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A Comparison of Maximum Permissible Concentrations for Pesticides in Brazilian Water Supply

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Abstract. Pesticides have been used for a long time in agriculture to prevent the growth of undesired organisms. However, depending on the type of production (i.e., conventional, organic, and regenerative), they might not be applied. Adequate types and uses of pesticides should not cause any damage to any non-target species or environments due to the exposure to it, especially if all farming operations have been done properly. Reversely, when pesticides are applied in inappropriate time, amount or technique, they may cause several impacts, among which is water contamination. Brazil stands out worldwide for its agricultural potential, but it is exposed to risks concerning the water supply security to its population. The current study is a comparison of the Maximum Permissible Concentrations (MPC) for pesticides in potable water supply in Brazil with the values set in the United States, Canada, European Union countries, Japan, and the guidelines issued by the World Health Organization. The regulations of each country were used, as well as the trading, consumption and agricultural production data. The Brazilian regulation is the one accounting for the largest number of pesticides. However, their MPC is 5,000 times more permissible than that from the European Union for the herbicide known as glyphosate, 300 times than that for 2,4-d and 20 times than that for atrazine. Finally, it was possible to observe the relevance of revising the regulation and public policies in place to minimize the indiscriminate use of pesticides in Brazil and adapt these compounds to the standards in a global level.

Key words: Water quality parameters, drinking water, contamination, pesticide.

Introduction

The evaluation of water quality is an important component of any effective health and environment protection policy (World Health Organization – WHO, 2017). This topic has gained global relevance and it has been associated with the United Nations (UN) Sustainable Development Goals (UN, 2015). As countries grow and develop, pollution caused by human activities tends to become more complex and intense (Damania *et al.*, 2019). Agriculture stands out among anthropic activities capable of affecting the quality of water resources. The agricultural sector is accountable for 70% of water use in the world, which plays an important role in its contamination. Among the agricultural contaminants are nutrients, salts, sediments, organic carbon, pathogens, metals, pharmaceutical residues and pesticides (Food and Agriculture Organization of the United Nations – FAO, 2017).

Pesticides can be defined as agents used to protect crops against weeds, pests and diseases (Mohamed & Paleologos, 2018). These agrochemicals can affect the hydrological cycle through different ways. Whenever water contamination takes place, one can expect to witness a whole series of negative sanitation and environmental impacts (Parween & Jan, 2019). Previous studies have shown correlations between human exposure to pesticides and the emergence of health issues. Among the main damages caused by such an exposure, one can mention breathing issues,

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skin and mucosal rashes, neurological and cognitive disorders, hormonal disorders, immunological diseases and cancer (Boulomytis & Bresaola Junior, 2013; Lopes & Albuquerque, 2018; Ji *et al.*, 2020; Lee & Choi, 2020; Taiwo, 2019). Thus, water contamination caused by pesticides is a relevant issue at local, regional and global scales (Sharma *et al.*, 2019).

According to the National Health Foundation – FUNASA (2014), the water quality parameters are established indicators for each type of water usage. Considering the specificities of each country or region, it is essential to establish regulatory frameworks and water quality parameters (WHO, 2017).In Brazil, these parameters must be continuously monitored by the agencies that are responsible for water supply, and informed to the National Program of Water Quality Monitoring for Human Consumption, according to the Ordinance No.888 (Brazil, 2021). The referred program is known as VIGIAGUA, and acts through the Information Monitoring System of Water Quality for Human-Consumption (SISAGUA) (Brazil, 2022a; Barbosa, Solano & Umbuzeiro, 2015).

The Ordinance No. 888 (Brazil, 2021) has extended the number of pesticides that must be monitored by a specific plan from 27 to 40. The list includes agrochemicals that may have negative impact on the human health and environment. Thus, an effective pesticide usage control is essential for the Brazilian population, given the intrinsic toxicity and large amount of pesticides used in the country (Chapman *et al.*, 2016). The monitoring of these substances allows the performance check of mitigation measures applied to uncontrolled usage (restricted usage, alternative application practices and pest management) and, the identification of time patterns and abnormalities in concentrations of monitored compounds (Chow *et al.*, 2020).

According to SISAGUA (Brazil, 2022a), only 618 Brazilian municipalities provided data about pesticides to the monitoring system in 2019, where more than 4,730 municipalities recorded agricultural production values higher than 1 million Brazilian reais (BRL) in the same year (which corresponds to about US$ 200,000 in 2023) (Brazil, 2022a; Brazilian Institute of Geography and Statistics – IBGE, 2023). On the other hand, data from the Ministry of Agriculture, Livestock and Supply have shown unprecedented increase in registers granted to new pesticides to be used in the country. In 2001, 33 new pesticides were registered in the country, whereas the number of new registers granted in 2021 reached 362 (Brazil, 2022b). Accordingly, the risk to human health and to the environment due to the growing numbers of registered pesticides, lack of appropriate monitoring of planting sites and usage of pesticides in these regions, have been growing since then.

Finally, the aim of the present study is to assess and discuss about the differences in Maximum Permissible Concentrations (MPCs) recorded for pesticides according to the water quality parameters established for human consumption in Brazil, in comparison to the MPCs adopted by the United States, Canada, European Union countries and Japan, and the guidelines issued by the WHO (2017). Altogether, these countries accounted for 47% of the world's pesticide consumption in 2020. The United States and Brazil were the leaders in pesticide consumption in that year, although they were important sources of agricultural imports to the European Union, Japan and Canada (Ministry of Agriculture, Livestock and Supply – MAPA, 2023; USDA, 2023). The productions of these countries are relevant to the global chain and the consumption of agricultural products. Thus, this study evaluates how the restrictive parameters, for the presence of pesticides in potable water, are seen as a guarantee for water security. It also points out factors that can contribute to water contamination by pesticides, despite the existence of restrictive MPC.

Materials and Methods

Agricultural production and pesticide-using analysis

Information about the agricultural production and the use of pesticides in Brazil, USA, European Union, Canada and Japan were considered in order to evaluate how the MPC restriction level can be related to these factors. The Corporate Statistical database of the Food and Agriculture Organization of the United Nations (FAO) was accessed to gather such information (FAO, 2023). Data about primary cultivation production (tons) from 2021 were also used, as well as data on pesticide usage per cultivated area (tons) from 2020, worldwide. This dataset allowed identifying and ranking at the global scale the herein assessed countries based on their agricultural production and on total pesticides per cultivated areas, and on their participation in the amount of produced food. By dividing the use of pesticides in 2021 (tons) by agricultural production in 2020, the usage-production ratio was calculated for each evaluated country.

Survey on the quality parameters applied to pesticides in human consumption water

The information used for the MPC analysis was collected in regulations related to human-consumption water quality parameters adopted in Brazil, in the European Union (EU), in the USA, Canada and Japan, and in the WHO guidelines (Table 1).

The pesticide parameters of the USA were gathered from National Primary Drinking Water Regulations (NPDWR), according to the United

Table 1

Regulations on human-consumption water quality parameters in Brazil, USA, Canada, Japan, European Union countries, and in guidelines by the World Health Organization

Countries	Regulation	Author
Brazil	Ordinance No. 888/2021	Ministry of Health
USA	National Primary Drinking Water Regulations	United States Environmental Protection Agency – USEPA
Canada	Drinking Water Guidelines	Health Canada
EU	Directive No. 2184/2020	European Council and Parliament
Japan	Waterworks Act	Ministry of Health, Labor and Welfare
WHO	Guidelines for Drinking Water Quality	World Health Organization

Source: Adapted from Brazil (2021), USEPA (2022), Health Canada (2022), EU (2020), Japan (2022), and WHO (2017).

States Environmental Protection Agency (USEPA, 2022). In the European Union, the water quality standards for human consumption are defined by the Directive No. 2184 (2020), from, updated from the Directive No. 83 (1998)(EU, 2020). The Canadian Drinking Water Quality Guidelines were established by Health Canada, in collaboration with the Federal-Provincial-Territorial Committee on Drinking Water (Health Canada, 2022). In Japan, the water quality standards were established by the Ministry of Health, Labor and Welfare, and the pesticide parameters were collected from the respective database (Japan, 2022). The drinking water parameters defined by WHO were collected from their own guidelines (WHO, 2017).

Comparison of Maximum Permissible Concentrations set for human consumption water

Regulations were compared to each other to identify the differences between water-quality parameters set for pesticides in the herein analysed countries. The MPCs for pesticides, the number and the type of active ingredients were collected from each the regulation. The MPCs regarding the active ingredients from the Brazilian regulation were compared to those in at least one of the countries of the current study. The number of active ingredients listed in the assessed regulations was also compared. Given the differences in volume/concentration units adopted by the analysed regulations, the MPCs were standardized in ($\mu g\ L^{-1}$).

Statistical Analysis

A statistical analysis was carried out to verify the existence of differences between the MPCs established for pesticides that are considered in Brazil and in at least one of the other countries analysed. The null hypothesis (H_0) was that there are no significant differences between the CPMs established in Brazil, the United States, the European Union, Canada, Japan and the WHO Guidelines. The alternative hypothesis (H_1) is that there are differences between the MPCs established in these countries. The Analysis of Variance (ANOVA) method was used at a significance level of 5% ($p= 0.05$) to test the null hypothesis. The Tukey test was applied, also at a significance level of 5%, to see where the possible differences exist between the sets of MPCs in each country.

Analysis about the current trade scenario and register of active ingredients provided by the Brazilian regulation

We also assessed the sales and *status quo* of registers granted to active ingredients listed among water quality parameters in Brazil. Such analysis aimed at identifying active ingredients that have already left the Brazilian market and/or that have had their registers for use cancelled for any reason, but that remain among Brazilian water-quality parameters.

The total trade of active ingredients (in tons) listed among the water-quality parameters for human consumption in 2020 was additionally assessed. To do so, we assessed the Brazilian annual pesticide production, imports and exports reports provided by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA, 2020).The current situation of registers for the use of active ingredients in Brazil was determined after the investigation of the National Agency of Sanitary Surveillance (ANVISA) documents.

Results

Agricultural production and usage of pesticides

Considering Brazil, United States, Canada, European Union and Japan, Figure 1 shows the spatial distribution of agricultural production in 2021 and the usage of pesticides in 2020 (FAO, 2023). Map (a) shows agricultural production (in tons) in each

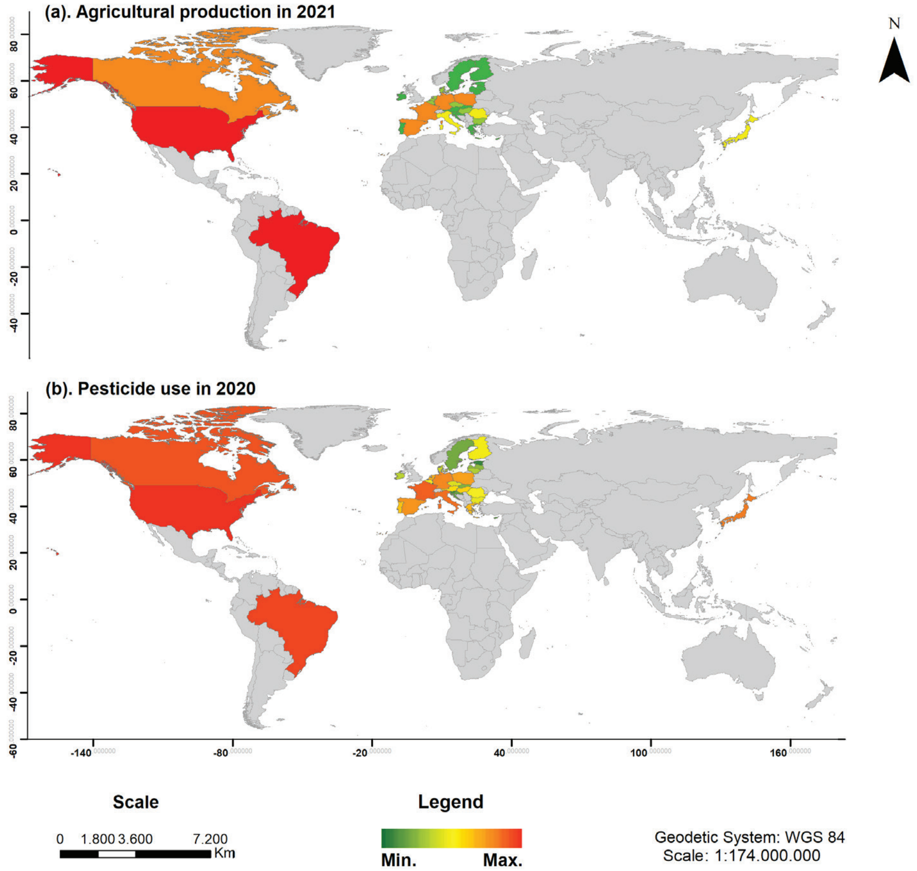

Figure 1. Distribution of (a) agricultural production in 2021 and (b) usage of pesticides usage in 2020, in Brazil, USA, Canada, Japan and European Union countries.

Source: Authors based on FAO (2023).

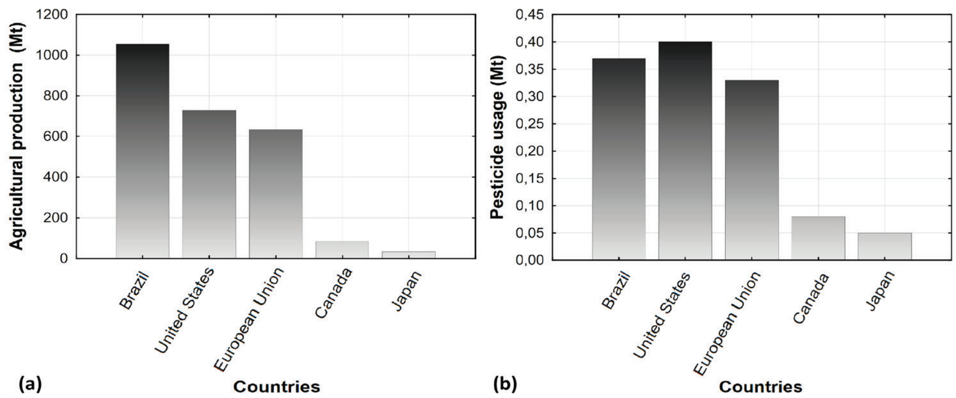

Figure 2. (a) Agricultural production in 2021; (b) pesticide usage in 2020. Brazil, USA, European Union, Canada and Japan.

Source: Authors based on FAO (2023).

country analysed, while map (b) shows the amount of pesticides used (in tons). The values are represented from minimum to maximum according to the colour scale.

The world agricultural production in 2021 reached 9,356,579,372 tons. Brazil and the USA were the 3rd (1,054,587,286 tons) and 4th (729,361,009 tons) largest agricultural producers in the globe in that year, and the 1st and 2nd largest countries among the herein assessed countries, respectively. Altogether, these two countries accounted for approximately 19% of the total world production. Canada was the 4th largest producer among the analysed countries, whereas Japan ranked the 5th position in this ranking. Figure 2 shows the variations among agricultural production and pesticide use for all countries.

In case we considered the European Union as a single entity, it would represent the 5th largest world agricultural producer in 2021, totalizing 631,882,763 tons. Among the countries considered in the study, it would rank in the 3rd position. However, it was exceeded by more than 422 million tons by the Brazilian production and by more than 97 million tons by the American production. If we analysed the associate countries in separate, France and Germany would be the 3rd and 4thlargest producers, and the 1st and 2nd among EU members; altogether, they represent 35% of the EU production.

As for the use of pesticide, the USA and Brazil were the 1st and (407,779 tons) and 2nd (377,176 tons) largest pesticide users per cultivated area in 2020, among the analysed countries, respectively, and worldwide. Together, these two countries account for 29% of the 2,646,972 tons of pesticides used in the world in 2020, and for 63% of the 1,243,055 tons used by the countries selected for the current analysis. Canada ranked the 3rd position on the usage of pesticide among the analysed countries. However, the used amount was 5 times lower than that recorded in the US, and 4 times lower than that recorded in Brazil. Japan ranked the 6th position in pesticide usage in 2020 among the analysed countries; the amount used in Japan in that year was 7 times lower than the total amount used in the USA and in Brazil.

The European Union used 325,309 tons of pesticides in 2020, and this amount corresponded to 26% of the usage recorded for all assessed countries and to 12% of the world consumption of pesticides. France and Italy were the main pesticide consumers among the European Union countries (65,216 tons and 56,556 tons, respectively). The amounts used in these countries were 5 times lower than those used by the USA and Brazil. Considering the usage-production ratio, Japan was the country ranking the 1st position in tons of used pesticides. The country recorded the ratio of 0.0015 ton of pesticide usage to each ton of agricultural products. Canada recorded the second highest value for this ratio, with 0.0010 ton of pesticide usage for each ton of agricultural products. The USA and EU presented 0.0006 (3rd largest) and 0.0005 (4thlargest) ton of pesticide usage per ton of agricultural products, respectively. Brazil was the country accounting for the lowest value in this parameter, only 0.004 ton of pesticide usage per ton of agricultural products. The value recorded for Japan is more than3 times higher than that observed in Brazil.

Comparison of Maximum Permissible Concentrations

The MPCs are summarized in Table 2. They were observed in Brazil, and in other countries based on the water quality parameters of the Brazilian regulation. Table 2 also presents the sales ranking position of the pesticides in each country in 2020.In total, 76 pesticides were screened in the assessed regulations. Brazil was the country with the highest number of pesticides listed in quality parameters. Its parameters encompass 40 compounds, whereas WHO's guidelines only mention 30. The USA has 22 compounds and Canada, 12. The EU and Japan have approaches different from those adopted in the other countries. The EU only has 4 compounds with specific parameters (aldrin, dialdrin, hetachlor and heptachlor epoxide), whereas there are 2 general parameters for pesticides, namely: Pesticides and Total pesticides. Japan, in its turn, gathers all pesticides in only one single parameter called "pesticides", whose monitoring is optional.

Overall, 14 of the 40 pesticides listed in the Brazilian human-consumption water quality parameters are also taken into account, at least, in one of the other countries. Among them, 11 pesticides have more restrictive MPCs in Brazil than in the US, Canada and Japan, namely: 2,4-d, atrazine, carbofuran, chlordane, chlorpyrifos, dimethoate, glyphosate, malathion, metribuzin, picloran and simazine. The active ingredient aldrim has equal amount of MPCs for pesticides in Brazil and in the US. Only 2 pesticides (among those listed in the regulations from Brazil and at least from one of the aforementioned countries) have more restrictive parameters: alachlor, in Canada; and lidane, in the US. The fixed value recorded in the USA is of, at most, 0.10 μg $L^{-1}$of pesticide for human-consumption water. This is more restrictive than that provided on the analysed regulations.

Lastly, 16 of the 30 pesticides listed in the WHO guidelines are found in the Brazilian regulation: glyphosate, 2,4-d, atrazine, chlorpyrifos, trifluralin, simazine, dimethoate, alachlor, carbofuran, aldicarb, aldrin + dieldrin, chlordane, DDT, hydroxyatrazine, metolachlor, and molinate. Among those, glyphosate, atrazine, dimethoate and hydroxyatrazine are the most restrictive in Brazil, whereas all others present MPCs equal to those listed by WHO. The Japanese regulation is the most permissible one, as it establishes 1,000 μg L^{-1} MPC for all pesticides that are used in the country.

From the analysis of variance, an F-value of 5.74929 and a p-value of 0.000270 were obtained, indicating that there is at least one significant difference between the sets of MPCs for each country. Therefore, H_0 is rejected and H_1 is accepted, as given in Table 3.

The Turkey test showed that the single MPC established in Japan, of 1000 μg L^{-1} for all pesticides,

Table 2

MPC for pesticides in drinking water established in Brazil, USA, EU, Canada, Japan and the WHO guidelines

Active ingredient	Total sales in 2020 (tons)	Position in the sales ranking (2020)	Register situation (*)	MPC BR (μg L^{-1})	MPC USA (μg L^{-1})	MPC EU (μg L^{-1})	MPC CAN (μg L^{-1})	MPC JP (μg L^{-1})	MPC WHO (μg L^{-1})
Glyphosate	246,017	1	A	500	700	-	280	-	900
2,4-d	57,598	2	A	30	70	-	100	-	30
Mancozeb	50,527	3	A	6	-	-	-	-	-
Atrazine	33,321	4	A	2	3	-	5	-	100
Chlorothalonil	24,191	6	A	45	-	-	-	-	-
Malathion	15,702	7	A	60	-	-	190	-	-
Chlorpyrifos	8,865	10	A	30	-	-	90	-	30
Diurom	7,902	12	A	20	-	-	-	-	-
Carbendazim	7,789	13	A	120	-	-	-	-	-
Picloram	4,444	18	A	60	500	-	-	-	-
Tebuconazole	4,353	20	A	180	-	-	-	-	-
Ametrine	3,665	27	A	60	-	-	-	-	-
Thiamethoxam	3,411	29	A	36	-	-	-	-	-
Prothioconazole	2,800	33	A	3	-	-	-	-	-
Cyproconazole	2,660	36	A	30	-	-	-	-	-
Difenoconazole	2,556	38	A	30	-	-	-	-	-
Fipronil	2,000	42	A	1	-	-	-	-	-
Thiodicarb	1,982	43	A	90	-	-	-	-	-
Trifluralin	1,706	48	A	20	-	-	-	-	20
Profanophos	1,300	56	A	0.3	-	-	-	-	-
Epoxiconazole	1,064	65	A	60	-	-	-	-	-
Tiram	670	73	A	6	-	-	-	-	-
Metribuzim	637	76	A	25	-	-	80	-	-
Flutriafol	595	79	A	30	-	-	-	-	-
Simazine	490	85	A	2	4	-	-	-	2
Propargitus	475	87	A	30	-	-	-	-	-
Dimethoate	169	126	A	1.2	-	-	20	-	6
Terbuphos	39	179	A	1.2	-	-	-	-	-
Alachlor	0	-	A	20	2	-	-	-	20
Carbofuran	0	-	A	7	40	-	-	-	7
Aldicarb	-	-	E	10	-	-	-	-	10
Aldrin + dieldrin	-	-	E	0.03	-	0.03	-	-	0.3
Chlordane	-	-	E	0.2	2	-	-	-	0.2
DDT	-	-	E	1	-	-	-	-	1
Hydroxyatrazine	-	-	E	120	-	-	-	-	200
Lidane	-	-	E	2	0.2	-	-	-	-
Methamidophos	-	-	E	7	-	-	-	-	-
Metolachlor	-	-	E	10	-	-	-	-	10
Molinate	-	-	E	6	-	-	-	-	6
Paraquat	-	-	E	13	-	-	-	-	-
Pesticides	-	-	-	-	-	0.1	-	1,000	-
Total Pesticides	-	-	-	-	-	0.5	-	-	-

Note (*): A – active register; E – excluded register; '-'which refers to null values.

Source: Authors based on the National Health Surveillance Agency – ANVISA (2023), Brazilian Institute of Environment and Renewable Natural Resources – IBAMA (2022), Ministry of Health (2021), USEPA (2022), Health Canada (2022), EU (2020), Japan – Ministry of Health, Labor and Welfare (2022), WHO (2017).

Table 3

Descriptive statistics of the MPC values established for the pesticides covered by the Brazilian regulations and those of at least one of the other assessed countries

Country	n*	Mean ($\mu g\ L^{-1}$)	Standard Deviation ($\mu g\ L^{-1}$)	Standard Error ($\mu g\ L^{-1}$)
Brazil	20	45.3	110.9	24.8
WHO	16	83.9	223.7	55.9
European Union	3	0.23	0.24	0.14
USA	9	146.8	262.8	87.6
Canada	7	109.3	96.4	36.4
Total sample	56	95.2	213.8	28.5

Note (*): n – number of samples.
Source: Authors.

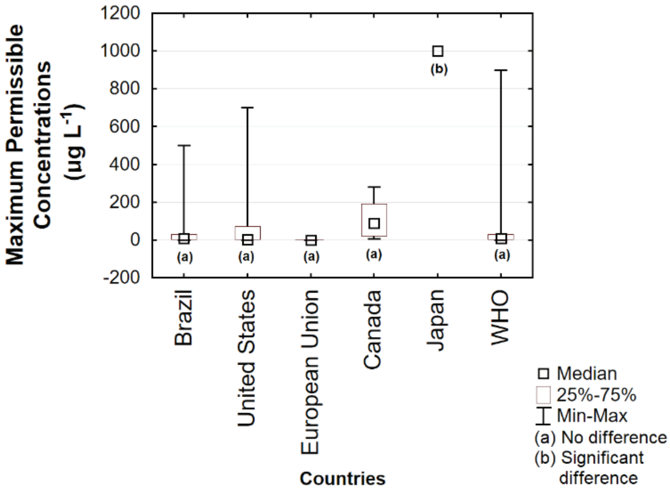

Figure 3. Distribution of MPCs observed in Brazil and in the USA, EU, Canada, Japan and in the WHO Guidelines, containing their median, 25% and 75% quartiles, minimum and maximum values and existence (a) or non-existence (b) of significant differences.

Source: Authors based on Brazil (2021), USEPA (2022), Health Canada (2022), EU (2020), Japan (2022), and WHO (2017).

differs statistically from the other assessed countries. Figure 3 shows the distribution of MPC values for each country. Averages followed by the same letters (a) do not differ statistically from the others.

Based on this result, it is possible to state that the MPCs established in the USA, the European Union, Canada and the WHO Guidelines for pesticides that are also considered in Brazilian regulations show no statistically significant difference between them.

Trading and register

Results recorded for the trade of active ingredients listed in the Brazilian regulation point out that some compounds stand out for their sales rates. The following active ingredients are 7 of the 10 most traded compounds in 2020: glyphosate (1st), 2,4-d (2nd), mancozeb (3rd), atrazine (4th), chlorothalonil (6th), malathione (7th) and chlorpyrifos (10th). Conversely, active ingredients, such as aldicarb, aldrim + dieldrim, chlordane, DDT, hydroxyatrazine, lidone, methamidophos, metolachlor, molinate and paraquat, did not have trading data recorded in 2020. Similarly, the compounds alachlor and carbofuran recorded zero (0) sales even though they had been traded.

The access to the register situation of active ingredients usage according to ANVISA showed that aldicarb, aldrin and DDT are in the list of monographies excluded by the agency and that are not available for access. The following compounds are also in this list: lidane, methamidophos, metolachlor, molinate and paraquat; they were excluded in 2006, 2011, 2019, 2019 and 2020, respectively. Active ingredients, such as chlordane and hydroxyatrazine, are not in the list of authorized monographies, not even in the list of excluded ones or in trade reports; therefore, it is assumed that their registers were excluded in Brazil.

Discussion

To identify the findings of this study, it was essential to understand the correlation among the data of the analysed countries. Altogether, they recorded 47% of the total amount of pesticides used in the world in 2020. The United States and Brazil led the world pesticide consumption in that year (FAO, 2023). Evaluating the trade among these countries, we observed that the EU, USA and Japan were among the five main destinations of the Brazilian agricultural exports in 2022 (MAPA, 2023). Similarly, the EU, Japan and Canada were the three main destinations for the American agricultural exports (USDA, 2023). Therefore, the Brazilian and American representativeness in the global dynamics of agricultural food production must be highlighted and, consequently, their impact on the human health and environment worldwide.

Brazil stands out as the country accounting for the largest number of pesticides included in the list of water quality parameters among the herein analysed countries. According to the Brazilian regulation, the number of compounds listed in the parameters has grown over the years. Ordinance No. 56/1977, in its first regulation on drinking water mentioned 12 pesticides. Ordinance No.36/1990 listed 13 ones and Ordinance n. 518/2004 listed 22 pesticides. Alternatively, Ordinance No.2.914/2011 and Consolidation Ordinance No.5/2017 specified 27 pesticides. Nowadays, we have 40 pesticides listed in Ordinance No. 888/2021. Such an increase in the number of pesticides might be associated with the advancements in scientific knowledge about pesticides, and also with the link with WHO guidelines, in view of the high similarity between their MPCs (WHO, 2017; Brazilian Collective Health Association – ABRASCO, 2018). However, it does not mean that the population, in general, feel safe having in mind that all these compounds might be part of the contaminants of their drinking water.

Although only the Japanese regulation showed a statistically significant difference from the others, the results demonstrate variation in MPCs values among the analysed countries. This variation has already been identified by other studies that compared such values in different countries and may occur in relation to the established values, the contemplated compounds, and the approach adopted for monitoring (Li & Jennings, 2017; Winckel *et al.*, 2021; Li & Fantke, 2022; Oliveira, Agostino & Seigloch, 2023). The development and implementation of quality standards for drinking water is a difficult task that depends on scientific, technical, political and economic factors (Barbosa, Solano & Umbuzeiro, 2015). The result obtained for the Japanese regulation may be associated with the fact that the country uses only one parameter with a discrepant value compared to the other countries.

Agriculture depends on environmental factors, such as climatic seasonality, soil type and land cover (Monteiro, 2019). Each country has a different agricultural sector, which relies on parameters that are considered safe for their reality, take into account their own capacities and needs (WHO, 2017). The introduction of stronger restrictions may point out higher costs for farmers and pesticide manufacturers. Therefore, even if experts proposed a regulation, they would probably have political pressure to make it less strict (Moraes, 2019).

Although Brazil presents more restrictive parameters than US, Canada and Japan for market-leader pesticides such as glyphosate, 2,4-D and atrazine, this feature must not be seen as guarantee of safety. One must take into consideration that the 40 compounds listed in the current Brazilian regulation represented less than 10% of the 493 registers granted to new pesticides just in 2020 (Brazil, 2022a). According to Portugal & Silva (2020), license granting to new pesticide products in Brazil tends to be faster than updates in environmental quality parameters, including those set for water. This is a posture also identified in other countries, which, like Brazil, tend to focus mostly on best-selling or historically known pesticides (Li &Fantke, 2022).This constitutes a potential risk for population health and for the environment.

When comparing the Brazilian MPCs with those of the EU, it is possible to observe a discrepancy between them that was not identified in the statistical analysis. Glyphosate, which was the active ingredient mostly sold in Brazil in 2020, has MPC that is 5,000 times more permissible than the European one. The same is observed for 2,4-d (2nd most traded active ingredient) and atrazine (4th most traded active ingredient), which have MPCs 300 and 200 times more permissible in Brazil, respectively (Bombardi, 2017; Freitas &Regino, 2020).

According to Freitas & Regino (2020), such asymmetries between the MPCs of Brazil and the European Union are a reflection of Brazil's positioning as an agro-export country. By taking this stand, the country tends to allow higher dosages of pesticides in water and the environment, in order to boost agricultural production for export purpose. Thus, the Brazilian agribusiness tends to ensure the maintenance of high production to the detriment of sanitary and environmental security (Bombardi, 2017).

The glyphosate usage is authorized in all herein analysed countries. Its impacts on health and in the environment have been extensively discussed in particular ways in the literature. Ospina *et al.* (2022) has shown that approximately 81% of the American population under 6 years old was recently exposed to glyphosate. Its presence was also detected in pregnant women living in Canada (Ashley-Martin *et al.*, 2023), and in the urine of children and adolescents living in Germany (Lemke *et al.*, 2021). In the EU alone, between 2007 and 2017, glyphosate was the pesticide with the largest number of MPC overrates in water (European Agency of the Environment, 2019). Studies also pointed out its presence in water bodies in Brazil, in the USA, Canada and Japan (Battaglin *et al.*, 2014; Stempvoort *et al.*, 2016; Derbalah *et al.*, 2018, Christofaro *et al.* 2020). Regarding Brazil, only few MPC overrates were recorded (Bastos *et al.*, 2022). However, the fact of not recording so many excesses can be associated with the allowed MPC established in the country or with gaps on information systems.

Although glyphosate is considered safe by most of the regulatory agencies, this fact is mostly based on its acute effects. However, chronic effects related to this pesticide have been poorly discussed (Agostini *et al.*, 2020). A study identified its neurotoxic effects on mice, even at concentrations allowed by regulatory authorities for human-consumption water (Masood *et al.*, 2021). The endocrine deregulation observed in humans was also associated with generalized and continuous exposure to glyphosate (Geier & Geier, 2023). Overall, it is possible to associate water contamination by this compound with the increase of diseases such as breast cancer, DNA damages, placenta tissue compromising, apoptosis and necrosis, as well as liver and kidney damages (Meftaul *et al.* 2020).

Therefore, it is essential to reinforce the risk observed in all the analysed countries of this study, regardless of their MPC restriction levels. The Brazilian and American regulation agencies must be more cautious about the high agricultural production rates and broad use of pesticides. The introduction of genetically modified cultures in Brazil, mainly soybean, different from the expected, accounted for the increase of pesticide usage in the country (Almeida *et al.*, 2017). Glyphosate is the main pesticide used as complementary input to genetically modified soybean and its usage was broadened, as well as the outspread of the soybean culture in Brazil (Dias, Rocha & Soares, 2019). Data provided by IBGE (2023) has shown the relevance of soybean for the Brazilian agricultural economic performance. This culture reached the highest value ever produced in the country of 341,747,600 BRL (about US$ 68,349,520) in 2021.

Another important factor is that Brazil does not have a parameter for the total number of pesticides present in water, as it occurs in the regulation of the EU. Therefore, when adding the VMP of the 40 compounds mentioned in the Brazilian regulation, it accounts for the amount of 1,677.13 (μg^{L-1}) of pesticides in water, which is allowed for human consumption (Oliveira, Agostinetto &Seigloch, 2023). This reinforces the risk arising from the mixture and interaction between different pesticides in the water, which can lead to combined and unpredictable effects on the environment and on public health (Weisner *et al.*, 2021).

The use of such chemicals outside rural sites is also a growing concern. Users tend to ignore recommendations in urban and domestic environments. Consumers end up using high dosages of pesticides contaminating the air, the soil, water, food and also themselves (Meftaul *et al.* 2020).

Scientific research has assessed the presence of pesticides in both surface water and underground water in Brazil (Possavatz *et al.*, 2014; Schelder *et al.*, 2017; Caldas *et al.*, 2019; Guarda *et al.*, 2020; De Deus *et al.*, 2022). Some pesticides excluded from the official list of authorized products were also detected, such as the case of aldrin-dieldrin, chlordane and DDT, which have been forbidden in Brazil since 1985, due to their high carcinogenic potential (Oliveira & Furtado, 2010; Panis *et al.*, 2022). It is important to highlight the observed flaws in control and usage systems, such as the rental of different properties for the crop seasons, not registered by the official agencies (Boulomytis, 2008). This practice may lead to pesticide usage at locations different from those recorded in invoices, which makes it challenging to promote an effective control process. Hence, the population is exposed to eminent risks which might be worsened by the lack of control systems.

Data provided by the Federal Government show that back in 2020, only 12% of Brazilian municipalities provided their results of, at least, one pesticide analysis to the National Program of Water Quality Surveillance (Brazil, 2022a). Such a reality is the reflex of lacks in the system to monitor the usage of pesticides, which presents several technical and operational barriers yet to be overcome (Brazil, 2006; Queiroz *et al.* 2012; Oliveira *et al.*, 2019). A functional control system applied to human-consumption water with pesticides would be an important tool to facilitate the decision-making process in this sector, because it could provide information about the effectiveness of control measures set for these substances and for the mitigation of their impacts (Chow *et al.*, 2020). Accordingly, the risks pointed out in the present study are clearly caused by lack of official information about the presence of pesticides in water.

Besides the contamination of human-consumption water, it is important to have in mind that the agricultural production nowadays circulates the globe through exports and imports. By working with inappropriate amounts of pesticides, the agribusiness puts consumers' health and environment at risk, because they will ingest agricultural products and dispose waste that has originated from other countries (Braga *et al.*, 2020). Brazil stands out as the 3rd largest agricultural food exporter in the world. It supplies 50% of EU's fruit juice and soybean imports. It is also the main origin of roasted coffee, tea and processed beef on the globe (European Commission, 2021a). Although the country counts in the largest number of MPC parameters for human-consumption water quality, back in 2020, the EU identified pesticide residues' rate higher than that allowed in cumin seeds and nuts imported from Brazil (European Food Safety Authority, 2022). In order to avoid such a risk, pesticides' residue limits for importation were set, and it can exclude countries that work with irresponsible procedures from this market (Coelho *et al.*, 2019). This fact can be a risk for the Brazilian agribusiness, whose Gross Domestic Product (GDP) participation has been growing on a yearly basis (Moraes, 2019).

Policies focused on the control and reduction of the use of these substances, on improvements in inspection and/or control systems, as well as on investments in research to find alternatives for a safer and more sustainable production system are necessary to help the mitigation against soil, air and water contamination by pesticides. In 2020, the EU adopted the 'Zero Pollution Action Plan', which aims at reducing by 50% water contamination by pesticides until 2030. It must be done by promoting the sustainable usage of these compounds, efficient biological and agro-ecological agricultural practices, and by preventing their use in sensitive or vulnerable areas (European Commission, 2021b). The UN's 2030 Sustainable Development Goals (SDG) include aims related to controlling the usage of agrochemicals and the consequent contamination of water and environment by them. This is the case of SDG 3 (health and well-being), SDG 6 (clean water and sanitation) and SDG 12 (sustainable production and consumption) (UN, 2015). The Organization for Economic Cooperation and Development (OECD) also supports the Agricultural Pesticides Program in order to help its member countries in registering and re-registering pesticides, balancing risk evaluations and contributing to reduce pesticides' impacts (OECD, 2023). Countries like the USA, Canada and Japan are covered by these measures.

Brazil still has no specific policy to control the use of pesticides and the contamination caused by them, although it is committed to the UN's 2030 SDG Agenda. However, there are Congressional Bills in the congress aimed at changing the pesticides' management situation in the country. Bill No. 6.670 from 2016 intends to endorse the National Policy for Pesticides reduction. Nevertheless, it has been in the Congress voting list since then. This Bill aims at promoting environmental health and sustainability through actions to reduce agriculture's dependence on pesticides (Moraes, 2019). On the other hand, Bill No. 6.299 from 2002, was approved in 2018 by the Special Commission of the National Congress (Neto & Costa, 2020) – it provides a series of changes to simplify the urban use of pesticides, to centralize their registration processes into a single accountable bureau and to propose the non-obligation of having an agronomic prescription for their acquisition (ABRASCO, 2018).

Results in the current study did not show statistically significant discrepancies between MPCs set in Brazil and in the USA, EU, Canada, and in WHO's guidelines. Japan is the country with the most different parameters from the others, being the most permissive for pesticides in drinking water. There are, however, important differences between the MPCs of Brazil and the EU that were not identified in the statistical analysis. Nevertheless, the weakening of inspection and surveillance institutions, lack of clarity about institutional competences and lack of inter-institutional and integrated actions are determining factors to broaden risks deriving from pesticides' uncontrolled usage (Correa *et al.* 2020).

The number of pesticides listed in the Brazilian regulation remains quite smaller than the total number of products in use, nowadays. The limited monitoring system can also be a risk, because it makes it harder to control and inspect water quality, environmental diffuse pollution and ecosystem impacts. Brazil and the USA are the countries, among the analysed ones in this study, which present the most active and pesticide-dependent agricultural sectors, although they hold the largest number of pesticide parameters. However, there was a great variation among the MPCs of all the analysed countries. Therefore, the need of establishing policies and measures to rationalize and better control the usage of these substances cannot be ignored. This would affect the environment and water security, as well as the sustainability of agricultural production systems.

Conclusions

The Brazilian regulation monitors a larger number of pesticides than the American and Canadian regulations, and the WHO's guidelines. The EU's and mostly all Japanese regulations do not pre-determine the amount of pesticides to be monitored, as their parameters refer to any pesticide matching the classes described in their regulations.

Based on the current results, at first, there is no significant discrepancy in water quality parameters set for the presence of pesticides in Brazil, in comparison to the USA, EU, Canada, and WHO. Brazil has more restrictive parameters than the other leaders in the market. However, there is significant discrepancy about MPCs for pesticides established by the Japan. There are also differences between the parameters established in the EU, which, although not pointed out in the statistical analysis, can be 5,000 times more restrictive than the Brazilian MPC for glyphosate, 300 times more restrictive to 2,4-d and 20 times more restrictive to atrazine.

The herbicide glyphosate is the most consumed active ingredient in the Brazilian agriculture. Although it is considered safe by the sector's regulatory agencies, this compound is still associated with poorly understood chronic effects. Such MPC for this compound, in the second country with the highest consumption of pesticides in 2020, can pose risk to public health and to the environment. Recognizing the relevance of the agribusiness to the Brazilian economy, the use of pesticide doses above the ones allowed by importer countries may lead to risk of having the country facing barriers to its agro-product exports.

The number of active ingredients taken into account among potable water quality parameters only means a small fraction of the total number of pesticides registered in the country. On the other hand, some active ingredients that are still listed among the water quality parameters in Brazil have already been ruled out from its legal market. This brings out the need of updating the list of pesticides provided on the Brazilian regulation.

Based on the study findings, the definition of appropriate water quality parameters, from either the sanitary or environmental viewpoints, may not be most challenging problem of the sector in Brazil, but the development and implementation of public policies to effectively control the pesticide usage of pesticides. At a global level, it is necessary to promote the harmonization of the MPCs for pesticides.

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