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Occupational exposure to pesticides and health in farmers Cienega, Jalisco, Mexico

Exposición laboral a plaguicidas y la salud en agricultores Ciénega, Jalisco, México

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ABSTRACT

Farmers are more vulnerable to pesticide poisoning. La Ciénega, Jalisco, has high agricultural productivity and high pesticide use. However, there are no previous studies evaluating the health effects on farmers. This study aimed to describe the consequences of pesticide occupational exposure on the health of farmers in La Ciénega de Jalisco area. A total of 121 surveys were applied to farmers with chronic exposure (2019 to 2022) on pesticide use incidents. The survey consisted of 64 dichotomous qualitative-type items and was validated by Cronbach's alpha coefficient, with a value of 0.6880. The most frequent symptoms were dizziness (66.7 % and 36.9 %) and headache (58.3 % and 48.8 %). The most frequent diseases were hypercholesterolemia (34.3 % and 26.7 %), hypertension (31.4 % and 36 %), and type 2 diabetes mellitus (22.9 % and 14.7 %). Glucose levels below 200 mg/dL were found in 92.08 % of the farmers. 63.89 % of the participants consumed food during pesticide application. Dizziness ($p = 0.027$) and burning skin ($p = 0.003$) were associated with gender, indicating that gender may be a condition related to pesticide poisoning symptoms

KEY WORDS: Pesticides, Occupational exposure, Poisoning, Cronbach's alpha coefficient, Symptoms.

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RESUMEN

Los agricultores tienen mayor vulnerabilidad de intoxicación por plaguicidas. La Ciénega, Jalisco tiene alta productividad agrícola y elevado uso de plaguicidas. Sin embargo, no hay estudios previos que evalúan los efectos en la salud de agricultores. El objetivo de este estudio fue describir las consecuencias de la exposición laboral a plaguicidas en la salud de agricultores de la Ciénega de Jalisco. Se aplicaron 121 encuestas a agricultores con exposición crónica (2019 a 2022) sobre incidentes en el uso de plaguicidas. La encuesta consta de 64 ítems tipo cualitativas dicotómicas y se validó mediante el coeficiente alfa de Cronbach, con valor de 0.6880. Los síntomas más frecuentes fueron mareos (66.7 y 36.9 %) y dolor de cabeza (58.3 y 48.8 %). Las enfermedades más frecuentes fueron hipercolesterolemia (34.3 y 26.7 %), hipertensión (31.4 y 36 %) y Diabetes Mellitus tipo 2 (22.9 y 14.7 %). El 92.08 % de los agricultores presentaron niveles de glucosa inferiores a 200 mg/dL. El 63.89 % de los participantes consumieron alimentos durante la aplicación de plaguicidas. Se encontró asociación de mareos (p = 0.027) y ardor en piel (p = 0.003) con el género lo cual indica que el sexo puede ser una condición relacionada con los síntomas de intoxicación a plaguicidas.

PALABRAS CLAVE: Plaguicidas, Exposición laboral, Intoxicación, Coeficiente alfa de Cronbach, Síntomas.

Introduction

Pesticides are chemical substances used to control the development of pests in economically important crops. Depending on their target organism, they can be classified as insecticides, fungicides, herbicides, acaricides, rodenticides, algaecides, and avicides, among others (Rani *et al.,* 2021). While pesticides increase agricultural production, they are highly toxic to humans and can be associated with the development of cancer, leukemia, type 2 diabetes mellitus (T2DM), asthma, Parkinson's disease, reproductive, renal, developmental, metabolic, and autoimmune diseases (Ceja-Gálvez *et al.,* 2021; Rani *et al.,* 2021). Pesticide toxicity depends on factors such as age, sex, genetic background, dose, exposure route, and exposure time (Valbuena *et al.,* 2020). There may be groups vulnerable to exposure such as children, older adults, pregnant women, and subjects with chronic occupational exposure (Salazar-Flores *et al.,* 2020). In Mexico, the pesticide use has increased significantly. Studies show that occupational and environmental conditions increase the susceptibility of farmers to intoxication with diverse health consequences (Esquivel-Valenzuela *et al.,* 2019). In two agricultural valleys in Sonora and Sinaloa, soil contamination with 10 highly hazardous pesticides was found (García-Hernández *et al.,* 2021). In addition, in Veracruz, it was determined that the association between occupational

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exposure to pesticides and their risk to human health is high due to the lack of training in the handling and application of these substances, as well as minimal and incomplete use of protective equipment (Ramírez-Mora *et al.,* 2019). In Jalisco, a high number of poisonings was found in both men (Figure 1a) and women (Figure 1b) compared to other states during the period 2012 to 2020 (Figure 1; Secretaria de Salud, 1984-2021). The municipalities with the highest number of poisonings were La Barca, Jocotepec, and Ocotlán; while Atotonilco el Alto and Tototlán (Figure 2) obtained the lowest frequencies, all belonging to La Ciénega region (Secretaría de Salud, 2012-2017). Previous studies in this region indicated the use of pesticides considered highly hazardous, specifically Salazar-Flores *et al.,* 2020 reported the percentage of use of carbofuran (21.4 %), paraquat (19.02 %) and terbufos (18.7 %), in addition, an alteration in oxidative stress markers such as lipoperoxides, nitrates/nitrites, carbonyl groups and membrane fluidity was observed (Salazar-Flores *et al.,* 2020; García-Hernández *et al.,* 2021; Silva-Madera *et al.,* 2021). Therefore, the objective of this study was to evaluate the health effects of occupational exposure to pesticides in farmers of La Ciénega Jalisco, Mexico.

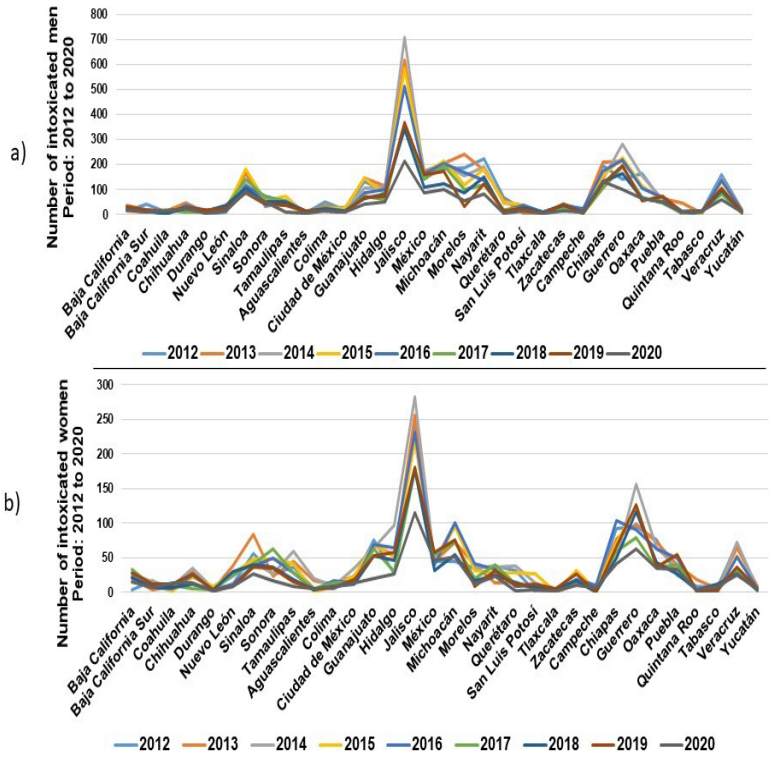

Figure 1. Frequency of poisonings by gender at the national level. a) results in men, b) results in women.

Source: Own elaboration based on IBM SPSS v.24.0 with data from Secretaría de Salud, 1984-2021.

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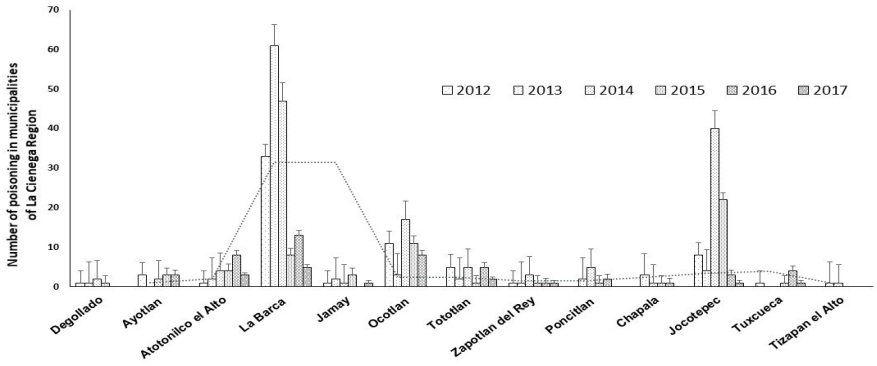

Figure 2. Number of poisonings in the state of Jalisco.

Source: Own elaboration based on IBM SPSS v.24.0 with data from Secretaría de Salud, 2012-2017.

Material and Methods

Study population

A descriptive study was conducted from 2019 to 2022, from June to August. A total of 121 self-reported surveys were administered to agricultural workers with chronic pesticide exposure, encompassing 39 women and 82 men. These participants were residents of rural communities, with the majority having primary schooling. The ages of both sexes were grouped to calculate an overall average of 49.8 ± 15.7 years. Since there were no differences between populations, the surveys were conducted in Poncitlán, Ocotlán, La Barca, and Atotonilco el Alto, municipalities of La Ciénega region (Figure 3). Additionally, all subjects underwent a random glucose test using a One-Touch Ultra2 glucometer.

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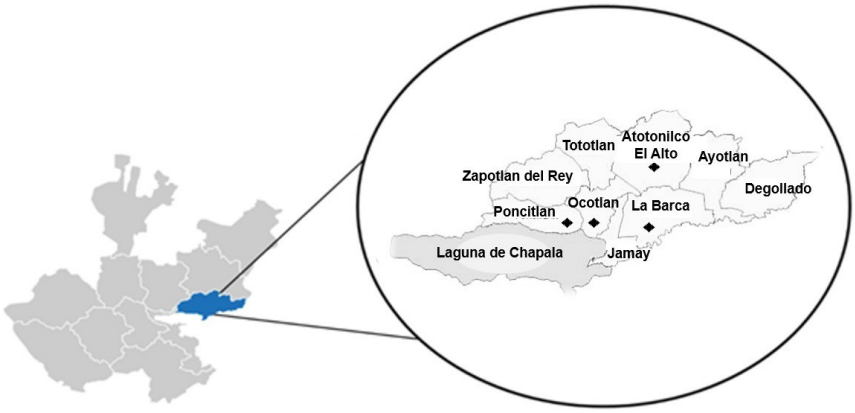

Figure 3. La Cienega Region of Jalisco. The municipalities studied are marked with ◆.

Source: Taken and modified from https://visitjalisco.com.mx/region/regionCiénega/; Castro-Sánchez & Galán-Briseño, 2020 on 20/02/2023.

Sample size calculation

The sample size was calculated using equation (1) for a descriptive design, where **n** represents the sample size, **Z** is the standard deviation at a 95 % confidence interval, **p** is the frequency of finding the study factor (0.50), **q** is the frequency of not finding the study factor (*0.50*), and **d** is the study bias (0.10). This calculation yielded a sample size (**n**) of 96 participants.

$$n = \frac{Z^2 pq}{d^2}$$ Equation (1)

$$n = \frac{(1.96)^2(0.50)(0.50)}{(0.10)^2} = 96.04$$

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Questionnaire design

The survey was structured into three sections: 1) sociodemographic data, with basic data such as name, age, weight, sex, and locality; 2) characteristics of pesticide exposure, types, health incidents, form of use, waste disposal, exposure time, use of protective equipment, food consumption, hygiene actions after exposure, and date of last contact with pesticides; 3) health effects due to exposure to pesticides, pre-existing chronic diseases, diseases of close relatives, sick kinship, consumption habits, physical activity and consumption of medicines. The survey consisted of 64 items and underwent validation using Cronbach's alpha coefficient equation, yielding a value of 0.6880, indicating good consistency and reliability (Cronbach, 1951). The instrument was administered during the rainy season (June to August) to ensure pesticide exposure.

Selection criteria

Inclusion

- Persons of legal age (> 18 years).
- Farmers exposed to pesticides.
- Persons working in La Ciénega region.
- Individuals of both sexes.

Non-inclusion

- Minors (< 18 years old).
- Farmers who do not use pesticides.
- Individuals not working in La Ciénega region.

Exclusion

- Individuals who have not provided necessary data for various analyses (e.g., symptoms, exposure duration).
- Individuals who did not sign the letter of consent.
- Participants who opted to withdraw from the study.

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Ethical considerations

The level of risk to participants in this study was minimal, given that only a small blood sample was obtained via capillary extraction. The study received approval from the Ethics Committee of the Centro Universitario de la Ciénega, Universidad de Guadalajara, under Folio 2019-037. Each participant provided informed consent, and the confidentiality of their data was guaranteed. The study adhered to the principles outlined in the Declaration of Helsinki.

Statistical analysis

Descriptive statistics were employed to calculate frequencies, percentages, and averages. The association of exposure time, sex, and age with the frequency of symptoms and diseases was assessed using Pearson's chi-square test or Yates correction. For random glucose levels, two analyses were conducted; The first analysis examined the association of high glucose levels with characteristic symptoms of diabetes (as included in the survey). The second analysis evaluated the correlation between glucose levels and exposure time to determine whether longer exposure times correlated with higher glucose levels. The statistical software IBM SPSS v.24.0 was utilized for analysis. A *p-value* of ≤ 0.05 was considered significant for associations, and an *r-value* between > 0.5 and < 1.0 was deemed indicative of a strong correlation.

Results

32 % of the participants were women, and 68 % were men. Both genders reported not using protective equipment during pesticide application. The most frequent symptoms experienced by women during pesticide application were dizziness (66.7 %), headache (58.3 %), blurred vision (33.3 %), sore throat (30.6 %), breathing problems (27.8 %), and tremors (25 %). Less frequently reported symptoms included heart palpitations, throwing up, and skin burning. Among men, the most common symptom was headache (48.8 %), followed by dizziness (36.9 %), blurred vision (33.3 %), burning skin (26.2 %), vomiting (23.8 %), tremors (21.4 %), sore throa, heart palpitations, and breathing problems (all reported at 16.7 %). Less frequently reported symptoms included muscle weakness, memory loss, and fainting (Table 1).

In the data analysis, only positive associations were found, considering sex as a risk factor, with dizziness ($p = 0.027$) and skin burning ($p = 0.003$). No statistical significance was found with the remaining symptoms, nor with the variables time of exposure and age (Table 1).

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Table 1. Frequencies of symptoms in women and men in La Cienega region.

Symptom	Women (%)	Men (%)	Sex	Exposure time	Age
Dizziness	66.7 %	36.9 %	***p = 0.027***		
Headache	58.3 %	48.8 %			
Blurry vision	33.3 %	33.3 %			
Sore throat	30.6 %	16.7 %			
Breathing problems	27.8 %	16.7 %			
Tremors	25 %	21.4 %			
Muscular weakness	16.7 %	14.3 %	*p > 0.050*	*p > 0.050*	*p > 0.050*
Heart palpitations	13.9 %	16.7 %			
Threw up	13.9 %	23.8 %			
Memory loss	0	9.5 %			
Fainting	0	1.2 %			
Burning in the skin	8.3 %	26.2 %	***p = 0.003***		

p = Pearson's chi-square test.

Source: Own elaboration.

In women, the frequencies of diseases found were as follows: hypercholesterolemia (34.3 %), hypertension (31.4 %), T2DM (22.9 %), neurosis (17.1 %), leukemia (14.3 %), cancer (11.4 %), and renal disease (8.6 %). Among men, hypertension was the most frequent disease (36 %), followed by hypercholesterolemia (26.7 %), renal disease (16 %), T2DM (14.7 %), neurosis (5.3 %), leukemia and cancer (both at 4 %). Other diseases found less frequently included hepatitis and dementia. No disease showed statistical significance with the variables sex, time of exposure, and age (Table 2).

For glucose levels, a parameter of 200 mg/dL was utilized, as one of the criteria for diagnosing diabetes is to exhibit symptoms of diabetes and have a random glucose concentration equal to or greater than 200 mg/dL. A random sample is defined as one obtained without considering the time elapsed since the last meal (Brunton *et al.,* 2019). 92.08 % of participants (111 individuals) had levels below 200 mg/dL (Figure 4a) and reported experiencing T2DM symptoms (polyuria, polydipsia, and polyphagia) during the previous month. It is noteworthy that participants self-reported a medical diagnosis of T2DM. In the glucose association analysis, no significance

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was found between high glucose levels and representative symptoms ($p > 0.05$). However, the correlation analysis indicated an $r^2 = 0.083$, suggesting no correlation between exposure time and glucose levels. Furthermore, 18.52 % of participants reported not consuming food during pesticide application, 17.59 % reported doing so sometimes, and 63.89 % reported consuming food (Figure 4b). Regarding waste disposal, 2.94 % of participants disposed of leftovers in the trash, 5.88 % returned them to the supplier, and 91.18 % kept them for reuse (Figure 4c).

Table 2. Frequency of diseases in women and men in La Cienega region.

Disease	Women (%)	Men (%)	Sex	Exposure time	Age
Hypercholesterolemia	34.3 %	26.7 %			
Hypertension	31.4 %	36 %			
T2DM	22.9 %	14.7 %			
Neurosis	17.1 %	5.3 %			
Leukemia	14.3 %	4 %	*p > 0.050*	*p > 0.050*	*p > 0.050*
Cancer	11.4 %	4 %			
Renal disease	8.6 %	16 %			
Hepatitis	5.7 %	1.3 %			
Dementia	0	1.3 %			

p = Pearson's chi-square test.

Source: Own elaboration

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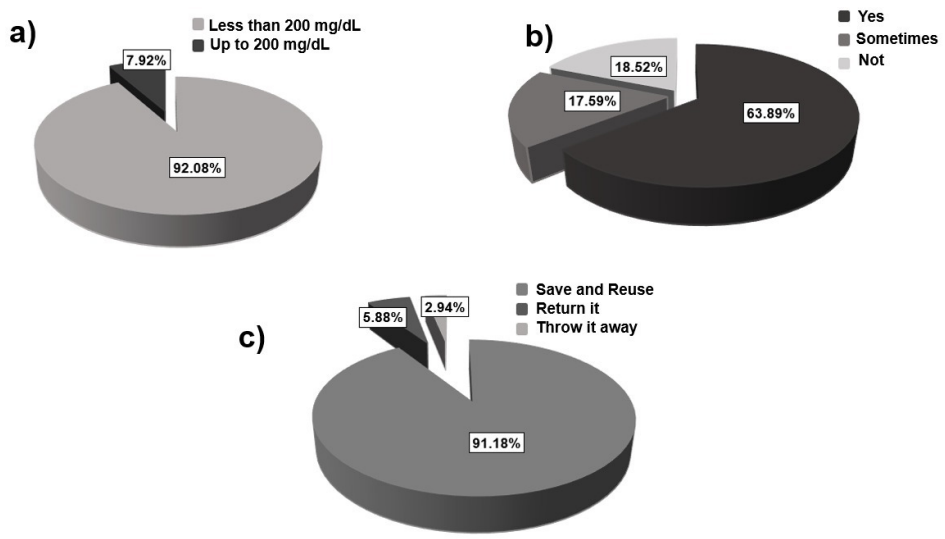

Figure 4. Additional data, a) Random glucose levels (mg/dL) in subjects occupationally exposed to pesticides. b) Frequency of food consumption during pesticide application. c) Fate of pesticide residues during a planting cycle.

Source: Own elaboration based on IBM SPSS v.24.0.

Regarding drug consumption, 16.9 % consume antihypertensives, 11.9 % nonsteroidal anti-inflammatory drugs (NSAIDs), 10.2 % oral hypoglycemic agents, 5.10 % oral antidepressants, and with frequencies of less than 5 % multivitamins, proton pump inhibitors (IPPs), antibiotics, statins and anticonvulsants (Figure 5).

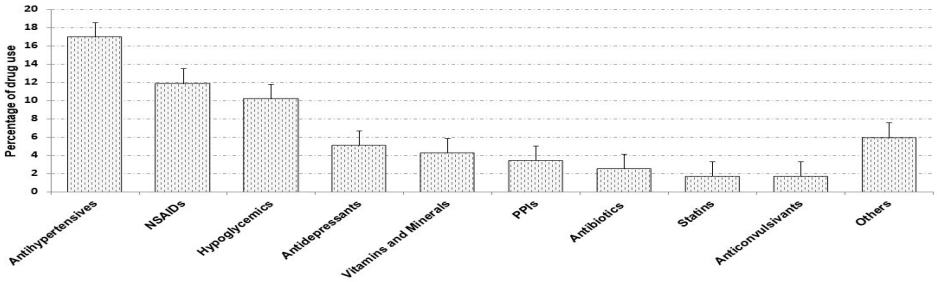

Figure 5. Percentages of use of different pharmacological groups in subjects occupationally exposed to pesticides in La Cienega, Jalisco, Mexico.

Source: Own elaboration based on IBM SPSS v.24.0.

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Discussion

This study was initiated in response to the elevated concentrations of pesticides found in surface water and runoff in La Ciénega region. Malathion and glyphosate were identified as the pesticides with the highest presence in the region, exceeding permissible levels according to data from the Environmental Protection Agency (EPA) (Silva-Madera *et al.,* 2021).

In La Ciénega region, the increased levels of pesticides in water sources (Silva-Madera *et al.,* 2021) may be associated with a higher intoxication incidence (Secretaría de Salud, 1984-2021; 2012-2017), which could be exacerbated by improper pesticide management. The resulting symptoms and diseases are described below.

The most frequent symptoms (Table 1) are related to cholinergic toxicity resulting from exposure to organophosphate pesticides, which inhibit the enzyme acetylcholinesterase (AChE), leading to overstimulation of acetylcholine (ACh) receptors. Mild cases may manifest with symptoms such as headache, nausea, dizziness, throwing up, pupil constriction, excessive sweating, tearing, and salivation. Additionally, these pesticides can disrupt hormonal regulation and function as endocrine disruptors (Ganie *et al.,* 2022; van Melis *et al.,* 2023). Dizziness and headache are attributed to increased ACh at cholinergic receptors in the central nervous system (CNS). Symptoms like blurred vision, sore throat, bronchospasm/bronchorrhea (respiratory problems), and throwing up, which are common in both sexes (Table 1), can occur due to overstimulation of muscarinic receptors for ACh (Lott & Jones, 2022).

A statistical significance between the sex variable and the symptoms of dizziness ($p = 0.027$) and burning of the skin ($p = 0.003$) was identified, suggesting that sex may be a factor related to symptoms of pesticide poisoning. Our findings indicate that women may be at higher risk, as they presented higher percentages of the described symptoms (Table 1). However, these results should be interpreted cautiously, as organophosphate exposure has been significantly associated with elevated odds of metabolic syndrome in individual components in men (Luo *et al.,* 2020). Moreover, it has been observed that, except for motor function deficits, males exhibit greater susceptibility to organophosphate exposure and, consequently, greater sensitivity to most adverse effects caused by these substances (Comfort & Re, 2017). This discrepancy underscores the need for further research into the pesticide effect classified by gender, with equal exposure rates for both men and women.

Regarding diseases, although no significance was found between exposure to pesticides and the variables studied, it is well-documented that pesticides can influence the development of the diseases identified in this study. For example, pesticides are associated with increased oxidative stress, leading to DNA damage, altered gene expression, deacetylation, and methylation, indicating an epigenetic relationship (Sabarwal *et al.,* 2018). This mechanism may explain the development of cancer and leukemia, which were found at high frequencies in women in this study (Table 2). The association between pesticide exposure and leukemia risk has been documented (Foucault *et al.,* 2021). Pesticide exposure elevates reactive oxygen species (ROS) levels, thereby

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increasing oxidative stress, which plays a pivotal role in the onset and progression of leukemia by promoting cell survival, growth signaling, and genomic instability (Kreitz *et al.,* 2019; Rafeeinia *et al.,* 2022). Unfortunately, in Mexico, there have been no previous studies evaluating leukemia in pesticide-exposed individuals.

According to the results presented in Table 2, the most prevalent diseases in both sexes were hypercholesterolemia, hypertension, and Type 2 Diabetes Mellitus (T2DM). This finding aligns with studies conducted on workers from Pakistan and Cameroon with chronic organophosphate exposure. Additionally, the latter study reported that contact with agrochemicals is associated with the development of metabolic disorders such as hypertension, hyperglycemia, overweight, and dyslipidemia (Leonel Javeres *et al.,* 2021). Pesticides have been implicated in increasing triglyceride and lipid levels by activating peroxisome proliferator-activated receptor gamma (PPARγ), a gene involved in adipocyte differentiation and glucose control. Activation of PPARγ could lead to dyslipidemia and hyperglycemia (Montaigne *et al.,* 2021; Seok *et al.,* 2022). In a study involving male rats exposed to the organophosphate chlorpyrifos orally, hyperglycemia and hyperlipidemia were observed (Samarghandian *et al.,* 2020).

Similarly, epidemiological studies demonstrate a correlation between pesticide exposure and diabetes, as indicated in Table 2 (Samarghandian *et al.,* 2020; Leonel Javeres *et al.,* 2021). Toxic metabolites generated during pesticide biotransformation increase the risk of glucose intolerance, as they can lead to lipotoxicity (Lytrivi *et al.,* 2020; Utembe & Kamng'ona., 2021). This risk may be exacerbated in farmers who consume food during pesticide application (Figure 2b) or fail to use personal protective equipment (Yarpuz-Bozdogan, 2018; Sapbamrer & Thammachai, 2020). According to data from the Mexican Institute of Statistics and Geography (INEGI, 2021), an estimated 10.32 % of individuals over 20 years of age in Mexico have a T2DM diagnosis. However, studies confirming the association between T2DM and pesticide exposure are lacking.

In the Mexican population without occupational exposure to pesticides, men exhibit a higher prevalence of arterial hypertension (50 %) and T2DM (35.5 %) compared to women (Vintimilla *et al.,* 2020). Nevertheless, no results are evaluating these variables for the population exposed to pesticides.

Neurosis emerged as a notable disease, particularly prevalent among women (Table 2). This condition may arise due to cholinergic overstimulation of the Central Nervous System (CNS). Studies indicate that 4 to 9 % of individuals who have experienced organophosphate intoxication exhibit diverse neuropsychiatric symptoms, including neurosis (Ganie *et al.,* 2022). Data from UNAM (2022) suggest that approximately 15 million people in Mexico, without occupational pesticide exposure, suffer from neurosis. However, determining the precise incidence and prevalence of this disorder remains challenging (De la Fuente Muñiz, 2022).

Additionally, a higher prevalence of renal failure is reported in men (16 %). Evidence suggests that exposure to malathion increases the risk of reduced renal function, implicating a potential nephrotoxic role (Stalin *et al.,* 2020; Wan *et al.,* 2021). In Mexico, 8 % of the population suffers from renal disease. Notably, in Poncitlán municipality (Jalisco state), an increase in Chronic

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Kidney Disease of unknown etiology (CKDu), known as Mesoamerican nephropathy, has been observed. The prevalence of renal disease in Poncitlán is 20.1 %, compared to 10.4 % in other municipalities. This suggests a possible association between high pesticide exposure and the increased incidence of CKDu in the region (García-García *et al.,* 2019).

The most commonly used drugs among the study participants were antihypertensives (16.9 %) and NSAIDs (11.9 %), which correlates with the high frequency of headaches (58.3 %). Additionally, hypoglycemic agents (10.2 %) were reported. Moderate use of statins (1.7 %) was observed (Figure 3). Antihypertensive and hypoglycemic drugs are typically prescribed to reduce LDL, triglyceride, and blood pressure levels, thus promoting weight loss, increased insulin sensitivity, and higher HDL levels (Diaz *et al.,* 2019). However, there is a lack of published data on drug consumption among farmers exposed to pesticides.

Furthermore, it is noteworthy that a significant percentage of individuals do not use protective equipment and consume food during pesticide application. These practices, coupled with inadequate knowledge of health risks, lack of standardization in application doses, and improper disposal, storage, and transportation of agrochemicals, significantly elevate the risk of intoxication and subsequent manifestation of various symptoms and pathologies related to pesticide exposure. These limitations are compounded by water contamination by pesticides in La Ciénega, further heightening the health risks for agricultural workers. Consequently, there is an urgent need to enhance biosafety conditions and enact appropriate legislation in this field, as previously advocated (Yarpuz-Bozdogan, 2018; Sapbamrer & Thammachai, 2020).

Conclusions

The most prevalent symptoms observed in the study were dizziness and headache. The analysis revealed statistical significance between sex and the occurrence of symptoms such as dizziness ($p = 0.027$) and skin burning ($p = 0.003$), indicating a potential association between sex and pesticide poisoning symptoms. However, further investigations are warranted to validate these findings. Although no significant associations were found between the diseases examined and the variables of sex, exposure time, and age, there is existing evidence suggesting that pesticides contribute to the pathology of the diseases reported in this study. Women engaged in occupational pesticide exposure appear to constitute a vulnerable group in terms of developing hypercholesterolemia, arterial hypertension, and T2DM, which were the most prevalent pathologies identified. Furthermore, a majority of the participants reported consuming food during pesticide application, which, coupled with inadequate protective equipment and hygiene practices, may elevate the risk of pesticide intoxication. This study represents the initial effort to document self-reported illnesses among farmers in La Ciénega region exposed to pesticides. The results underscore the importance of further research aimed at elucidating the detrimental effects on human health, particularly in scenarios where appropriate protective measures and application practices are lacking. Such investigations are critical for informing policy measures and interventions aimed at safeguarding the health and well-being of agricultural workers.

Author contribution

Conceptualization of the work: TSED, SFJ. Methodology development: FGCA, TJJH, RUE. Software management: FGCA, SFJ. Experimental validation: TSED, TJJH. Analysis of results: TSED, FGCA, RUE. Data management: FGCA, SFJ. Manuscript writing and preparation: TSED, FGCA, SFJ. Writing, revising, and editing: TSED, SFJ. Project manager: SFJ.

All the authors read and accepted the public version of this manuscrip

Financing

This research did not receive external funding.

Ethical statements

This study was approved by the Ethics Committee of the Centro Universitario de La Ciénega, University of Guadalajara, under Folio 2019-037.

Statement of Informed Consent

Informed consent was obtained from all subjects involved in the study.

Conflict of interest

The authors declare that they have no conflicts of interest.

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