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Impacts of tobacco cultivation on human health and water pollution in Chapadão do Lageado, Santa Catarina, Brazil

Impactos da agricultura de tabaco na saúde humana e na poluição da água em Chapadão do Lageado, Santa Catarina, Brasil

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ABSTRACT: Brazil is the second largest tobacco producer. We investigated the pesticides used by tobacco farmers, their occurrence in the drinking water resources of Chapadão do Lageado (Santa Catarina, Brazil), and the relationship between tobacco cultivation and farmers' health. A liquid chromatography-tandem mass spectrometry method was used to quantify pesticide residues in water samples from rivers and wells. Both the handling of pesticides and the handling of the tobacco plant have negative consequences, even if preventive measures are taken. Of the 107 tobacco farmers surveyed, 91.6% reported symptoms related to green leaf disease and 19.6% reported symptoms related to pesticide handling. About 40% of the well water samples contained residues of imidacloprid, sulfentrazone, thiamethoxam and iprodione. In the river water samples, more than 70% had residues of the same pesticides detected in the well water, plus clomazone. Traditional tobacco cultivation and post-harvest management endanger human and environmental health. The harmful effects of exposure to tobacco leaves compound health problems. In areas where tobacco cultivation is a major industry, critical thinking is needed on policies, approaches and tools to address these complex and alarming public health risk situations.

Keywords: tobacco; pesticides; green leaf disease; toxicity symptoms.

RESUMO: O Brasil é o segundo maior produtor de tabaco. No presente estudo investigaram-se os agrotóxicos utilizados, sua presença nos recursos hídricos do Chapadão do Lageado (Santa Catarina, Brasil) e a associação entre produção de tabaco e saúde dos agricultores. Utilizou-se cromatografia líquida-espectrometria de massa em tandem para determinar e quantificar resíduos de agrotóxicos em amostras de água de rios e poços. A manipulação de pesticidas e do tabaco têm consequências negativas, mesmo usando medidas preventivas. Dentre os 107 fumicultores entrevistados, 91,6% relataram sintomas relacionados à doença da folha verde do tabaco e 19,6% relataram sintomas decorrentes da manipulação de agrotóxicos. Cerca de 40% das amostras de água de poço apresentaram resíduos de imidaclopride, sulfentrazona, tiametoxam e iprodiona. Nas amostras de água de rios, mais de 70% apresentaram resíduos dos mesmos agrotóxicos identificados em águas de poços, mais clomazone. As suas práticas de produção e manejo ameaçam a saúde humana e ambiental. A situação torna-se alarmante já que os efeitos nocivos da exposição às folhas verdes do tabaco intensificam os problemas de saúde dos produtores. É necessária uma reflexão crítica sobre políticas, abordagens e ferramentas para enfrentar essas complexas situações de risco de saúde pública nos territórios onde o cultivo do tabaco é uma das principais atividades econômicas.

Palavras-chave: tabaco; agroquímicos; doença da folha verde do tabaco; sintomas de toxicidade.

1. Introduction

Tobacco cultivation is predominant in the southern region of Brazil and represents more than 95 % of the national production, according to the Brazilian Cotton Yearbook (Kist *et al*., 2021). The main inputs used in this crop are fertilizers (Hoyos *et al*., 2015) and pesticides (Kahl *et al*., 2018) used in high concentrations (60 L ha^{-1}) (Pignati *et al*., 2017).

In the 2022/23 Brazilian tobacco harvest, this activity was carried out by more than 124,993 families and tobacco production reached 605,703 tons (Afubra, 2023). The choice of tobacco growing is influenced by various factors, including the availability of unskilled family labor and the assurance of a consumer market. However, several studies have reported health risk situations in tobacco farmers due to green tobacco sickness (GTS) and the use of pesticides. In both cases, symptoms can include nausea, vomiting, headache, dizziness, weakness, and abdominal pain described (Bertoluzzi, 2007; Park *et al*., 2018; Fassa *et al*., 2018; Cezar-Vaz & Cargnin 2019; Sujoso *et al*., 2020; Campos *et al*., 2020). In the case of GTS, other symptoms such as sweating, insomnia, agitation, palpitations, and dyspnea after harvesting tobacco were also reported (Fassa *et al*., 2018).

It is important to emphasize that simple tests cannot determine whether the worker's poisoning was caused by GTS or pesticides, as exposure to nicotine or pesticides is common in tobacco cultivation. In both poisoning cases, the symptoms reported in acute cases are similar, making it difficult to identify the causative agent. Therefore, a more specific investigation is required, using blood tests to determine whether there is poisoning from agrochemicals and urine tests to determine if there is poisoning from nicotine. However, this premise is not always followed, which can lead to misdiagnosis and mistreatment with negative consequences for human health.

The pesticides used in tobacco farming can have a negative impact on the quality of water resources, influenced by various factors (Bertoluzzi *et al*., 2007). To the best of our knowledge, no studies have been conducted to assess the presence of pesticide residues in water resources in tobacco-growing areas in Santa Catarina and the combined effects of GTS and pesticide exposure.

Therefore, this study aimed to assess the prevalence of symptoms associated with GTS in tobacco farmers and to evaluate the presence of pesticides in the water resources in Chapadão do Lageado (ChL), in Santa Catarina, Brazil.

2. Materials and methods

2.1. Profile of the Chapadão do Lageado tobacco farmers

The Brazilian Institute of Geography and Statistics (IBGE) has estimated the population of ChL City at 3,006 inhabitants, of which more than 90 % live in rural areas (IBGE, 2021). The total surface area (Figure 1) is 124,866 km² (IBGE, 2021).

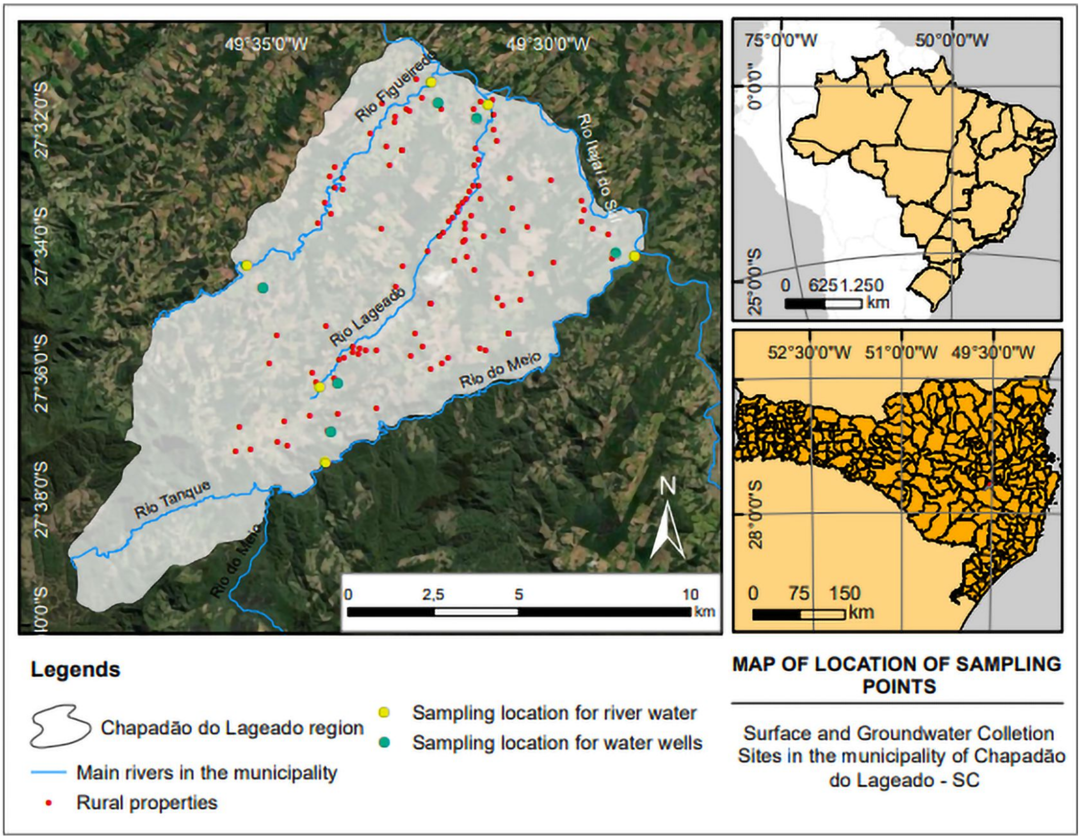

FIGURE 1 – Localization of the study area in the municipality of Chapadão do Lageado, Santa Catarina, Brazil.
SOURCE: authors (Modified from IBGE, 2021).

In general, the farms are smaller than 10 hectares, and the primary production is tobacco. The profile of tobacco growers in ChL (S 27º35′1″ W 49º32′39″) was characterized based on the analysis of a questionnaire administered to 107 participants (a random sample that represents 3.6 %i of the population).

The survey conducted by community health officials revealed that there are 258 tobacco producers (N) in ChL. This information was used to determine the minimum sample size (see supplemental material).

In this manner, 107 tobacco producers (sample) in the municipality of ChL were invited to participate in the survey. Data collection took place between May and August 2019 through method semi-structured interviews with 77 questions. The purpose was to define the profile of tobacco farmers in the municipality, their practices and attitudes towards the use of pesticides, characterize tobacco cultivation and assess the impact of tobacco cultivation on the environment.

Interviews were conducted individually during on-site visits to selected rural properties and typically lasted between 60 to 90 minutes each. The interviews were transcribed verbatim and analyzed both qualitatively and quantitatively. Demographic, socioeconomic, behavioral, and occupational data of the participants were gathered, including the occurrence of potential GTS symptoms and the effects of pesticides on human health. The survey proforma was developed based on the literature (Bartholomay *et al.*, 2012; Creswell and Plano Clark, 2013; Kalyani *et al.*, 2016). This study was approved by the Research Ethics Committee of the FURB (approval number 2.609.792) on April 18, 2018 and was conducted in accordance with the National Health Council Resolution number 466/12 on research involving human subjects.

2.2. Sampling and sample preparation

In 2019, water samples were collected upstream and downstream of the three main rivers in ChL (Rio do Meio, Rio Figueiredo, and Rio Lageado). Additionally, water samples were obtained from wells used for human consumption, which were located near (approximately 200 m to 500 m) the Collection River's sampling points. In general, the rivers and wells were situated within 150 meters of the tobacco farmer's residence (Figure 1).

Since annual tobacco cultivation in Brazil usually begins in July, a total of three water sampling campaigns were carried out, during which 12 sampling points were identified. Six of these points were for river water collection (two in each river, both upstream and downstream of the farms), and six were from wells (see Figure 1). Water collection occurred before soil preparation (in June), during the tobacco's growth stage (in September), and in November when tobacco is ready for harvest. In total, 36 water samples were collected at an approximate depth of 220 cm, using 1000 mL glass bottles, with 1 mL of concentrated sulfuric acid (95-97 %) added for analysis. These samples were transported to the Water and Effluent Analysis Laboratory, Lanae, at the Institute of Technology of the National Service of Industrial Training, SENAI. Subsequently, they were filtered through nitrocellulose membranes (0.45 µm) and stored at -20 ºC until pre-concentration using Solid

Phase Extraction (SPE), following the methodology described in EPA 3535A (USA, 2007).

2.3. Chemical analysis

Following the Solid Phase Extraction (SPE), the concentration of pesticide residues in the water samples (see Table 3) was analyzed using liquid chromatography-tandem mass spectrometry (LC-MS/MS) equipment from Agilent Technologies, USA. The system components included a quaternary pump (G1311B 1260), an autosampler (G1329B 1260 ALS), a thermostatted column compartment (G1316A 1260 TCC), a K6420 Triple Quad Mass Spectrometer with electrospray ionization, and the Agilent Masshunter Quantitative Analysis software (see supplemental material).

3. Results and discussion

3.1. Population profile

According to the data collected in the present study, tobacco farmers in ChL are mostly male (73.8 %) (Table 1). Studies have shown a male predominance in tobacco growing (Rokhmah *et al*., 2019; Schamne *et al*., 2021). Factors such as type of work, sociocultural, financial issues, and education influence male prevalence.

The rural exodus of young people is common in the region. Although the age of farmers ranged from 18 to over 60 years old, farmers 40 years old or older are predominant among tobacco growers (44.9 %). In this regard, previous studies on the social profile of tobacco growers have also confirmed the predominance of this age group (Khoiron *et al*., 2016; Murakami *et al*., 2017; Cargnin *et al*., 2017; Fassa et al., 2020; Schamne *et al*., 2021; Rokhmah *et al*., 2021).

Most tobacco growers are married and have children, 75.7 % and 79.4 %, respectively. 85 % of the families are composed of up to four members. Comparatively, other studies focus on the marital status of tobacco growers report that more than 90 % are married (Cargnin *et al*., 2017; Rokhmah *et al*., 2019; Rokhmah *et al*., 2021) and that, in general, three or more people reside on the properties (Fassa *et al*., 2020; Rokhmah *et al*., 2021; Schamne *et al*., 2021). More than half of the participants have been in school for less than 10 years; 34.6 % completed high school, and 9.4 % are graduates (Table 1).

In this sense, a similar trend was described in previous studies from southern Brazil (Schamne *et al*., 2021; Rezaei *et al*., 2019; Dube & Mugwagwa, 2017; Murakami et al., 2017) indicate that, although it is an activity carried out mainly by men in a similar age range to that in this study, other family members are also involved. A similar trend also occurs among workers who cultivate other crops (Khoiron *et al*., 2016; Cargnin *et al*., 2017; Rezaei *et al*., 2019; Rokhmah *et al*., 2021).

Among the studies conducted in Brazil, Schamme *et al*. (2021) demonstrated the presence of nicotine poisoning among tobacco farmers in Paraná. In this study, the adverse effects of nicotine exposure were associated with smoking, physical exertion, and intense focus on productivity. Murakami *et al*. (2017) reported a high prevalence of acute poisoning from pesticide use among tobacco farmers in Rio Grande do Sul. The authors emphasized the need to strengthen government

TABLE 1 – Socio-economic profile of tobacco farmers in Chapadão do Lageado, Santa Catarina, Brazil.

Characteristics	N	%
Gender		
Male	79	73.8
Female	28	26.2
Age (years)		
15-19	1	0.9
20-29	23	21.5
30-39	28	26.2
40-59	48	44.9
≥ 60	6	5.6
Marital status		
Single	12	11.2
Married	81	75.7
Widower	2	1.9
Other	12	11.2
Number of children		
1	21	19.6
2	32	29.9
3	15	14.0
4	10	9.3
5	5	4.7
Other	2	1.9
Family composition (number of members)		
2 to 4	91	85.0
4 to 6	15	14.1
6 to 8	1	0.9
Education		
Illiterate	1	0.9
Incomplete Elementary School	29	27.1
Complete Elementary School	27	25.2
Incomplete High School	3	2.8
Complete High School	37	34.6
University graduate	10	9.3

SOURCE: authors.

measures to regulate the use of these products and to introduce more sustainable cultivation practices as well as the importance of prevention through the correct use of Personal Protective Equipment (PPE). In a study based on interviews with tobacco farmers in the northwest of Rio Grande do Sul, it was concluded that health problems related to pesticides were due to the only partial use of PPE (Fassa *et al*., 2020). The importance of incorporating holistic health care into practices that include prevention, promotion, support, and reporting of poisoning cases was emphasized.

On the other hand, Fassa *et al*. (2020) made original contributions to the human health harms associated with tobacco cultivation based on a study conducted in Rio Grande do Sul. They pointed to an issue rarely addressed in the scientific literature, namely the relationship between exposure to pesticides and nicotine and neck pain. Due to the low level of education observed, it is possible that these people do not continue their education to help their families in the property's activities Fassa *et al*. (2020).

3.2. Activities related to labor in tobacco cultivation

Most properties in the study local are small areas of up to 10 hectares (Table 2). Among the rural producers, 74.8 % allocate up to 5 hectares for the cultivation of tobacco, which is produced in their area by 71 %, while the others (29 %) depend on third-party areas. The fact that most tobacco cultivation occurs on small farms, whether they own or lease the land, which usually cannot be mechanized, has already been noted in

TABLE 2 – Characteristics of properties and activities related to labor in tobacco cultivation Characteristics of properties and activities related to tobacco growing labor and knowledge of health effects in Chapadão do Lageado, Santa Catarina, Brazil, in 2019.

Characteristics	n	%
Property area (ha)		
Up to 5	26	24.3
6 to 10	39	36.4
11 to 15	14	13.1
More than 15	28	26.2
Tobacco cropland allocation in the property (ha)		
Up to 5	80	74.8
6 to 10	24	22.4
11 to 15	2	1.9
More than 15	1	0.9
Agrarian condition - land tenure		
Owner	76	71.0
Tenant	19	17.8
Partner/occupant	12	11.2
Time devoted to tobacco growing (years)		
Up to 5	16	15.0
6 to 10	16	15.0
11 to 15	22	20.0
More than 15	53	49.4
Participation of children and adolescents in tobacco cultivation (sowing - harvesting)		
Ever	3	2.8
Often	3	2.8
Sometimes	3	2.8
Rarely	13	12.1
Never	85	79.5
Labor in tobacco cultivation during the harvest period		
Only family members	20	18.7
Hired tobacco worker	13	12.1
Partnership (exchange of days)	74	69.2
Average time required by the tobacco harvest		
More than 75%	57	53.3
Up to 75%	25	23.4
Up to 50%	23	21.5
Up to 25%	2	1.9
Rest or leisure time with the family during the harvest		
Ever	12	11.2
Often	23	21.5
Sometimes	60	56.1
Never	12	11.2

Characteristics	n	%
Average monthly family income		
Up to $ 700,00	91	85.0
More than $ 700,00	16	15.0
Knowledge about health risks associated with tobacco production		
Yes	38	35.5
No	69	64.5
Knowledge of GTS		
Yes	98	91.6
No	9	8.4
Identification and differentiation of symptoms of intoxication by GTS and by Pesticides		
Yes	45	42.1
No	62	57.9
Looking for health services in case of GTS symptoms		
Yes	17	80.9
No	4	19.1
Existence of GTS symptoms at some point in life		
Yes	54	50.5
No	53	49.5
If so, had a medical diagnosis		
Yes	23	42.6
No	31	57.4
GTS causes recognized by tobacco farmers		
Contact of sweaty skin with wet green leaf	65	60.7
Wearing a wet suit	17	15.9
Awareness about GTS causes	25	23.4
GTS symptoms and effects recognized by tobacco farmer		
Vomiting	51	47.7
Nausea	36	33.7
Dizziness	24	22.4
Delirium	22	20.6
Discomfort and weakness	18	16.8
Lack of appetite	14	13.1
Stomach upset	12	11.2

SOURCE: authors.

previous studies in Brazil (Murakami *et al*., 2017). In comparison, a study conducted in Zimbabwe (Dube & Mugwagwa, 2017) demonstrated that 42 % of tobacco farmers are property landowners and allocate an average of 4.05 hectares for the cultivation of tobacco.

We identified that most farmers (69.4 %) have been producing tobacco for over ten years, a period that can span over four decades. This has also been reported in previous national and international studies (Bortoluzzi *et al*., 2007; Cargnin *et al*., 2017; Kahl *et al*., 2018; Rokhmah *et al*., 2019; Fassa *et al*., 2020; Rokhmah *et al*., 2021).

Tobacco monoculture is preferred because it is considered more profitable than other crops on the same land area. Producing tobacco is the way found by many farmers to support their families in several countries. In general, the farmers' land areas are small and are mainly intended for tobacco monoculture. This condition makes families financially dependent on the economic result of tobacco. Tobacco harvesting involves the participation of all family members, including children and the elderly (20.5 %) (Table 2).

Most farmers work with other family members and have tobacco as their primary source of income, but they diversify their production by growing beans, corn, onions, and other crops in smaller proportions. Many producers use the off-season to grow other crops and conserve the soil. However, there are farmers who maintain crop rotation that counteracts soil fatigue. This shows that farmers are aware of the importance of diversification, which not only provides additional sources of income alongside tobacco but also contributes to some financial stability for their families, promoting sustainable development.

In tobacco production, in addition to family's participation, most producers hire workers, mainly during the harvest period (Rokhmah *et al*., 2019; Hasan, 2020). Regarding the demand for labor, especially during the harvest period, we identified that the majority (69.2 %) of farmer's partner with other families and 12.1 % hire employees to assist in the harvesting process. Among the tobacco-growing families, more than half (53.3 %) dedicate more than 75 % of their working time to tobacco (Table 2).

Due to the labor demand during tobacco harvesting, around 11 % of the farmers mentioned that there is no time available for leisure activities and more than half (56.1 %) stated that they only sometimes spend time for rest and leisure with their family, while 21.5 % stated that they almost always dedicate time to these activities, even during the tobacco harvest period (Table 2). Tobacco growing is a full-time activity Bertoluzzi *et al*., 2007; Park *et al*., 2018; Rokhmah *et al*., 2019). Especially during the tobacco harvest season, other activities are neglected, including leisure and sleep, which influence the health and quality of life of tobacco growers.

Tobacco is an important source of income for many families and, in its majority (85 %), represents up to $ 700.00 monthly (Table 2). In Zimbabwe, tobacco production is one of the main sources of livelihood, and represents, on average, 73 % of the annual income of families engaged in this activity (Dube & Mugwagwa, 2017). Indonesian tobacco farmers generated, on average, $ 243.4

in total monthly household income from tobacco crops in 2018 (Araujo *et al*., 2018). A recent study in Indonesia shows that more than 80 percent of tobacco growers had an income below the minimum wage ($ 123.81) (Rokhmah *et al*., 2021).

Tobacco production is characterized by arduous working hours and unhealthy conditions, which poses a risk to all family members, including underage children who participate in the activities. Among the risks to human health stand out occupational exposure to pesticides and GTS (Park *et al*., 2018; McMahon, 2019; Raja, 2021). Despite evidence of unhealthy work, most tobacco growers (64.5 %) are unaware of the health risks of tobacco growing (Table 2). In the tobacco growing process, contact with nicotine and pesticides can lead to occupational diseases (Rokhmah *et al*., 2019; Hasan, 2020). Intoxications associated with GTS require accurate diagnosis and treatment (Park *et al*., 2018). In case of suspicion, urinary or serum nicotine tests should be performed (Reddy & Ashok, 2019). In general, tobacco workers seek medical, and hospital help only in cases of severe symptoms (Khoiron *et al*., 2016; Park *et al*., 2018; Reddy & Ashok, 2019).

Although most tobacco farmers (91.6 %) know about GTS, about 60 % do not identify the symptoms of intoxication from GTS or pesticides. In case of suspicion of intoxication, 80.9 % think that the best alternative is to seek medical help (Table 2). Symptoms of GTS are like those induced by exposure to pesticides or heat exhaustion symptoms (Reddy & Ashok, 2019). In general, tobacco growers are not very familiar with the GTS (Rokhmah *et al*., 2021) and they cannot differentiate them from symptoms caused by pesticide poisoning and heat exhaustion (Reddy & Ashok, 2019). This situation is hampered due to the lack of knowledge about GTS among medical personnel. Many cases are diagnosed as pesticide poisoning or damage due to heat exhaustion (high temperature) (Fotedar & Fotedar, 2017; Reddy & Ashok, 2019).

In the present study, more than half (50.5 %) admitted having felt the symptoms of this disease, and 42.6 % even had a medical diagnosis (Table 2). Park *et al*., (2018) reported that in case of severe symptoms, tobacco growers seek medical help. The main causes of tobacco nicotine poisoning mentioned by farmers are the contact of sweaty skin with wet green leaves (60.7 %) and not using waterproof clothing (15.9 %), while 23.4 % ignore the cause (Table 2).

Not practicing preventive actions and the non-use of PPE are significantly related to the symptoms of GTS (Reddy & Ashok, 2019; Rokhmah *et al*., 2019). The best way for tobacco growers to protect themselves from nicotine exposure is to wear PPE, especially gloves (Rokhmah *et al*., 2021). Worker contact with moist tobacco and the use of work clothes dampened by dew or perspiration contribute to increased exposure and absorption of nicotine through the skin (Bertoluzzi *et al*., 2007; Fotedar & Fotedar, 2017; Reddy & Ashok, 2019), and even through the airways (Park *et al*., 2018). The most reported symptoms were vomiting (47.7 %), nausea (33.6 %), dizziness (22.4 %), delirium (20.6 %); discomfort and weakness (16.8 %), lack of appetite (13.1 %), stomach upset (11.2 %), among others (Table 2). The same symptoms have been related previously (Bertoluzzi *et al*., 2007; Fotedar &

Fotedar, 2017; Park *et al*., 2018; Reddy & Ashok, 2019; Hasan, 2020; Schamne *et al*., 2021; Rokhmah *et al*., 2021).

Regarding the prevention of GTS, tobacco growers indicate self-medication (29.9 %), ingestion of homemade tea (18.7 %), use of waterproof clothing (13.1 %), stopping working with tobacco (10.3 %), staying hydrated (9.3 %), among others (Figure S1).

In addition to self-medication, tobacco growers only propose to wait for discomfort to pass (22.4 %); seek the emergency room (19.6 %); rest (8.4 %). Some believe that it can be treated with homemade serum (3.7 %); prescription medication (1.9 %), drinking coke (1.9 %), or lemon juice with bicarbonate (1.9 %); in addition to other indications. However, 14 % of farmers report that there is no treatment for this disease (Figure S1). It has already been described that, to prevent and treat the symptoms of GTS, many tobacco growers practice self-medication, consuming teas, while others seek medical and hospital treatment (Khoiron *et al*., 2016). Schamne *et al*. (2021) find that more than 40 % of tobacco growers use tea, cola drinks, brandy, water, and even fruit salt to prevent and alleviate the symptoms of GTS.

Moreover, the precariousness about safety measures and individual hygiene actions of tobacco growers due to their little information and knowledge has been evidenced (Bertoluzzi *et al*., 2007; Ngajilo *et al*., 2018). Moreover, these authors suggested launching a public awareness campaign on GTS at the national and international levels regarding workers' health regulations and a strong regulatory effort to address the potential hazards of GTS. Other recommendations emphasize adopting all safety measures and, especially, using the complete PPE kit to reduce contact with nicotine and pesticides (Bertoluzzi *et al*., 2007; Reddy & Ashok, 2019).

On the other hand, around 20 % of tobacco growers reported health problems due to the handling or application of pesticides and more than 80 % had a medical appointment (Table S1). In all cases, the diagnosis of intoxication was confirmed, and received medical treatment. Among the symptoms of intoxication, more than half (52.4 %) reported vomited, dizzy (38.1 %); headache (28.6 %); body pain (19 %), nausea (19 %), weakness (9.5 %), diarrhea and fever (9.5 %), among others (Table S1).

It is important to emphasize that simple tests cannot determine whether intoxication is caused by exposure to nicotine (GTS) or pesticides. In both poisoning cases, the symptoms reported in acute cases are similar, making it difficult to identify their causative agent.

More investigations are needed, using blood tests to determine whether there is poisoning from pesticides, and urine tests to determine whether there is poisoning from nicotine. However, this premise is not always followed, which can lead to misdiagnosis and mistreatment with even more negative consequences for human health.

3.3. Personal protective equipment

Different studies address the health risks due to exposure to pesticides. Symptoms include dizziness, blurred vision, hypersalivation, nausea, vomiting, diarrhea (Witcahyo & Ma'rufi, 2017), skin, eye irritation, other disorders of the nervous and respiratory systems, and kidney damage (Rokhmah *et al*., 2021), central hearing dysfunction (França *et al*., 2017), as well as cancer (Kahl *et al*., 2018), among others. In general, in the pesticide handling process, several organs are exposed to toxins (Witcahyo & Ma'rufi, 2017).

The non-utilization or incomplete use of PPE during handling pesticides or by contact with the moist green leaf of tobacco increases the producer's vulnerability and the risks of contamination and intoxication, with several symptoms and short- and long-term consequences. Appropriate control measures reduce tobacco growers' vulnerability to chronic and acute poisoning (Ngajilo *et al*., 2018).

In farming, these materials protect the skin, eyes, and respiratory system and consist of neoprene gloves, rubber boots, water repellent clothing; waterproof apron; visor, caps, and respiratory protection (mask). Most tobacco growers (99.1%) are aware of the importance of PPE in the application of pesticides in agriculture (Figure 2A). The correct use of PPE can prevent both direct contact with nicotine (Bertoluzzi *et al*., 2007; Reddy & Ashok, 2019) and pesticides (Bertoluzzi *et al*., 2007).

However, boots are the only equipment ever used by all tobacco growers while water-repellent shirts and pants (89.7 %); gloves (86.9 %); masks (86 %); hoods or caps (73.8 %), and visors aprons (71 %) are used less often (Figure 2B). During the handling of pesticides, 51.4 % of tobacco growers always use PPE while 5.6 % never wear (Figure 2C).

Our results are like those shown by another study, showing that 43 % of tobacco producers use PPE when handling pesticides (Rezaei *et al*., 2019). Only 10 % of tobacco growers use the complete

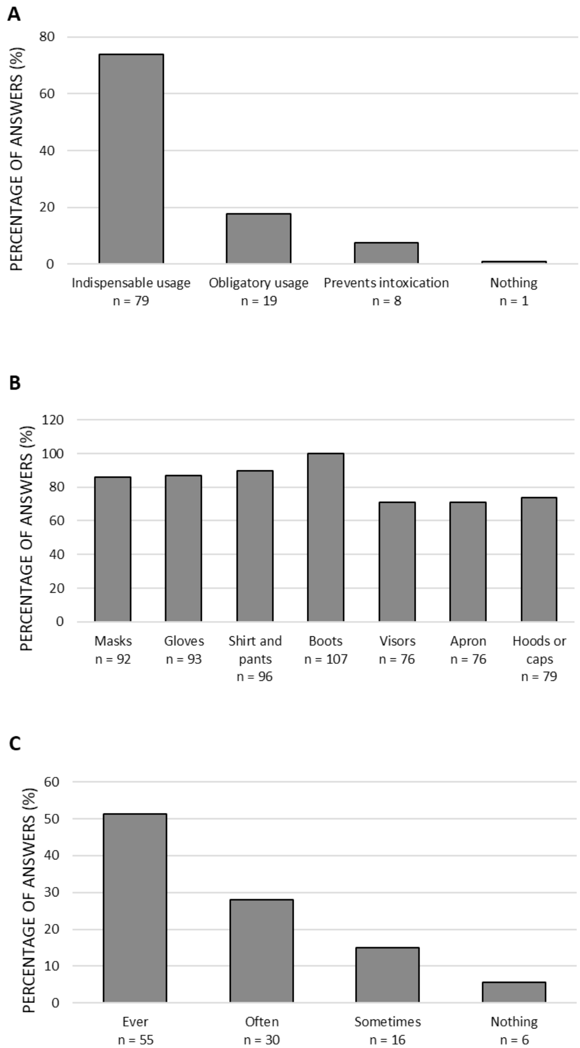

FIGURE 2 – Use of PPE during pesticide handling by tobacco farmers in Chapadão do Lageado, Santa Catarina, Brazil, in 2019: A: Tobacco farmers' level of knowledge about the importance and necessity of using PPE; B: Frequency of use of specific PPE items by tobacco farmers while handling pesticides; C: Percentage of tobacco farmers who use PPE while handling pesticides.

SOURCE: authors.

PPE kit, while 32.5 % use some PPE and 25 % use only gloves (Kahl *et al*., 2018). Previous studies describe that most interviewees use PPE and warn against safety measures and individual hygiene actions, which are precarious, due to the lack of knowledge of farmers (Bertoluzzi *et al*., 2007; França *et al*., 2017; Ngajilo *et al*., 2018). Despite regulatory provisions, the non-utilization of PPE during the handling of pesticides has been reported previously (Garrigou *et al*., 2020). This situation increases the risk of poisoning as producers have been cultivating tobacco for years, which means that it is a prolonged exposure both to the effects of nicotine, present in the moist green tobacco leaves, as well as to pesticides. In this sense, it is necessary to promote the safe use of pesticides to reduce the harmful effects on humans and the environment and to prevent accidents. However, this equipment has its limitations, i.e. its lack of efficiency and safety, as it can even be a source of contamination during the dressing and undressing process and during disinfection (Garrigou *et al*., 2020; Meirelles *et al*., 2016; Abreu & Alonzo, 2014). This condition can be minimized through guidance and awareness of the farmer (Meirelles *et al*., 2016; Sapbamrer & Thammachai, 2020).

Moreover, it is the responsibility of the public and private sectors training and guidance of tobacco farmers guidance about the importance and ways to prevent and mitigate the risks and negative consequences of the production process. The best strategy farmers can adopt to mitigate the risks and dangers is to reduce the use of pesticides, even if the ideal is to avoid them altogether (Abreu & Alonzo, 2014; Veiga *et al*., 2007). It is important that strategies for organic production that enable the grower to adapt to new opportunities be promoted.

3.4. Pesticides residues in river and groundwater samples

In addition to the high number of asymptomatic cases (Fassa *et al*., 2018) health care providers should pay attention to possible symptoms of poisoning due to simultaneous exposure to pesticides and nicotine at the time of pruning and trimming (Santos *et al*., 2017). In this sense, world statistics reveal that around 25 million farmers are lightly poisoned each year and three million suffer severe pesticide poisoning (Rezaei et al., 2019). In previous studies, it was shown that bodies of water adjacent to agricultural areas can present residues of pesticides in the vicinity of tobacco plantations and especially in the absence of riparian forests around the rivers (Garrigo *et al*., 2020; Taufeeq *et al*., 2021). Among the 14 pesticides most cited by tobacco growers (Chart S1), we found residues of six and three pesticides in water from rivers and wells, respectively (Table 3).

To the best of our best knowledge, no studies address both the effects of smoking and exposure to pesticides on workers' health, as well as the detection of pesticide residues in water bodies close to tobacco crops in Santa Catarina, Brazil. Few studies have been paid to the presence of pesticide residues in waters close to tobacco cultivation and the associated environmental risks (Gerónimo *et al*., 2014; Ali *et al*., 2023).

Of the eighteen samples with pesticide residues, twelve (33.3 %) were from river waters and six (16.7 %) from wells (Table 3, Figure S2). Our results also indicate that, considering the three sampling periods, the active ingredient sulfentrazone is the one with the highest occurrence (50 %) followed by imidacloprid (27.8 %)

TABLE 3 – Presence of residues of active ingredients of the more frequently used pesticides in river and groundwater sampled before, during and after tobacco cultivation, Chapadão do Lageado, Santa Catarina, Brazil, 2019.

	Chemical compound	Commercial name	Guideline value			Commercial product dosage	Source of the water samples	Collection site	Pesticide concentration ($\mu g\ L^{-1}$)		
			Brazil	USEPA	EU				Before planting	During production	After harvesting
Active Ingredient	Clomazone	Gamit® 360 CS	ND	ND	3	2.2 – 2.8 L ha^{-1}	River	Upstream Rio Lajeado	-	0.037	-
								Downstream Rio Lajeado	-	0.145	-
								Downstream Rio Figueiredo	-	0.075	-
	Sulfentrazone[1]	Boral® 500 SC	ND	ND	0.1	0.6 – 08 L ha^{-1}	River	Downstream Rio do Meio	-	0.062	0.036
								Upstream Rio Lajeado	0.095	-	0.136
								Downstream Rio Lajeado	0.058	0.336	0.127
								Upstream Rio Figueiredo	0.035	0.048	0.091
								Downstream Rio Figueiredo	-	0.248	0.099
							Groundwater (well)	Upstream Rio do Meio	-	-	0.390
								Downstream Rio Lajeado	0.098	-	0.217
								Upstream Rio Figueiredo	0.096	0.079	0.069
	Iprodione	Rovral®	ND	ND	0.1	NI	River	Upstream Rio do Meio	-	-	0.490
							Groundwater (well)	Upstream Rio Figueiredo	-	-	0.303
	Imidacloprid[2] b-cyfluthrin	Evidence® 700 WG	ND	ND	0.1	360 g ha^{-1}	River	Downstream Rio do Meio	-	0.073	0.008
								Upstream Rio Lajeado	0.060	0.143	0.082
								Downstream Rio Lajeado	-	0.193	0.035
		Confidor® Supra	ND	ND	0.1	21.77 g m^{-2}		Upstream Rio Figueiredo	-	0.077	-
								Downstream Rio Figueiredo	-	0.559	0.054
							Groundwater (well)	Downstream Rio Meio	0.038	-	-
	Thiamethoxa	Actara® 250 WG	ND	ND	0.1	0.6 g m^{-2} 600 – 840 g ha^{-1}	River	Downstream Rio do Meio	-	0.027	0.033
								Upstream Rio Lajeado	0.130	-	0.041
								Downstream Rio Lajeado	-	0.029	0.050
								Downstream Rio Figueiredo	-	-	0.028
							Groundwater (well)	Upstream Rio Figueiredo	0.030	-	-

[1] EU – banned active ingredients. [2] USA – banned active ingredients. MCL – Maximum Contaminant Level – The highest level of contaminant that is allowed in drinking water. Commercial product dosage – information described in the package leaflets of the respective products. The Council of the European Union (1998) establishes a maximum concentration for the sum of pesticides of 0.5 $\mu g\ L^{-1}$, where the concentration per individual molecule cannot exceed 0.1 $\mu g\ L^{-1}$. ND – Not determined in the legislation, is commonly used the value 0.1 $\mu g\ L^{-1}$.

SOURCE: adapted from European Commission, 2008; Brasil, 2011; USA, 2017; Brasil, 2019.

from river water and 2.8 % from wells. In 22.2 % for sampling points thiamethoxam was recorded, corresponding to river water (19.4 %) and well water (2.8 %) (Table 3; Figure S2).

Clomazone was identified in 8.3 % of the river water samples, only in the second collection. Iprodione pollution was registered in well water and river samples corresponding to the third collection (2.8 %). Among the 12 sampling points only two wells, Upstream Rio Lageado and Rio Figueredo, showed no pesticide contamination.

Following the recommendations of the World Health Organization, in Brazil, the Ministry of Health established the Ordinance nº 2914 (Brazil, 2011) that establishes the standards for handling and application of pesticides. However, there is no Maximum Permitted Value (VMP) or water potability parameters established for many commercialized active ingredients, nor the framework of the classes of water use nor is there a framework for water use classes (Brazil, 2005). According to the National Health Surveillance Agency (ANVISA), in May 2021, there were 5.974 active ingredients registered and approved for the treatment of various agricultural crops in use in Brazil (Brazil, 2022). The evaluation of pesticide registration is not only the competence of ANVISA, but also includes the Ministry of Agriculture, Livestock and Supply and the Brazilian Institute of Environment and Renewable Natural Resources.

If no parameters or VPM are stipulated by legislation, there is no legal basis for assessing whether the water is fit for human consumption. If we use the maximum individual limit set for drinking water by the European Commission (European Commission, 2008) being 0.1 μg L^{-1}, many results obtained in this study exceed this level (Table 3). Studies conducted in different continents, North America (Stayner *et al*., 2017), Europe (Rousis *et al*., 2017; Herrero-Hernández *et al*., 2017), and Asia (Qian *et al*., 2017), has reported the pollution of surface water by pesticides, and, in some cases, the presence of these substances in values above the maximum individual limit established for drinking water by the European Commission (0.1 μg L^{-1}) (Council of the European Union, 1998).

To mitigate the socio-environmental impact of pesticides and protect the quality of water resources it is necessary to monitor water bodies (Bach *et al*., 2017). The high presence of pesticides in waters is related to their use in agricultural activities and hydrological conditions (Pignati *et al*., 2017; Dragon *et al*., 2019). There are residues of pesticides that can persist in the soil for years and can be moved by stormwater with the potential for surface water contamination (Schleiffer & Speiser, 2022). Even if there is little precipitation, migration of many substances occurs because they accumulate in the environment and can be removed from the soil matrix by infiltration and transported through the aeration zone to groundwater along flow paths (Dragon *et al*., 2019).

The transport of pesticides is mainly determined by their solubility and partition coefficient. Chart S2 shows the values of these factors for sulfentrazone, imidaclopride, thiamethoxam, clomazone and iprodione.

Due to their high solubility in water (Chart S2), these pesticides present high potential for leaching and polluting surface and groundwater resources.

The quantification of pesticide residues in the water of rivers and wells indicates a potential risk of contamination, considering that the surface waters from the Itajaí Açu River basin are used for human consumption, as well as for crop irrigation and pisciculture. It is possible that these substances have impacts on the quality of the local biota and human health because the fate of pesticides in the environment is determined by retention processes, transformation, transport, and interactions among these processes.

In the period in which the water samples were collected, the amount, intensity and frequency of rainfall was very low, a factor that may contribute to the results. During periods of greater precipitation, these substances may enter groundwater, which has the potential to negatively impact all organisms, and pose a risk to the public and the environment, so it should be treated as a public health issue.

The results of this study show that producers are exposed to human health and socio-environmental risks. This reality must be changed through joint actions by different stakeholders to combat misinformation. It is needed to promote actions aimed to prevent intoxication among workers exposed to pesticides and nicotine. In case of poisoning, it is necessary to carry out blood and urine tests to determine whether the cause was pesticides or nicotine.

4. Conclusions

The working conditions in tobacco cultivation expose farmers to various production-related risks, such as the intensive use of pesticides and contact with the nicotine of the green, moist tobacco leaves. In addition, the low compliance and inherent limitations of PPE further increase the risk of poisoning. Tobacco cultivation demands long working days, usually involving all family members, including minors and the elderly, who become vulnerable to intoxication. This scenario can be considered a socio-environmental risk factor due to the presence of pesticide active ingredient residues in the rivers and wells of water. An integrated approach between companies and regulatory agencies must be developed to create strategies to educate and train the workers to mitigate the risks to human health and the environment. In addition to the public health issues, it is also necessary to monitor water quality, especially in areas where native forests are being replaced by tobacco crops, in terms of effective watershed management.

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