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Use of genetically modified crops and pesticides in Brazil: growing hazards

Uso de sementes geneticamente modificadas e agrotóxicos no Brasil: cultivando perigos

Vicente Eduardo Soares de Almeida [1]
Karen Friedrich [2]
Alan Freihof Tygel [3]
Leonardo Melgarejo [4]
Fernando Ferreira Carneiro [5]

Abstract *Genetically modified (GM) crops were officially authorized in Brazil in 2003. In this documentary study, we aimed to identify possible changes in the patterns of pesticide use after the adoption of this technology over a span of 13 years (2000 to 2012). The following variables were analyzed: Pesticide use (kg), Pesticide use per capita (kg/inhab), Pesticide and herbicide use per area (kg/ha) and productivity (kg/ha). Contrary to the initial expectations of decreasing pesticide use following the adoption of GM crops, overall pesticide use in Brazil increased 1.6-fold between the years 2000 and 2012. During the same period, pesticide use for soybean increased 3-fold. This study shows that the adoption of GM crops in Brazil has led to an increase in pesticide use with possible increases in environmental and human exposure and associated negative impacts.*

Key words *Pesticide, Herbicide, Soybean, Environmental health*

Resumo *Culturas geneticamente modificadas (GM) foram oficialmente autorizadas no Brasil em 2003. O presente estudo documental buscou identificar possíveis alterações no padrão de uso de agrotóxicos a partir da adoção dessa tecnologia, considerando um período de 13 anos (2000 a 2012). Foram avaliadas as variáveis:* uso de agrotóxicos *(kg)*, uso de agrotóxicos per capita *(kg/habitante)*, uso de agrotóxicos e uso de herbicidas por área plantada *(kg/ha) e* produtividade *(kg/ha). Contrariando as expectativas iniciais de diminuição do uso de agrotóxicos após a introdução de culturas GM, observou-se que o uso total de agrotóxicos no Brasil aumentou 1,6 vezes entre os anos de 2000 e 2012. No mesmo período, destacou-se o uso de agrotóxicos na cultura de soja, aumentando em mais de 3 vezes. As análises estatísticas reforçam baixa correlação entre o consumo de agrotóxicos e herbicidas e a produtividade da soja. Sugere-se que a introdução de culturas GM levou ao aumento no uso de agrotóxicos, com a possibilidade de aumento da exposição humana e ambiental e, consequentemente, aos impactos negativos associados a essas substâncias.*

Palavras-chave *Agrotóxicos, Herbicidas, Soja, Saúde e ambiente*

[1] Departamento de Pesquisa e Desenvolvimento, Empresa Brasileira de Pesquisa Agropecuária. Rodovia Brasília/Anápolis BR 060 Km 09, Gama. 70359-970 Brasília DF Brasil. vicentalmeida@gmail.com
[2] Escola Nacional de Saúde Pública, Fiocruz. Rio de Janeiro RJ Brasil.
[3] Campanha Permanente Contra os Agrotóxicos e Pela Vida. São Paulo SP Brasil.
[4] Associação Brasileira de Agroecologia. Porto Alegre RS Brasil.
[5] Fiocruz Ceará. Fortaleza CE Brasil.

Introduction

Brazil's status as one of the largest producers of agricultural commodities in the world is associated with an increase in the consumption of agricultural inputs such as pesticides; the national pesticide market was worth US$12.2 billion in 2014[1]. Between 2000 and 2012, the use of these chemicals by unit area more than doubled[2]. This is worrisome because the impacts on environmental and human health due to pesticides have been extensively documented both by international organizations and in the scientific literature[3-7].

Several studies have pointed to a direct association between the increase in global consumption of pesticides and the use of herbicide-resistant genetically modified (GM) crops[8,9]. In the US, Benbrook[10] revealed that between 1996 and 2011, GM crops led to a 183,000-ton increase in pesticides, which is equivalent to 7% of the overall pesticide use for all crops. Between 1995 and 2002, the use of the herbicide glyphosate in soybean production increased from 2,500 to 30,000 tons/year[8]. During the process of authorization for GM crops resistant to the herbicide 2,4-D, a 3- to 7-fold increase in consumption of 2,4-D was estimated[11].

In Brazil, GM crops were initially introduced illegally at the end of the 1990s and officially authorized in 2003[12]. Six types of GM crops are authorized, but only three are effectively in use, namely, soybean, corn and cotton. Although genetic manipulation has broader goals such as pharmaceutical applications and biofortified food development, there are currently three types of GM crops currently in use in Brazil: herbicide-resistant, insect-resistant or both[13,14]. In 2014, when pesticide sales in Brazil were the highest, the cultivated area of GM crops reached 42.2 million hectares, which represented an increase of 1306.67% over the 3 million hectares registered in 2003[15].

In this context, this paper aims to identify and characterize changes in the patterns of use of pesticides and herbicides after the adoption of GM cropsin Brazil. The emphasis is on soybeans, the main commodity produced in the country, in which 90% of the crops are GM according to the ISAAA[15]. The period analyzed was 2000 to 2012, which corresponds to the most recent statistical data on pesticide consumption provided by the Brazilian Institute of Geography and Statistics (IBGE)[16] from the Sustainable Development Indicators publication. This time span also covers the period before and after the official adoption of GM soybean, corn and cotton, which facilitated the analysis of the impactof the adoption of GM crops on pesticide demand.

Methods

In this study, a descriptive research was adopted that was focused on documentary research and based on secondary data under the framework of critical epidemiology[17,18].This work was developed through systematizing, tabulating, and statistically treating agronomic and demographic data from the IBGE and the Brazilian Crop Protection Industry Union (Sindiveg).

The first step was to calculate for the study period the cumulative growth (Δ) and the compound annual growth rate (CAGR) of the following indicators: *general pesticide use*, *pesticide use per capita*, *pesticide and herbicide use per area*, *pesticide and herbicide use per cropland*, *productivity* per hectare and population growth. Δ and CAGR were calculated as follows:

(1) $\Delta = (V_f / V_i) -1$ and

(2) $CAGR = (V_f / V_i)^{1/T}-1$,

where V_f and V_i represent the final and initial values of the analyzed period, respectively, and T represents the difference in years between the final and initial values.

The next step was to carry out a linear correlation analysis between annual pesticide and herbicide use per area and the productivity of each GM crop (soybean, corn and cotton) from 2000 to 2012. The Pearson's correlation coefficient (r) was used to determine the correlation between *pesticide use per area* (independent variable) and *productivity* (dependent variable). The determination coefficient (R^2) was used to determine the proportion of the variation in *productivity* that could be predicted from the *pesticide use per area*.

More specific analyses focused on the changes in patterns of *herbicide use* and *productivity* gains for soybean. Genetically modified, herbicide-resistant soybean was the first GM crop officially introduced in Brazil in 2003.

Results and Discussion

During the period investigated, the gross (t) formulated pesticide use in Brazil increased more than 2-fold. Table 1 shows that the cumulative growth (Δ) in *pesticide use* was three times higher than the growth in *productivity* (kg/ha) and 10 times higher than population growth for the same period. Each year, *pesticide use* per capita increased by 7%, while productivity increased by only 3.5%.

Table 2 presents the data for soybean, corn and cotton in Brazil for the analyzed period. Soybean production was associated with a greater than 3-fold increase in *pesticide use* over the period analyzed (Table 2), while overall *pesticide use* increased 1.6-fold (Table 1). Furthermore, the determination coefficient (R^2) of *pesticide use* and soybean *productivity* was 22.73% (Table 2) and of *herbicide use* and soybean *productivity* was 17.82% (Figure 1).Figure 2 shows the sudden increase in *herbicide use* in soybean crops in the year 2003when GM soybean was authorized in Brazil. *Herbicide use* in corn and cotton also increased, but the change was not as pronounced.

Figure 3 highlights the *herbicide use per area* (kg/ha) and production of soybean (kg) based on herbicide (kg). Between 2000 and 2002, *herbicide use per area* decreased by 9% and *soybean production per kg herbicide used* increased by 18%. From 2003 and onward, *herbicide use per area* increased by 64% while *soybean production per kg herbicide used* decreased by 43%. For each ton of herbicide used on soybean crops, there was an annual reduction of 16.79 tons in soybean production (Figure 3).

The cumulative growth of pesticides use in Brazil was higher than the overall productivity of crops between 2000 and 2012. Our data show an increase of 3.2 pp (percentage points) in pesticide use and of 1.78 pp in pesticide use per area, but only 1 pp of productivity increase in the same

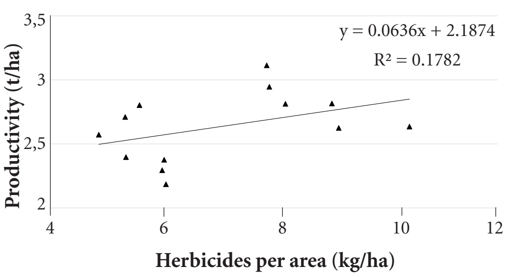

Figure 1. Soybean Productivity (t/ha) related to Herbicides use per area (kg/ha) in Brazil between 2000 and 2012.

Table 1. Accumulated growth (Δ) and compound annual growing rate (CAGR) in pesticide use, agricultural productivity and population between 2000 and 2012 in Brazil.

Indicators	2000	2012	Δ	CAGR
Pesticide use (t)	313,824	823,226	162.32%	8.37%
Pesticide use per capita (kg/inhab)	1.89	4.24	124.67%	6.98%
Pesticide use per area (kg/ha)	6.09	15.97	90.31%	8.37%
Productivity (kg/ha)	9.70	14.62	50.71%	3.48%
Brazilian Population (inhab)	166,112,518	193,946,886	16.76%	1.30%

$\Delta = (V_f / V_i) - 1$; and $CAGR = (V_f / V_i)^{1/T} - 1$, where V_f and V_i represents the final and initial values of the analyzed period, and *T*, the difference of years between V_f and V_i.

Table 2. Increase of pesticides per crop and area and productivity of genetic modified (GM) crops between 2000 and 2012 in Brazil.

Culture	Share in pesticide use	Δ Pesticide use per crop	Δ Pesticide use per area (a)	Δ Productivity (b)	r	R^2	(a)/(b)
Soybean	44.31%	310.71%	124.15%	9.50%	0.48	22.73%	13.07
Corn	13.07%	137.81%	99.65%	84.61%	0.82	67.71%	1.18
Cotton	7.41%	155.78%	46.22%	41.53%	0.64	41.34%	1.11

Share in pesticide use is the average of percentage of pesticide use per crop related to the total amount of pesticide use in the period studied (2000-2012). Productivity represents the amount of crop production per hectare. $\Delta = (V_f / V_i) - 1$; and $CAGR = (V_f / V_i)^{1/T} - 1$, where V_f and V_i the final and initial values of the analyzed period, and *T*, the difference of years between V_f and V_i. Pearson's correlation coefficient (r) and the determination coefficient (R^2) were used in order to achieve the relation between productivity and use of pesticides per area.

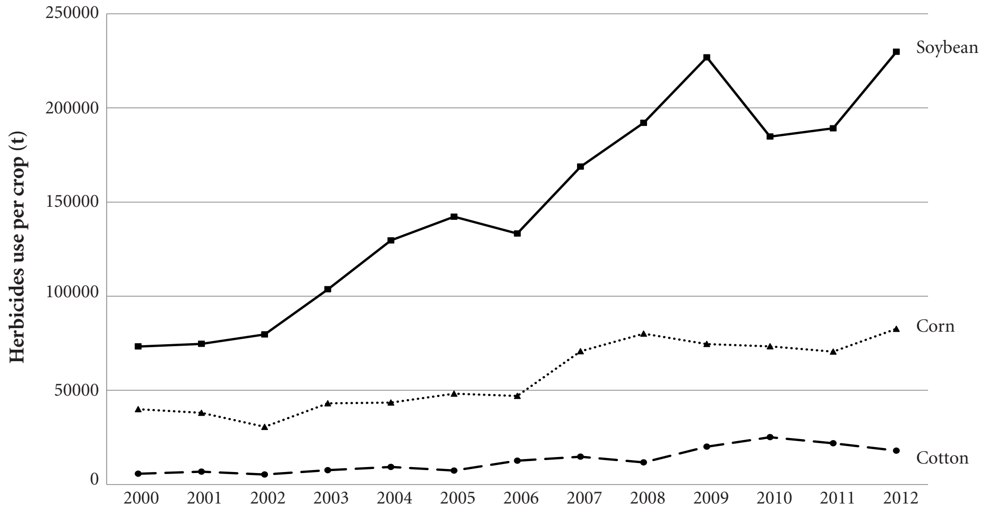

Figure 2. Evolution of the *Herbicides use* (t) for soybean (■), corn (▲) and cotton (●) in Brazil between 2000 and 2012.

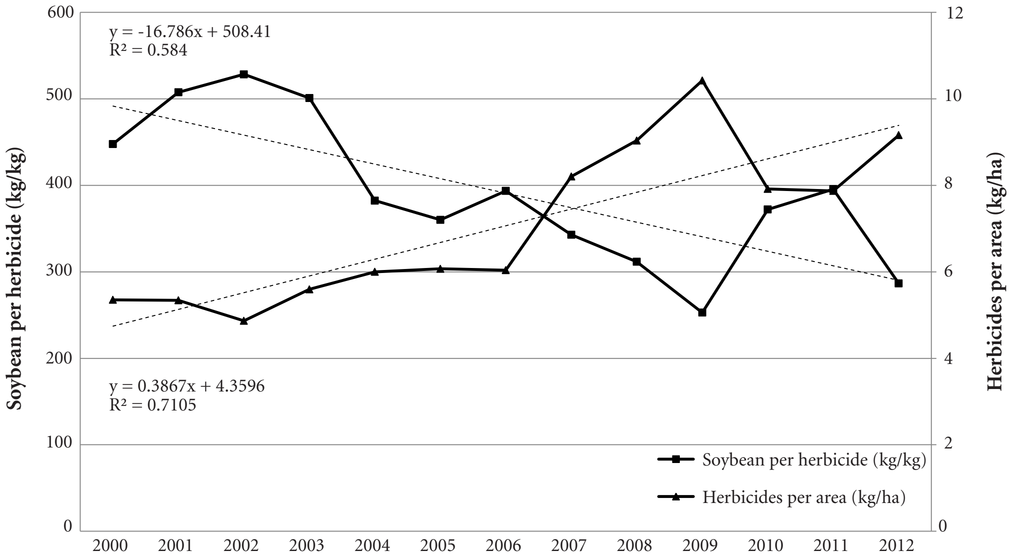

Figure 3. Evolution of the use of herbicides (kg/ha) for soybean production per herbicide used (kg/kg) in Brazil. Dashed lines show the linear tendencies for production of Soybean per herbicide (■) and *Herbicides per area* (▲).

period (Table 1). This observed increase in pesticide use was not accompanied by an increase in the cultivated area or an increase in the growth of the Brazilian population. These findings disagree with other studies[15,19] that predicted reduced pesticide use after the adoption of GM crops.

A more detailed analysis of the indicator *pesticide use per crop* showed that only three crops, soybeans, corn, and cotton, accounted for 65% of the overall total pesticide use whereas soybean, which is the dominant GM crop, accounted for 71%.The results also show that soybean presented the highest increase in *pesticide use* per cultivated area and the lowest gain in *productivity* (Table 2). The indicator *pesticide use per area* showed that a 1 pp increase in soybean productivity required a 13-pp increase in pesticide use, while for corn and cotton this relationship was approximately 1:1 (Table 2).These data suggest that the genetic modification ofsoybeanwas not associated with growth in productivity and instead contributed to an increase in pesticide use.

One explanation for these results is that most GM crops were not developed to enhance productivity or edaphoclimatic adaptability, but mainly to be resistant to herbicides. Other studies have demonstrated that changes in patterns of herbicide use such as an increase in the total amount of glyphosate applied (kg/ha) were related to the adoption of GM soybean[14,20,21]. A study performed in the US between 1990 and 2002 also showed an increase in glyphosate use when herbicide-resistant GM soybeans were authorized (1996)[8]. These changes were not observed for corn and cotton crops, which is likely attributable to the fact that the GM versions of these crops were commercialized in the US at the end of the period of analysis, as also shown in our study.

Several factors associated with the cultivation of herbicide-resistant GM crops may contribute to the increased use of pesticides and losses in productivity, including biological vulnerability, weed resistance, and decreased soil fertility[14,21-30].

Some alternative approaches such as increasing the use of different herbicides and development of GM crops resistant to other herbicides have been considered[31,32]. However, these alternatives are also concerning due to the increased probability of serious toxic hazards to humans and the environment by mixing different herbicides[33,34]. It is noteworthy that the two most widely used herbicides in Brazil[2], glyphosate and 2,4-D,were recently classified as probable and possible carcinogens, respectively, by the International Agency for Research on Cancer (IARC).

The results obtained in this study agree with similar studies in the US, Argentina, and other parts of the world[9,10,35,36]. Data from these studies strongly suggest that the adoption of GM crops increased pesticide use, specifically herbicides sprayed on soybean, as shown by the present study for Brazil. Ecological studies performed in Brazil have shown correlations between soybean cultivation (in tons) and mortality due to prostate cancer and between pesticide use and endocrine disturbances[37,38]. As discussed in other studies, data for pesticide and GM crop use may be used as indicators of human and environmental exposure to serious threats, and these data should motivate public actions to prevent or mitigate these hazards[39].

The results from this study suggest that GM crops have contributed to an increase in pesticide use in Brazil and consequently, increased human and environmental exposure to these potentially hazardous chemical substances. Therefore, the potential for an increase in pesticide use should also be considered during the process of licensing for GM crops. Pesticide use in soybean production increased over the analyzed period, especially after the adoption of GM seeds in 2003. Pesticide use per area also increased significantly, indicating a possible chemical dependency of these croplands and excluding the hypothesis that GM crops could reduce pesticide use. Another relevant aspect, specifically for soybeans, is that this increase did not result in an increase in average productivity. It is also noteworthy that data regarding pesticide use may serve as indicators to support environmental and health surveillance measures such as soil, water and food monitoring for pesticide residues, and such data may strengthen actions related to the diagnosis and treatment of intoxication.

Collaborations

VES Almeida worked on the conception and design of the study, and VES Almeida, K Friedrich, AF Tygel, L Melgarejo and FF Carneiro worked on analysis and data interpretation and manuscript writing and revision.

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References

1. Sindiveg. Balanço 2015: Setor de agroquímicos confirma queda de vendas. Press release. São Paulo: Sindiveg; 2016. [cited 2016 Jun 6]. Available from: http://dados.contraosagrotoxicos.org/group/comercializacao
2. Instituto Brasileiro de Geografia e Estatística (IBGE). *Indicadores de Desenvolvimento Sustentável Brasil 2015*. Rio de Janeiro: IBGE; 2015. [cited 2016 Jun 6]. Available from: http://www.ibge.gov.br/home/geociencias/recursosnaturais/ids/default_2015.shtm
3. González-Alzaga B, Lacasa M, Aguilar-Gardu C, Rodríguez-Barranco M, Ballester F, Rebagliato M, Hernández AF. A systematic review of neurodevelopmental effects of prenatal and postnatal organophosphate pesticide exposure. *Toxicol Lett* 2014; 230(2):104-121.
4. World Health Organization (WHO), International Agency for Research on Cancer (IARC). *Volume 112: evaluation of five organophosphate insecticides and herbicides.* Lyon: IARC, WHO; 2015. [cited 2016 Jun 6]. Available from: http://monographs.iarc.fr/ENG/Monographs/vol112/index.php
5. Mascarelli A. Growing up with pesticides. *Science* 2013; 341(6147):740-741.
6. Mesnage R, Defarge N, Vendomois JS, Seralini GE. Potential toxic effects of glyphosate and its commercial formulations below regulatory limits. *Food Chem Toxicol* 2015; 84:133-153
7. Schmitz J, Hahn M, Bruhl CA. Agrochemicals in field margins – An experimental field study to assess the impacts of pesticides and fertilizers on a natural plant community. *Agric Ecosyst Environ* 2014; 193:60-69.
8. Young BG. Changes in herbicide use patterns and production practices resulting from glyphosate-resistant crops. *Weed Technol* 2006; 20(2):301-307.
9. Peshin R, Zhang W. Integrated Pest Management and Pesticide Use. In: Pimentel D, Peshin R, editors. *Integrated Pest Management*. Amsterdam: Springer; 2014. p. 1-46.
10. Benbrook CM. Impacts of genetically engineered crops on pesticide use in the U.S. – the first sixteen years. *Env Sci Eur* 2012; 24:24.
11. United States Department of Agriculture (USDA). Animal and Plant Health Inspection Service (APHIS). *Dow AgroSciences Petitions (09-233-01p, 09-349-01p, and 11-234-01p) for Determinations of Nonregulated Status for 2,4-D-Resistant Corn and Soybean Varieties—Draft Environmental Impact Statement*. Washington: USDA/APHIS; 2013. [cited 2016 Jun 6]. Available from: https://www.aphis.usda.gov/brs/aphisdocs/24d_deis.pdf
12. Brasil. Lei nº 10.688, de 13 de junho de 2003. Estabelece normas para a comercialização da produção de soja da safra de 2003 e dá outras providências. *Diário Oficial da União* 2003; 16 jun.
13. Acosta O, Chaparro A. Genetically modified food crops and public health. *Acta bio Colomb* 2008; 3:13.
14. National Research Council (NRC). *Impact of Genetically Engineered Crops on Farm Sustainability in the United States.* Washington: The National Academic Press; 2010.
15. International Service for the Acquisition of Agri-Biotech Aplications (ISAAA). *Global status of Commercialized biotech/GM Crops*. 2014. [cited 2016 Jun 6]. Available from: http://www.isaaa.org/resources/publications/briefs/44/executivesummary/default.asp
16. Instituto Brasileiro de Geografia e Estatística (IBGE). *Indicadores de Desenvolvimento Sustentável Brasil 2015*. Rio de Janeiro: IBGE; 2015. [cited 2016 Jun 6]. Available from: http://www.ibge.gov.br/home/geociencias/recursosnaturais/ids/default_2015.shtm
17. GIL AC. *Métodos e técnicas de pesquisa social*. 6ª ed. São Paulo: Atlas; 2008.
18. Breilh J. *Epidemiologia Crítica; ciência emancipatória e interculturalidade*. Rio de Janeiro: Editora Fiocruz; 2006.
19. Huang J, Hu R, Rozelle S, Pray C. Insect-Resistant GM Rice in Farmers' Fields: Assessing Productivity and Health Effects in China. *Science* 2005; 308(5722):688-690.
20. United States Department of Agriculture (USDA). National Agriculture Statistics Service (NASS). *Agricultural Chemical Use Database*. Washington: USDA-NASS; 2008. [cited 2016 Jun 6]. Available from: www.pestmanagement.info/nass
21. Johnson WG, Davis VM, Kruger GR, Weller SC. Influence of glyphosate-resistant cropping systems on weed species shifts and glyphosate-resistant weed populations. *Europe J Agron* 2009; 31(3):162-172.
22. Cerdeira AL, Gazziero DL, Duke SO, Matallo MB. Agricultural impacts of glyphosate-resistant soybean cultivation in South America. *J Agric FoodChem* 2011; 59(11):799-807.
23. Shaner DL, Lindenmeyer RB, Ostlie MH. What have the mechanisms of resistance to glyphosate taught us? *PestManag. Sci* 2012; 68(1):3-9.
24. Service RF. When weed killers stop killing. *Science* 2013. 341: 1329.
25. Ismail B, Kader A, Omar O. Effects of Glyphosate on Cellulose Decomposition in Two Soils. *Folia Microbiol* 1995; 40(5):499-502.
26. King C, Purcell L, Vories E. Plant growth and nitrogenase activity of glyphosate-tolerant soybean in response to foliar glyphosate applications. *Agronomy Journal* 2001; 93(1):179-186.
27. Zablotowicz R, Reddy K. Nitrogenase activity, nitrogen content, and yield responses to glyphosate in glyphosate-resistant soybean. *Crop Prot* 2007; 26(3):370-376.
28. Kremer R, Means N. Glyphosate and glyphosate-resistant crop interactions with rhizosphere microorganisms. *Eur J Agronomy* 2009; 31(3):153-161.
29. Zobiole L, Oliveira R, Visentainer J, Kremer R, Bellaloui N, Yamada T. Glyphosate affects seed composition in glyphosate-resistant soybean. *J. Agric. Food Chem* 2010; 58(7):4517-4522.
30. Zobiole L, Kremer R, Oliveira R, Constantin J. Glyphosate affects microorganisms in rhizospheres of glyphosate-resistant soybeans. *Journal App. Microb*. 2011; 110(1):118-127.

31. Hungria M, Nakatani AS, Souza RA, Sei FB, de Oliveira Chueire LM, Arias CA. Impact of the ahas transgene for herbicides resistance on biological nitrogen fixation and yield of soybean. *Transgenic Res* 2015; 24(1):155-165.
32. Pandolfo CE, Presotto A, Carbonell FT, Ureta S, Poverene M, Cantamutto M. Transgenic glyphosate-resistant oilseed rape (Brassica napus) as an invasive weed in Argentina: detection, characterization, and control alternatives. *Environ Sci Pollut Res Int* 2016; 23(23):24081-24091.
33. Braun JM, Gennings C, Hauser R, Webster TF. What Can Epidemiological Studies Tell Us about the Impact of Chemical Mixtures on Human Health? *Environ Health Perspect* 2016; 124(1):A6-9.
34. Carlin DJ, Rider CV, Woychik R, Birnbaum LS. Unraveling the health effects of environmental mixtures: an NIEHS priority. *Environ Health Perspect* 2013; 121:A6-8.
35. Pengue W. Transgenic Crops in Argentina: The Ecological and Social Debt. *Bull. Sci. Technol Soc* 2005; 25(4):314-322.
36. Landrigan PJ, Benbrook C. GMOs, Herbicides, and Public Health. *N Engl J Med* 2015; 373(8):693-695.
37. Koifman K, Koifman RJ, Meyer A. Human reproductive system disturbances and pesticide exposure in Brazil. *Cad Saude Publica* 2002; 18(2):435-445.
38. Silva JFS, Silva AMC, Lima-Luz L, Aydos RD, Mattos IE. Correlação entre produção agrícola, variáveis clínicas-demográfcas e câncer de próstata: um estudo ecológico. *Cien Saude Colet* 2015; 20(9):2805-2812.
39. Pignati W, Oliveira NP, Silva AMC. Vigilância aos agrotóxicos: quantificação do uso e previsão de impactos na saúde-trabalho-ambiente para os municípios brasileiros. *Cien Saude Colet* 2014; 19(12):4669-4678.

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