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RISKS TO WORKERS' HEALTH AND GOOD OCCUPATIONAL SAFETY PRACTICES IN THE APPLICATION OF HERBICIDES IN SUGARCANE

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ABSTRACT

Brazil stands internationally as the largest producer of sugarcane, a key crop for national agribusiness. In this crop, weeds can cause serious damage, thus, making its control necessary. To this end, chemical control is mainly based on herbicides. However, the exposure of rural workers to herbicides has been associated with several health problems in these individuals. Therefore, this paper seeks to raise awareness through a bibliographic survey of the importance of sugarcane culture, herbicide use in these crops, the risks to which rural workers are exposed, and which health problems can occur by handling and applying these products, as well as the legislation that supports these workers and the challenges to ensuring this legislation's effectiveness. A literature search was conducted using the integrative review method. The deleterious effects of workers' exposure to herbicides are well reported in the literature for different active ingredients. Brazil has dense legislation in force focused on occupational safety, which, in theory, would make the handling and application of herbicides and other pesticides a low-risk activity for rural workers' health. However, unfortunately, this is not the picture seen in many agricultural regions of the country, mainly due to the lack of use of Personal Protective Equipment (PPE). Actions such as periodic training for these professionals are necessary, and a more rigorous inspection of their use should also be implemented.

Keywords: Contamination; Personal Protective Equipment; Exposure.

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INTRODUCTION

Sugarcane is an economically important crop for Brazilian agribusiness, and Brazil is the largest producer of this crop in the world (Costa *et al.*, 2021). Brazilian production corresponds to approximately 38% of the global production of this crop, and the country is also responsible for 50% of world sugar exports. Moreover, Brazil also figures as the second-largest producer of ethanol, second only to the U.S., and these two countries together account for about 90% of the global production of this fuel (Marin *et al.*, 2019).

Weed infestations are among the problems that can compromise the yield of this crop (Nazir *et al.*, 2013). To control these agents, different controls are used, especially chemical control based on herbicides (Kaur *et al.*, 2015).

Since 2008, Brazil has been the largest consumer of pesticides worldwide. In the last decade, the consumption of these products in the country increased 190% compared to previous years, growing more than double the growth rate of the global market in the same period (Rigotto *et al.* 2014). Among the pesticides used in agriculture, herbicides represent more than half of the total amount of consumption, and in Brazil, most of the pesticides applied are used in areas with sugarcane cultivation (Chagas *et al.*, 2019).

Exposure of farm workers to herbicides has been associated with several health problems in these individuals (Tsai, 2013; Mazlan *et al.*, 2016; Myers *et al.*, 2016; Islam *et al.*, 2018; Naspolini *et al.*, 2021). Farmworkers who handle and conduct herbicide and other pesticide application operations are usually exposed to high levels of contamination from these products, and this exposure occurs mainly during preparation, mixing, loading, and spray applications (Yarpuz-Bozdogan and Bozdogan, 2016; Pinto *et al.*, 2020). Still, regarding direct exposure, farmers can also be exposed to herbicides in their daily activities in the field (Mazlan *et al.*, 2016), such as during the crop care and harvesting stages (Yarpuz-Bozdogan and Bozdogan, 2016).

Therefore, this work seeks to raise through a bibliographical survey the importance of sugarcane cultivation and herbicide use in these crops, the risks to which the rural workers are exposed and which health problems are caused by handling and applying these products, and the legislation that supports these workers and the challenges to guaranteeing this legislation's effectiveness.

This bibliographic research searched national and international scientific articles and Brazilian occupational safety legislation. The integrative review method was adopted since it provides a synthesis of the knowledge available in the specialized literature and the applicability of the results of significant studies in practice (Beyea and Nicoll, 1998).

DEVELOPMENT

Sugarcane

Sugarcane (Saccharum officinarum L.) belongs to the family Poaceae, subfamily Panicoideae, and tribe Andropogoneae (Gentile et al., 2015). It is a perennial grass native to tropical Asia (Singh et al., 2015), and constitutes an important agricultural crop, being cultivated in more than 110 countries, both in tropical and subtropical regions, a fact that is due to this species thriving in a variety of climates, from hot and dry to cold and humid (Mehnaz, 2013).

This species has a thick longitudinal stem, normally three to five meters high and approximately 5 cm diameter. For its good development, it requires well-drained soil with high levels of organic matter and a warm and humid environment (Singh *et al.*, 2015). It presents a C_4 photosynthetic mechanism, making it a plant with high efficiency in transforming sunlight into usable biochemical energy, positively implying the production of sugars and biomass accumulation (Singh *et al.*, 2020).

Sugarcane is characterized by its sweet taste due to its high sucrose content. It is noteworthy that an adult plant can accumulate up to 25% of its fresh weight in the form of this sugar under normal growing conditions (Ansari *et al.*, 2013), which makes this crop the raw material for producing about 75% of the sugar consumed globally (Srivastava *et al.*, 2020). Although it is mainly grown for sugar production, this crop produces numerous value-added by-products, such as molasses, bagasse, and other items with industrial destinations to manufacture chemicals, plastics, paints, synthetics, fibers, insecticides, and detergents (Mehnaz, 2013). Furthermore, it should be noted that this crop is widely used for ethanol production, and with the growing demand for renewable energy, sugarcane has become a promising crop for bioenergy production (Gentile *et al.*, 2015). Its multiple uses make it a key crop for the regions where it is produced, providing economic growth and food security in the world's tropics and subtropics (Singh *et al.*, 2020).

Sugarcane is estimated to be grown globally on an area of more than 26 million hectares. Brazil is the world's largest producer, followed by India and China (Costa *et al.*, 2021). The areas cultivated with sugarcane in Brazil are largely concentrated in the Center-South region, especially in the state of São Paulo, the largest national producer of this crop (**Table** 1). In this state, there is an advance in sugarcane activity, which has occurred mainly in areas previously used for cattle raising and mainly through land leasing (Palludeto *et al.*, 2018). In terms of sugarcane production, the state of São Paulo's yield is equivalent to more than 80% of India's production, in addition to being higher than the sum of the

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total production of four other major world producers (China, Thailand, Pakistan, and Mexico) (Rudorff *et al.*, 2010).

Table 1. Main sugarcane producing states in Brazil

State	Planted area (ha)	Quantity produced (ton)
São Paulo	5,540,511	425,617,093
Goiás	946,985	75,315,239
Minas Gerais	944,051	72,968,836
Mato Grosso do Sul	727,753	52,245,291
Paraná	597,198	41,658,888
Alagoas	304,748	18,702,251
Mato Grosso	297,100	23,319,052
Pernambuco	228,177	12,138,197
Paraíba	97,751	5,430,290
Bahia	76,423	5,167,595

Source: IBGE (2019)

The Northeast, a region that historically had its colonization linked to sugar mills, is another important producing region of this crop. It should be noted that sugarcane productivity levels in the country's producing regions vary substantially, resulting in productivity gaps of different magnitudes (Dias and Sentelhas, 2018). Thus, states with larger planted areas, such as Alagoas, produce a lower quantity than others with smaller planted areas, such as Mato Grosso (**Table** 1).

Variations in productivity can be associated with several factors, such as the low use of inputs, the non-adoption of proper cultural practices, water deficits, the attack of pests and pathogens, and competition with weeds (Bassey *et al.*, 2021).

Weeds and herbicide use in sugarcane

Weed infestation in sugarcane fields is a serious problem for sugarcane producers since these plants compete with the crop for light, nutrients, and moisture, and serve as alternative hosts for diseases and pest insects, thus compromising yields and negatively impacting affecting cane quality (Nazir *et al.*, 2013). Yield losses caused by weeds can range from 15 to 75%, depending on the nature of the weeds and the intensity of infestation (Olaoye and Adekanye, 2006).

Thus, successful weed control is essential for economic sugarcane production. The control of these species is critical at the beginning of the cane's vegetative development when the crown has not yet closed over the inter-row spaces. It should be noted that heavy weed infestations can also interfere with the harvesting process, making this stage more expensive (Almubarak and Al-Chalabi, 2014).

Farmers usually rely on three techniques for weed management in sugarcane: manual weeding, inter-row cultivation, and herbicides. However, due to their practicality, efficiency, and the availability of formulations, herbicides are the most widely used (Kaur *et al.*, 2015).

Several herbicides are registered for this crop, with a wide range of mechanisms of action, chemical groups, and active ingredients (**Table** 2). In addition to herbicides marketed with a single active ingredient in the formula, there are also the options of herbicide mixtures formulated doubly and triply (Reis *et al.*, 2019).

Pesticides, such as herbicides, represent an important economic tool, which, in addition to saving labor, is efficient in weed management, making them widely used in most sectors of agricultural production. However, despite their popularity and extensive use, these products cause serious concerns regarding health risks due to farmers' exposure in the handling and application steps and the possible residual effect on food and environmental contamination of soil and water (Damalas and Eleftherohorinos, 2011).

Herbicides and worker health

Commercially available herbicides and those under development aim to prevent, eliminate, or control undesirable plants, thereby reducing the damage caused by these weeds and making a major contribution to agriculture worldwide. However, concerns over herbicide dangers to the environment and human health have been raised by much research conducted under *in vivo* and *in vitro* conditions (Yarpuz-Bozdogan and Bozdogan, 2016; Islam *et al.*, 2018).

Workers' exposure to herbicides occurs mainly by inhalation and dermal routes and can occur during contact with these pesticides, whether during the preparation and application stages or even while cleaning equipment and entering sprayed areas. Contamination usually occurs when herbicide handlers do not use Personal Protective Equipment (PPE) and/or when safe handling practices are not adopted (Pinto *et al.*, 2020). Thus, herbicide overdose and misuse can negatively affect human health and environmental quality (Yarpuz-Bozdogan and Bozdogan, 2016). Deleterious effects of worker exposure to herbicides are well reported in the literature for different active ingredients, such as Paraquat (Tsai, 2013), Glyphosate (Myers *et al.*, 2016), Imazapic (Mazlan *et al.*, 2016), and 2,4-D (Islam *et al.*, 2018).

Paraquat's toxicity in humans and mammals is associated with its redox potential, the same mechanism that gives it herbicidal activity. Paraquat's mechanism of toxic action involves cyclic reduction-oxidation reactions, in which reactive oxygen species are produced, and NADPH depletion is

Table 2. Mechanism of action, chemical groups, and active ingredients of the main herbicides used in the largest sugarcane production regions in Brazil

Mechanism of action	Chemical group	Active ingredient
Synthetic auxins	Phenoxycarboxylic acid	2,4-D
	Pyridinecarboxylic acid	Picloram
Inhibitors of carotenoid biosynthesis	Isoxazole	Isoxaflutole
	Triketone	Mesotrione
	Isoxazolidinone	Clomazone
ALS Inhibitors	Pyrimidinyl (thio)benzoate	Bispyribac-sodium
	Imidazolinones	Imazapic
	Imidazolinones	Imazapyr
	Triazolopyrimidine	Diclosulam
	Sulphonylurea	Ethoxysulfuron
	Sulphonylurea	Flazasulfuron
	Sulphonylurea	Halosulfuron-methyl
	Sulphonylurea	Iodosulfuron-methyl
	Sulphonylurea	Metsulfuron-methyl
	Sulphonylurea	Trifloxysulfuron-sodium
Inhibitors of fatty acid and lipid biosynthesis	Chloroacetamide	Alachlor
	Chloroacetamide	S-metolachlor
EPSPS inhibitors	Glycine	Glyphosate
Inhibitors of Photosynthesis II	Triazine	Ametryn
	Triazine	Atrazine
	Triazinone	Hexazinone
	Triazinone	Metribuzin
	Urea	Diuron
	Urea	Tebuthiuron
PROTOX Inhibitors	N-phenylphthalimide	Flumioxazin
	Diphenyl Ether	Oxyfluorfen
	Oxadiazole	Oxadiazon
	Triazolinone	Amicarbazone
	Triazolinone	Carfentrazone-ethyl
	Triazolinone	Sulfentrazone
Mitosis Inhibitors	Dinitroaniline	Pendimethalin
	Dinitroaniline	Trifluralin
Inhibitors of Photosynthesis I	Bipyridylium	Paraquat
Unknown	Organoarsenical	MSMA

Source: Reis *et al.* (2019)

reduced (Tsai, 2013), which confers high toxicity to humans (Naspolini *et al.*, 2021). If swallowed, Paraquat produces a burning sensation in the mouth and throat, leading to nausea, vomiting, and diarrhea. Even though it is not significantly absorbed by human skin, if intact, direct contact with Paraquat solutions or aerosols can cause skin burns and dermatitis. The main sites of accumulation of this herbicide in the human body are the lungs and kidneys because these two organs are more susceptible to Paraquat-induced damage. Experimental studies in animals and epidemiological evidence also indicate that chronic exposure to this herbicide may be associated with the development of Parkinson's disease (Tsai, 2013). This history of damage to human health has led to Paraquat being banned or severely restricted in more than 20 countries worldwide. However, it was not until September 2020 that Brazil joined the list of countries that banned it, even though its use in some Brazilian crops was still allowed until July 2021 (Naspolini *et al.*, 2021).

Glyphosate's mode of action that confers herbicidal activity is inhibition of an extremely important plant enzyme, 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS). This enzyme is part of the shikimic acid pathway (conversion of shikimate-3-phosphate to EPSP), which is required for producing the aromatic amino acids that govern several essential metabolic processes in plants, fungi, and some bacte-

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ria (Myers *et al.*, 2016; Van Bruggen *et al.*, 2018). Since this EPSPS-controlled pathway does not exist in vertebrate cells, it was assumed that glyphosate would pose minimal risks to mammals (Myers *et al.*, 2016; Agostini *et al.*, 2020). However, several studies have shown that this herbicide can negatively affect mammalian biology through various mechanisms. Scientific evidence indicates that several vertebrate pathways are likely targets of glyphosate action, which can generate, among other damages, hepatorenal damage, effects on nutrient balance, and endocrine dysregulation (Myers *et al.*, 2016), as well as correlations have been found between increased glyphosate use and a wide variety of human diseases, including various forms of cancer (Van Bruggen *et al.*, 2018).

Imazapic herbicide has shown a low level of risk to farmers exposed to its use. However, the improper use of PPE by farmers, the lack of knowledge about the use, and the use of inadequate dosages may lead to a potential health risk for individuals exposed to this herbicide. Thus, a differentiated approach should be considered to ensure the proper use of safety measures among farmers (Mazlan *et al.*, 2016).

2,4-D is a herbicide that has been commercially available since the 1940s and is toxic to a variety of organisms, ranging from bacteria to vertebrates (Lakind *et al.*, 2017). Farmworkers are exposed to 2,4-D through inhalation, non-dietary ingestion, and dermal contact. Although there is ample evidence that exposure to 2,4-D causes adverse health effects in animals and humans, the mode of action leading to this herbicide-induced toxicity remains unknown. At the molecular level, 2,4-D targets the cellular microtubule networks of the lung, leading to disruption of the cell cytoskeleton and promoting the generation of reactive oxygen species. Short-term exposure to 2,4-D can also affect vital cell function and lead to the development of emphysema and chronic obstructive pulmonary diseases that lead to shortness of breath, coughing, and chest pain. In addition, the male reproductive system is sensitive to 2,4-D, which contributes to the severity of infertility problems (Islam *et al.*, 2018).

Therefore, actions such as the use of Personal Protective Equipment (PPE), use of the manufacturer's recommended dose, and good application practices are some of the practices necessary to minimize the potential negative effects of using these products on workers' health and on maintaining environmental quality (Yarpuz-Bozdogan and Bozdogan, 2016; Pinto *et al.*, 2020).

Legislation and good practices in herbicide application

Most herbicide applications are carried out in the sugarcane crop using tractor-mounted boom sprayers (Machado Neto *et al.*, 2007). The other producers use a knapsack sprayer, exposing them to the same risks due to contact (Ignácio *et al.*, 2016). The correct application of pesticides requires the mastery of specific knowledge for the handling and correct placement of the product on the target, thus avoiding contaminating the application environment and the worker. A major concern when applying these products is the part of them that is not retained on the target, called drift, which is dispersed in the environment and can reach and contaminate both non-target organisms and the exposed worker. Drift thus results in a real risk of environmental and human intoxication (Machado Neto *et al.*, 2007).

Regarding the occupational risks generated by herbicide application, they can cause acute or chronic poisoning, resulting in manifestations in the body in various ways, such as headaches, stomach pain, drowsiness, dizziness, weakness, disturbed vision, excessive saliva, sweating, difficulty breathing, and diarrhea. In the chronic form, the manifestation of the effects of intoxication is slower and may appear months or even years after exposure to the product (Ignácio *et al.*, 2016).

The working conditions to which workers are subjected are composed of the environment where the activities are performed and the material components used by workers to perform their work activities. Safety measures, in turn, can be grouped into two classes: preventive and protective, which can be grouped into individual and collective (Machado Neto *et al.*, 2007). Individual safety measures are related to the care inherent in the worker's body, while collective measures are linked to the work environment in which the activities involving pesticides are performed. These safety measures act mainly as shields in the path of the herbicide. The application of collective safety measures occurs in machinery and equipment, management, and agronomic recommendations and operational procedures, thus aiming to contribute to the reduction of potential exposure (Momesso and Machado Neto, 2003; Machado Neto *et al.*, 2007).

Safety measures applied to working conditions with herbicides can be further classified into passive and active. Passive safety measures reduce the actual exposure to risks, whereas active measures reduce the potential exposure provided by the working conditions and, consequently, the actual exposure. Passive safety measures can be individual and collective, while active measures are only collective (Momesso and Machado Neto, 2003).

These protective measures, aimed at controlling occupational exposures to pesticides, act to prevent the contact of these products with the exposure pathways of the body (Oliveira and Machado Neto, 2003). Thus, in general, the first safety measure recommended for those who work with pesticide handling and application is the use of Personal Protective Equipment (PPE) (Momesso and Machado Neto, 2003; Oliveira and Machado Neto, 2003).

The obligation to provide PPE to workers was initially described in the Consolidation of Labor Laws, Law No. 5,452/1943, and later in Decree No. 3,214/1978 by Regulatory Norm (NR). Every device or product for individual use by workers to protect against risks that may endanger worker's safety and health is considered a PPE (Cargnin *et al.*, 2017). In March 2005, Regulatory Norm No. 31 (NR-31) came into force to ensure the protection of rural workers' health and the correct application of chemical pesticides in agriculture, livestock, forestry, and aquaculture activities. NR 21 emphasizes that the rural employer or similar should provide training on technology and accident prevention with pesticides to all workers directly exposed to them and describes the PPE to be used according to the needs of each work activity. This standard ensures the protection of workers who deal directly with these products and those exposed to them indirectly, such as those who circulate near the places where these products are handled or workers who perform activities in newly treated areas.

Regarding personal protection measures for the application of pesticides, such as herbicides, NR 21 requires the rural employer to provide workers with Personal Protective Equipment (PPE) free of charge. **Chart 1** shows some of the main types of protection and equipment required for workers' safety in handling and applying pesticides.

Besides Regulatory Norm No. 31, Brazil has dense legislation focused on occupational safety, which theoretically would make the handling and application of herbicides and other pesticides an activity of low risk to the worker's health. However, unfortunately, this is not the picture seen in many countries' agricultural regions.

Challenges for implementing good practices in herbicide application

Given the above, the safe use of pesticides requires the correct use of Personal Protective Equipment (PPE). However, a major problem present in Brazilian crops is the under-utilization or inefficient use of this equipment, which represents a great danger to the health of the applicator, resulting in a considerable increase in the number of poisonings (Monquero *et al.*, 2009).

PPE use in pesticide application in Brazil shows different patterns, with different results among producing regions and among the profiles of employers. In a field study at a sugarcane plant in the municipality of Edéia, Goiás, Ignácio *et al.* (2016) discovered that everyone is aware of the importance of wearing personal protective equipment during the activities. In this case, the PPE considered standard is caps, goggles, gloves, safety boots, respirator, coveralls, and apron/jacket, whose use was reported by 100% of respondents for applying pesticides, such as herbicides. It is noteworthy that although the use and awareness are well established among these workers, they pointed out that using PPE causes several discomforts regarding the intense heat and open-air work.

The discomfort of using PPE is also reported in other works as an obstacle listed by workers for not using such protective equipment (Monquero *et al.*, 2009; Zorzetti *et al.*, 2017). In a study in Araras, São Paulo, an important sugarcane producing area in Northwest São Paulo, Monquero *et al.* (2009) found that 22.2% of the interviewed farmers did not use any PPE. The main reasons given by respondents for not using personal protective equipment were that the standard PPE is too hot, uncomfortable, and hinders breathing and mobility.

Another major problem is the partial use of PPE. Zorzetti *et al.* (2017), in a survey in municipalities located in the North Central region of Paraná, a region also with sugarcane crops, found that all respondents said they knew what PPE was, but 23% said they did not use this equipment during their work. Among the 77% of respondents who said they adopted PPE as a protection method, more than half (54%) did so incompletely and only when they considered the product very toxic did they try to use all the equipment.

This precarious use of PPE by Brazilian rural workers has become a major public health problem, mainly due to the effects resulting from this exposure (Silva and Amorim, 2020). By not using PPE or using it only partially, the worker is subject to the absorption of the active ingredients of herbicides, which can occur through the respiratory, dermal, and oral tracts, possibly causing acute or chronic poisoning (Cargnin *et al.*, 2017). This problem is even more persistent in small farms, where it is common to find workers without the mandatory PPE during the handling and application of these products (Silva and Amorim, 2020).

The criticism related to the discomfort of working with PPE is a known technological problem, which should receive more attention from the responsible bodies, towards the development of more comfortable versions to encourage the full use of this equipment (Zorzetti *et al.*, 2017). Added to this scenario, another reason for the non-use of PPE by workers is the rural worker's lack of knowledge of the importance of this equipment, which often occurs because the employer does not offer proper training to these workers, even though this is a legally required action. Still, the lack of supervision and incentive for using preventive measures is also a reason for non-adherence to PPE use (Alves and Guimarães, 2012).

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Protection Type	Equipment
Head, eye, and face protection	Helmet against impacts from falling or thrown objects;
	Hat or other protection against sun, rain, and splashes;
	Impermeable and resistant protectors for work with chemical products;
	Face protectors against injuries caused by particles, splashes, chemical vapors, and intense light radiation;
	Goggles against injuries from particle impact, or from sharp or pointed objects and splashes;
	Glasses against irritation and other injuries.
Hearing protection	Ear protectors for activities with unhealthy noise levels.
Airway protection	Respirators with mechanical filters; respirators with chemical filters; respirators with combined filters; insulating, self-contained, or air supply equipment for workplaces where there is a reduction in oxygen content.
Upper limb protection	Protective gloves and sleeves.
Lower limb protection	Waterproof, slip-resistant boots, with toecap, long shaft, leggings.
Full body protection	Aprons, jackets and coats, overalls, vests or signal strips, special clothing for specific activities.
Fall protection with level difference	Safety belts and straps.

Chart 1. Type of protection and individual protection equipment to minimize the impacts on the worker's safety and health
Source: Regulatory Norm No. 31

FINAL CONSIDERATIONS

The use of herbicides in sugarcane has increased in Brazilian plantations, contributing to obtaining better production results. However, due to the chemical characteristics of these products, they can compromise rural workers' health, which can be avoided or minimized if occupational safety actions are employed, such as the proper use of Personal Protection Equipment (PPE).

The Brazilian legislation ensures worker protection when handling and applying pesticides such as herbicides. Regulatory Norms, such as NR 21, show the employer's obligation to offer free PPE to rural workers. However, due to the lack of awareness of many workers and the lack of supervision by the responsible bodies, there are still several cases of non-use or partial use of this equipment, leading to health damages for these workers and greater contamination potential of these individuals, which will reflect negatively on the image of companies, in addition to economic and legal costs.

Given the need for measures to mitigate the contamination of rural workers by herbicides, and considering the problem of the difficulty of PPE use by many workers, actions such as periodic training with these professionals are necessary. Moreover, a more rigorous inspection of use should also be implemented. To this end, employers could implement a program of good practices and occupational safety, setting goals and encouraging the achievement of these goals.

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