu/food/plant/gmo/legislation/index_en.htm
2. See also page 4 of this paper.
3. http://www.fda.gov/downloads/ForConsumers/ConsumerUpdates/UCM352193.pdf

4. Law 11105 / 2005 (Brazilian Biosafety Law).

Committees (CIBio), which act as managers and supervisors of any activity with GMOs within institutions that develop any work in modern biotechnology (research, development, innovation or production). On a higher level the law established the responsibilities for supervision of uncontrolled activities with GMOs and registration of new products, making the Ministry of Agriculture and Livestock (MAPA), the National Agency for Sanitary Surveillance (ANVISA) and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) responsible for these activities. The law also created at the top level the National Biosafety Council (CNBS), which analyses the eventual socioeconomic impacts of GMOs, and may revoke a formal decision to commercially release a new biotechnology product following its risk assessment.

In Argentina the process to approve the trial of a new GM crop and its eventual commercialization has remained basically the same since 1991. All applications are submitted to the Ministry of Agriculture, as the Minister of Agriculture is the Competent Authority on the matter. The applications are analyzed and assessed on a case-by-case basis by the Ministry and its regulatory and advisory bodies and by other areas of the government. The early regulations for the biosafety assessment of GM crops in Argentina were similar to those of the European Union and the United States. Subsequently, Argentina modified the regulations based on new scientific knowledge and developments and its own understanding of biotechnology and biosafety. These biosafety guidelines were ‘put under test’ in the European Union’s moratorium. Argentina, together with Canada and the United States, presented a demand before the World Trade Organization (WTO), because of delays in the imports following the EU moratorium. The WTO ruled in favor of Argentina, Canada and the United States, because the products were considered to have followed all the environmental and food safety standards.

As is the case for the U.S., Brazil and Argentina are parties to the Codex Alimentarius but not of the Cartagena Protocol.

The two principal GMO regulatory systems– the U.S one and that of the EU – differ substantially because of the diverse underlying philosophical grounds from which they originate. The US-system seems to be based on a “why not” principle, while the EU approach appears to put more weight on the “why”. Is it about optimism against pessimism? And, is it only about beliefs and culture, or has it to do also with business? Actually, one (the US) is the largest producer; the other (the EU) has the largest market. If the loudest advocacy voice is expressed by the producers, the first approach will tend to prevail in the policy. Otherwise, when the concern is what buyers and food consumers will want to pay for; in this case the strongest lobbies will be those who need to ensure their lead positions in the marketplace; politicians and policies will need to conform.

Business value

According to an assessment on global income and production impact (Brookes and Barfoot, 2015) on GE cropping, the annual net economic benefits at the farm level amount to US$20.5 billion (2013). This is equivalent to having added 5.5% to the value of global production of the four main crops of soybeans, corn, canola and cotton. Since 1996, farm incomes have increased by US$133.4 billion. The cost to farmers for accessing GM technology, across the 4 main crops, in 2013, was equal to 25% of the total value of technology gains. This is defined as the farm income gains referred to above plus the cost of the technology payable to the seed supply chain (US$5.1 billion, annually). Note that the cost of the technology accrues to the seed supply chain including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the GM technology providers. The analysis shows that about 70% of the gains have derived from yield and production gains with the remaining 30% coming from cost savings. At the country level, US farmers have been the largest beneficiaries of higher incomes (obviously, given that the USA is ranked 1st worldwide in terms of GMO cropped area; see Table1), realizing over $58.4 billion in extra income between 1996 and 2013. During the same period important farm income benefits ($31.1 billion) have occurred in South America (Argentina, Bolivia, Brazil, Colombia, Paraguay and Uruguay), while GM cotton has been responsible for a $32.9 billion additional income for cotton farmers in China and India. Pragmatically, should adequate investment be made and biotechnology be encouraged to advance fast in the low-income countries the impact on farmers' livelihoods would also be similar to what occurs where it is already widely adopted.

On the other side, and according to a Research Institute for Organic Farming (FiBL) and IFOAM 2015 reporting[1], global sales of organic food and drinks reached US$72 billion in

2013. At farmers level though, profitability is possible only if farmers are able to fetch premium prices for their produce. The financial performance of organic and conventional agriculture has been looked at by conducting a meta-analysis of a global dataset spanning 55 crops grown on five continents (Crowder and Reganold, 2015). When organic premiums were not applied, benefit/cost ratios (−8 to −7%) and net present values (−27 to −23%) of organic agriculture were significantly lower than conventional agriculture. However, when premiums were applied, organic agriculture was significantly more profitable (22–35%) and had higher benefit/cost ratios (20–24%) than conventional agriculture.

Concluding remarks

We are all citizens of the world with equal rights. The right to food is a primary right for existence. We have the moral duty to feed ourselves sustainably and to set the same conditions for the future of humankind. There is a need for increased agricultural productivity on the same or even a likely decreasing area of cropped land, and for a growing number of people to feed.

All existing, suitable and sustainable technologies will need to be used to sustain the right to food. In short, all technologies that are aligned to the principles of Sustainable Production Intensification - and the GMO technology has full rights to belong to the "club" – must be made available to all world agricultural producers.

Evidence is there to show that biotechnology and GE can effectively contribute to this goal. Twenty and more years of experience and continued R&D is making biotechnology even more efficient and reaffirming its safety. Regulatory frameworks to guarantee food safety and ensure technology efficiency are also improving and are becoming increasingly more attentive of the public interest but will need to become more risk proportionate to facilitate development of small scale crops to address specific needs of the poorest, most vulnerable and most disadvantaged populations. Farmers in various countries are showing increased preference for certified seeds and innovative high-yielding varieties. Extensive use of biotechnology in seed development is resulting in new and high-end varieties, which is driving the global seed market.

Only a small fraction of GM capabilities are being widely exploited. Other tested discoveries, which are extremely valuable for addressing climate change challenges, productivity concerns and human health plagues/malnutrition that

1. https://www.fibl.org/fileadmin/documents/shop/1663-organic-world-2015.pdf

are widespread in low income countries, are still to be adopted on a meaningful scale. The production constraints of the developed world agriculture are being addressed. Those applicable to the low income countries are being inhibited and kept on the shelves.

The US and the Americas are leading the biotech adoption process. Major developing countries in Asia are advancing fast. Europe is resisting: the EU is trying to keep an open mind but most of its member countries are enacting barrier policies against GM cultivation. African countries are being left behind.

For enhanced investment towards advancing sustainable agriculture intensification - including GE - national and international public sectors in the developing world will have to play a key role, much of it by accessing proprietary tools and products from the private sector. Incentives and mechanisms by which such public-private partnerships can be realized need to be analyzed and put in place.

The global market is one. GM food and food ingredients are on the table of the developed and to a large extent of the developing world, every day and during every meal.

Food security for all though is still far from being achieved and its prospects may be worsening with a growing world population. Access to food and to all the available food ensuring technologies is the challenge.

Norman Borlaug was awarded the Nobel Peace Prize because he was able through his powerful vision and work to save the lives of 1 billion people, by enabling them to achieve food security. He believed in humankind progress as a result of applying good man-made technology. Let us continue in this legacy.

Let us work for a world where privileges are for all, where right to food is for all, and where choices including food choices are free. Let us work for a world that is not skewed by the interest of few a world that is free from ideological bias, paternalism and obscurantism.

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