Effect of pesticides on cognitive and motor performance in habitants of rural areas of Tolima

Efecto de los pesticidas sobre el rendimiento cognitivo y motor en habitantes de zonas rurales del Tolima

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Abstract.

Organophosphate pesticides can cause cognitive impairment. However, the farmer uses different pesticides in all phases of the same crop. The aim of this study was to analyze the effect of serial pesticides on cognitive and motor performance in samples of exposed, indirectly exposed, and unexposed people. In the exploratory study with a cross-sectional design, a total of 135 small farmers from the informal sector participated. Mini-Mental, Trail Making, Rey-Osterrieth Complex Figure, Digit Retention, Hopkins Verbal Learning and the Grooved Pegboard tests were administered. The results show that the highest serial exposure occurs with Glyphosate, Lorsban, Furadan and Paraquat. The group with direct exposure to pesticides presented a lower performance in working memory, explicit verbal memory, constructive praxis and fine motor control of the right hand, than the indirectly exposed group and the unexposed group. In conclusion, direct and serial exposure to pesticides generates neuropsychological and motor impairment in informal sector farmers, it is recommended the development of public politics that promote healthy and safe practices, to minimize the risks due to the use of these substances.

Keywords: Pesticides, attention, memory, motor skills, neuropsychology.

Resumen.

Los pesticidas organofosforados pueden generar deterioro cognitivo. No obstante, el agricultor emplea diferentes pesticidas en todas las fases de un mismo cultivo. El objetivo de este estudio fue analizar el efecto de los pesticidas en serie en el rendimiento cognitivo y motor en una muestra de personas expuestas, expuestas indirectas y no expuestas. En el estudio de tipo exploratorio con diseño transversal, participaron en total 135 pequeños agricultores del sector informal. Se administró el Mini-Mental, el Trail Making Test, la Figura Compleja de Rey-Osterrieth, Retención de Dígitos, el Test de aprendizaje verbal de Hopkins y el Grooved Pegboard. Los resultados muestran que la mayor exposición en serie ocurre con el Glifosato, Lorsban, Furadan y Paraquat. El grupo con exposición directa a los pesticidas presentó menor rendimiento en memoria de trabajo, memoria explícita verbal, praxias constructivas y control motor fino mano derecha, que el grupo expuesto indirectamente y el no expuesto. En conclusión, la exposición directa y en serie a los pesticidas, genera deterioro neuropsicológico y motor en los agricultores del sector informal, se recomienda el desarrollo de políticas públicas que promuevan prácticas saludables y seguras, para minimizar los riesgos por el uso de estas sustancias.

Palabras clave: Pesticidas, atención, memoria, habilidades motoras, neuropsicología.

Introduction

Cognitive functions are mental processes that allow the processing of information and the development of any task, facilitate the reception, selection, storage, transformation, elaboration and recovery of stimuli from the environment (Ardila & Roselli, 2019). The main cognitive functions are attention, memory, language, thinking, spatial and constructional skills (Harris et al., 2001). These mental processes can be affected by mechanisms that generate brain damage, such as constant exposure to pesticides, which cause neuropsychological disorders and clinical symptoms (Malekirad et al., 2013; Corral et al., 2017).

Pesticides are chemical substances or a mixture of liquid or solid, organic, inorganic or microbiological substances. These substances prevent, destroy or control pests, including insects and fungi, rodents or unwanted plant species that cause damage during the production and storage of crops; includes insecticides, herbicides, fungicides, and rodenticides (Abubakar et al., 2020). The Department of Tolima is located in the intertropical zone, characterized by the Andes mountain range and isothermal climates, which explain its high biodiversity and facilitate the planting of various crops throughout the year (Jiménez et al., 2019). This agricultural wealth favours the massive use of pesticides (Varona et al., 2017).

Farmers have been considered especially vulnerable to acute or chronic health effects, due to the use of pesticides (Jiménez-Quintero et al., 2016), especially small farmers in the informal sector, who work in small-scale farms, they often face severe financial and infrastructure constraints (Mehrabi et al., 2018). These farmers are more exposed to acute and chronic intoxication since they do not participate in occupational health, surveillance and poison control programs (López et al., 2015).

Studies show in agricultural workers, low scores in executive function, psychomotor speed, verbal fluency, visual and auditory memory (Corral et al., 2017), selective and divided attention, verbal and non-verbal memory, prospective memory, spatial functioning and initiative/energy (Malekirad et al., 2013). However, most of these results come from studies that aim to identify the neuropsychological effects of people exposed only to organophosphate pesticides (Corral et al., 2017; Blanc-Lapierre et al., 2013; Mackenzie Ross et al, 2012; Muñoz-Quezada et al., 2016; Naughton & Terry, 2018).

Organophosphate pesticides cause four neurotoxic disorders in humans: cholinergic syndrome, intermediate syndrome, organophosphate-induced delayed polyneuropathy, and organophosphate-induced chronic neuropsychiatric disorder. The latter characterized by cognitive deficits (impaired memory, concentration and learning, attention problems, information processing, hand-eye coordination and reaction time), mood swings (anxiety, depression, psychotic symptoms, emotional lability), chronic fatigue, autonomic dysfunction, peripheral neuropathy and extrapyramidal symptoms such as dystonia, tremor at rest, bradykinesia, postural instability and stiffness of the muscles of the face (Jamal et al., 2016; Taghavian, et al., 2016).

For Jokanović (2018), agricultural workers examined two years after an episode of pesticide exposure showed inferior performance in verbal and visual attention, visual memory, sequencing and problem-solving. They also showed deterioration in motor reflexes. Farmworkers with mild poisoning symptoms that did not require hospitalization fared worse on cognitive and psychomotor tests. They also developed a greater vulnerability to psychiatric disorders, such as anxiety and depression. Other dysfunctions represented in agricultural workers are alterations in language, attention and memory, as well as psychomotor, visual and coding alterations, and even irritability, cognitive deterioration, ataxia and Parkinson's disease (Ismail et al., 2017)

However, there are numerous types of pesticides used in all phases of the same crop (Federal Insecticide, Fungicide & Rodenticide Act, 2019).

In Colombia, there are not enough studies that address the effects of pesticides on the rural population the little evidence mostly has an orientation from medical science (Ramírez-Botero & Pachajoa, 2016; Hernández et al., 2008) and occupational (López, Pinedo and Zambrano, 2015; Varona et al., 2016). Taking into account that Tolima is one of the Colombian departments with the highest agricultural production in the country (Agronet, 2020), there are few studies on the neuropsychological effects on the health of farmers exposed to pesticides.

This study is important because it contributes to understanding how serial pesticides affect working memory, explicit verbal memory, constructive praxis and fine motor control, the results allow guide actions aimed at improving the health and quality of life of patients. small farmers, through prevention and promotion programs, intervention in occupational health, management and organization of minority farmers, and development of public policies that promote practices to minimize the effects of pesticides on the health of farmers and their families.

Method

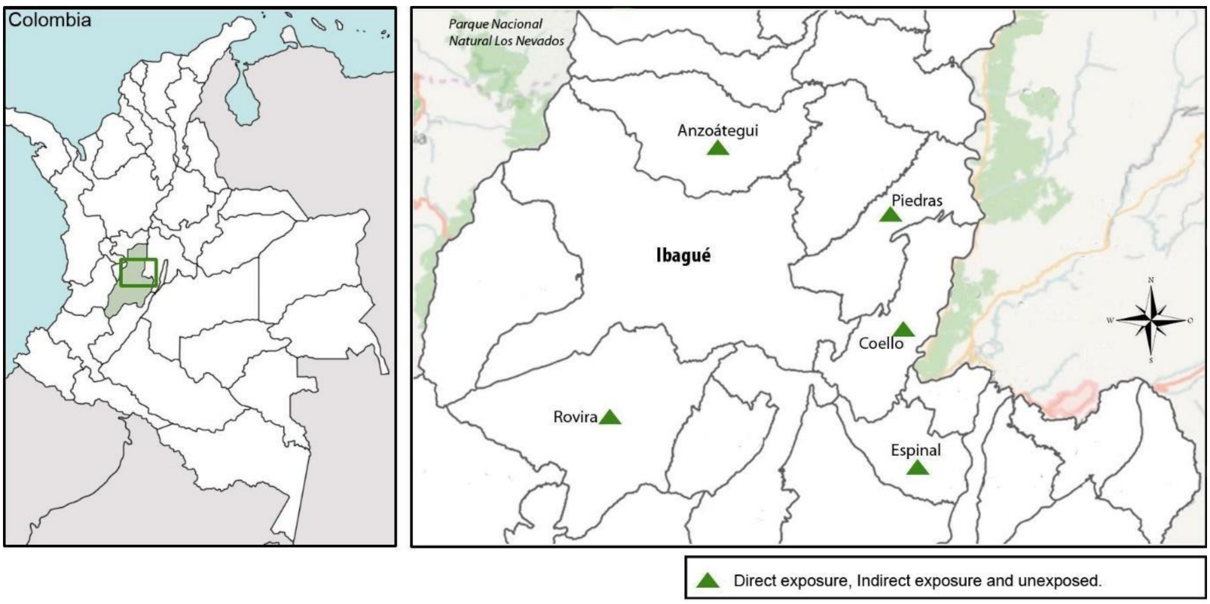
Study type and design

The exploratory type study with a cross-sectional design aims to examine a little-studied topic the data is recorded at a specific and unique moment (Hernández, Fernández & Baptista, 2010).

Sample

The non-probabilistic intentional convenience sample made up of 135 participants from the municipalities of Espinal, Coello, Rovira, Saldaña and Anzoátegui of the department of Tolima, Colombia (see figure 1). This area is conducive to the cultivation of rice, passion fruit, melon, corn, banana, orange, lemon, guava, coffee, tomato and mango (Norton, 2017). The farmer uses pesticides in series to control insects, fungi and weeds, alternating or mixing these substances throughout the cultivation process, depending on the harvest or the time of year.

Figure 1
Municipalities department of Tolima where the samples were obtained



Nota: Adaptado de *Google maps* por Juan José Ospina

In the sample, men and women between the ages of 18 to 55 years were considered (see table 1). With the following inclusion criteria: group of direct exposure in series, minimum three years handling pesticides in series (use of several pesticides during the cultivation process); Serial indirect exposure group, at least three years living near agricultural areas where they use different pesticides, but without direct manipulation of these substances and the unexposed group does not live in agricultural areas, nor do they work with chemical substances. Exclusion criteria included intoxication due to use of psychoactive substances, diagnosis of a psychiatric or medical illness with drug use, and the presence of neurodegenerative disorders.

In total, the samples consisted of 9.62% (n = 40) of direct exposure in series, agricultural workers with contact through dispersion, storage, cleaning of equipment and waste; 34.81% (n = 47) of indirect exposure in series and 35.55% (n = 48) not exposed to pesticides.

Table 1
Sociodemographic variables by group according to degree of exposure to pesticides

Variables		Not exposed	Indirect exposed	Exposed
Sex	Female	32	30	5
	Male	16	17	35
Scholarship	Primary	9	18	25
	High school	27	25	11
	Others	12	4	4
Marital status	Free Union	15	18	15

Single	24	19	13
Widower	2	1	1
Married	7	9	9
Divorced	0	0	2

Instruments

A work team in psychology participated in training for the application of neuropsychological assessment. The tests are standardized in Colombia (Arango & Rivera, 2015) and are the following:

Questionnaire of sociodemographic data, use of pesticides and medical history: self-elaborated in which age, sex, education, marital status, affiliations to social security, socioeconomic status, types of pesticides, spraying mechanisms, medical and psychiatric history.

Mini-Mental State Examination (MMSE): an instrument for the evaluation of mental state, designed by Folstein et al. (1975) and validated for the Colombian population (Rosselli et al., 2000). The scale contains 11 items that allow the evaluation of various functions such as orientation, the registration and evocation of information, attention and calculation, recall, oral and written language and constructive praxis. Reliability is 0.94 (cronbach's alpha) and Test-retest is 0.87 (cronbach's alpha) (Blesa et al., 2001). MMSE is a widely used psychometric screening scale (Ismail et al., 2009; Myrberg et al., 2020).

Trail Making Test (TMT A and B): Form A assesses sustained visual attention, speed, and visual tracking. Form B assesses alternating attention and mental flexibility (executive functions). Its main qualification criterion is the execution time (Drane et al., 2002). It is a test widely used to assess attentional capacity and has normative data for the

Colombian population with a reliability of 0.77 (cronbach's alpha) for part A and 0.79 (cronbach's alpha) for section B (Arango & Rivera, 2015).

Rey-Osterrieth Complex Figure (Copy and memory): Evaluates visuoconstructive skills, visual perception, visual memory and motor planning. In the first part, the evaluated makes a copy of a complex figure with 36 elements, after 3 minutes and interference exercises, the participant draws the figure without having it in sight (Rey, 1941). It has the normative data for the Colombian population, with a reliability of 0.87 (cronbach's alpha) (Arango & Rivera, 2015).

Digit Retention (Wechsler Intelligence Scale for Adults IV (WAIS-IV): This test widely used for assessing the intellectual abilities, and frequently incorporated as standard components in diagnostic batteries for neuropsychological evaluations (Lezak et al., 2004). This is a two-part attention and working memory task. The direct version is considered a measure of the effectiveness of sustained verbal attention. Inverse digit task involves mental tracking involving verbal processes and working memory. In the first, the subject must repeat a sequence of numbers in the same order presented and in the second, they must repeat the sequence in reverse order to its presentation (Wechsler, 2012).

Digits and symbols test (SDMT). Evaluates divided attention, visual exploration and tracking, perceptual and motor speed, and memory; this test involves converting nonsensical geometric designs into written and spoken numerical responses. Weighted reliability coefficient 0.79 (cronbach's alpha) (Arango & Rivera, 2015) and has 110 elements, is often used as a measure of information processing speed (Berrigan et al., 2014).

Hopkins Verbal Learning Test (HVLT-R 2): Evaluates verbal learning and memory, consists of presenting a list of 12 semantically related words divided into three categories in three trials, the correct answers for each trial are recorded. After 20 -25 minutes, the participant must mention the words that remember from the initial list. The test has a weighted reliability coefficient of 0.68 (cronbach's alpha) (Arango & Rivera, 2015). Different researchers (Chase Bailey et al., 2018; Diaz-Santos et al., 2019) have used the test to evaluate different clinical and non-clinical samples.

Grooved Pegboard: This test values right hand (RH) and left hand (IM) visual-motor coordination and speed. The examinee must insert 25 pegs into randomly placed slotted holes that have a key along one side. The test is done first with the right hand and then with the left. The score is obtained from the time and number of hits. The test has been used in various neuropsychological test batteries, in student laboratories, and as a screening technique in industrial settings (Merker et al., 2017).

Process

This study has three phases: the first, the community leaders of the agricultural municipalities convened and gathered the participants in the communal room or school in the rural area, the researchers explained the objectives of the study and the criteria for informed consent; the second phase, participants in one session completed neuropsychological tests, the researchers applied the tests to all participants in the same order (questionnaire of sociodemographic data, Mini-Mental State Examination (MMSE), Hopkins Verbal Learning Test (HVLT-R 2), Rey-Osterrieth Complex Figure (Copy and memory), Trail Making Test (TMT A and B), Digit Retention (Wechsler Intelligence Scale for Adults IV (WAIS-IV) and Digits and symbols test (SDMT)), lasting

40 to 50 minutes each, and the third phase, the researchers delivered the test results per participant and to the community.

Analysis of data

We used SPPS 25 software for statistical analysis of the study. The descriptive analysis allowed determining the distribution, frequency and average of sociodemographic variables and neuropsychological tests. We transformed the variables to solve problems of asymmetry, heterogeneity of variance, non-linearity and outliers using square root then we found the Pearson correlation values and the variables with a correlation (r <-0.7 or> 0.7) were excluded to avoid multicollinearity.

We applied a one-way multivariate analysis of variance (MANOVA, p <0.05) to analyze the relationship between response variables (neuropsychological tests) and a set of predictors (exposure groups), we used the Pillai Trace test due to size uneven of the groups. Then, the post-hoc comparison test was applied using HSD Tukey. For these analyzes, we included the variables with normal distribution and that met the MANOVA requirements (TMTA, SDMT, HVLT-R 2 total recall, HVLT-R 2 delayed recall, and Grooved MI). Finally, the Mann-Whitney U test (p <0.05) determined the significant differences between the data not normally distributed.

Ethical considerations

This study followed the bioethical principles of autonomy, beneficence, non-maleficence and justice. The ethics committee of the Universidad de Ibagué approved the research protocol and informed consent. The researchers followed ethical protocols. To collect the information, the participants attended a meeting, were informed of the objectives of the research and the characteristics of their participation. All participants agreed to participate voluntarily and signed informed consent.

Results

Pesticide use habits

Of the group with direct exposure to pesticides, 44.9% apply them weekly or biweekly, 18.45% every four or six months, 14.4% monthly and 6.1% annually. Of the 83% are exposed to pesticides in series. 46.9% use water as a solvent, 14.3% use another pesticide, 8.2% apply it pure. 87.7% apply the pesticide by ground sprinkler loaded by the operator and 8.2% manually. The most widely used pesticide is glyphosate 26.5%, followed by Lorsban 16.3%, Furadan 11.76%, Paraquat 6% and other agrochemicals with 26% (see table 2).

Table 2
Classification of agrochemicals used by the study sample

Pesticide	Classification	Toxicity category *
Roundup®	Glyphosate. Broad spectrum herbicide	II. Moderadamente tóxico
Losrban®	Broad spectrum organophosphate insecticide	II. Moderadamente tóxico
Furadan®	Carbannate pesticide	I. Extremely toxic
Paraquat®	Broad spectrum herbicide	I. Extremely toxic
Paratión®	Organophosphate pesticide	I. Extremely toxic
Malatión®	Synthetic organosphosphate insecticide	III. Moderately toxic
Amina®	Selective herbicide.	II. Highly toxic

*FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act)

Of the group of indirect or secondary exposure to pesticides, 63.23% have contact with the substance because they live in agricultural areas close to the crops, but their principal economic activity does not depend on the field, 33% are housewives whom they wash clothes with traces of pesticides and 3.77% work in a rural school near the crops.

Neuropsychological performance

The MANOVA indicated that there are statistically significant differences in cognitive ability by a group of direct and indirect exposure (Table 3) (F (10, 258) = 3.421 p <.0005; Pillai trace = 0.234, partial η2 = 0.117, where the higher pesticide exposure is related to lower cognitive scores on TMT A, SDMT, HVLT-R 2 total recall and Rey-Osterrieth-Recovery Complex Figure.

Table. 3

Average scores of cognitive tests with comparisons between the different exposure groups

Cognitive function	Test	Not exposed(n=48)		Indirect exposed (n=47)		Direct exposed (n=40)		p	Comparison Post-hoc
		x̄	SD	x̄	SD	x̄	SD		
Cognitive tracking	Minimental	27,75	2,31	26,77	2,94	26,30	2,67	<0,05	NE> ED, EI
Attention	TMTA	51,88	19,85	63,06	29,91	68,05	28,07	<0,05	NE< ED
	TMTB	100,53	33,47	143,90	67,94	163,15	70,16	<0,05	NE<EI, ED
	SDMT	38,60	13,86	30,35	11,42	23,53	11,95	<0,05	NE> EI, ED
	Progression digits	5,06	1,35	4,91	0,99	4,56	0,94	0,13	ND
Working memory	Regression digits	3,65	1,02	3,28	1,24	3,05	0,80	<0,05	NE,EI>ED.

Verbal memory	HVLT-R 2 Total memory	19,60	5,02	19,06	4,91	16,58	5,04	<0,05	NE, EI>ED
	HVLT-R 2 Deferred memory	7,21	2,12	6,67	2,11	6,24	2,34	0,2	ND
Constructive praxis	Rey-Osterrieth Complex Figure- Copy	27,96	7,00	25,83	8,53	22,33	8,42	<0,05	NE,EI>ED
Visual memory	Rey-Osterrieth-Recovery Complex Figure	15,44	7,25	13,83	7,38	11,37	5,61	<0,05	NE>ED
Fine motor control	Groveed RH	70,35	12,57	76,39	17,07	81,38	16,90	<0,05	NE, EI< ED
	Grooved LH	78,07	10,40	78,00	15,58	79,78	13,83	>0,05	ND

*RH: right hand, LH: left hand, NE: Not exposed, ED: Direct exposed. EI: Indirect exposed ND: No differences between groups

We found statistically significant differences in scores referred to Minimental (H = 9.03, p <0.05), TMT B (H = 31.8, p <0.005), digits in regression (H = 7.32; *p* <0.05), Rey-Osterrieth-Copia Complex Figure (H = 11.99; *p* <0.005) and in the right hand Grooved test (H = 11.04; *p* <0.005). The digit tests in progression and delayed recall did not show significant differences.

Post-hoc comparisons showed that the direct exposure group presented a lower performance in the regression digit tests, total recall, Rey-Osterrieth-Copia and Grooved MD Complex Figure than the indirectly exposed and unexposed groups. On the other hand, the higher performance was observed in the unexposed group in the Minimental, TMTB and SDMT tests compared to the exposed group (indirect-direct). These results suggest that the group exposed directly and series presents a lower performance in the processes of selective alternating and divided visual attention, working memory, explicit verbal memory, visual memory, constructive praxis and fine motor control.

Discussion

This study is the first to be carried out in Colombia to evaluate the cognitive performance of farmers in rural areas of the Department of Tolima, from the discipline of neuropsychology. Our results show that there is a negative effect of pesticides on cognitive performance in people directly and indirectly exposed. Some studies show similar findings (Farahat et al. 2003; Rothlein et al. 2006; Khan et al. 2014, Ismail et al. 2017; Muñoz-Quezada et al. 2016; Sankoh, Whittle, Semple, Jones & Sweetman 2016; Ismail et al. 2017; Anger et al. 2020). However, they correspond mostly to the use of organophosphate pesticides.

Due to the requirements in the different phases of the crop and their rotation, the farmers in the sample used pesticides in series, among the most frequent are: Roundup®, Lorsban®, Furadan® and Paraquat®. Roundup®, also known as glyphosate is a broad-spectrum herbicide; Lorsban® is an insecticide from the group of organophosphates, Furadan® is an Insecticide-nematicide and Paraquat® is a herbicide. All these pesticides pose risks to human health (Agostini et al., 2020; Zyoud, 2018).

According to the results related to the attention processes evaluated through the visual channel, we identified differences in divided, alternating and selective attention, the lower performance was found in people exposed directly and indirectly (Malekirad et al., 2013; Starks et al., 2012, Jamal et al., 2016; Taghavian, et al., 2016; Jokanović (2018). This result is related to what was stated by Zhang, Wang & Li (2021) who identified that organophosphates cause cognitive impairment, characterized by decreased attention or vigilance and reduced information processing speed. Therefore, the attention is a basic process for general cognitive functioning, its deterioration affects the ability of farmers to focus and alternate their attention towards stimuli that are relevant to the execution of tasks.

Ross, McManus, Harrison & Mason (2012) show that pesticides affect working memory. Result consistent with that reported by Dassanayake, Weerasinghe, Gawarammana & Buckley (2020), where the group of direct exposure to organophosphate pesticides presented a significantly lower performance. Working memory is essential for the execution of daily activities that involve maintaining information while an operation is carried out. Also, in verbal and visual memory, the group with direct exposure presents a lower performance (Meyer-Baron et al., 2015). However, in the test, there are only differences in the variable that assesses the recording of verbal information and not in the delayed or long-term recall.

In contrast to the previous findings, we did not identify differences in the processes of auditory selective attention and delayed recall between the groups. However, Berent et al. (2014) and Corral et al. (2017) found lower performance in these functions. Although the results are not conclusive, Kamel & Hoppin (2004) establish that pesticide damage can be diffuse and not focal.

Regarding praxis, we found that the group with direct exposure to pesticides presented a lower performance in the Rey figure test (TFR), which indicates failures in constructive praxis. Roldan-Tapia, et al. (2005) and Roldán-Tapia et al. (2006) reported that TFR is sensitive to cognitive impairment induced by exposure to pesticides. However, we did not identify differences between the unexposed and indirectly exposed groups, possibly because it requires high cumulative exposure to pesticides to generate a decrease in praxis function.

About fine motor control, we found differences between the groups in the score of the right hand but not the left, suggesting less dominance in activities that involve hand-eye coordination. However, the results may be linked to lateral dominance and not to the effect of pesticides. Therefore, we suggest caution when generalizing these findings.

In conclusion, pesticides have a cumulative effect on health and lead to lower cognitive and motor performance. Neuropsychological disorders depend on the type of exposure, the more a person is exposed to serial pesticides without any protection, the greater the risk. Therefore, we consider it important to generate best practices through prevention and promotion programs for agricultural workers and their families. This study is of interest to leaders in the formulation of public politics in health and labour, given the harmful potential of pesticides for the health of small farmers in the informal sector.

As limitations we identified the following: the participants presented different times of exposure to pesticides in series, so we were unable to make comparisons between the groups; the sample size is small therefore we recommend being cautious in generalizing the results. Despite the above, some methodological aspects of the present study contributed to the validity and reliability of the data, the rigour in the inclusion criteria to the sample and the MMSE screening test, allowed us to refine some variables (medical, psychiatric and neuropsychological disorders) that affected test performance. To collect the data, we carried out a prior and rigorous training of the neuropsychological tests, as well as the application of the tests in the same order for all participants and we controlled for external variables that could interfere with performance at the time of evaluation.

For future studies, we recommend expanding the sample following the criteria of rigorous selection, conducting studies with a longitudinal design of all cognitive domains. We also propose the use of biomarkers, as well as investigating the effects of pesticides on children and expectant mothers, a population that has been little studied and lives close to crops.

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Conflict of interests

The authors declare that they have no conflicts of interest.

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