Chapter

Current Approaches to Pesticide Use and Glyphosate-Resistant Weeds in Brazilian Agriculture

Kassio Ferreira Mendes, Rodrigo Nogueira de Sousa and Ana Flávia Souza Laube

Abstract

The aim of this chapter is to show a general vision about the pesticides use in Brazil. Pesticides are chemical products that contribute to agricultural production processes, mainly large scale, as agents of chemical, physical and biological processes. The glyphosate is the most widely used pesticide in Brazil to vast area cultivated with genetically modified glyphosate-resistant crops. Also, this herbicide is the most widely used in the world to control weeds in various crops, making chemical control cheap, easy and efficient. However, with the advance in the cultivation of glyphosate-resistant crops and the intensive use of this herbicide associated with the non-use of other herbicides, glyphosate-resistant weed biotypes are emerging very quickly. In this way, its use must be performed consciously in order not to occur significant increase in the amount of weeds resistant to this herbicide. Despite its great use in the country, it presents few records of resistant weeds when compared to other herbicide action mechanisms. Thus, good agricultural practices are indispensable and more innovations in technologies are necessary for the future. Therefore, adopting a long-term weed management perspective and integration systems for all agricultural practices is of paramount importance to farmers.

Keywords: herbicide resistance, mode of action, chemical product, conventional farming

1. Introduction

The domestication of plants over a long time came with several challenges to maintain their sustainability. It is known that cultivated crops would suffer attacks from pests and diseases, causing great yield losses with the ever-present possibility of hunger for the population, mainly due to the lack of resources and knowledge. Even today with advances in technologies to control invaders, food losses due to pests and diseases range from 10 to 90%, with an average of 35–40%, for all potential crops of food and fiber [1]. Pesticides are chemical products that contribute to agricultural production processes, mainly large scale, as agents of chemical, physical, and biological processes [2]. In the south of Brazil, the monoculture of soybeans, wheat, and rice was associated with the mandatory use of pesticides for those who intended to use government rural credit. Today, pesticides are disseminated in conventional agriculture, as a short-term solution for pest and disease infestation [3].

Brazil is one of the largest agricultural producers in the world and the second country that exports these products, playing an important role in the local economy. To maintain such production, this sector intensively uses transgenic seeds and chemical inputs, such as fertilizers and pesticides. Brazil is the largest consumer of pesticides in the world, with an extensive area of planting [4]. The consumption of herbicides in Brazil was about 540,000 tons of formulated (commercial) products in 2017 [5]. Glyphosate is the most widely used pesticide in Brazil, with 173,150.75 tons of acid equivalent marketed in 2017 [6]. One of the main consequences of weed resistance to herbicides is the increase in weed control costs, which is hardly addressed in scientific publications, but of great importance for the productive sector.

Glyphosate (*N*-phosphonomethyl glycine) is a nonselective and systemic herbicide applied in postemergence, which belongs to a chemical group of replaced glycines. It presents a wide spectrum of actions, enabling the control of annual and perennial weeds with broad and narrow leaves. Due to excellent weed control along with its ease of handling, low cost, and increased productivity, glyphosate has become the most widely used herbicide in the world [7]. This herbicide is registered in Brazil for the following crops: cotton, rice, plum, banana, cocoa, coffee, sugarcane, citrus, coconut, eucalyptus, beans, tobacco, apple, papaya, corn, nectarine, pear, peach, pine, rubber tree, soybean, wheat, grape, pastures, forage ryegrass, and black oats [7]. Glyphosate acts by inhibiting the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPs) and, consequently, the biosynthesis of aromatic amino acids, lignins, flavones, isoflavones, anthocyanins, and several indispensable components for the plant, leading to plant death [7].

It is of paramount importance to understand the behavior of the herbicide in the plants. Therefore, the absorption of glyphosate takes place in the aerial part of the plants, having a maximum absorption 96 h after application, translocated by simplasto with photoassimilates of the leaves for meristematic tissue reaching the target site. In water it presents a weak acid behavior and presents four variable dissociation constants (pKa between 2.6 and 10.3), in which it presents cell absorption facilitated by phosphate carriers that are in the cell membranes [8].

Glyphosate is the most widely used pesticide in the world due mainly to the large number of genetically modified crops resistant to this product [9]. However, with the increase in the number of agricultural areas with transgenic crops (glyphosate-resistant), mainly soybean, cotton, and corn, together with the high use and incorrect application of this herbicide, new cases of resistant weeds appear [8]. In the world, 47 species of glyphosate-resistant weeds are already reported, and 9 of them are in Brazil [10]. **Figure 1** presents the number of weed species resistant to various herbicides of different resistance mechanisms reported worldwide.

Acetolactate synthase (ALS) inhibitor herbicides have the highest number of resistant species (162 species) (**Figure 1**). 4-Hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor herbicides have the smallest number of resistant species (two species). **Figure 2** shows that the United States is the country with the most cases of unique resistance. Brazil has 51 cases of herbicide-resistant weeds already recorded.

Figure 3 presents the amount of herbicide-resistant weed species within weed families. The family that has the most cases of herbicide resistance is the Poaceae family with 82 registered cases. The Caryophyllaceae family presents fewer cases of resistant weed species (six species).

Figure 4 presents the amount of weed species that have simple resistance to each herbicide. Atrazine presents the largest number of weed species with simple resistance, with 66 species registered. For glyphosate there are reported 43 species of weed resistance, the second being herbicide with the highest number reported.

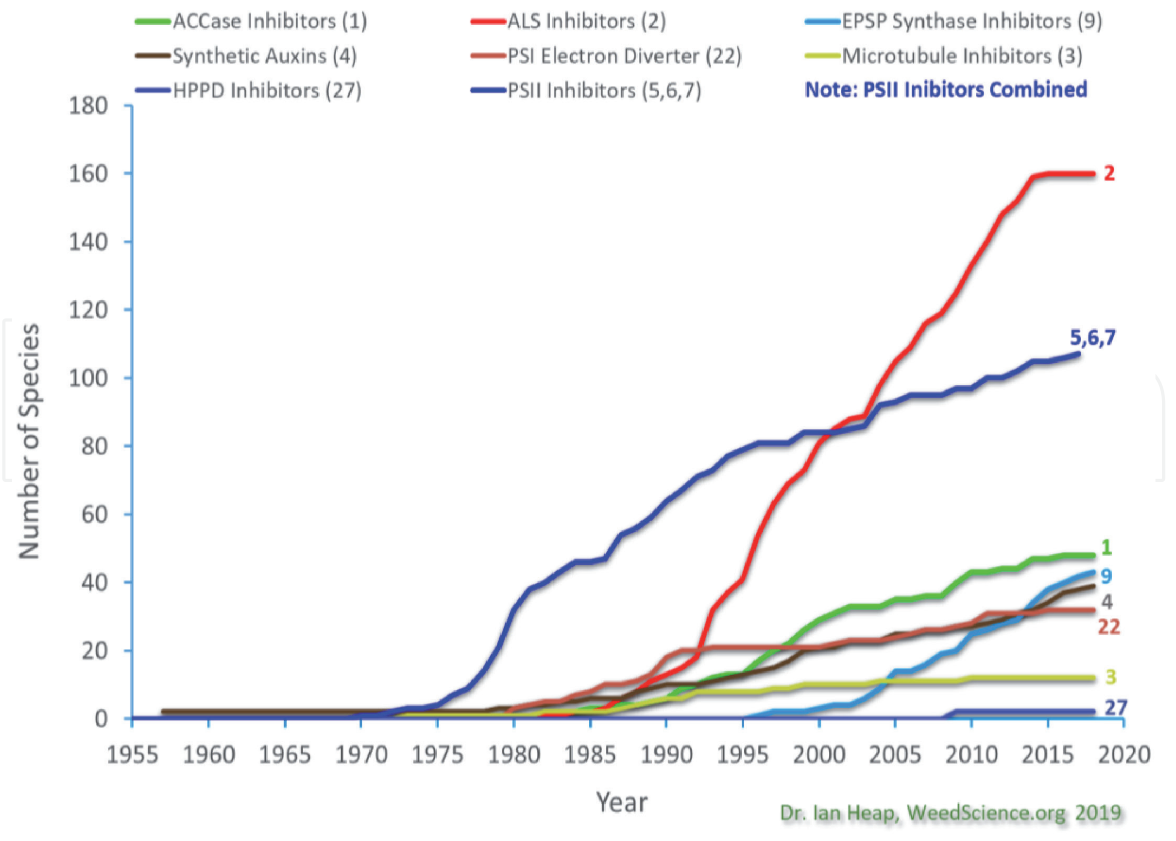

Figure 1.
Number of weed species resistant to various herbicides of different resistance mechanisms reported worldwide. Source: Heap [10].

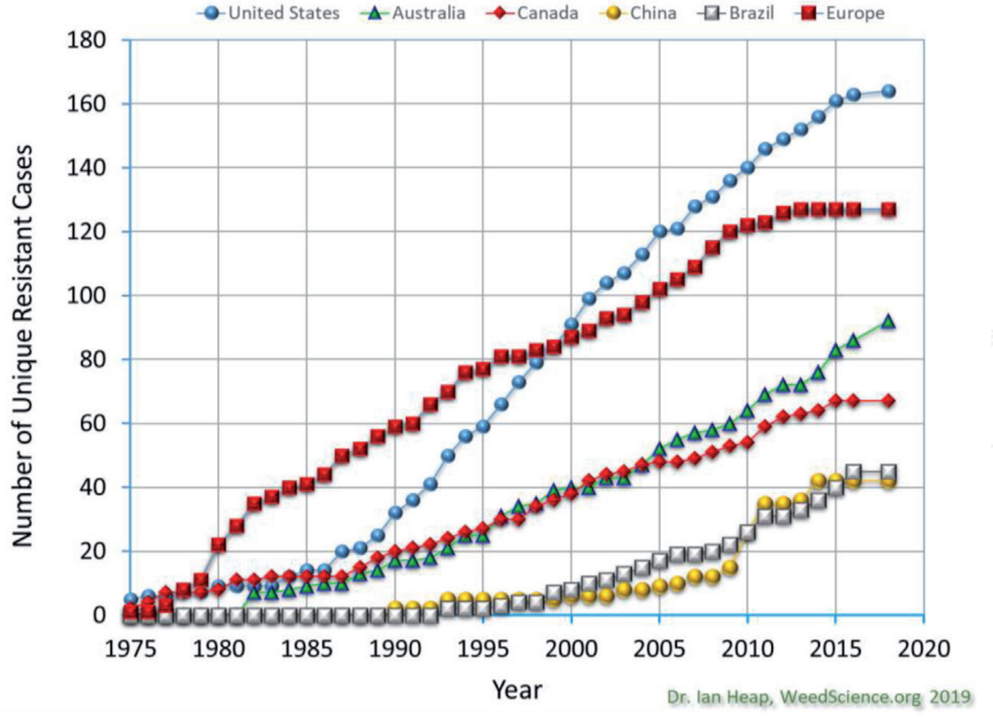

Figure 2.
Increased cases of resistant weeds reported in various countries and Europe. Source: Heap [10].

The mechanisms that generate resistance to herbicides in weeds can be separated into the following: (i) related to the site of action (target-site resistance, TSR) and/or (ii) not related to the site of action (nontarget-site resistance, NTSR) [9]. Mutation of the gene encoding enzyme EPSPS and amplification of this gene are

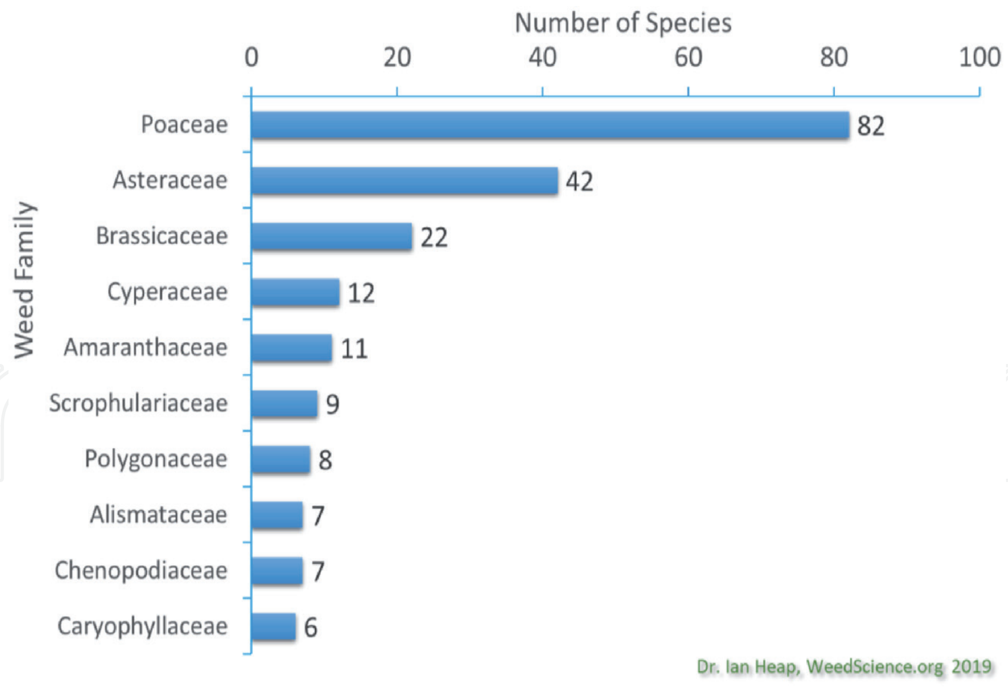

Figure 3.
Number of herbicide-resistant weed species per weed family. Source: Heap [10].

examples of TSR mechanism, while reduced absorption, differential translocation, high metabolism, and glyphosate sequestration by the vacuoles are examples of NTSR mechanism [11]. Thus, it is necessary to know about the mechanisms of weed resistance to herbicides to perform good management practices for the prevention of the occurrence of new resistant biotypes in other areas and, mainly, for the determination of preventive management programs to the selection of resistant biotypes and also for the determination of the practices of weed control already selected [9].

The aim of the authors in this chapter was to present pesticide use and general characteristics of glyphosate- and herbicide-resistant weeds in Brazil.

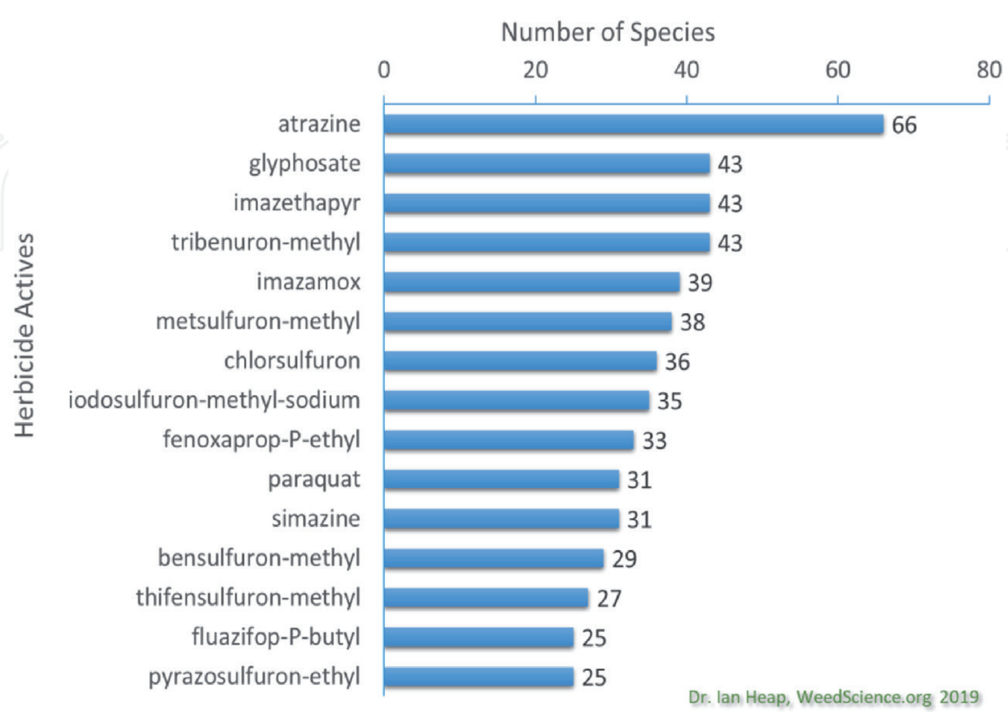

Figure 4.
Number of weed species with simple resistance to herbicides. Source: Heap [10].

2. Pesticide use in Brazilian agriculture

The agricultural production in Brazil plays an important role in the Brazilian economy, thanks to which this country is one of the world's leading producers of agricultural commodities. To keep up with production, this sector uses intensively transgenic seeds and chemical inputs, such as fertilizers and pesticides—chemical or biological substances used to protect crops against the introduction and spread of pests such as insects, fungi, bacteria, viruses, mites, nematodes, and weeds [4, 12]. Regarding the function of pesticides, they all have the same common action, which is to block the vital metabolic processes of the organisms in which they are toxic.

Currently, the total amount of pesticide commercialized in Brazil is US$10,522 billion per year, 14% less than 2014 (**Figure 5**), or 21% in a global market estimated to be worth US$50 billion. In a country with a high pest index due to tropical climate, the farmers' challenge is to reduce pesticide application (which is nowadays the main pest management), as well as to reduce the cost of production and the associated risks to human health and natural resources.

Among the several alternatives for pest control in crops, the chemical method is still the most widely used, due to its practicality, efficiency, and speed. However, if pests are not controlled, they can drastically reduce the crop productivity. Among the pesticide classes, herbicides (selective and nonselective) used for weed control and also applied for crop desiccation represent 33% of consumption in the country, followed by insecticides (29%) and fungicides (28%) (**Figure 6**).

Due to the high total amount of pesticides used, some agricultural crops deserve attention, not because these products are intensively applied per unit of cultivated area but because these crops occupy large areas in Brazil. Half of the pesticides commercialized in the country are used in soybean crop, followed by the main crops such as sugarcane (12%), corn (11%), and cotton (9%) (**Figure 7**).

Pesticide use differs in the various regions of the country, where intensive and traditional agricultural (not use chemical product intensively) activities are mixed. Located in Midwest, the Mato Grosso state is the one that uses the most pesticides (24%) in the country, and the second is São Paulo state, located in Southeast

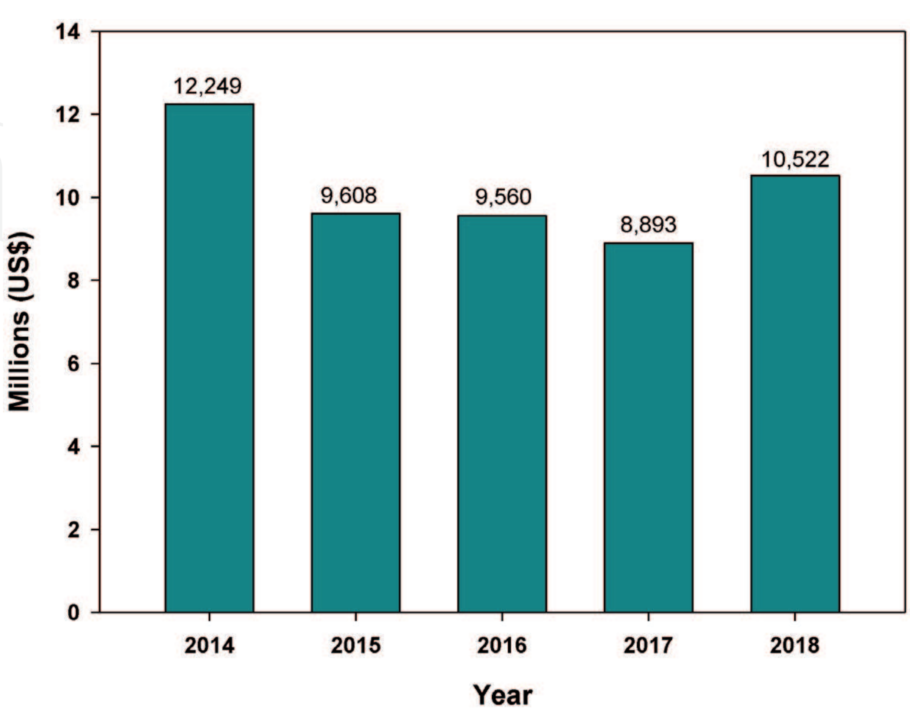

Figure 5.
Total commercialization of pesticides in Brazil from 2014 to 2018. Source: SINDIVEG [13].

(**Figure 8**). The consumption of pesticides in the Midwest increased in the 1970s and 1980s due to the occupation of the Cerrados and the cultivation of soybean, cotton, corn, and sugarcane continues to increase in this region. The South region represents 26% of pesticide consumption, while in the Northeast region, it is only 9%.

Empty pesticide packaging, unlike any plastic packaging, cannot be reused for domestic uses. This is because the products are aggressive, i.e., harmful to human and animal health, and can cause contamination if reused. And due to the toxicity of pesticides, their handling requires extreme care, attention, and personal protective equipment, and empty containers cannot be disposed in the dumping ground due to the aforementioned eminent risks. Therefore, all pesticides that are marketed in Brazil have empty packaging collected by the National Institute for Empty Packaging Processing (inpEV), which is responsible for the final destination of this material.

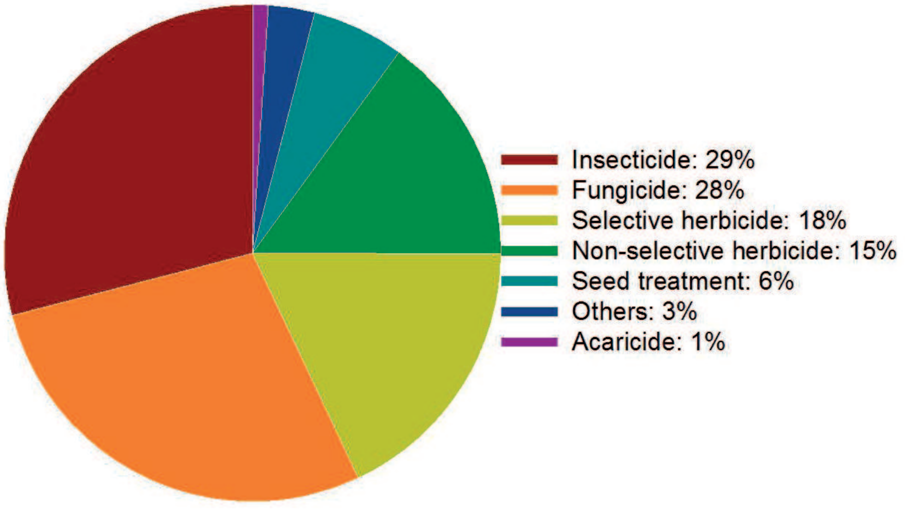

Figure 6.
Commercialization of classes of pesticides used in Brazil. Source: SINDIVEG [13].

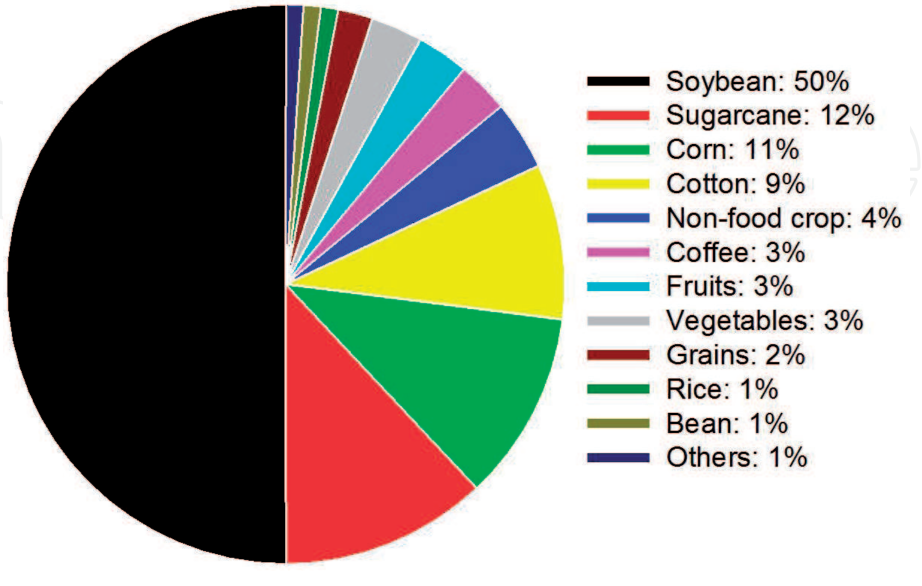

Figure 7.
Commercialization of pesticides used by crops in Brazil. Non-food crops: reforestation, pasture, floriculture, and tobacco. Fruits: citrus, apple, grape, melon and watermelon, banana, and others. Vegetables: potatoes, tomatoes, onions, garlic, and others. Grains: wheat, oats, rye, barley, and peanuts. Others: stored grains and others. Source: SINDIVEG [13].

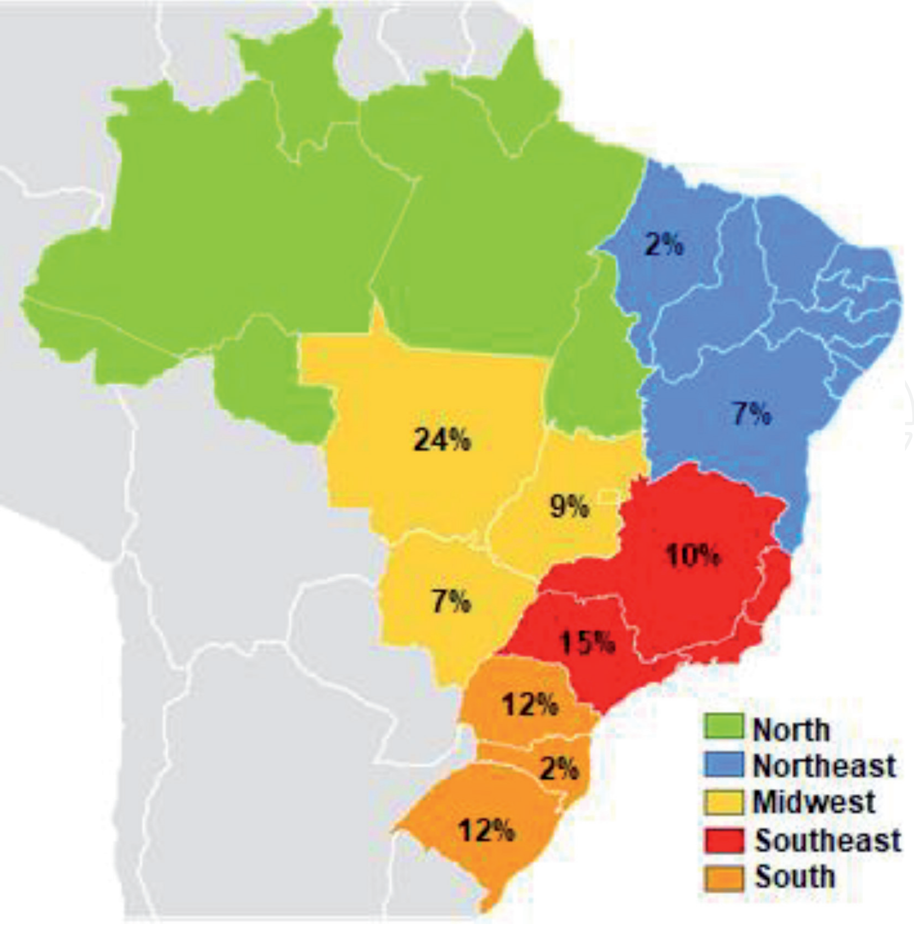

Figure 8.
Commercialization of pesticides for use in agriculture by Brazilian states. Source: SINDIVEG [13].

3. Glyphosate: sales in Brazil and worldwide, origin and mode of action

Currently, the most efficient method used for weed control is the use of herbicides, mainly in large areas of cultivation, for which its rapid action added more viable costs. Among the herbicides used, glyphosate is the most marketed worldwide in more than 119 countries with about 150 trademarks for this product [14]. **Figure 9** presents the commercialized quantities of glyphosate and its channels in Brazil.

According to the ABRASCO [16], 110 products with glyphosate alone have been sold in Brazil, in 29 different companies, and 173,150.75 tons sold in 2017, the amount being 3 times more than the second most commercialized herbicide, the 2,4-D. This considerable increase in sales was due to the production of corn and cotton after the development of transgenic soybeans, from 40,000 tons of products marketed to 300,000 per year in Brazil. In 2013, Asian countries, especially China and India, were the ones that consumed glyphosate-based products the most. At the same time, the United States accounted for more than 25% of all glyphosates marketed. The estimate is that in 2020, the demand for this herbicide is worldwide, which exceeds one ton [17].

The discovery of glyphosate occurred in 1950, and this acid was an interesting complexion agent, a pH reducer, a detergent, and several other applications [18]. The glyphosate molecule was invented by the Cilag/Ciba industry in Switzerland, during the process of selection of chelating compounds for paints. In the mid-1960s, some scientists at Stauffer discovered other chelating properties of glyphosate. However, only in the early 1970s did Monsanto scientists discover the herbicide properties of glyphosate. Two decades after it began to be marketed, there were

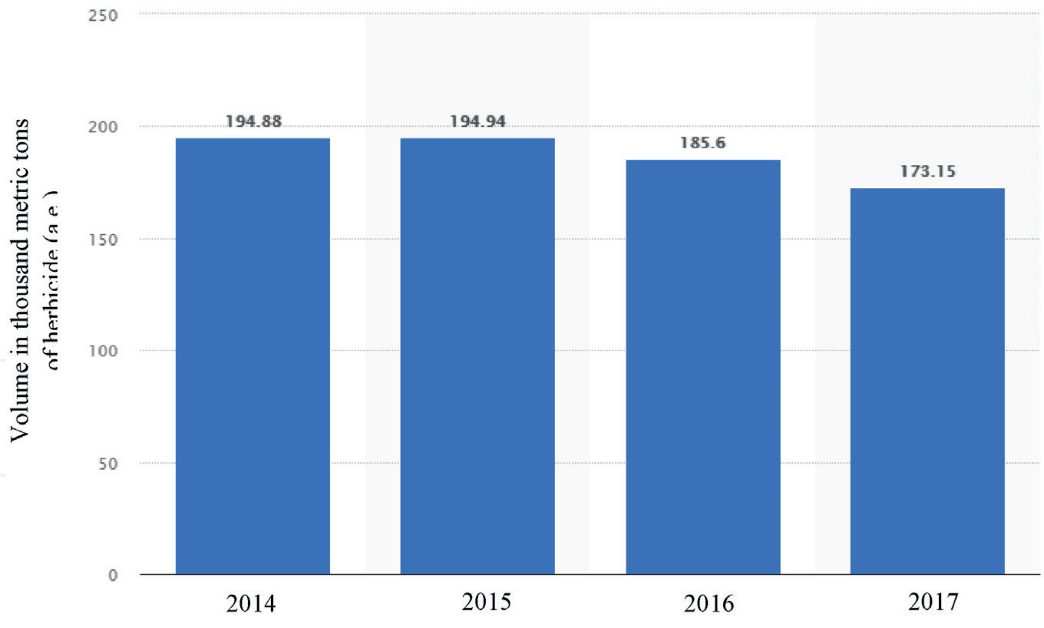

Figure 9.
Annual distribution of the quantity, in tons, of glyphosate in Brazil, from 2014 to 2017. Source: IBAMA [15].

more than 90 commercial products with this active equivalent [19]. Today, glyphosate is widely used and has become the most marketed herbicide in the world.

Due to its lack of selectivity, the use of glyphosate was initially limited to preplanting, directed jet, pre-harvest, and postemergence of weeds. With the introduction of glyphosate-resistant crops in the mid-1990s, it is now used for weed control in resistant crops without concerns about crop damage. Currently, glyphosate-resistant crops are grown in several countries, with great adoption in the United States, Canada, Argentina, and Brazil. The wide adoption of glyphosate-resistant crops has caused changes in weed species in these crops and resulted in the evolution of resistant weeds [20].

Glyphosate is a nonselective herbicide (affecting all "natural" or non-transgenic plants), which has a broad spectrum, is systemic, and is applied in postemergence, belonging to the glycine-derived chemical group that has been widely used in the world in the last four decades [20].

The mechanism of action of glyphosate is the inhibition of the enzyme EPSPS and, consequently, the biosynthesis of aromatic amino acids, tryptophan, phenylalanine, and tyrosine [18, 20], and precursors of compounds such as lignins, flavonoids, and benzoic acids [21]. This leads to several metabolic disorders, inhibiting the biosynthesis of proteins and secondary products and generating a significant increase in the concentration of shikimate, a common precursor in the metabolic route of the three amino acids (**Figure 10**) [22]. Glyphosate inhibits the enzyme EPSPS by competing with the phosphoenolpyruvate (PEP) substrate, preventing shikimate from being transformed into chorismate. The synthesis of the enzyme EPSPS occurs in the cytoplasm, which is transported to the chloroplast where it operates; glyphosate binds to it by glutamic acid carboxylic (glutamine) at position 418 of the amino acid sequence. The final action of the herbicide is not explained by the reduction of amino acids and the accumulation of shikimate. It is believed that the deregulation of the shikimic acid route causes the loss of carbons available for other cellular reactions in the plant, once 20% of plant carbon is used in this metabolic route, because tryptophan, phenylalanine, and tyrosine are forerunners of most aromatic compounds in plants. Glyphosate causes the reduction of phytoalexin synthesis. There is an increased concentration in toxic levels of nitrate, ethylene, kinetic acid, and other compounds that accelerate plant death [22].

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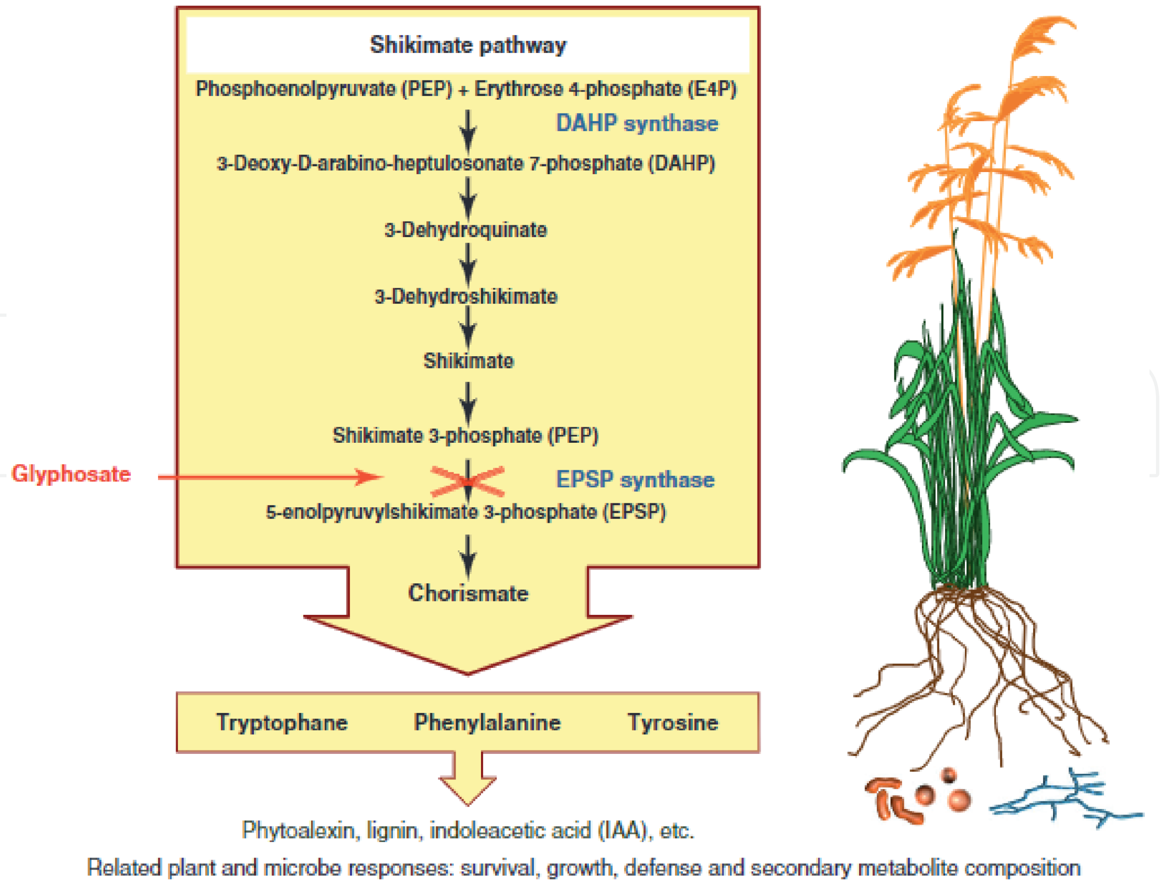

Figure 10.
Glyphosate acts by inhibiting the enzyme 5-enolpyruvylshikimate-3-phosphate synthase in the shikimate pathway, blocking the production of tryptophan, phenylalanine, or tyrosine. Source: Adapted from Helander et al. [23].

The dose of glyphosate used depends on the species that will be controlled and can range from 0.18 to 2.16 kg a.e. ha^{-1}. After application of this herbicide, a period of 4–6 h without rain is necessary to increase the efficiency. After being treated with this herbicide, the plants die between 7 and 14 days. For absorption to be facilitated, it should be used in low flow and larger drops. The yellowing of meristems is a symptom in plants that can lead to necrosis and then to death in days or weeks [21].

4. Physicochemical properties of glyphosate

Glyphosate presents the molecular formula $C_3H_8NO_5P$ (molecular weight = 169.1 g mol^{-1}) [24]. This herbicide can be formulated as isopropylamine salt, ammonium salt, or trimethylsulfonic salt [25] (sulfate) [19]. The chemical glyphosate group is a replaced glycine. The glyphosate structure is presented in **Figure 11**.

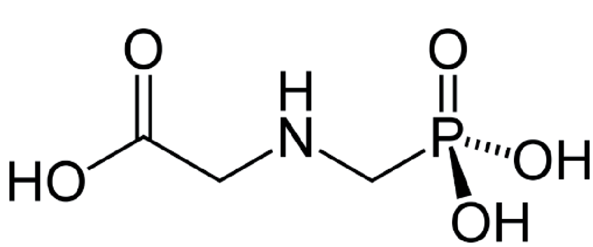

Figure 11.
Chemical structure of glyphosate.

Under environmental conditions, both glyphosate and its salts are crystalline solids, which have high solubility in water (12 g L^{-1} to 25°C, for glyphosate) and are practically insoluble in common organic solvents such as acetone and ethanol. Glyphosate melts at 189.5°C and has an apparent density of 0.5 g cm^{-3} and presents significant water solubility in the presence of light, including at temperatures above 60°C [24]. **Table 1** shows the physicochemical properties of glyphosate.

As shown in **Table 1**, glyphosate has high S_w and pK_a values with acid character and a low K_{ow} value, indicating that glyphosate has a great hydrophilic tendency, which decreases soil sorption. However, glyphosate quickly binds to positive soil charges (mainly in clays) such as in soils abundant in iron and aluminum oxides. This indicates high values of sorption coefficient normalized by soil organic carbon (OC) (K_{oc}) than other herbicides, limiting their leaching in the soil profile [27].

The pK_a values found in the literature for glyphosate are pKa1, 0.8; pKa2, 2.16; pKa3, 5.46; and pKa4, 10.14. These dissociation constants indicate the degree of dissociation of the herbicide as a function of pH [24]. This shows the relationship between the amount of matter that exists after a certain reagent has been consumed and the amount of material that exists initially.

At pH values below 0.8, most glyphosate is found in a protonation on the amine site. In a pH of 0.8, being the value of the first constant, 50% of the molecules present this protonation and the other 50% with a dissociation in the phosphate group. From this value up to pH of 2.2, the molecular formula is predominant, with a dissociation ($-PO_2H-$) and a protonation ($-NH_2^+-$), and in a pH of 2.2, 50% of the compound will have dissociation despite maintaining protonation in the amine group. Among the pH values of 2.2 and 5.4, the predominant form of the herbicide

Properties	Values
Chemical name (IUPAC)	*N*-(phosphonomethyl) glycine
Common name	Glyphosate
CAS number	1071-83-6
Molecular formula	$C_3H_8NO_5P$
Molecular weight	169 g mol^{-1}
Class	Herbicide
Group	Replaced glycine
Melting point	189.5°C
Boiling point	Decomposes before boiling
Degradation point	200°C
Vapor pressure (PV)	1.31×10^{-5} Pa (25°C, acid)
Henry's law constant to 25°C (H)	2.10×10^{-07} (Pa m^3 mol^{-1})
Solubility in water (S_w)	10.5 g L^{-1} (20°C)
Acid partition coefficient (pK_a)	2.34 (at 25°C)
Octanol-water coefficient (K_{ow})	6.31×10^{-4} (pH 7, 20°C)
Sorption coefficient (K_d)	209.4 mg L^{-1}
Half-life time degradation in soil (DT50)	15 days

Source: Adapted from PPDB [26].

Table 1.
Physicochemical properties of glyphosate.

is with two dissociations, thus having 50% of the molecules with three pH dissociations of 5.5. In a pH ranging from 5.5 to 10.2, there are three and four dissociations of glyphosate. Above pH = 11, the glyphosate is fully dissociated [24].

Amino acids and their derivatives present a zwitterionic behavior, that is, in its structure the carboxylic acid has a more acidic characteristics than the ammonium group. In glyphosate, phosphate and carboxylic groups have a greater acidic characteristics than the ammonium group. Cikalo et al. [28] observed the zwitterionic behavior of glyphosate when describing its dissociation. Thus, in the first dissociation of glyphosate, it would lose hydrogen linked to oxygen and only in the last dissociation that hydrogen linked to nitrogen.

5. Glyphosate-resistant weeds in Brazil

The occurrence of weed resistance to herbicides is a natural and inheritable capacity of certain biotypes within a given population to develop and reproduce after being exposed to herbicide doses that would be lethal to a normal population of the same species. This resistance is from an evolutionary process, occurring naturally at low frequency, and the selection pressure exerted by repetitive application of some herbicide or different types of herbicides that have the same mechanism of action increases the number of resistant individuals in the population. Herbicide resistance is identified when, generally, 30% of the plants are resistant [29].

Several weed species are inherently more resistant to glyphosate than others. A biotype of glyphosate resistance that occurred naturally was the *Convolvulus arvensis* without reporting the use of glyphosate [20]. A biotype of *Lotus corniculatus* resistant to glyphosate doses was identified by Boerboom et al. [30]. The natural resistance to this herbicide, these and other species, was not a problem until the emergence of glyphosate-resistant crops. With the adoption of these crops, many species became problematic because they occupied places where other weed species did not inhabit and glyphosate-resistant crops were cultivated [20].

Biotypes that have glyphosate resistance have been selected in crops such as corn, soybeans, and various orchards. In Brazil, glyphosate-resistant biotypes of *Conyza bonariensis* [31], *Conyza canadensis* [32, 33], *Conyza sumatrensis* [34], *Lolium multiflorum* [35, 36], *Digitaria insularis* [9, 37], *Chloris elata* [38], *Eleusine indica* [39], *Amaranthus palmeri* [40], and more recently *Amaranthus hybridus* [41] and *Euphorbia heterophylla* [42] were identified.

Due to the increase in the adoption of glyphosate-resistant crops, there was a great difficulty in selecting the herbicide to be used in weed populations in the past decade. The alternating herbicides that have different modes of action or herbicides mixed in tanks are recommended in resistance management programs; however, this is often ignored by farmers, because the cost to control weeds only with glyphosate is much cheaper.

It is recommended that a rotation be made between cultivating glyphosate-resistant crops and nonresistant crops, so that the development of glyphosate resistance in weeds is delayed. However, the correct use of glyphosate with other herbicides, a survey of the weed population, extension of the area, and economy of producers are important factors in the management of weeds in glyphosate-resistant crops [20].

Figure 12 shows all the species of glyphosate-resistant weeds worldwide. The first case of reported resistance was in 1996 of the species *Lolium rigidum* in Victoria, Australia. In Brazil, the first case of glyphosate-resistant weed identified was in 2003, which was the species *Lolium perenne* ssp. *multiflorum*. In 2019, four

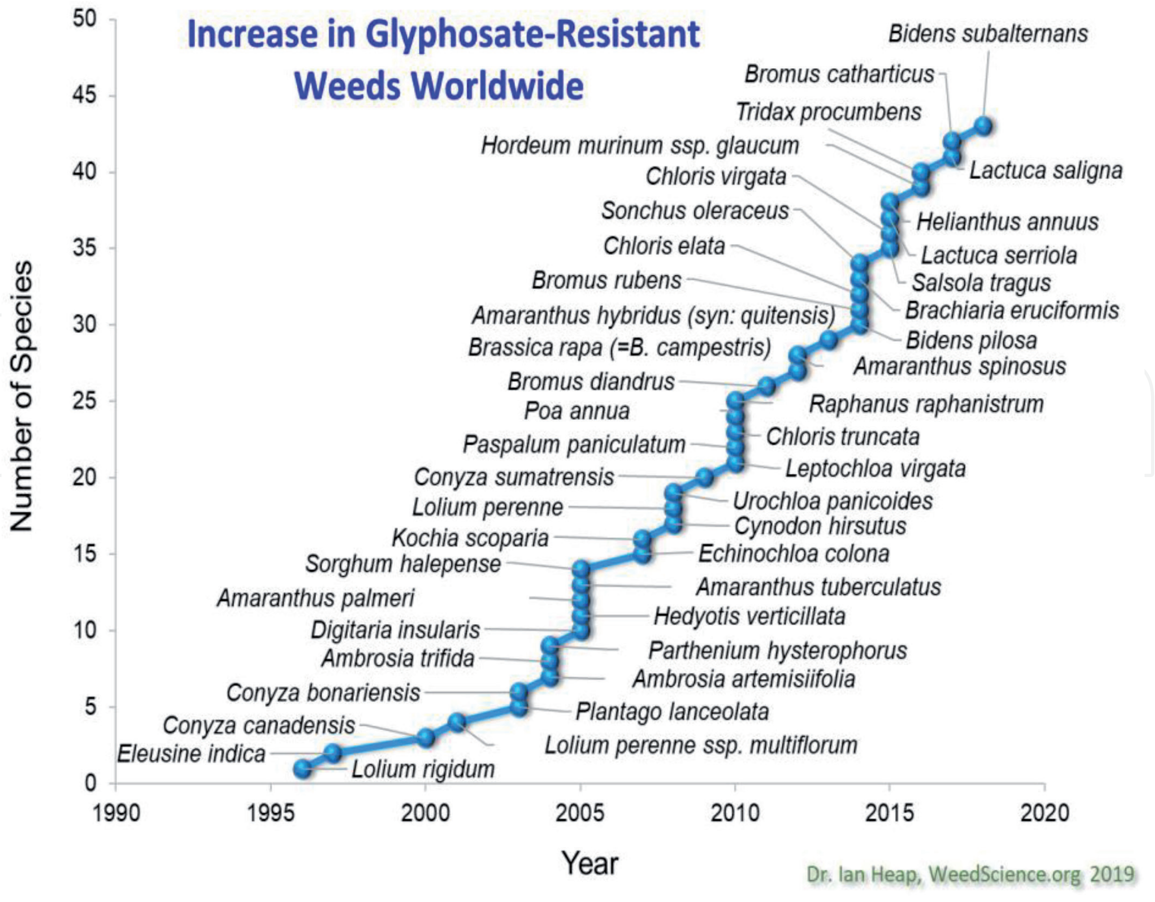

Figure 12.
Glyphosate-resistant weeds worldwide. Source: Heap [10].

cases of new glyphosate-resistant weeds were reported: in Australia, the species *Avena sterilis* ssp. *ludoviciana*; in Argentina, the species *Carduus acanthoides* which presented multiple resistance to 2,4-D and glyphosate; in Colombia, the species *Chloris radiata* which showed simple resistance to glyphosate; and also in Argentina, resistance of the species *Echinochloa crus-galli* var. *crus-galli* which was reported [10].

6. Conclusions

Among the pesticides, glyphosate is widely used in Brazil and in the world to control weeds in various crops. However, its use should be performed consciously, since there is no significant increase in the amount of weeds resistant to this herbicide. Despite its great use in the country, it presents few reports of resistant weeds than another mode of action of herbicides, such as acetolactate synthase and photosystem II (PSII) inhibitors.

Knowledge of glyphosate characteristics, weed biology, resistance mechanisms, and the production system used that favors the emergence of herbicide-resistant weed biotypes is important to appropriately manage and prevent or delay new cases of resistant weeds in the field.

Crops with glyphosate-resistant transgenic technologies will continue to be important in the future for weed management, and resistant biotypes will continue to be selected. Thus, good agricultural practices are indispensable, and more innovations in technologies are necessary for the future. Therefore, adopting a long-term weed management perspective and integration system for all agricultural practices is of paramount importance to farmers.

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References

[1] Dekker M. Economic benefits of pest management. In: Peshin R, editor. Encyclopedia of Pest Management. New York, USA: Springer; 2002. pp. 224-227. ISBN: 0618249060

[2] BRASIL. Ministério do Meio Ambiente. 2019. Available from: http://www.mma.gov.br/seguranca-quimica/agrotoxicos [Accessed: 13 December 2019]

[3] Portal São Francisco. História dos Agrotóxicos. 2019. Available from: https://www.portalsaofrancisco.com.br/biologia/historia-dos-agrotoxicos [Accessed: 13 December 2019]

[4] Pignati WA, Lima FANS, Lara SS, Correa MLM, Barbosa JR, Leão LHC, et al. Spatial distribution of pesticide use in Brazil: A strategy for Health Surveillance. Ciência & Saúde Coletiva. 2017;**22**(10):3281-3293. ISSN: 1413-812

[5] IBAMA—Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. Consolidação de dados fornecidos pelas empresas registrantes de produtos técnicos, agrotóxicos e afins, conforme art. 41 do Decreto n° 4.074/2002. Vendas de Ingredientes Ativos por UF. 2018. Available from: https://www.ibama.gov.br/agrotoxicos/relatorios-de-comercializacao-de-agrotoxicos [Accessed: 13 December 2019]

[6] ANVISA—Agencia nacional de vigilância sanitária. Nota Técnica N° 23/2018/SEI/CREAV/GEMAR/GGTOX/DIRE3/ANVISA. 2018. Available from: http://portal.anvisa.gov.br/documents/111215/117833/Nota+t%C3%A9cnica+23+de+2018+-+Glifosato/faac89d6-d8b6-4d8c-8460-90889819aaf7 [Accessed: 13 December 2019]

[7] Galli AJB. A molécula glyphosate e a agricultura brasileira. In: Velini ED, Meschede DK, Carbonari CA, Trindade MLB, editors. Glyphosate. Botucatu: FEPAF; 2009. pp. 4-493. ISBN: 978-85-98187-09-9

[8] Ferreira SD. Resistência ao glyphosate em biótipos de *Digitaria insularis* e nível de dano econômico em soja e milho. 2019. 178 f. Tese (Doutorado em Agronomia), Universidade Estadual do Oeste do Paraná, Marechal Cândido Rondon; 2019

[9] Brunharo CACG. Resistência da planta daninha capim-branco (*Chloris polydactyla*) ao herbicida glyphosate. 2014. 153 f. Dissertação (Mestrado em Ciências—Fitotecnia). Piracicaba: Escola Superior de Agricultura "Luiz de Queiroz"—Universidade de São Paulo; 2014

[10] Heap I. The International Survey of Herbicide Resistant Weeds. Available from: http://www.weedscience.org [Accessed: 13 December 2019]

[11] Kaspary TE, Lamego FP, Langaro AC, Ruchel Q, Agostinetto D. Investigation of the mechanism of resistance to glyphosate herbicide in hairy fleabane. Planta Daninha. 2016;**34**(3):555-564. ISSN: 1806-9681

[12] Vasconcelos Y. Pesticides in the Balance. São Paulo, Brazil: FAPESP; 2018. Available from: https://revistapesquisa.fapesp.br/en/2019/02/25/pesticides-in-the-balance/ [Accessed: 25 July 2019]

[13] SINDIVEG—Sindicato Nacional da Indústria de Produtos para Defesa Vegetal. Estatísticas do Setor. 2018. Available from: https://sindiveg.org.br/estatisticas-do-setor/ [Accessed: 25 July 2019]

[14] Mesquita HC, Rodrigues AP, Mendonça Júnior AF. Riscos toxicológicos

do herbicida glyphosate. Agropecuária Científica no Semiárido. 2011;**7**(2):1-5. ISSN: 1808-6845

[15] IBAMA—Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. Relatórios de comercialização de agrotóxicos. 2017. Available from: https://www.ibama.gov.br/agrotoxicos/relatorios-de-comercializacao-de-agrotoxicos [Accessed: 14 December 2019]

[16] ABRASCO—Associação Brasileira de Saúde Coletiva. Entenda o que é glifosato, o agrotóxico mais vendido do mundo. Available from: https://www.abrasco.org.br/site/outras-noticias/movimentos-sociais/entenda-o-que-e-o-glifosato-o-agrotoxico-mais-vendido-do-mundo/40996/ [Accessed: 14 December 2019]

[17] CONITEC—Comissão Nacional de Incorporação de Tecnologias no SUS. Abordagem do Paciente Intoxicado por Produtos Comerciais Formulados à base de Glifosato. Available from: http://conitec.gov.br/images/Protocolos/DiretrizesBrasileiras_Agrotoxico_Cap3.pdf [Accessed: 14 December 2019]

[18] Oliveira Júnior RS. Mecanismos de ação de herbicidas. In: Oliveira Júnior RS, Constantin J, Inoue MH, editors. Biologia e manejo de plantas daninhas. Vol. 1. Curitiba: Omnipax; 2011. pp. 141-192. ISBN: 978-85-64619-02-9

[19] Kruse ND, Trezzi MM, Vidal RA. Herbicidas inibidores da EPSPS: Revisão de literatura. Revista Brasileira de Herbicidas. 2000;**1**(2):139-146. ISSN: 2236-1065

[20] Nandula VK, Reddy KN, Duke SO, Poston DH. Glyphosate-resistant weeds: Current status and future outlook. Outlooks on Pest Management. 2005;**16**(4):183-187. ISSN: 14658933

[21] EMBRAPA—Empresa Brasileira de Pesquisa Agropecuária. Principais herbicidas indicados para cultura de milho no preparo convencional do solo e plantio direto, para controle total da vegetação. 2006. Available from: http://www.cnpt.embrapa.br/biblio/do/p_do61_15.htm [Accessed: 14 December 2019]

[22] Ferreira FA. Mecanismos de ação dos herbicidas. 2005. Available from: https://www.cnpa.embrapa.br/produtos/algodao/publicacoes/trabalhos_cba5/336.pdf [Accessed: 14 December 2019]

[23] Helander M, Saloniemi I, Saikkonen K. Glyphosate in northern ecosystems. Trends Plant Science. 2012;**17**(10):569-574. ISSN: 1360-1385

[24] Amarante Júnior OP, Santos TCR, Brito NM, Ribeiro ML. Glifosato: Propriedades, toxicidade, usos e legislação. Química Nova. 2002;**25**:589-593. ISSN: 0100-4042

[25] Roman ES, Vargas L, Rizzardi MA, Hall L, Beckie H, Wolf TM. Como funcionam os herbicidas: Da biologia à aplicação. Passo Fundo: Berthier; 2007. p. 158. ISBN: 9788589873512

[26] PPDB—Pesticide Properties Data Base. Glyphosate (Ref: MON 0573). Available from: https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/373.htm [Accessed: 14 December 2019]

[27] Sprankle P, Meggitt WF, Penner D. Adsorption, mobility and microbial degradation of glyphosate in the soil. Weed Research. 1975;**23**(3):229-234. ISSN: 1365-3180

[28] Cikalo MG, Goodall DM, Matthews W. Analysis of glyphosate using capillary electrophoresis with indirect detection. Journal of Chromatography A. 1996;**745**(1-2):189-200. ISSN: 0021-9673

[29] Christoffoleti PJ, López-Ovejero R. Principais aspectos da resistência

de plantas daninhas ao herbicida glyphosate. Planta Daninha. 2003;**21**(3):507-515. ISSN: 1806-9681

[30] Boerboom CM, Wyse DL, Somers DA. Mechanism of glyphosate tolerance in birdsfoot trefoil (*Lotus corniculatus*). Weed Science. 1990;**38**(6):463-467. ISSN: 1550-2759

[31] Vargas L, Bianchi MA, Rizzardi MA, Agostinetto D, Dal MT. *Conyza bonariensis* biotypes resistant to the glyphosate in Southern Brazil. Planta Daninha. 2007;**25**(3):573-578. ISSN: 0100-8358

[32] Moreira MS, Nicolai M, Carvalho SJP, Christoffoleti PJ. Resistência de *Conyza canadenses* e *C. bonariensis* ao herbicida glyphosate. Planta Daninha. 2007;**25**(1):157-164. ISSN: 0100-8358

[33] Lamego FP, Vidal RA. Resistance to glyphosate in *Conyza bonariensis* and *Conyza canadensis* biotypes in Rio Grande do Sul, Brazil. Planta Daninha. 2008;**26**(2):467-471. ISSN: 0100-8358

[34] Santos G, Oliveira Júnior RS, Constantin J, Francischini AC, Osipe JB. Resistência múltipla de *Conyza sumatrensis* ao chlorimuron-ethyl e ao glyphosate. Planta Daninha. 2014;**32**(2):409-416. ISSN: 0100-8358

[35] Roman ES, Vargas L, Rizzardi MA, Mattei RW. Resistance of Italian ryegrass (*Lolium multiflorum*) to glyphosate. Planta Daninha. 2004;**22**(2):301-306. ISSN: 0100-8358

[36] Vargas L, Roman ES, Rizzardi MA, Silva VC. Identification of glyphosate-resistant ryegrass (*Lolium multiflorum*) biotypes in apple orchards. Planta Daninha. 2014;**22**(4):617-622. ISSN: 0100-8358

[37] Carvalho LB, Cruz-Hipolito H, González-Torralva F, Alves PLCA, Christoffoleti PJ, Prado R. Detection of sourgrass (*Digitaria insularis*) biotypes resistant to glyphosate in Brazil. Weed Science. 2011;**59**(2):171-176. ISSN: 1550-2759

[38] Brunharo CACG, Patterson EL, Carrijo DR, Melo MS, Nicolai M, Gaines TA, et al. Confirmation and mechanism of glyphosate resistance in tall windmill grass (*Chloris elata*) from Brazil. Pest Management Science. 2016;**72**(9):1758-1764. ISSN: 1526-4998

[39] Takano HK, Oliveira Júnior RS, Constantin J, Braz GBP, Gheno EA. Goosegrass resistant to glyphosate in Brazil. Planta Daninha. 2017;**35**:e017163071. ISSN: 0100-8358

[40] Gonçalves Netto AG, Nicolai M, Carvalho SJP, Borgato EA, Christoffoleti PJ. Multiple resistance of *Amaranthus palmeri* to ALS and EPSPs inhibiting herbicides in the State of Mato Grosso, Brazil. Planta Daninha. 2016;**34**(3):581-587. ISSN: 0100-8358

[41] Oliveira C, Mathioni SM, Lemes L, Ozório E, Jauer A, Altmann T, et al. População de caruru (*Amaranthus hybridus*) resistente ao glyphosate são encontradas no Rio Grande do Sul. Boletim Informativo—SBCPD; 2019. pp. 23-25

[42] EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. Mais uma planta daninha resiste ao glifosato no Brasil. 2020. Available from: https://www.embrapa.br/busca-de-noticias/-/noticia/50622096/mais-uma-planta-daninha-resiste-ao-glifosato-no-brasil [Accessed: 18 March 2020]