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# Gene Revolution in Agriculture: 20 Years of Controversy

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Additional information is available at the end of the chapter

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## Abstract

In the spirit of the general debate over genetically modified (GM) food which is not slowing down, we wanted to answer some questions, such as: Is Gene Revolution an answer to world hunger? Do GM crops with more complex transformation contribute to the enrichment of multinationals? Why U.S. increases food aids? To this end, we firstly describe the diffusion of GM crops around the world during the previous 20 years. Starting from 1996, we present global progress with adoption of biotech crops, its distribution in developed and developing countries, global area by trait, adoption rate and global value of biotech crops. The findings reveal 10 countries, four crops, and two traits domination. The findings of this study clarify the failure of transgenic technology to eradicate hunger. In addition, the results have shown statistically significant correlation between stacked trait and global market value of biotech crops as well as between raising production of biotech crops in U.S. and an increase in U.S. food aid through World Food Program (WFP).

**Keywords:** gene revolution, famine, stacked traits, global market value, U.S. food aid

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## 1. Introduction

Although a significant amount of food, which is obtained from genetically modified (GM) plants, is involved in a food chain, public debate on the issue is not slowing down. There is a large expert disagreement about environmental and health effect as well as about socio-economic implications [1–4].

The consumer willingness to use and pay GM products varies among the nations [5–8]. From the very beginning, the U.S. supported biotechnology industry. The same policy that considers

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GM and conventional foods substantially equivalent carried out all administrations, from R. Reagan to B. Obama administration. At present, the total U.S. revenues from GM systems reached at least \$350 billion, the equivalent of approximately 2.5% of GDP [9]. Directly or indirectly numerous international organizations have contributed to the spread of GM products [10]. Among them, the most important are World Bank (WB), World Trade Organization (WTO), Consultative Group on International Agricultural Research (CGIAR), Food and Agriculture Organization (FAO), various international foundations, research centers, and universities. The WTO's Agreement on trade-related intellectual property rights (TRIPS) negotiated at the end of the Uruguay Round obliges member states to patenting biotech inventions (products and processes) and plant varieties and for the first time provides a legal means for the protection of intellectual property rights. Patent protection in this field gives the corporations unprecedented control over research and development as well as over whole food chain [11]. This strongly accelerated already started transformation process of the commercial seed industry from a sector composed primarily of family-owned small firms to a small number corporate domination [12]. After many acquisitions and joint ventures formation, the top three seed firms currently control 85% of transgenic corn patent in the U.S. [13]. Global recession has contributed to the further strengthening of the monopoly power of the biggest biotech companies [14]. Because overall industry data are not shared publicly, *Farm Journal* magazine has reported market shares by interviewing consultants, industry executives, and other sources to assemble the data [15]. According to this source in 2014, DuPont, Pioneer, and Monsanto dominate, accounting for 70% of the corn seed business and 60% of the soybean seed business.

While majority of farmers worldwide still rely on saving their own seeds, the prevalence of this practice, especially in developed countries, is declining rapidly [16]. In the leading GMOs country, the U.S., the rate of saving soybean seed fell to 10% in 2001 from 63% in 1960 [17], while the rate of saving corn seed fell to less than 5% [18]. Ignoring the interests of the poor countries can be observed from the fact that multinational corporations from North America and Europe take advantage of natural wealth located mainly in the Global South [10, 19]. The best example is maybe the neem tree, *Azadirachta indica*, which has religious and cultural significance throughout India. U.S. Patent Office issued Patent No. 5,124,349 to W.R. Grace & Co. on the particular derivative of the neem tree. Long before any official discovery, farmers in India had been using a neem, among many other purposes, as a powerful insecticide that is not harmful to humans [20].

## 2. Research methodology

In the spirit of the general debate, which is not slowing down in this chapter, we wanted to answer some questions, such as Is Gene Revolution an answer to world hunger? Do GM crops with more complex transformation contribute to the enrichment of multinationals? Why U.S. increases food aids? To this end, we have set up the following research hypotheses:

1. GM food has failed to feed the hungry.

2. There is a statistically significant correlation between stacked trait and global market value of biotech crops.
3. There is a correlation between raising production of biotech crops in the U.S. and an increase in the U.S. food aid through World Food Program (WFP).

For the purpose of general understanding of the issue at the beginning, we present global progress with adoption of biotech crops, its distribution in developed and developing countries, global area by trait, adoption rate, and global value of biotech crops. The first hypothesis “GM food has failed to feed the hungry” we set because agribusiness segment has often promoted transgenic technology as the next hunger-quenching Green revolution. “There is a statistically significant correlation between stacked trait and global market value of biotech crops” hypothesis has been settled because the multinationals claim that this complex transformation can allow farmers to address multiple old problems with two or more traits in the same seed and are more effective at meeting the needs of farmers and consumers than the traditional, mono-trait seed varieties [21]. Finally, our last hypothesis “There is a correlation between raising production of biotech crops in the U.S. and an increase in the U.S. food aid through WFP” was tested due to the controversy over the food aid. Excluding the many benefits of emergency humanitarian aid, recent finding shows that an increase in U.S. food aid increases the incidence of armed civil conflict in recipient countries by prolonging existing conflicts [22]. In addition to this aspect, a disagreement over the food aid in terms of GM food arose in 2000s when several African countries and countries in transition (such as Serbia and Montenegro) refused to accept U.S. aid due to GM ingredients presence. “A fiery” debate continues via WTO Doha Round in 2003 and 2004, when the other countries have put pressure on the U.S., as the principal donor country, to move away from in-kind food aid. The great power of lobby groups in America could be visible due to the U.S. Congress rejection of Bush administration proposal that one-quarter of U.S. food aid should be cash-based [11]. The principal reason why the U.S. continues to insist on giving its food aid in-kind may be the inability to find export market for its GM maize [23].

Data required for the analysis were collected from relevant sources: ISAAA, FAO, USDA, Earth Policy Institute. The arithmetic means of the confidence interval as a measure of variability in the descriptive statistics have been used. The method of parametric statistics (*t* test, ANOVA) was applied in processing the results, while Pearson's correlation coefficient and simple linear regression were used as a measure of association. To detect trends in the variables considered, the collected data were compared by linear regression analysis using the factor time as independent variable. Data were analyzed using Microsoft Excel and R Studio software.

### **3. Global diffusion**

#### **3.1. International diffusion of biotech crops**

In the period 1996–2015, up to approximately 18 million farmers grew biotech crops annually. Global biotech hectares increased more than 100-fold, from 1.7 million hectares in 1996 to

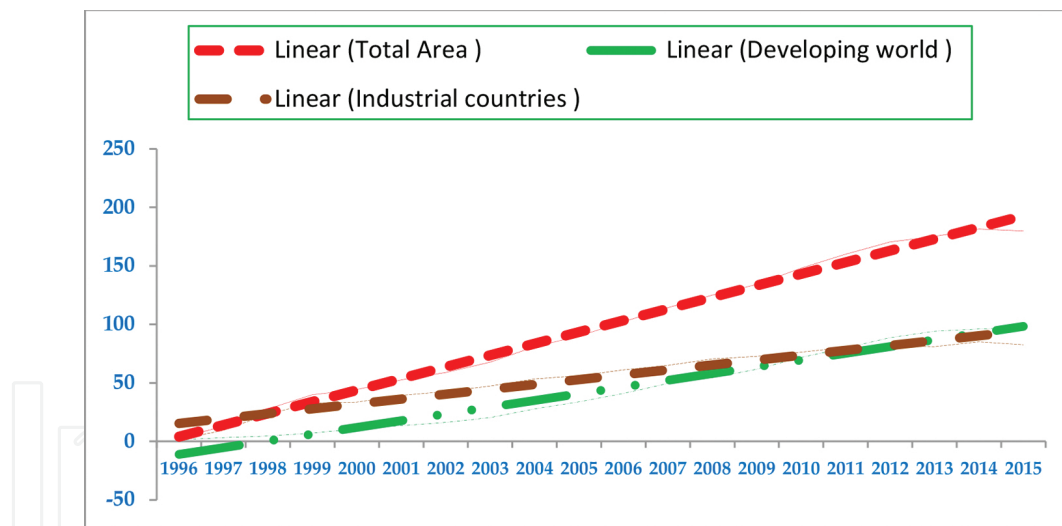
179.7 million hectares in 2015. In other words, GM crops are grown on approximately 3.7% of the world's total agricultural land and 13% of arable land and by <1% of the world's farming population [24]. In the 19 years period 1996–2014, the growth rate of area under GM was continually growing. Total crop plantings were decreased for the first time in 2015 comparing with 2014 (-1%). A clear linear trend of the total biotech hectarage growth can be expressed by equation:

$$y = 9.919x - 5.781 (R^2 = 0.993) \quad (1)$$

As represented in **Figure 1**, linear trend of GM crops diffusion is obvious in both developing and developed countries. Linear trend equation for developing and developed countries, respectively, is as follows:

$$y = 5.749x - 16.79 (R^2 = 0.969) \quad (2)$$

$$y = 4.161x + 11.07 (R^2 = 0.946) \quad (3)$$

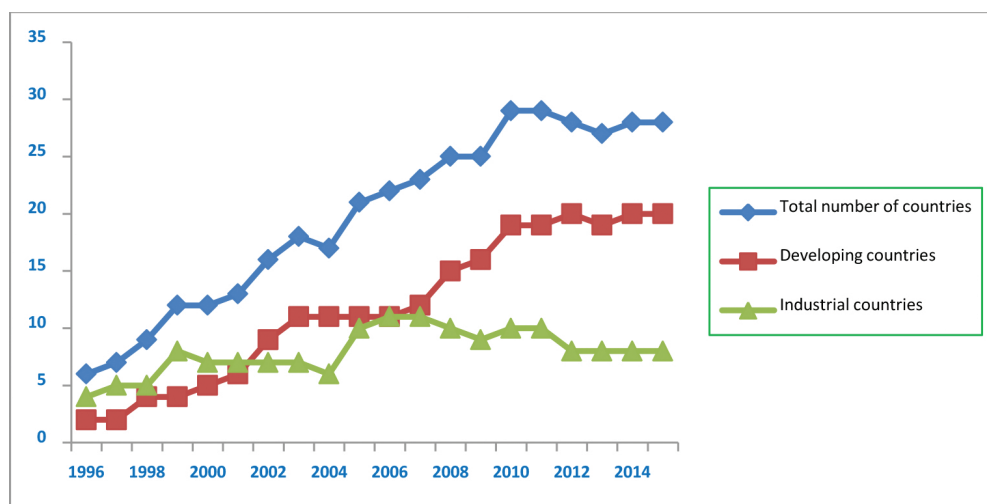


**Figure 1.** Total area under GM, distribution in developing and developed countries (million hectares). Source: Author's calculations based on data from James (1996–2015).

For the first time in 2012, developing countries planted more biotech crops than industrial countries, 51.2 and 48.8%, respectively. Higher participation of developing countries was also observed in subsequent years. Latin American, Asian, and African farmers collectively grew 53.6% of the global biotech hectares in 2013, 52.9% in 2014, and 54% in 2015.

The number of producer countries also grew by time, starting from 6 in 1996 to 28 in 2015 (**Figure 2**). The first countries that engaged themselves in the transgenic production were U.S.,

China, Argentina, Canada, Australia, and Mexico. In 1998, South Africa, Spain, and France grew transgenic crops for the first time. Portugal, Rumania, and Ukraine joined them in 1999 and Bulgaria, Uruguay, Indonesia, and Germany in 2000. India planted GM crops for the first time in 2002. In the same year, Colombia and Honduras started their production. Two countries, Brazil and the Philippines, approved planting of GM crops in 2003. In 2004, for the first time, Paraguay reported its cultivation. New producing countries become Iran and Czech Republic in 2005; Slovakia in 2006; Chile and Poland in 2007; Burkina Faso, Egypt, and Bolivia in 2008; Costa Rica joined them in 2009; Pakistan, Myanmar, and Sweden in 2010; Sudan and Cuba in 2012; Bangladesh in 2014; Vietnam in 2015. From Graph 2, it can be seen a significant increase in the producing countries in numbers. For example, the number of developing countries increases from 2 in 1996 to 20 in 2015 [21, 25–43]. It is very important to stress that total number of producing countries has not increased since 2010. This is an indication of problems in the geographical diffusion of GMOs.



**Figure 2.** Producing countries developing and developed. Author's calculations based on data [21, 25–43].

From the very beginning, U.S. is absolute leader in the production, but U.S. involvement has decreased with the inclusion of the other countries. For example, U.S. accounted for 64% in the total area under GM in 1997, while their share in 2015 was 39.4%. Brazil, the second largest producer, started relatively late with the production but at present accounts for 24.6% in the total areas. Argentina, the third biggest producer, participates in the total acreage of 13.6%. India and Canada areas reached 6.4 and 6.1% of global hectareage, respectively. China share in the total area is reduced significantly, from 16% in 1997 to 2% in 2015. Australia produces GM on just 0.7 million hectares (0.4% of total area under GM crops), which is a just slight increase from 1997 (0.1 million hectares). In 2015, there were 28 countries that grew GM crops, but in reality, a large majority of the area planted to GM crops still remains in just a few countries. Top 10 countries accounted for 98% of the total global GM hectareage. The list of countries that grew GM crops in 2015 includes Bangladesh, which grew as little as 25 hectares of GM crops in 2015, and Costa Rica, which grew 38 hectares in 2014 [21, 25–43]. After the initial years of high growth rates, the global growth of GM crops is, in fact, slowing down, as the amount of

land under GM crops in the few countries that are large-scale adopters has become saturated [24]. Annual global growth rates were between 3 and 10% in the past seven years, with the global GM area in 2013 and 2014 approximately 3% higher than the years before [43].

At first glance, this diffusion is impressive but certainly is not without problems. Despite the great support to genetically modified organisms (GMOs) in the several countries of Latin America, there is a resistance on this continent. Venezuela with over 30 million inhabitants approved a new law on December 23, 2015, that imposes one of the world's toughest regulations on GMOs. The Seed Law seeks to consolidate national food sovereignty, regulates the production of hybrid seed, rejects the production, distribution, and import of GMO seeds, and also bans transgenic seed research [44]. Similarly, in the Middle East, Iran, country which initiated its rice biotech activities in 2005 with several hundred farmers growing 4000 hectares of Bt rice on their farms and cloned the first GM animal, sheep in 2006 [45] very soon, has decided to drop the commercialization of GMOs. Currently, government is preparing new law to facilitate GMO production. At the same, time the resistance of certain groups strengthens [46].

Apart from Russia where situation is more than clear and where the food safety regulator Rosselkhozadzor bans GMO production and import [47] and Prime Minister has described as amounting to little more than a form of biological warfare weapon [48], the biggest challenge in terms of adoption and acceptance of GMOs remains Africa and Europe. For a long time, South Africa was the only country on the continent of Africa to commercialize biotech crops. GMO proponents have expressed their pleasure because of broad geographical coverage in Africa in 2008 when Egypt as represent of North Africa and Burkina Faso from West Africa become GM producer countries [37]. Historically, important event was also the involvement of Sudan in 2012. But, all commercial production in Egypt is currently stalled due to Ministerial Decree 378 (MD378), 2012, rescinding the registration of Ajeeb-YG corn variety for its commercial use [49]. Bt cotton remains the only crop commercialized in Burkina Faso [50]. Sofitex, Burkina Faso's major cotton production association, on April 5, 2015, decided to switch its production to 100 percent conventional methods and has announced a rejection of GM cotton in the next three years due to the disappointing yields and poor quality fiber [51]. South Africa, the largest producer country in Africa, has experienced the greatest reduction—23% less for its GM maize crop hectareage in 2015 comparing to 2014. Sudan, GM cotton producer country, seized a shipment of GM soybeans reportedly imported from the U.S. [52]. Nigeria, one country being targeted for expansion, has recently submitted a written petition (more than 100 groups representing at least 5 million Nigerians) to the country's authorities in hopes of impeding GMO entrance [53].

Cultivation in the EU fell 10.4% in 2015 to only 128.103 hectares, almost all of that insect-resistant corn grown in Spain (93.7%). Share of GM corn in total corn area is just 1.3%. Commercial cultivation of GE crops is minimal in other EU producing countries: Portugal, Czech Republic, Romania, Slovakia, France, Germany, and Poland. According to USDA Foreign Agriculture Services, EU member states can be divided into three categories depending on GMOs view. The adopters include the GM producer countries as well as countries where the government and industries mostly favor biotechnology (Denmark, Estonia, Finland,

Flanders in northern Belgium, the Netherlands, and the United Kingdom). Conflicted members are those states where scientific community, farmers, and the feed industry are willing to adopt the technology, but consumers and governments, influenced by activist Green parties and NGOs, reject it (France, Germany, Poland, Southern Belgium (Wallonia), Bulgaria, Ireland, Lithuania Sweden, Germany). In the opposed member states, most stakeholders reject the technology and government generally supports organic agriculture and geographical indications (Austria, Croatia, Cyprus, Greece, Hungary, Italy, Malta, Slovenia, and Latvia) [54]. One of the leading opposed countries is Hungary which initiated a joint alliance of EU member states rejecting the use of GE crops with the objective to make the entire EU free from GM crops.

### 3.2. Four crops domination

Between 1986 and 1995, 56 GM crops were field tested around the world the majority of which were on eight crops [25]. Besides expiration that there are more than 85 potential new products in the pipeline now being field tested [43], 20 years later, only 10 crops are grown commercially (soybean, corn, cotton, canola, alfalfa, sugar beet, papaya, squash, potato, and eggplant/brinjal). There are no commercialized GM varieties of a number of key global staple crops, including wheat, rice, barley, millet, sorghum, cassava, and yam. The first generations of GM potato that resist blight were planted on 162 hectares in 2015 after FDA approval [55]. In significant quantities (about 99%), only four crops soybean, corn, cotton, and canola have been grown over the past 20 years. Principal four crops are generally used in food system as ingredients in processed food and in animal feed. Exceptions used as whole foods are some fruit and vegetables GM sweet corn, squash, papaya, eggplant/brinjal, potato which together with sugar beet and alfalfa collectively account for only 1% of global GM crop hectares. Area under all four crops, soybean, maize, cotton, and canola, depicts linear trend of growth, respectively (**Figure 3**):

$$y = 4.740x + 1.742 (R^2 = 0.986) \quad (4)$$

$$y = 3.265x - 5.836 (R^2 = 0.959) \quad (5)$$

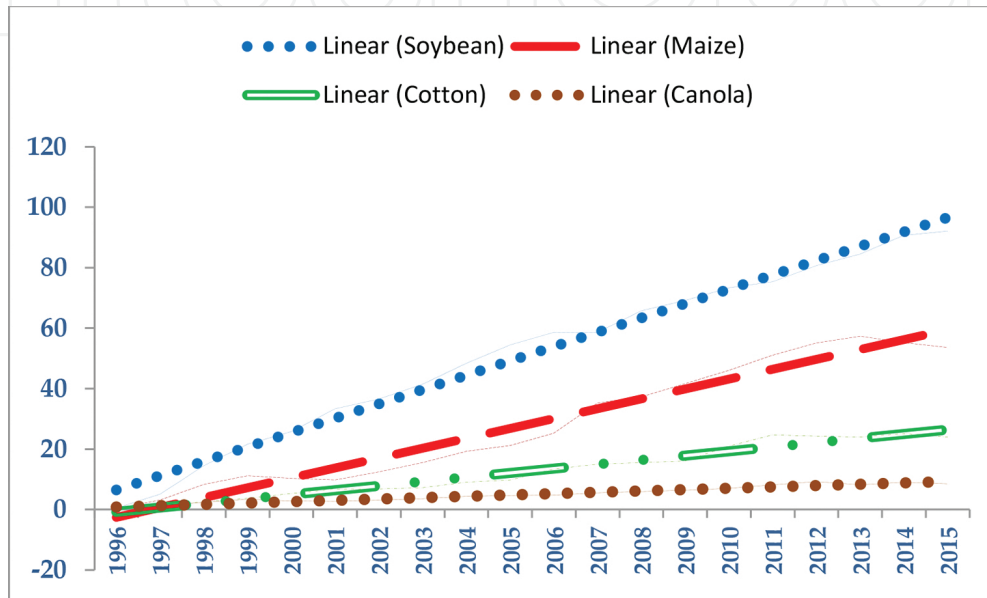
$$y = 1.43x - 2.2 (R^2 = 0.964) \quad (6)$$

$$y = 0.445x + 0.367 (R^2 = 0.954) \quad (7)$$

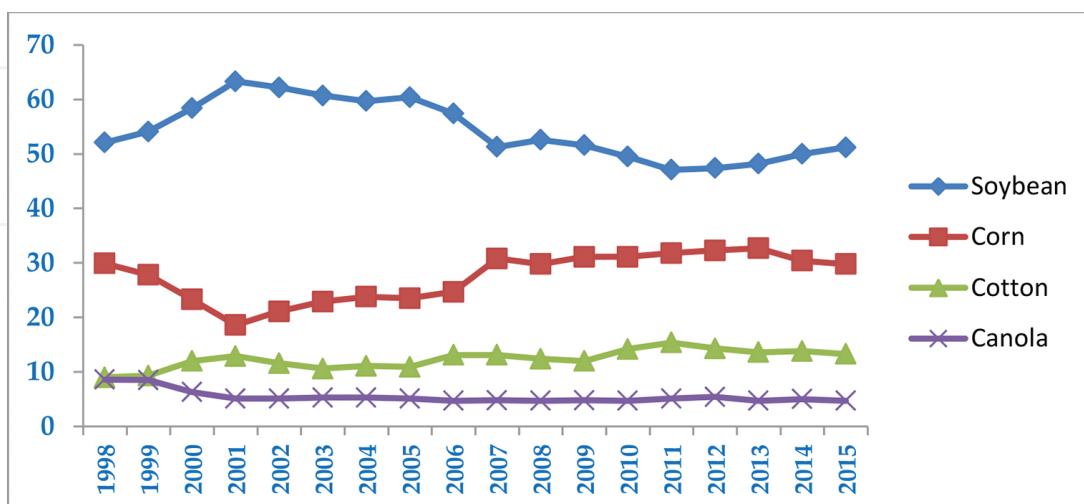
As could be seen in **Figure 4**, maximum share of soybeans in total areas was in 2001 (63.3%), and overtime, it decreases to 51.2% in 2015. Share of corn stabilized at the level of about 30% in 2015 such as it was in 1998. Share of cotton increases from 9% in 1996 to 13.3% in 2015. The biggest drop is recorded in the share of canola in the total GM area, from 8.6% in 1998 to 4.7%



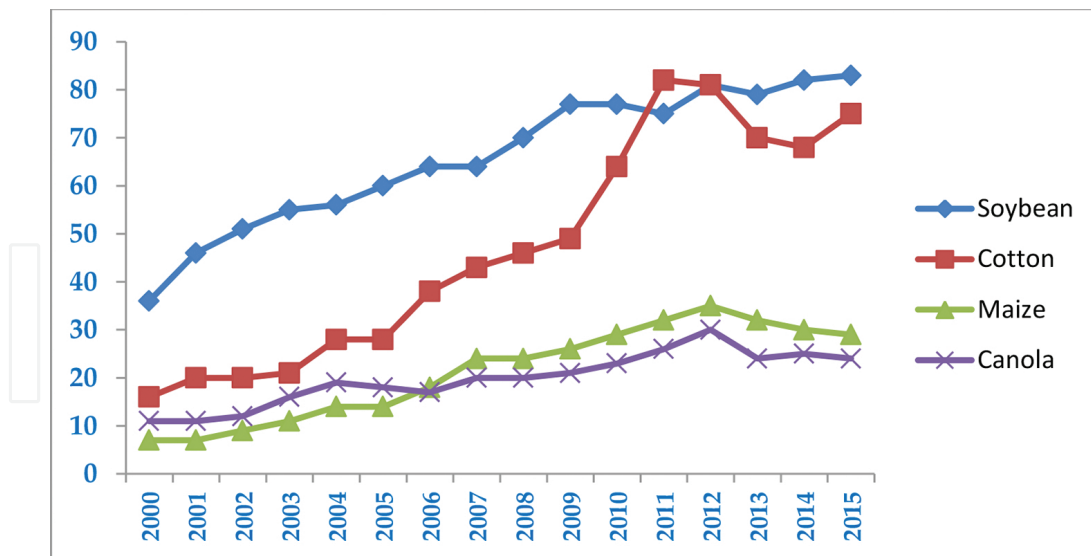
in 2015. GM sugar beet production started in 2008, but until now areas under this crop are about 0.5 million hectares, which means there is no enlargement as it was the case with previous crops. Regarding global adoption rate, it can be noticed from **Figure 5** that only soybean rate continuously was growing but with a sharp slowdown after 2009. Cotton adoption rate reached its maximum value in 2011 (82%) and then fell to 75% in 2015. Similarly, maximum corn value was 35% in 2012, after slipped to 29% in 2015. Canola global adoption rate slipped from max 30 to 24% in 2012 and 2015, respectively.



**Figure 3.** Linear growth trend for four principal GM crops (million hectares/year). Author's calculation based on Refs. [21, 25–43].



**Figure 4.** Percentage share of the most important crops in the total area under GMOs (1996–2015). Author's calculation based on Refs. [21, 25–43].



**Figure 5.** Global adoption rate of the principal GM crops (2000–2015). Author's calculation based on Refs. [21, 25–43].

One look at the slower growth of plantation area is due to the saturation of adoption rate in countries with mature GM models. For example, adoption rate of GM cotton in Australia is 99%, in Canada 95% of canola is GM, 95% cotton in India is GM, 99% cotton and 100% soybean in Argentina are GM, 95% of soybean in Paraguay is GM and over 90% of all four principal GM crops in U.S. is already GM [56]. Another view indicates that the resistance becoming stronger by opposition from consumer and environmental groups, regulatory hurdles, and, in some cases, scientific obstacles. There are opinions that the problems with diffusion of GM canola lay in the fact that canola is worst candidate crop species for practical segregation of GE and non-GE because it is inherently promiscuous [57]. Also, there are reports that state “Hundreds of thousands of farmers have died in India, after having been allegedly forced to grow GM cotton instead of traditional crops. The seeds are so expensive and demand so much more maintenance that farmers often go bankrupt and kill themselves” [58]. One might ask whether the refusal of consumers around the world to accept GM sugar is the reason for the stagnation of GM sugar beets production. Anyway, the fact is that the U.S. corn and soybeans more and more are channeled into biofuels production. For example, in the marketing year MY Aug/Sept 2015/2016, 38.8% of the total corn disappearance was ethanol share, 10.1% of total use was directed to total food, seed, and industrial use (not including ethanol), feed and residual use accounted for 38.8%, while export accounted for 12.2% of the total corn disappearance. The situation was very different in MY Aug/Sept 1995/1996: 4.6% of the total use was ethanol use, 14.4% was total food, seed, and industrial use (not including ethanol), 54.9% was dedicated to feed and residual use, and 26.1% for export [59]. In the period 1995–2015, U.S. almost doubled its corn production, from  $7.4 \times 10^9$  to  $13.6 \times 10^9$  bushels [60]. Taking into consideration problems with exports market, it is logical routing of surplus into ethanol production. Share of soybean oil used for biodiesel increased from 0.3% in 2000/2001 to 23% in 2014/2015. In the same period of time, soybean oil production has increased for just 11.7% (from  $18.4 \times 10^9$  to  $20.6 \times 10^9$  pounds). It can be observed that share of the U.S. soybean oil export in total use significantly declined from 17.6% in 2009/2010 to 10% in 2014/2015 [59]. The reasons

for these trends may lay in the efforts of the European retailers and major manufacturers (including REWE Group, Lidl, Edeke in Germany, Carrefour in France, and many of the retailers in Austria, along with Waitrose in the United Kingdom) to support the transition from GMO to non-GMO for animal production. The most prominent initiative Danube Soy was launched in 2012 as a “mainstream” vehicle for providing access to non-GMO soy for EU markets. It is undergoing rapid growth as a source of sustainable and non-GMO soy for Europe, and soya production in the Danube area (excluding Ukraine) has increased from 560,000 hectares in 2011 to 960,000 hectares in 2015 [61]. Signing this declaration means that EU wants to increase self-sufficiency in soy production. As of 2011, the EU imported 72% of its protein feed needs (majority coming from the U.S., Argentina, and Brazil – GM producing countries), so the plan is to provide at least 50% soybean needs until 2025 from non-GMO Danube region.

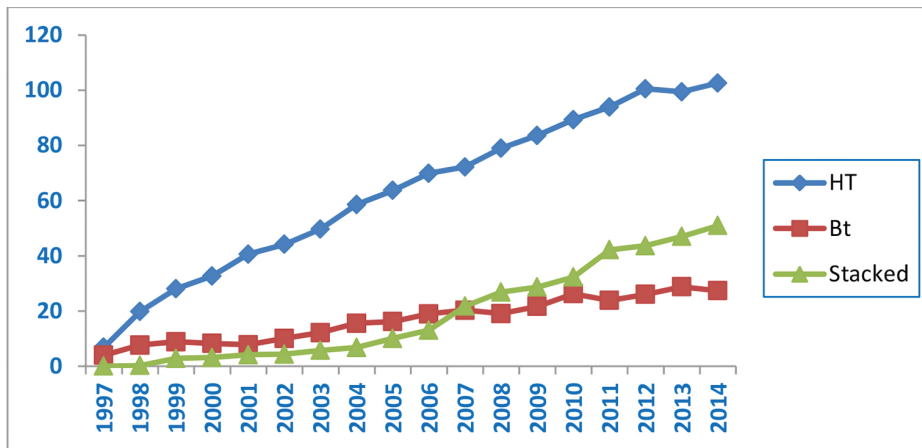


Figure 6. GM plants, by traits 1997–2014 (million hectares) [21, 26–42].

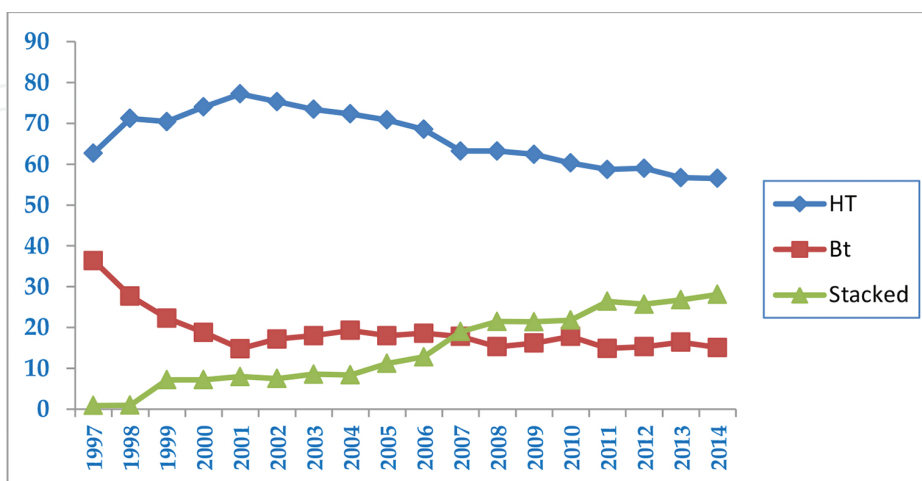


Figure 7. Percentage share of the most important traits in the total area under GMOs (1997–2014). Author's calculation based on Refs. [21, 26–42].

### 3.3. Herbicide tolerance and insect resistance domination

GMOs diffusion is uneven if we are speaking about traits also. The most widely used commercial GM traits are herbicide tolerance (HT) and insect resistance (IR). HT crops are developed to survive application of specific herbicides, which would otherwise kill the crop plants. "Roundup Ready" is the most common HT crops today. These crops have been created by Monsanto in order to tolerate applications of the company's glyphosate-based herbicide "Roundup." IR crops are engineered with a gene from the bacteria *Bacillus thuringiensis* (Bt), which is toxic to some insects. When certain insects ingest the protein produced by Bt, the function of their digestive systems is disrupted, producing slow growth and, ultimately, death. In recent years, various combinations of these two properties are used in creation of stacked plants. Gene stacking refers to the process of combining two or more genes of interest into a single plant; the combined traits resulting from this process are called stacked traits. As represented in **Figure 6**, HT plants occupied from the very beginning the most of area under GMOs. From 2007, areas under stacked crops are higher than the areas under Bt crops. In 2014, 56.4% of the GM crops worldwide were engineered to be HT, 15.1% were engineered to be Bt, and 28.1% were stacked with both HT and Bt traits (**Figure 7**). These numbers are significantly different in 2001 when 77.2% of crops were HT, 14.8% were Bt, and 8% were stacked. It is important to stress that referred data do not mean that the area under HT crops was reduced. Contrarily, it was increased. When we consider stacked and single trait crops together in 2014, 84.5% of all GM crops in the world are engineered to be tolerant to herbicides. Companies that have patent protection over GM seeds in the same time are herbicides producers. This means that multinationals in the same time sell both seeds and pesticides. HT and Bt crops account for almost all the GM crops grown commercially over the past 20 years. Other traits, virus resistance and drought tolerance, are very important for poor small-scale farmers in developing countries, collectively account for <1% of global GM crop hectares [43].

### 3.4. Global market value of biotech crops

Global market value of transgenic crops has increased overtime 165 times in terms of current prices and 115 times in terms of constant prices (2002 = 100) (**Figure 8**). Linear trend of growth in current prices can be expressed through equation:

$$y = 899.0x - 2028 (R^2 = 0.969) \quad (8)$$

The trend growth in constant prices is expressed as:

$$y = 691.3x - 940.7 (R^2 = 0.978) \quad (9)$$

We have also obtained the simple linear trend for transgenic crops global market value per hectare in current prices and polynomial trend of transgenic crops global market value per hectare in constant prices (**Figure 9**):

$$y = 2.029x + 47.20 (R2 = 0.919) \tag{10}$$

$$y = 0.050x^2 - 0.477x + 59.36 (R2 = 0.561) \tag{11}$$

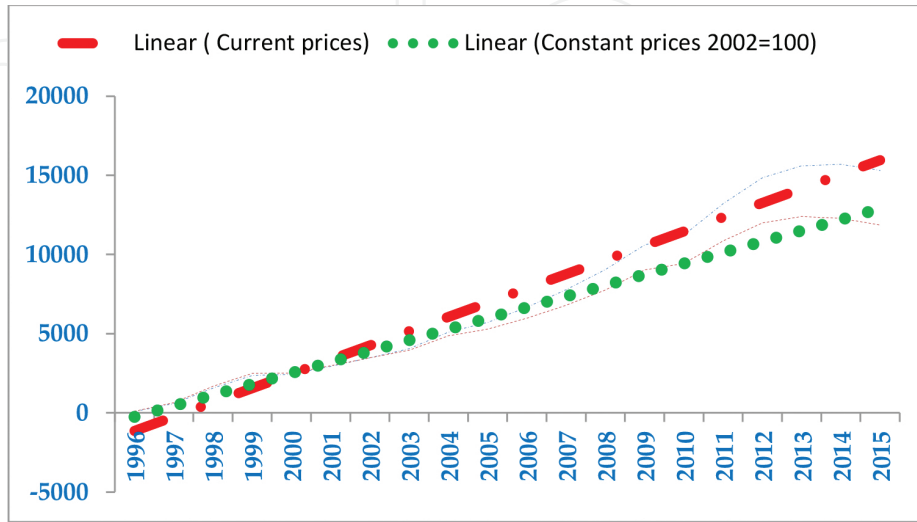


Figure 8. Global market value of biotech crops (million US\$). Authors calculation based on Refs. [21, 25–43].

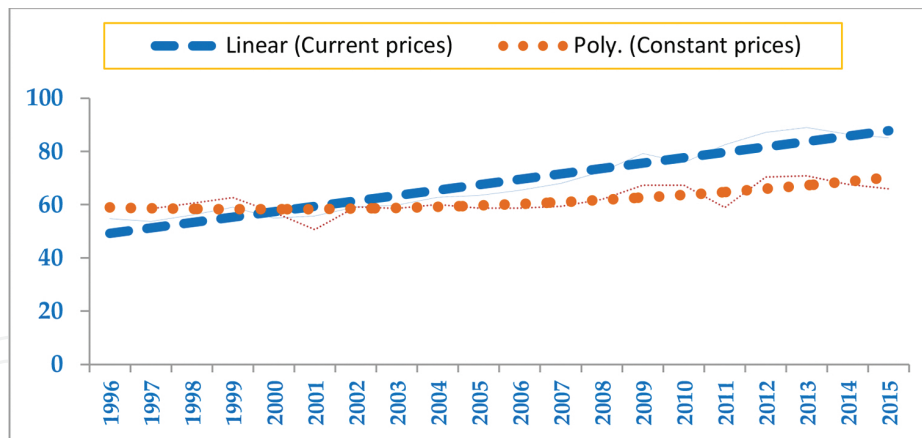
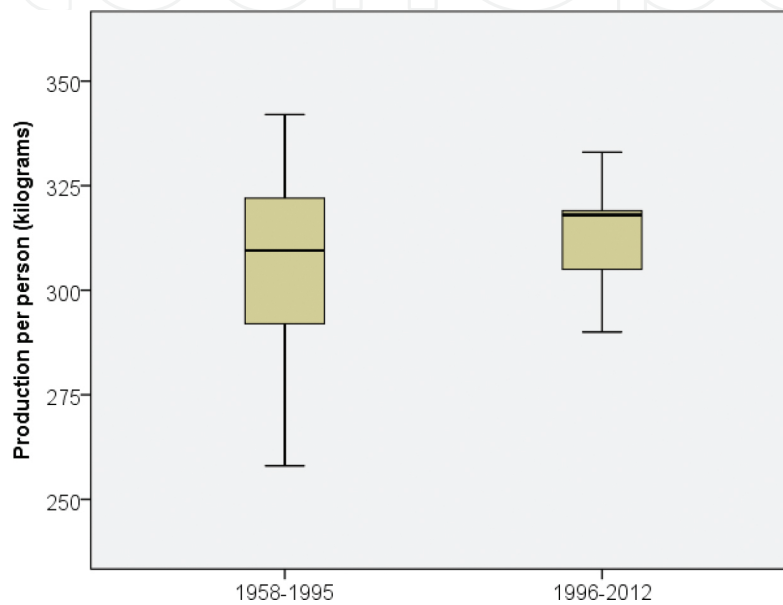


Figure 9. Transgenic crops global market value per hectare in current and constant prices. Source: Author's calculation based on Ref. [21, 25–43].

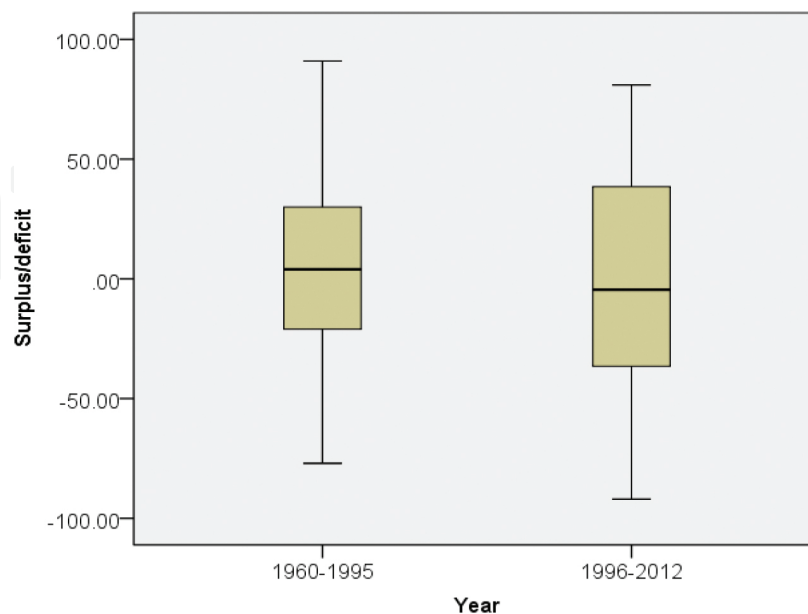
#### 4. Results of hypotheses testing

In order to test our first hypothesis “GM food has failed to feed the hungry,” we calculate the significance of the difference between *per capita* grain production and surplus/deficit cereal productions in the two periods, period before and after GM commercialization, 1958–1995 and

1996–2012. We found that there is no statistically significant *per capita* grain production differences between the two observed periods ( $t = -1.481$ ;  $df = 53$ ;  $p = 0.145$ ) (**Figure 10**). Average cereals production level in the period 1958–1995 was 305.13 kg/person/year (CI 297.57–312.69) and 313.94 in the period 1996–2012 (CI 307.54–320.34). Transgenic technology has not contributed to the improvement in food balance, since there is no statistically significant difference in surplus/deficit cereal production between the two observed periods  $t = 0.941$ ;  $df = 51$ ;  $p = 0.51$ ) (**Figure 11**). Average value of this parameter was  $7.91 \times 10^6$  tons (CI  $-5.02$  to  $20.86$ ) in the period before transgenic plant cultivation and  $-4.0 \times 10^6$  tons (CI  $-30.48$  to  $22.48$ ) in the period after GMOs cultivation. These results clearly demonstrated that transgenic technology has failed to



**Figure 10.** Cereals production (1958–1995, 1996–2012). Authors' calculation based on Ref. [62].



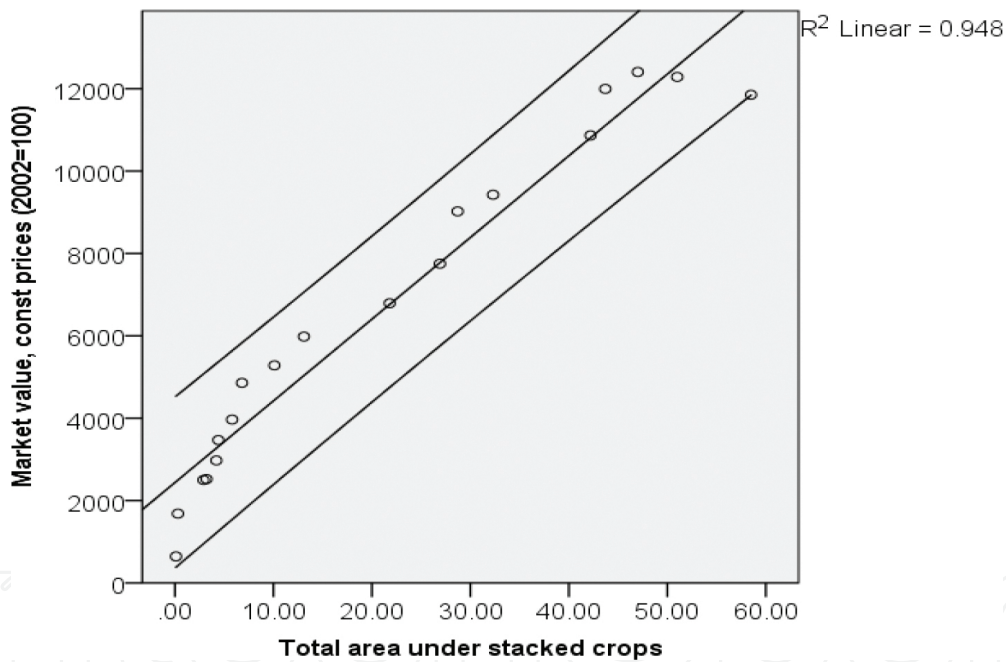
**Figure 11.** Cereal surplus/deficit before and after GM cultivation. Author's calculations based on Ref. [62].

contribute to hunger and famine reduction. Unfortunately, food insecurity and world hunger are still a recurring problem in a significant number of countries.

The second hypotheses “There is a statistically significant correlation between stacked trait and global market value of biotech crops” have been confirmed as presented in **Figure 12**. A statistically significant correlation exists between global market value (G) (const price, 2002 = 100) of biotech crops and areas under stacked crops (S) ( $r = 0.984$ ;  $p < 0.001$ ). The regression analysis suggests that an increase in 1 million hectares under stacked crops causes an increase in global market value by 198.3 million in terms of 2002 US\$ (**Table 1**). This can be represented by the following equation:

$$G = 198.3xS + 243.834 \tag{12}$$

The results can lead us to conclusion that stacked traits obtained through more complex transformations potentially leading to a further enrichment of multinational companies.



**Figure 12.** Correlation between global market value of transgenic crops and stacked crops. Authors’ calculations based on Refs. [21, 25–43].

		Coefficients		<i>t</i>	<i>p</i>
		<i>B</i>	Std. Error		
1	Constant	2438.834	320.191	7.517	0.000
	S	198.335	11.247	17.734	0.000

**Table 1.** The regression analyses (stacked crops/global market value).

Finally, we pay attention to U.S. food aid which is in all forms procured by the U.S. Department of Agriculture (USDA) and administered by either the USDA or the U.S. Agency for International Development (USAID). A substantial portion of the U.S. food aid is channeled through the WFP where the U.S. as the major donor provided over the last 18 years around 43% of total WFP contributions [63]. With some fluctuation, U.S. food aid increased 3.2 times in const prices and 4.5 times in current prices from 1996 to 2015 (Figure 13). Maximum value reached in 2008 in terms of 2002 US\$ prices. Polynomial trend line equations in current and constant prices are as follows:

$$y = 0.009x^6 - 0.556x^5 + 11.99x^4 - 122.8x^3 + 604.4x^2 - 1169x + 1183 \quad (R^2 = 0.826) \quad (13)$$

$$y = 0.008x^6 - 0.482x^5 + 10.5x^4 - 108.8x^3 + 538.9x^2 - 103.4x + 1147 \quad (R^2 = 0.721) \quad (14)$$

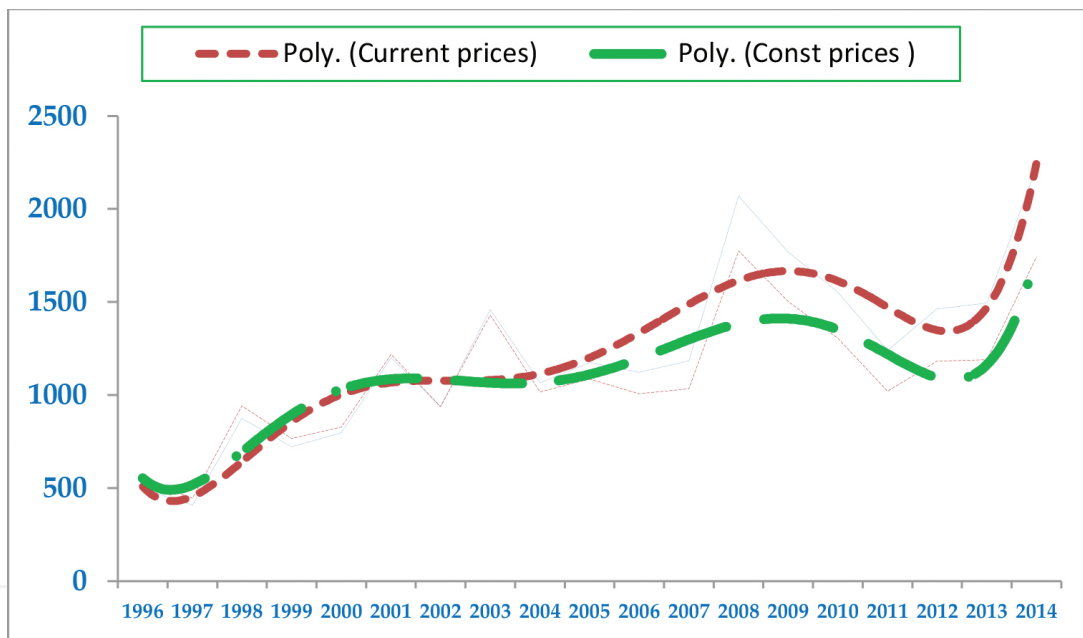
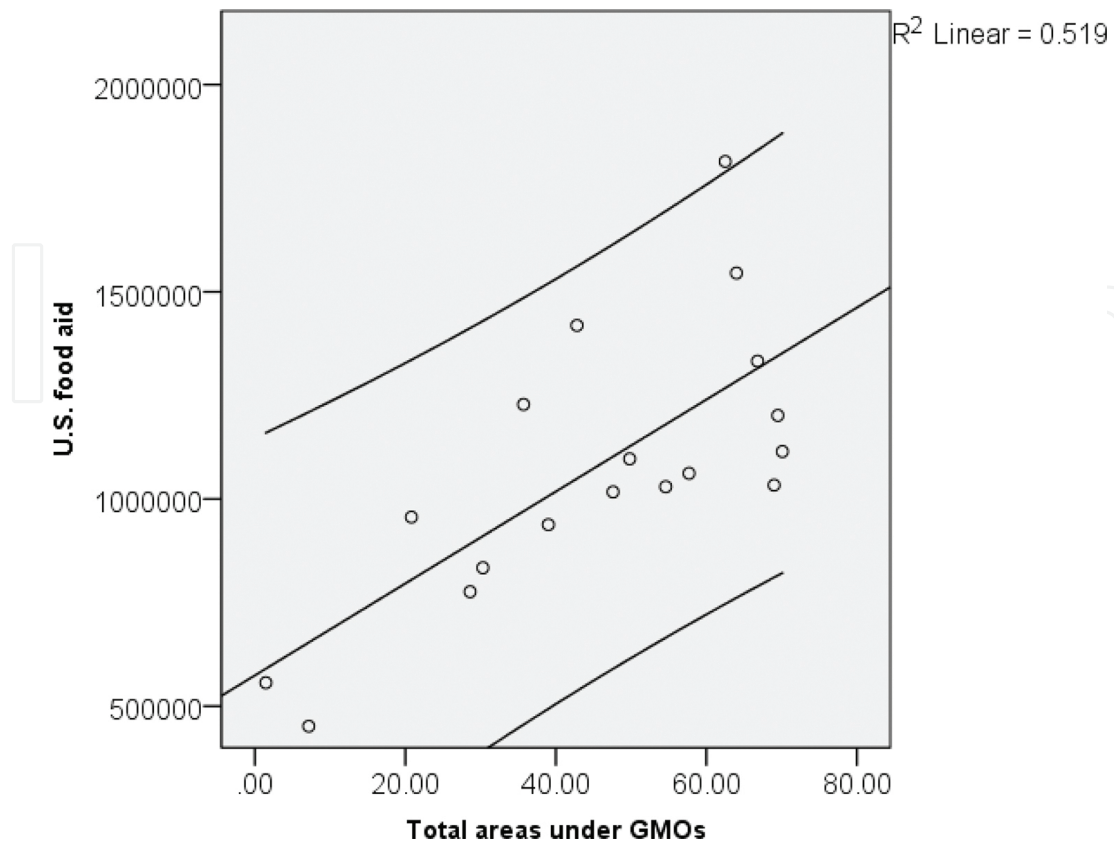


Figure 13. The U.S. food aid (1996–2014). Author’s calculations based on Refs. [63, 64].

Taking into consideration that the U.S. increases in food emergencies in the last two decades, we have settled our third, last research hypothesis: “There is a correlation between raising production of biotech crops in the U.S. and an increase of the U.S. food aid through WFP.” The results have shown significant correlation between U.S. GMOs areas (G) and the U.S. aid (A) ( $r = 0.72$ ;  $p = 0.001$ ) (Figure 14). The regression analysis (Table 2) suggests that an increase in 1 million hectares under biotech crops causes an increase in U.S. aid for 11.1 million US\$ (const price, 2002 = 100) as expressed by the following equation:

$$A = 11093.17xG + 574475.15 \quad (15)$$





**Figure 14.** Correlation between U.S. GMOs areas and U.S. food aid. Authors’ calculation based on Refs. [21, 25–43, 63, 64].

		Coefficients		<i>t</i>	<i>p</i>
		<i>B</i>	Std. Error		
1	Constant	574475.15	133289	4.310	0.009
	G	11093.17	2669.74	4.156	0.000

**Table 2.** The regression analyses (GMOs/U.S. aid).

## 5. Conclusion

Unlike the Green revolution, in which public research institutes developed technologies and freely disseminated them around the world, Gene revolution is led by multinational corporations, which place on the market GM crops protected by patents. Despite the claims of GMOs impressive diffusion, unequal distribution is present in all segments. Herbicide tolerance and insect resistance are the main GM traits that are currently under commercial cultivation, and the main crops are soybean, maize, canola, and cotton. Soybean and maize share in the total acreage was 81% in 2015. The reason for such a large share is their widespread use as food, feed, for industrial purposes and for biofuels production. These two plant species are broadly

present as ingredients of processed foods. For example, soya components are in margarine, cooking fat, mayonnaise, biscuits, coffee creams, fried products, ice creams, baked goods, chocolate, smoothies, tofu, sauces, as well as in meat, meat products, milk, and eggs (as 75% of soy worldwide is used for animal feed, especially for poultry and pigs) [65].

GM crops are grown by <1% of the world's farming population on 13% arable land mostly located in Americas and in some part of Asia. Transgenic technology is facing problems on all continents. Russia has learned a lesson from the past when even a strong nuclear power failed to provide food self-sufficiency. That's why the modern tendency of the Russian Federation is to ensure food security. In case, it comes to fruition that Russia will be a key player in reshaping tomorrow's global food system. Because the U.S. is powerless to oppose the Russian ban on GMOs and because of strong possibility of further strengthening of the European opposition, the U.S. intensifies the pressure on weak, poor countries or countries in transition to accept transgenic technology. Apart from several African countries (Cameroon, Egypt, Ghana, Kenya, Malawi, Nigeria, and Uganda) where multinationals conducted in recent years field trials on GM crops as the penultimate step prior to its approval, in the Balkan region Serbia faces the greatest pressure to accept this technology. The reason lays in the facts that Serbia is leading agricultural country in the region, among the 10 largest world exporter of corn (non-GM), one of the biggest European producing countries of non-GM soya exporting soybean products into five continents and because the U.S. has lost export market for soybean meal. So far, 127 municipalities in Serbia have signed "declaration against GMOs." On May 29, 2009, National Parliament adopted new law on GMOs that fully prohibit the possibility of commercial growing of GMOs, or trade and products derived from GMOs. On the other hand, corrupt politicians and livestock agribusiness sector are pressuring to amend the Law on GMOs. Although multinationals conduct court disputes with farmers who sown GM seed without paying from the countries that allow the GM cultivation, in Serbia as a part of its expansion, strategy does not require protection of patent rights for illegally planted seeds.

Transgenic technology has failed to contribute to hunger and famine reduction since there is no statistically significant *per capita* grain production differences between the two periods, period before GM cultivation and period after it. In order to ensure food security for a growing population, it is necessary to launch a new revolution in food production or revoke the patent protection of transgenic technology and develop crops and traits vitally important for poor farmers and developing countries. At present, generally speaking, the main winners are multinationals who as time passes more and more strengthening its financial position. It can be seen, *inter alia*, on the basis of a correlation between the stacked trait and global market value of biotech crops. U.S. food aid will still remain a controversial issue as there is a significant correlation between raising production of biotech crops in the U.S. and an increase in the U.S. food aid through WFP.

Finally, it is important that governments around the world provide a transparent source of information for consumers on GM foods, which clearly listed of what GM foods are on the market. That way, consumer rights to informed choice will be satisfied.

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