

## REVIEW ARTICLE

## The link between pesticide exposure and suicide in agricultural workers: a systematic review

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## ABSTRACT:

**Introduction:** The aim of this study was to conduct a systematic literature review to find the association between pesticide exposure and the incidence of suicide in agricultural workers, focusing on analyzing the profile of agricultural workers, the countries with the highest number of publications and, especially, the link between occupational exposure to pesticides, the degradation of mental health and suicide among agricultural workers.

**Methods:** A systematic literature review was conducted following the PRISMA protocol using Scopus, Web of Science, and PubMed databases, where 33 articles were screened to compose the final

portfolio.

**Results:** There is a strong link between pesticide exposure and suicide in agricultural workers. Smoking, alcohol consumption, exposure time, and marital status influence the decision to die by suicide. Brazil and the US lead the ranking in publications, demonstrating that it is not a problem only for developing countries. Organophosphates are the main pesticides used, and they degrade an enzyme crucial for the nervous system, which can result in mental disorders and consequent suicide in agricultural workers.

**Conclusion:** There is a need for stricter norms for the

commercialization and use of pesticides. There is also a need for providing training to agricultural workers on the application and

storage of pesticides, and to communicate about the compounds and the consequences of pesticides to mental health.

## Keywords:

agricultural worker, Brazil, farmer, mental health, pesticide, suicide.

## FULL ARTICLE:

### Introduction

The need to maximize the productivity of agricultural lands to meet the demand for food has led to an increasing use of pesticides. In this large-scale use, agricultural workers have high levels of exposure that can trigger health problems as a result of a lack of knowledge of how pesticides can be lethal to health and the consequences of their use<sup>1</sup>; thus, agricultural workers are one of the groups most affected by suicide and mental health problems<sup>2,3</sup>.

It is essential to distinguish between some terms involving suicide: suicide ideation, suicide attempt, and suicide itself. Suicide ideation is a risk factor that can lead to suicide because it makes people think of ending their lives without necessarily implying a material fact<sup>4</sup>. A suicide attempt is an act of attempting to take one's life, but it does not necessarily imply intention to die by suicide. Exposure to agrochemicals is a factor that can lead to suicide in agricultural workers; however, there are different opinions on this topic<sup>4</sup>. Thus, more studies are necessary to confirm and understand this phenomenon<sup>5</sup>.

Several studies confirm that the use of pesticides is closely related to adverse effects on human mental health, such as anxiety and depression<sup>5-9</sup>. These mental disorders can potentially lead people to die by suicide, and has become a public health problem because it is responsible for approximately 250 000 deaths annually, most of which occur in developing countries<sup>10</sup>. Moreover, a previous review showed that rural workers are more likely than other professions to die by suicide<sup>11</sup>.

The existing literature on suicide and exposure to pesticides shows a crude reality. An evaluation of 409 suicide attempts of rural workers in China showed that working in agriculture produces mental disorders and depression, which can lead people to suicide<sup>12</sup>. In Australia, another study argued that the highest suicide rates are among agricultural workers regardless of gender<sup>13</sup>. On analyzing these previous studies, the need to understand the motivation of agricultural workers to die by suicide in rural areas arises.

Current literature on rural work and suicide focuses on the mental health of agricultural workers in certain countries<sup>1</sup> and analyzes the consequences of pesticide exposure for mental illness, cancer, and teratogenicity<sup>14</sup>. These studies note a higher risk of suicide due to mental disorders produced by constant and acute exposure to pesticides; this reaffirms the need to understand the association between pesticide exposure and suicide in agricultural workers.

Therefore, this study aimed to conduct a systematic literature

review to find the association between pesticide exposure and the incidence of suicide in agricultural workers. It is worth highlighting that this research focuses on suicide due to the exposure to pesticides and not the poisoning with pesticides as a means to attempt or carry out suicide.

### Methods

The systematic literature review of this research followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol<sup>15</sup>. This protocol reviews the abstract, introduction, methods, and results in all selected papers in the research bases following a checklist of 27 items. After a previous verification, a documentary flow is described (Fig 1) to construct the final portfolio selected for the systematic literature review.

The databases used in this review were Scopus, Web of Science, and PubMed. Searches in these databases were conducted using the following strings of keywords.

- Rural worker OR Agricultural worker OR Farm worker OR Farmer
- Suicide OR Suicide intention OR Suicide attempt
- Agrochemicals OR Pesticides OR Pesticide exposure OR Agrochemical exposure

The searches in databases initially screened 307 documents (Fig1). However, after excluding duplicates and grey literature and filtering by type of document (articles or reviews) and language (English or Portuguese), 232 documents remain.

After reading the title, abstract, and keywords, we realized that some papers were not related to this study, eg articles where notably agricultural workers or the use of pesticides were not the object of study, resulting in 174 remaining.

Finally, a full read of the text of these articles was conducted, excluding the papers that were not closely related to the research theme. This resulted in 30 articles, and three were added because they were relevant to this study, resulting in a final portfolio of 33 articles.

From the final portfolio, the following data were extracted:

- sample size
- type of crop
- type of pesticide
- effects caused on rural workers' health
- country of research
- variables studied.

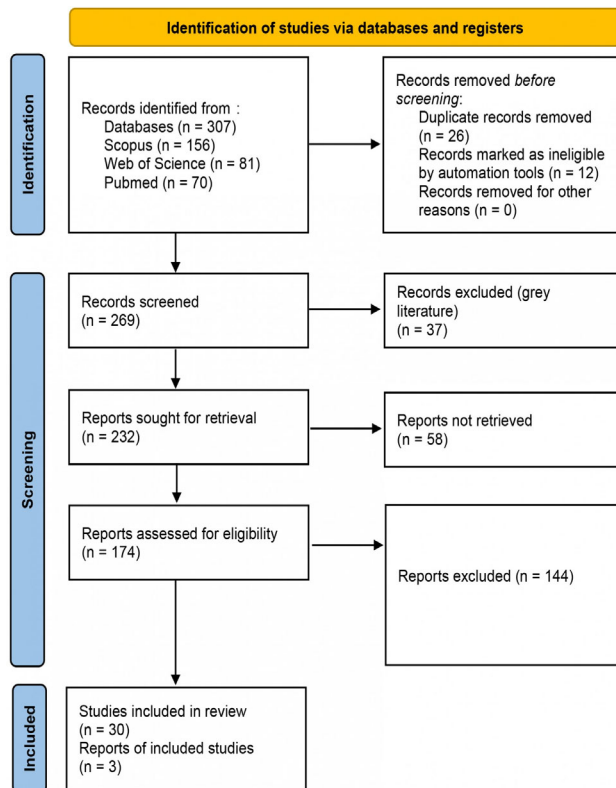


Figure 1: Steps for constructing the final portfolio.

### Ethics approval

No approval and/or consent was required, since this study is based on a review of the existing literature.

### Results

The 33 articles selected for the literature review were analyzed and are described in Table 1<sup>4,8,16-46</sup>.

The country with the highest number of publications was Brazil with nine articles<sup>18,20,27-29,32,33,38,42</sup>, the US had five articles<sup>8,24,30,39,40</sup>, the UK had four articles<sup>16,19,36,46</sup>, Iran<sup>17,31</sup> and Spain<sup>37,41</sup> had two articles, and another 11 countries had one publication each.

The year with the highest number of publications is 2014, with four<sup>4,20,32,42</sup>, followed by 2007<sup>30,35,36</sup>, 2010<sup>23,24,44</sup>, and 2016<sup>17,19,28</sup> with three surveys in each year; then 2002<sup>16,46</sup>, 2005<sup>21,29</sup>, 2013<sup>31,33</sup>, 2018<sup>22,34</sup> and 2021<sup>38,41</sup> with two publications in each year. The years 1996<sup>37</sup>, 1998<sup>43</sup>, 2000<sup>26</sup>, 2003<sup>18</sup>, 2006<sup>40</sup>, 2008<sup>8</sup>, 2011<sup>39</sup>, 2012<sup>45</sup>, 2017<sup>25</sup>, and 2020<sup>27</sup> have one publication each year.

The data sources analyzed in the review surveys are mostly from reports and censuses (13 occurrences). However, the authors proposed their own questionnaires for the research in seven articles. Other tests included the neuropathy questionnaire in two studies; cholinesterase activity tests in two surveys; the Self-Report Questionnaire in four surveys<sup>27,28,32,38</sup>, being combined with the authors' own questionnaire<sup>27,28</sup> and with the Intoxication Protocol of the State of Paraná and Alcohol Use Disorders Identification Test<sup>27</sup>; quality of life, stress, depression, and anxiety scales in one

survey; the Subjective Neurocognition Inventory combined with a blood glucose test in one study<sup>31</sup>; the Beck Depression Inventory<sup>34</sup>; Brief Symptom Inventor<sup>44</sup>; the Hospital Anxiety and Depression Scale<sup>19</sup>; the Barrat Impulsivity Scale combined with the Aggression Inventory in one survey<sup>22</sup>; and the General Health Questionnaire-28 in one survey<sup>31</sup>. The cholinesterase levels test was applied in four studies<sup>18,24,26,44</sup>.

The variables influencing suicide are smoking<sup>4,27,38,39</sup>, low level of education<sup>4,38</sup>, difficulty paying debts<sup>20,38</sup>, and frequent alcohol consumption<sup>27,39</sup>. Concerning the rural workers' age, studies found a set of varied result. Based on the literature, some age groups are more vulnerable: children from both genders aged less than 15 years<sup>28</sup>, people aged more than 40 years, and women of any age group<sup>20</sup>, men and women aged between 15 and 24 years<sup>35</sup> and people aged more than 65 years<sup>39</sup>. Moreover, the marital status of rural workers, predominantly separated, divorced, or widowed, is another factor influencing suicide<sup>4,39</sup>.

The chemical agents that are more present in the articles are the organophosphates, which were analyzed separately in 13 articles; organophosphates and carbamates appeared in four articles; and other types of pesticides were presented in 12 articles.

Regarding the effects of exposure, depression and anxiety are the most recurrent consequences in the publications (n=18); next is suicidal behavior, in four articles; mental disorders were present in three publications; nausea, tiredness, headache, and pain appeared in three publications; stomach diseases and asthma were present in two publications; the reduction of intellectual capacity in one publication; and three articles did not analyze the consequence of exposure.

**Table 1: Analysis of the portfolio**

Authors (year)	Sample size	Type of crop	Type of pesticide	Effects on rural workers' health	Variables studied
Jamal et al (2002) [ref. 16]	A case-control study (79 participants) aligned with a cross-sectional study (685 participants)	Not specified	OP	Clinical neuropathy and sensory abnormalities. The results did not show that cumulative exposure to OPs correlated with the presence of neuropathy, but the study was not designed to look at this question.	The neuropathy status was determined from the outcome of neuropathy scores derived from the responses to a questionnaire and sensory tests performed during the second phase of an epidemiological field study with predefined criteria. These were based on the Mayo Clinic's recommendation.
Taghavian et al (2016) [ref. 17]	A cross-sectional study with 67 participants (35 exposed to OP and 32 unexposed/control group)	Not specified	OP	Change in workers' mental health with emphasis on psychological aspects (quality of life, depression, anxiety, and stress)	Quality of life, depression, anxiety, and stress scales in farmers exposed to OP compared to the control group
Salvi et al (2003) [ref. 18]	A longitudinal study with 62 participants	Tobacco	OP	Neuropsychological (extrapyramidal symptoms), psychiatric (depression, anxiety). Plasma acetylcholinesterase activity levels of all subjects were within the normal range and were not different between on- and off-exposure periods.	Clinical, neuropsychiatric, and laboratory evaluations (plasma acetylcholinesterase activity). Psychiatric symptoms using the Mini-International Neuropsychiatric Interview
Harrison and Ross (2016) [ref. 19]	A case study with 205 participants (127 participants exposed to OP and 78 unexposed/control group)	Sheep farming	OP	Levels of anguish, anxiety, mood disorders, and depression. An association was found between low levels of exposure and anxiety and depression in farm workers. The only significant predictor in the model was the subjective health rating.	Exposure historic, self-reported mood, psychiatric diagnosis, depression, and self-reported anxiety, concerning demographic, psychosocial, and physical health assessments. Following the recommendations of the Hospital Anxiety and Depression Scale.
Faria et al (2014) [ref. 20]	Exploratory analysis. Between 1996 and 2010, there were 117 469 suicides among people aged $\geq 15$ years; approx. 45 000 were between 2006 and 2010	Not specified	OP	Psychiatric, psychological, and neurobehavioral problems related to depression and/or high impulsivity and suicidal ideation; behavioral changes similar to depressive disorders. The times series showed that there were higher suicide rates among people aged 35–64 years and among men aged 15–34 years.	Associations between pesticides (exposure and poisoning) and suicide rates (for the entire population and stratified by age and gender). Data obtained from government reports.
Thanh et al (2005) [ref. 21]	A retrospective analysis with 603 participants	Not specified	Not specified	Acute life stressors were the leading causes (73.8%) of suicide attempts. Only 6% of cases had a psychiatric illness diagnosed before the suicide attempts.	Psychosocial conditions and attempted suicide; the relationship between suicide and psychiatric illnesses or disorders. Medical reports
Lyu et al (2018) [ref. 22]	A case-control study with 43 participants (suicide attempt cases) and 43 control participants	Fruits	OP	The female-to-male ratio of patients living in urban areas (2.1:1) was higher than in rural areas (1.2:1). In urban areas, students (32%) and homeworkers (28%) and, in rural areas, farmers (56%) and students (17%) were the salient occupational categories.	Associations between exposure to OP, aggression, impulsivity, and suicide attempt. Barratt Impulsivity Scale and the Aggression Inventory
MacFarlane et al (2010) [ref. 23]	A retrospective analysis with 1084 female and 12 050 male participants exposed to pesticides	Livestock (cattle, sheep), grains, rice, vegetables, fruits, and forestry	OP, carbamates	From 81 suicides, its type was evaluated, and elevated standardised mortality ratios were seen across all subtypes, although small numbers meant only firearm suicides were statistically significant. Poisoning and hanging suicides were of borderline statistical significance. Of the 13 intentional self-poisoning deaths in the cohort, coding data about the cause suggested that eight were likely to have been pesticide poisonings.	Mortality rates and cancer incidence in Australian workers exposed to pesticides. Data obtained from government reports
Quandt et al (2010) [ref. 24]	A case-control study with 231 participants	Not specified	OP, carbamates	Cholinesterase levels in the sample varied by month, with the highest in August and the lowest in June. Depressions of 15% or more of an individual's maximum cholinesterase activity occurred throughout the season. Cholinesterase levels were significantly higher in August than in all other months.	Patterns and variation in cholinesterase levels across the agricultural season (May–August) among field workers; the relationship between the association of cholinesterase depression with pesticide exposure throughout the agricultural season. Blood sample (cholinesterase activity) and urine
Corral et al (2017) [ref. 25]	An exploratory cross-sectional study with 102 participants (32 directly exposed to pesticides, 32 living in agricultural areas and indirectly exposed, and 38 unexposed/control group)	Not specified	OP, carbamates	Deficiencies in intellectual capacity, academic skills, abstraction skills, reasoning, motor and social skills, psychomotricity, memory, working memory, deficiencies in planning skills, and mood	Relationship between cognitive impairment in workers and neuropsychological performance assessments. The following variables were considered potential confounders when analyzing scores from the cognitive tests: gender, educational level, age, and years of exposure. The assessed cognitive processes included memory, executive functions, attention, language praxis, and visuconstruction.
Beseler et al (2006) [ref. 8]	An exploratory cross-sectional study of 29 074 participants (wives of pesticide applicators) enrolled in the US Agricultural Health Study between 1993 and 1997	Not specified	Insecticides, herbicides, fumigants and fungicides	Depressive symptoms, especially mood swings. Women were more likely to be in the indirect-exposure group than men, while men were more likely to be in the unexposed group than women. Despite these differences, t-tests and Mann–Whitney U-tests were used to compare all cognitive scores between men and women, but no differences were found. Education: a $\chi^2$ test was conducted and showed no significant differences among groups. Age was not a confounder of the study. Regression analysis results showed that exposure time did not significantly predict cognitive scores.	Association between depression and pesticide exposure among women. Questionnaires were developed in the research. Mini-Mental State Examination, Digit span test, applying the Wechsler Adult Intelligence Scale in its revised version, Rey–Osterrieth Complex Figure test, Stroop test, d2 Test of Attention, Frontal Assessment Battery, Semantic Verbal Fluency, Barcelona Sub-test for Animals and Letter P
Cole et al (2000) [ref. 26]	Report forms on websites and subsequent follow-up of families with questionnaires; a case-control study with 50 cases reported from June 1991 to May 1992	Potatoes (mainly), grains, and dairy cattle	Carbofuran, methamidophos, mancozeb (most common), methomyl, parathion, and cholinesterase inhibitors (carbamates and OP)	Nervous and gastrointestinal cholinergic symptoms among all cases with carbamate and OP exposure. Skin symptoms were more common among those with a fungicide.	Economic burden of disease caused by pesticide poisoning in developing countries. Data from reports
Gonzaga et al (2021) [ref. 27]	A cross-sectional, analytical study with 547 participants (311 under pesticide exposure)	Bananas and other fruits	OP	Participants exposed to pesticides showed suicidal ideation in the last 30 days compared to control participants. The groups were statistically different in all the evaluated characteristics: problematic use of alcohol, current smoking, previous poisoning by pesticides, and suicidal ideation in the last 30 days.	Socioeconomic/demographic variables: gender, age, skin color, marital status, education; health-related variables: suicidal ideation, current smoking, problematic alcohol use, and previous pesticide poisoning. Self Reporting Questionnaire-20, Protocol for the Evaluation of Chronic Poisoning by Pesticides in the State of Paraná, Alcohol Use Disorders Identification Test.
Campos et al (2016) [ref. 28]	A descriptive analysis with 869 participants (October 2011 to March 2012)	Tobacco	Pyrethroids, aliphatic alcohol, dinitroaniline, and sulfonylurea	Mental disorders, disorders, and self-reported depression. The prevalence of common mental disorders and self-reported depression in the sample population was 23% and 21%, respectively. Among individuals who reported depression, an increase of 73% was observed in the odds of pesticide exposure at an age $\leq 15$ years	Self-Report Questionnaire-20. Use of a general questionnaire to collect individual data on identification, domicile, risk perception, general conditions of health, women's health, food insecurity, work, agriculture, use of transgenic seeds, tobacco farming, and use of pesticides and a clinical questionnaire to collect information on acute poisoning and exposure to pesticides by a chemical group. The self-reported depression outcome (yes/no) from a previous clinical diagnosis was obtained through a question incorporated into the general



					question incorporated into the general questionnaire.
Pires et al (2005) [ref. 29]	An exploratory analysis of 1355 notifications of poisoning caused by the handling and use of pesticides used in agriculture, with 501 of these notifications coming from voluntary ingestion of these products (suicide attempt), with 139 deaths	Cotton, rice, sugar cane, beans, corn, soy, and wheat	Insecticides and herbicides	A high prevalence of suicides due to various causes was also observed in Dourados, with an increasing trend in the last 10 years.	Information on rural establishments' module areas and urban and rural populations was obtained from the 1996 Agricultural Census of the Brazilian Institute of Geography and Statistics (IBGE) 11 and the IBGE Population Census.
Lee et al (2006) [ref. 90]	A cross-sectional study with 1851 deaths (588 among chlorpyrifos users) and retrospective analysis	Not specified	OP (chlorpyrifos)	Among external causes of death, mortality from suicide (codes X60–X84) and non-motor-vehicle accidents (codes W00–X59) were increased with lifetime exposure days, with more than two-fold relative risks in the highest category. However, the suicide finding was restricted to Iowa applicators.	Using a self-administered enrollment questionnaire, comprehensive exposure data on 22 pesticides and ever/never use information on 28 additional pesticides were collected, as well as information on the use of personal protective equipment, pesticide application methods, pesticide mixing, equipment repair, smoking history, alcohol consumption, medical conditions, other lifestyle factors, and primary demographic data.
Malekiran et al (2013) [ref. 31]	A cross-sectional study with 187 participants exposed to pesticides and 187 control participants	Not specified	OP	Rates of anxiety/insomnia and severe depression increased in farmers. The rate of social dysfunction was significantly higher in controls; clinical symptoms such as eczema, saliva secretion, fatigue, headache, sweating, abdominal pain, nausea, upper distal muscle weakness, lower distal muscle weakness, tingling hands, tingling feet, epiphoria, polyuria, miosis, dyspnea, bradycardia, and rhinorrhea were significantly correlated with the number of years of work, which allows the inference that farmers in contact with organophosphates are prone to neuropsychological disorders and diabetes.	Information on working history, socioeconomic status (salary, education), and lifestyle (smoking, alcohol consumption, drug use, vitamin or antioxidant supplementation, and dietary habits) were obtained at an interview with an expert examiner. Neurocognitive impairment was measured using the Subjective Neurocognition Inventory, and mental health status was evaluated using the General Health Questionnaire-28.
Faria et al (2014) [ref. 32]	A cross-sectional study with 2400 participants	Tobacco	Flumetralin, clomazone, neonicotinoids, dithiocarbamate, glyphosate, OP, metalaxyl, sulfentrazone, iprodione, pyrethroids and triazine	Minor psychiatric disorders were higher among women, workers aged more than 40, tenants/employees, and those who reported difficulty in paying debts. Low socioeconomic status was inversely associated with minor psychiatric disorders prevalence. Demographic factors (gender, age), employment status, economic indicators (annual tobacco production, difficulty in paying debts, vehicle ownership, percentage of income arising from tobacco), and family history of suicide. Lifestyle habits (smoking and alcohol consumption); religious activity; occupational exposures (working hours spent on agricultural activities, intense working pace, tasks requiring strenuous work); and pesticide exposure (types of individual exposure, intensity of exposure, frequency of use). Comorbidities: green tobacco sickness, chronic low back pain, and pesticide poisoning	Two questionnaires were used. The first collected economic indicators from farms. The second collected sociodemographic information in relation to people and farms. The outcome – minor psychiatric disorders – defined as non-psychotic mental disorders, was assessed using the SRQ-20 questionnaire.
Weisskopf et al (2013) [ref. 33]	A case-control study with 1547 participants	Not specified	Fungicides (amide, aromatic, dicarboximide, dithiocarbamate, triazole, copper, sulfur). Herbicides (amide, dinitroaniline, dinitrophenol, nitrile, phenoxy compounds, picolinic acid, quaternary ammonium)	The hazard ratio for depression among those who used herbicides was 1.93 (95%CI: 0.95, 3.91); there was no association with insecticides or fungicides. The main analyses included all farmers and were adjusted for sex, Parkinson's disease status, education (age at the end of schooling: <11 years, 11–13 years, >13 years), cigarette smoking, and history of head trauma with loss of consciousness.	To obtain detailed data on pesticide use, pesticide exposure was assessed using a two-phase procedure consisting of initial self-reported occupational history followed by extensive home interviews of everyone who used pesticides professionally. Participants were personally administered questionnaires by a Mutualité Sociale Agricole physician, who asked whether they had ever been treated (antidepressants, lithium, seismotherapy) or hospitalized for depression as a single question. For brevity, we refer to this as 'depression'.
Conti et al (2018) [ref. 34]	An exploratory survey of 220 participants	Coffee	OP, glyphosate	Adjusted multivariate analysis showed that pesticide exposure, tobacco use, poor self-perceived health, and the presence of chronic disease were determinants of a high Beck score.	The Beck Depression Inventory is not a diagnostic tool for depressive disorder, rather it is a self-report instrument that assesses the presence and severity of depressive symptoms in both normal and psychiatric populations.
Chowdhury et al (2007) [ref. 35]	A retrospective record review of 1775 cases of deliberate self-harm and 174 cases of suicide	Not specified	OP, kerosene, lice killer, rodenticides, indigenous poison (datura, yellow oleander seed), mixtures of alcohol with unknown poison, and kerosene with alcohol	Impulsivity was inherent in the psychodynamics of suicidal behavior. Among suicide cases, there were no significant differences between men and women. The largest numbers of both deliberate self-harms and suicide patients were in the 15–24-year-old group (49.9% and 41.4% respectively).	Analysis of methods of self-harm and its lethality, epidemiology of pesticide-related morbidity and mortality among patients, documentation of suicide and suicidal behavior concerning deliberate self-harm, level of awareness of pesticide toxicity, safe storage, and use. Retrospective record review. A local language questionnaire in Bengali was developed to inquire about pesticide practices.
Solomon et al (2007) [ref. 36]	A cross-sectional study with 9844 participants	Sheep farming	Sheep dip and others	Past use of pesticides not associated with anxiety and depression	The occurrence in the last month of each of the seven neurological symptoms that were associated with chronic organophosphate-induced neuropsychiatric disorder; symptoms of anxiety and depression in the last 7 days; the extent to which the subject was troubled or troubled during the past 7 days by each of the five somatic symptoms (fainting or dizziness, heart or chest pain, nausea or stomach pain, difficulty breathing, and hot or cold spells); and life history of consultation with a family doctor for four categories of health problems that have been suggested as a consequence of exposure to OP and that form part of the postulated COPIND syndrome.
Parrón et al (1996) [ref. 37]	A retrospective ecological study of 251 suicide cases	Not specified	Not specified	Rates and risk of suicide and affective disorders were found to be higher in populations exposed to higher levels of pesticides than in populations exposed to lower levels.	All suicides from three different areas of Ahneria province between 1976 and 1987 were carefully recorded and analyzed. We used data on 118 suicide cases from El Poniente in this period. All of them died in unequivocal circumstances and were eventually certified as having died by suicide.
Kim et al (2014) [ref. 4]	An environmental survey of 1958 participants (2011)	Rice, fruits, vegetables	OP and carbamates	The educational status of middle school graduates, marital status of separated, divorced, or widowed, and smoking were significantly associated with the risk of suicidal ideation. Lower-income groups showed decreased risks of association with suicidal	21 symptoms and signs were selected for screening acute pesticide poisoning based on the pilot study and reference reviews. These include nausea, vomiting, diarrhea, sore throat, runny nose, dyspnea, headache, dizziness.

				ideation. There was a significant univariate association between suicidal ideation and depressive symptoms.	hyperactivity, profuse sweating, blurred vision, paresthesia, slurred speech, paralysis, chest pain, syncope, muscle weakness, skin irritation, eye irritation, lacrimation, and fatigue. To measure chronic pesticide exposure, the authors calculated lifetime pesticide application days by multiplying the number of years of pesticide application by days of pesticide application. Suicidal ideation was identified by the question, 'In the past year, have you ever thought of harming yourself or trying to take your own life?'
Szortyka et al (2021) [ref. 38]	A cross-sectional study with 2469 participants	Tobacco	Pesticides and nicotine	Age, marital status, education, religion, vehicle, the family story of suicide, inadequate posture, hours of leisure, pesticide-related task, lifetime pesticide poisoning, lifetime green tobacco sickness. Suicidal ideation was directly associated with hours of domestic work during harvest and negatively associated with participation in religious activities, climbing up scaffolds, and frequently or constantly working as a harvester. Concerning comorbidities, suicidal ideation was positively associated with the medical diagnosis of asthma, chronic low back pain, and lifetime pesticide poisoning. Suicidal thoughts were also directly associated with the number of lifetime green tobacco sickness episodes. Suicide attempts were positively associated with low education levels, difficulty paying debt, and smoking. It was also directly associated with working intensively for 4–7 months. As for comorbidities, chronic low back pain and lifetime pesticide poisoning were positively associated with suicide attempts. The number of lifetime green tobacco sickness episodes was directly associated with the outcome.	Suicidal ideation, suicide attempt, investigation of factors associated with suicidal ideation. Suicidal ideation was characterized by the Self-Report Questionnaire-20 question: 'Have you thought about ending your life?'
Beard et al (2011) [ref. 39]	A desk review of 110 suicides identified through links to state mortality files and the National Death Index from the enrollment in the Agricultural Health Study (1993–1997) to 31 May 2009	Not specified	Phenoxy, triazine, carbamates, organochlorine, OP and pyrethroid herbicides	Applicators and spouses provided information on pesticide use and other factors via questionnaires completed at enrollment. In models adjusted for age at enrollment and sex, the risk for suicide was significantly greater if participants were >65 years of age compared with 36–45 years of age; were living in North Carolina; were of a race/ethnicity other than White/non-Hispanic; were divorced or separated compared with married or living as married; drank alcohol every day during the 12 months prior to enrollment compared with drank alcohol less than every day; were current smokers compared with never smokers; or had ever been diagnosed with diabetes or depression.	Association between pesticide use and suicide in pesticide applicators and their spouses. Via linkage to state mortality files and the National Death Index. All covariates significantly associated with suicide in both unadjusted and age- and sex-adjusted models as potential confounders were evaluated. As an alternative model selection method, a manual forward selection and selecting the same model as the backward selection method was performed. The applicator-only base model included age at enrollment (18–35, 36–45, 46–65, >65 years), the number of children in the family, frequency of alcohol consumption during the past 12 months (never, less than every day, every day), and smoking status (never, past, current). The base model for applicators and spouses together also included sex.
Stallones (2006) [ref. 40]	A desk review of 4991 suicide deaths and 107 692 deaths as a comparison group	Not specified	OP	Defensiveness, paranoia and social introversion, mood swings, increased feelings of hopelessness, depressive disorders, hopelessness and impaired problem-solving ability, increasing acts of self-harm	Description of suicide among individuals potentially exposed to pesticides through their occupation. Data from Colorado death certificate files for 1990–1999 were obtained.
Zhao et al (2021) [ref. 41]	A cohort study of 288 215 participants for the high-pesticide-use area and 166 746 participants in the low-pesticide-use area (2001 Census)	Not specified	Not specified	Farmers in the high-pesticide-use area showed a lower mortality rate of suicide and unintentional accidents than farmers in the rest of Spain, with mortality rate ratios of 0.74 (95%CI 0.65–0.85) and 0.57 (95%CI 0.52–0.62), respectively.	Association between farmer suicides and pesticide use through reporting
Krawczyk et al (2014) [ref. 42]	An ecological study of 122 036 deaths analyzed, 15 671 agricultural workers and 106 365 non-agricultural workers (National Mortality System, 1996–2005)	Tobacco	OP	Mood changes and fluctuations, the incidence of depression and/or suicide. Overall, agricultural workers in all Alagoas cities had a 2.96 times greater risk of death by suicide than non-agricultural workers.	Investigation of the risk of suicide among agricultural workers in regions with greater use of pesticides and/or tobacco farming. Agricultural census data were used.
Pickett et al (1998) [ref. 43]	An exploratory research and case-control study with 1457 male agricultural participants and 116 32 controls (ratio 1:8)	Oat and other grains	Herbicides, insecticides, other agricultural chemicals	A suggestive increase in risk for suicide was associated with herbicide and insecticide spraying among a subgroup of farm operators who were most likely to be directly exposed to pesticides. Additional risk factors identified included seasonal versus year-round farm and high levels of paid labor on the farm for >13 versus 0 weeks per year. Factors that were protective included having confidence in their marriage, having more than one person resident in the farmhouse (eg two versus one person) and higher levels of education (eg postsecondary versus primary)	Pesticide exposure and suicide. Comparisons focused on past exposures to pesticides reported to the 1971 Canada Census of Agriculture
Wesseling et al (2010) [ref. 44]	A cross-sectional study with 156 participants who had single and multiple episodes of cholinesterase inhibitor poisoning and 130 non-poisoned participants randomly selected from company payrolls	Banana	OP and N-methylcarbamate	Head trauma, alcohol and tobacco consumption, long-term exposure to cholinesterase inhibitors and other pesticides, and exposure to solvents. Past poisoning with OP, but not carbamate, pesticides was related to an overall excess of symptoms of psychological distress. OP poisonings were related to increased symptoms in eight out of nine symptom dimensions and the general severity index. Symptom scores significantly increased with the number of past poisonings for five dimensions. More poisoned workers reported suicidal thoughts than the never poisoned reference workers, with the highest prevalence of suicidal ideation among workers with the highest number of poisonings.	Relationship between acute occupational poisoning by OP and psychological distress, including suicidal ideation. Psychological distress symptoms during the month prior to the interview were obtained using the Brief Symptom Inventory, which has a general severity index and nine subscale scores.
Chang et al (2012) [ref. 45]	Desk review of 358 counties in Taiwan (2002–2009) based on data from the National Health Research Institute	Not specified	Not specified	Rural/urban differences	Investigation of geographical variations in suicide by pesticides, impact of suicide by pesticides on the spatial distribution of suicide. Government reports
Gregoire (2002) [ref. 46]	A desk review of 190 suicides between 1991 and 1996	Not specified	Not specified	Psychological symptoms (tension, poor sleep and irritability, stress); physical symptoms (tiredness and back pain); neuropsychological symptoms (cognitive disturbance, psychiatric morbidity, and suicidal ideation or behavior).	Association between suicide and mental health problems; the impact of mental health in the farming community and on suicide; preventive actions to treat stress and mental health problems in the agricultural community, indirect impact on suicide. Government reports

## Discussion

The main results of the research show that constant and acute pesticide exposure leads to health disorders. In this sense, organophosphates are the most common type of pesticide in the studies; hence, one might notice a link between the use of organophosphates and suicide (itself, ideation, or attempt). Furthermore, since more than half of the studies did not specify the crop cultivated by agricultural workers, no relation between suicide and cultivated crops could be found.

There is a great variety of data collection instruments in the methods and variables studied; most applied questionnaires to agricultural workers. However, most studies neglected the use of clinical tests that are important for confirming a poisoning with pesticides; these tests may be applied in hematologic or hair tests<sup>47</sup>.

Moreover, many studies did not consider the most significant possible number of variables related to pesticide exposure and suicide, and only a few articles showed an association between intervening variables such as smoking, alcohol consumption, age group, length of exposure to agrochemicals. However, it was possible to identify some factors determining the profile of agricultural workers ideating, attempting, or dying by suicide.

### **Profile of agricultural worker and suicide issues**

In general, agricultural workers have low educational levels because of the inherent manual labor and physical efforts they must conduct<sup>13</sup>. However, some factors increase the likelihood of suicide at every level (ideation, attempt, and carrying out). These factors include the consumption of hazardous drinks (alcohol) or smoking.

Gender is a variable that does not show a conclusive relationship; thus, we cannot affirm that gender (male or female) affects the tendency to carry out suicide due to exposure to pesticides. Nevertheless, a recent review<sup>11</sup> argues that, in general, male agricultural workers have more risk of suicide than female agricultural workers, but this study cannot confirm this.

Furthermore, marital status is also a factor that influences suicide. In this sense, divorced, separated, or widowed agricultural workers are more vulnerable to suicide than single agricultural workers. Moreover, socioeconomic situation is also a variable that can lead rural workers to carry out suicide; the difficulty of paying debts is a common factor in taking the decision of ending one's life.

This study found that moderate participation in religious activities is associated with suicide in only one article<sup>38</sup>. In India<sup>48</sup>, practitioners of Hinduism were part of the population that died by suicide the most, in addition to other variables, such as low literacy rates and high levels of agricultural employment.

Regarding the age of rural workers, we did not identify a typical age for suicide or attempts. WHO<sup>49</sup> describes suicide as the fourth leading cause of death in young people aged between 15 and 29 years. In this sense, two studies conclude that similar ages are risk factors for suicide among rural workers, 15–24 years<sup>20</sup> and 15–34 years<sup>35</sup>.

### **Analysis by geographic localization**

Another factor that may influence suicide issues is the localization of agricultural workers. This section analyzes the geographic distribution of workers to recognize relationships between geographic localization and suicide among agricultural workers.

In this review, the countries with the highest number of publications are Brazil and the US. According to the Food and Agriculture Organization of the United Nations (FAO)<sup>50</sup>, the countries that consume the most pesticides in the world are the US, Brazil, and then China. Hence, the results of our review demonstrate a significant concern with the issue of suicide among rural workers in these countries, corroborating the FAO data.

Although the US has the second highest number of publications, an article did not find support for moderate use of pesticides and suicide<sup>39</sup>. This result may be linked to the dose of pesticide used since, in Spain, a study found high suicide rates when there were high doses of pesticide<sup>37</sup>. The same was found in Brazil, where an area with intensive use of pesticides had a higher number of poisonings and suicides<sup>29</sup>.

Current literature<sup>10</sup> argues that most cases of suicide are in developing countries, especially Brazil, China, and India, countries with intensive use of pesticides and where access to them is easier than in developed countries; however, in this study, there is also a prevalence of studies in the US. It might be an indicator that more attention to suicide should be given, not only in less developed countries. In this sense, another review<sup>11</sup> found Australia has an acute problem with suicide among rural workers; thus, it is crucial to understand that the suicide of agricultural workers due to occupational pesticide exposure is a global problem and not exclusively of developing or least-developed countries.

### **Occupational exposure to pesticides, mental disorders and suicide**

In this review, occupational exposure to pesticides was found to be a factor for suicide at every level: ideation, attempt, and commitment. It is worth mentioning that self-poisoning with pesticides is the most used method of suicide among agricultural workers<sup>51</sup>; however, our purpose was not to study pesticide ingestion as a mechanism to carry out suicide but to study the relationship between occupational exposure to pesticides and suicide.

In this sense, the most common pesticides in our portfolio was organophosphates; thus, there is a potential link between them and suicide. In this regard, since the mid-1980s, organophosphates have been considered a significant risk to human health that can increase human morbidity and mortality<sup>52</sup>.

Organophosphates are one of the most used pesticides worldwide, and they are compounds that can be lethal to humans; they damage the enzyme acetylcholinesterase, which is crucial for controlling nerve signals in the human body<sup>52</sup>. Thus, there is a real relationship between the occupational acute exposure of agricultural workers to pesticides, especially organophosphates, and the degradation of the nervous system, making people suffer some mental disorders, such as anxiety, depression, and impulsivity<sup>53</sup>, which favor the ideation, attempt, and subsequent suicide among agricultural workers.

At the same time, exposure time may be another risk factor. The more time exposed to pesticides, the greater the poisoning and

the risk of diseases aggravating the suicidal intention<sup>38</sup>. In the US, the results of a survey show that in times of high productivity, when pesticide use is increased, there are high levels of pesticide compounds in the blood of farm workers<sup>24</sup>, representing a risk for human health due to the degradation of enzymes to control nerves. The same occurred in Brazil, with the indiscriminate use of pesticides in times of high productivity, also increasing the risk of neurological diseases<sup>53</sup>.

For Peres and Moreira<sup>54</sup>, one of the implications of the expressive use of pesticides resides in the high rates of suicide attempts in Brazil. According to the researchers, the recurrent exposure of rural workers to these products causes nervous system disturbances. Work by Bombardi<sup>55</sup> corroborates this finding, emphasizing that the cases of death resulting from intentional exposure to pesticides are related to the development of psychiatric disorders by their users, especially organophosphates, causing the development of neuropathology.

Another factor that may influence suicide among agricultural workers is the access to pesticides, not necessarily for the risk of self-poisoning, but for the risk of informal commerce that can promote the sale of pesticides of untrained people, that encourages an inadequate application and storage of these compounds.

In this regard, Zhang et al<sup>56</sup> found that 63.9% of the 5088 farmers interviewed in their study stored pesticides in easily accessible places, and only 4.9% of respondents stated that they stored them properly in a predetermined place. Among those who stored pesticides properly, 89% of respondents confirmed the presence of organochlorines, especially methamidophos, an insecticide with high persistence in the environment and classified by WHO<sup>49</sup> as extremely toxic; WHO remarks that the focus should be on more types of pesticides than organophosphates.

Finally, another factor is the limited access to mental health services in rural areas. In addition, rural workers may be afraid to use these services when available because of the stigma of having a mental disorder when asking for help<sup>57</sup>. In this sense, the barriers to access to health in rural areas, such as professional capacity, understanding of the health of the rural population, and the costs of access to health, must be eliminated<sup>58</sup>.

## Conclusion

This article aimed to conduct a systematic literature review to find the association between pesticide exposure and the incidence of suicide in agricultural workers. Thus, the literature showed a strong link between occupational pesticide exposure and suicide at all levels: ideation, attempt, and commitment among agricultural workers.

The main findings suggest that there is an agricultural worker profile that is more likely to carry out suicide. The factors that influence it are smoking and consuming alcohol, as well as marital status (divorced, separated, or widowed) and financial stressors (difficulty in paying debts). Surprisingly, there is no age group or gender in which a more significant number of suicides among rural workers is concentrated.

Initially, it seemed that this problem is exclusive to developing countries, such as Brazil, India, or China, because of the intensive use of pesticides to increase agricultural productivity. However, the

results suggest that it is a global problem since developed countries, such as the US, may have a significant occurrence of suicide among agricultural workers as a consequence of exposure to pesticides.

Organophosphates are the pesticides most used in the cases found in the literature. Organophosphates cause the degradation of acetylcholinesterase, a crucial enzyme for the nervous system, originating mental disorders and illnesses, eg anxiety, depression, or aggressivity that may result in suicide; thus, it is crucial to properly regulate the use and commerce of organophosphates, without neglecting other pesticides that can be equally or even more harmful to human health.

Regarding the methods used in the studies of the portfolio, there is a need for more studies on poisoning with a diversified use of data collection instruments. Despite its importance, the acetylcholinesterase test was used in a few studies and is responsible for quantifying pesticide exposure, and the use of this test has been increasing. Thus, applying this test is encouraged to quantify and confirm an objective relationship between pesticide exposure and suicide among agricultural workers due to the damage to their nervous systems.

Most suicides worldwide occur through self-poisoning (pesticide ingestion); our review showed that exposure to these pesticides produces mental problems, especially in countries with easier access to pesticides that promote informal commerce. Therefore, there is a need for norms to regulate the commerce of pesticides, restricting their access only to trained people and controlling their use and storage. Hence, it is noted that training and empowering agricultural workers in the proper use and storage of pesticides is necessary, as well as communicating about pesticide compounds and their consequences on mental health.

Furthermore, since it is a public health problem, suicide among agricultural workers must have the appropriate attention of governments and society, ensuring their access to mental health services, prompt diagnosis, and adequate treatment and support to avoid suicide among agricultural workers.

This review attempted to be as objective as possible; however, as with every research, it had some limitations because some articles that could be deemed relevant to this topic were not indexed in the databases used or were excluded in the filtering due to subjective reasons. Moreover, the information in some articles could be generalized due to synthesis purposes, and not reflect some details of studies that could contribute to this review.

Finally, we encourage the research community to continue researching suicide among agricultural workers due to pesticide exposure, but with a particular focus on the correlation of secondary variables (gender, age, habits, exposure, and others) and the application of medical laboratory tests to measure the level of poisoning due to pesticides and the degradation of mental health in agricultural workers.

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