Rocz Panstw Zakl Hig 2025;76(1):29-37
https://roczniki.pzh.gov.pl/
https://doi.org/10.32394/rpzh/200912

ORIGINAL ARTICLE

OCCUPATIONAL PESTICIDE EXPOSURE AND COGNITIVE IMPAIRMENT AMONG ADULT FARMERS IN NORTHERN THAILAND

Nichapa Phitsadang[1], Warangkana Naksen[1], Parichat Ong-Artborirak[2]

[1]Faculty of Public Health, Chiang Mai University, Thailand
[2]Department of Research and Medical Innovation, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, Thailand

ABSTRACT

Background. Thai farmers are directly exposed to pesticides, which may result in adverse effects including cognitive impairment.

Objectives. The aim of this study was to examine the association between occupational pesticide exposure and cognitive decline among adult farmers in northern Thailand.

Material and Methods. This cross-sectional study included 303 pesticide-using farmers over the age of 50 from Doi Tao District in Chiang Mai Province. Pesticide exposure score was calculated using an algorithm that considered personal protective equipment (PPE) scores and exposure intensity scores, as well as lifetime application days. The scores were classified as high or low exposure based on their median. The Thai version of the Montreal Cognitive Assessment (MoCA) test was used to assess cognitive function.

Results. The mean age of adult farmers was 58.74 years. The prevalence of cognitive impairment was 93.7%, with an average score of 19.6. Spearman's rank correlation coefficient showed that the MoCA score was adversely correlated with lifetime application days (r_s = -0.145), PPE score (r_s = -0.163), exposure intensity score (r_s = -0.184), and pesticide exposure score (r_s = -0.225). Linear regression revealed that high exposed farmers had significantly lower MoCA scores than low exposed farmers, as measured by PPE score (B = -0.75; 95% CI: -1.46, -0.05), exposure intensity score (B = -0.97; 95% CI: -1.66, -0.27), and pesticide exposure score (B = -0.77; 95% CI: -1.47, -0.06), after controlling for sex, age, education, income sufficiency, and body mass index.

Conclusions. Thai farmers are at risk of cognitive impairment linked to occupational pesticide exposure, depending on their PPE use and exposure intensity. There is still a critical need for action to reduce the risk of negative health effects from pesticide exposure among Thai farmers.

Keywords: *pesticide, cognitive function, MoCA, agriculture, farmer*

INTRODUCTION

Pesticides are widely used to prevent and control pests, and their usage continues to trend upward. In 2022, total pesticide use in agriculture had doubled since 1990, with usage per arable area increasing by 94 percent [1]. In Thailand, pesticides are commonly used, including herbicides (e.g., glyphosate and paraquat), insecticides (e.g., abamectin, chlorpyrifos, and cypermethrin), and fungicides (e.g., carbendazim and propineb) [2, 3]. These chemicals can directly affect the health of farmers exposed to them through multiple routes, including dermal contact, ingestion, and inhalation. In particular, exposure to organophosphates and carbamates is known to inhibit acetylcholinesterase activity, increasing the risk of pesticide poisoning. A previous study revealed that 17.3% of Thai farmers experienced pesticide poisoning after applying pesticides [3]. Chronic health effects may include an increased risk of cancers such as leukemia, non-Hodgkin lymphoma, brain, prostate, bladder, colorectal, lung, kidney, and pancreatic cancers [4-6]. Pesticide exposure may also impact the mental health of farmers [3, 7, 8] and contribute to neurodegenerative diseases, including Alzheimer's disease and dementia [9-11].

The global number of people living with Alzheimer's disease and other dementias more than doubled from 1990 to 2016, with the number of deaths increasing by 148%, making it the second-largest cause of death in individuals aged 70 and older, following ischemic heart disease, in 2016 [12]. In Thailand, deaths from Alzheimer's and other dementias among individuals aged 75 and older rose to 8.1% in 2019, doubling from

Corresponding author: Parichat Ong-Artborirak, Department of Research and Medical Innovation, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, 3 Thanon Khao, 13000, Bangkok, Thailand; email: ong.artborirak@gmail.com

Publisher: National Institute of Public Health NIH - National Research Institute

3.9% in 2015 [13]. Alzheimer's disease can develop in individuals with mild cognitive impairment, highlighting the importance of early identification for effective intervention [14]. Evidence also indicates that pesticides adversely affect farmers' cognitive function [15], potentially contributing to dementia and Alzheimer's disease [16].

The association between pesticide exposure and cognitive function has been investigated in many study populations, such as those in the U.S. [17, 18], France [19, 20], Chile [21, 22], Korea [23], Costa Rica [24], and Indonesia [25]. In Thailand, it was found that farmers had a higher risk of cognitive impairment compared to nonfarmers [26]. However, the effects of long-term and high-level pesticide exposure on cognitive performance warrant further investigation [27]. The objective of this study was to investigate the association between occupational exposure to pesticides and cognitive function among adult Thai farmers. The findings can provide essential insights to guide health surveillance and inform actions to protect farmers from pesticide-related risks.

MATERIAL AND METHODS

Design, setting, and subjects

This is a cross-sectional study of adult farmers in Doi Tao District, Chiang Mai Province, in northern Thailand. Doi Tao District covers an agricultural area of approximately 70 square kilometers, with about 63% of all households registered as farmer households. Longan is a popular fruit in the area, often grown alongside other crops such as rice, corn, and shallots. Farmers commonly use insecticides, herbicides, and fungicides in the cultivation of these crops.

Participants were selected using convenience sampling, with public relations efforts by local organizations. Leaflets and community loudspeakers were used to invite farmers who met the inclusion criteria. Thai farmers aged 50 and older, representing farming households, were eligible if they had at least five years of experience in agriculture, had a history of pesticide use, had no history of mental illness or neurological disorders requiring treatment, and were literate in Thai.

The sample size for the study was estimated using the G*Power program for two independent mean comparisons, with a power of 80% and a confidence level of 95% (2-tailed). A mean difference in cognitive performance scores between the low and high pesticide exposure groups was set at 1 point, with a standard deviation (SD) of 3 points [23]. The required sample size was 143 participants per group, with an additional 10% added to account for incomplete data, resulting in a total of 326 adult farmers. Ultimately, 303 farmers provided complete data for the study. The Committee of Research Ethics, Faculty of Public Health, Chiang Mai University, approved the study (No. ET021/2023). Prior to data collection, all participants provided written informed consent.

Data collection

Data were collected between October and December 2023. The interviewer-administered questionnaire was conducted by three researchers who had received training prior to data collection. The questionnaire consisted of three sections: (a) demographic characteristics, such as sex, age, education, marital status, household income, body mass index (BMI), underlying diseases, smoking, alcohol use, entry into agriculture, distance from home to the nearest farm, and household insecticide use; (b) work characteristics, including agricultural work experience, farm size, and history of pesticide use (insecticides, herbicides, and fungicides); and (c) pesticide exposure estimation, including the duration (in years) of pesticide use, frequency of pesticide application per year, pesticide use characteristics (mixing/spraying), frequency of personal protective equipment (PPE) use (dust mask/mask with carbon filter, goggles, gloves, long-sleeve shirt, long pants, and boots), and the practice of showering and changing clothes after pesticide application.

To estimate cumulative lifetime pesticide exposure, the study adapted a semi-quantitative algorithm developed for low- and middle-income contexts in previous studies [3, 28, 29]. The pesticide exposure score was calculated based on lifetime days of pesticide application and the intensity level of exposure (Equation (1)).

Lifetime application days were calculated by multiplying the number of days per year by the number of years of pesticide use. The exposure intensity score was estimated based on five exposure-modifying factors: mixing pesticides, spraying pesticides, showering, changing clothes, and using PPE (Equation (2)).

Two factors – mixing active ingredients and spraying pesticides – were assigned scores of 5 and 8, respectively. Showering and changing clothes

$$\textit{Pesticide exposure score} = \textit{lifetime application days} \times \textit{exposure intensity score} \tag{1}$$

$$\textit{Exposure intensity score} = (\textit{mix} + \textit{spray}) \times \textit{shower} \times \textit{clothes} \times \textit{PPE score} \tag{2}$$

$$\textit{PPE score} = 0.1 \times \textit{mask} + 0.1 \times \textit{goggles} + 0.4 \times \textit{gloves} + 0.2 \times \textit{shirt} + 0.1 \times \textit{pants} + 0.1 \times \textit{boots} \tag{3}$$

immediately after pesticide application were scored as follows: 0.7 for *always*, 0.8 for *sometimes*, 0.9 for *rarely*, and 1 for *never* [28]. The PPE score was calculated as shown in Equation (3).

The frequency of PPE use was scored as follows: *always* (dust mask, shirt, and pants = 0.3; gloves = 0.2; mask with carbon filter, goggles, and boots = 0.1), *often* (dust mask, shirt, and pants = 0.48; gloves = 0.4; mask with carbon filter, goggles, and boots = 0.33), *sometimes* (dust mask, shirt, and pants = 0.65; gloves = 0.6; mask with carbon filter, goggles, and boots = 0.55), *rarely* (dust mask, shirt, and pants = 0.83; gloves = 0.8; mask with carbon filter, goggles, and boots = 0.78), and *never* (all PPE = 1) [28]. The possible PPE score ranged from 0.14 to 1, with lower scores indicating reduced exposure.

Lastly, lifetime application days, PPE score, exposure intensity score, and pesticide exposure score were divided by the median to create high and low exposure groups.

The Thai version of the Montreal Cognitive Assessment (MoCA), a brief cognitive screening tool for mild cognitive impairment (MCI), was used to assess multiple cognitive function domains, including attention, concentration, executive function, memory, language, visuoconstruction skills, conceptual thinking, calculation, and orientation [30, 31]. The test takes approximately 10 to 15 minutes to complete, with a maximum score of 30 points. MCI is determined when the MoCA score is less than 25 points. The validity and reliability testing for the Thai MoCA for MCI screening reported a sensitivity of 80% and specificity of 80%, with a Cronbach's alpha coefficient of 0.91 [32].

Data analysis

All statistical analyses were performed using SPSS Version 28 (IBM Corp., Armonk, NY, USA). The study variables were analyzed using descriptive statistics, including frequency, percentage, percentile, mean, median, standard deviation (SD), and interquartile range (IQR). Spearman's rank correlation coefficient was used to assess the relationship between pesticide exposure data (which were not normally distributed) and MoCA scores. An independent t-test was conducted to compare MoCA scores between the high and low exposure groups. To account for potential confounding factors, linear regression was employed to investigate the association between pesticide exposure and cognitive decline. Statistical significance was set at a p-value of less than 0.05.

RESULTS

Table 1 presents the demographic characteristics of adult farmers, as well as their exposure to residential pesticides. The participants had a mean of 30.3 years (SD = 9.7) of agricultural work experience and a mean farm size of 16,200 m² (SD = 11,400). The mean duration of pesticide use was 24.8 years (SD = 9.5), with 80.2% reporting both mixing and spraying pesticides, and 19.8% spraying only. The prevalence of MCI among the farmers was 93.7% [95% confidence interval (CI) = 91.0% – 96.5%], with a mean MoCA score of 19.6 (SD = 3.3). A significant difference in MoCA scores was found for six variables: sex, age, education level, income sufficiency, BMI, and smoking. These variables were controlled for in the adjusted model for association analysis, with the exception of smoking, which was excluded due to its strong association with sex.

Table 2 summarizes the history of pesticide use reported by farmers, along with the active ingredient classification recommended by the WHO. Farmers reported using insecticides and fungicides in equal proportions (99.7%), while 97.4% reported using herbicides. The most commonly used insecticide class was avermectin (99.0%), followed by organophosphates (17.2%), carbamates (10.6%), and pyrethroids (7.6%). Some farmers used multiple active ingredients from the organophosphate and carbamate classes.

Table 3 presents the pesticide exposure assessments. The median lifetime application days was 490 (IQR = 340), and the median pesticide exposure score was 1327 (IQR = 1597). Sperman's rank correlation coefficient revealed that the MoCA score was negatively correlated with lifetime application days (r_s = -0.145), PPE score (r_s = -0.163), exposure intensity score (r_s = -0.184), and pesticide exposure score (r_s = -0.225). When the pesticide exposure score was divided into high and low exposure groups based on the median, the prevalence of MCI was 96.7% in the high-exposure group and 90.8% in the low-exposure group.

Table 4 compares MoCA scores between the high and low exposure groups using an independent t-test. Significant differences were found in MoCA scores for the PPE score (mean difference = -0.97, p = 0.011), exposure intensity score (mean difference = -1.28, p = 0.001), and pesticide exposure score (mean difference = -1.35, p < 0.001). No significant difference was observed for lifetime application days.

Table 5 shows the association between pesticide exposure and cognitive impairment among farmers after adjusting for sex, age, education level, income sufficiency, and BMI. In the adjusted model, farmers with high exposure had significantly lower MoCA scores than those with low exposure: -0.75 (95% CI: -1.46, -0.05) for the PPE score, -0.97 (95% CI: -1.66, -0.27) for the exposure intensity score, and -0.77 (95% CI: -1.47, -0.06) for the pesticide exposure score.

Table 1. Farmers' general information, residential pesticide exposure, and MoCA scores (n=303)

Variables	n (%)	MoCA score Mean (SD)	p-value
Sex			0.034*
Male	158 (52.1)	19.26 (3.12)	
Female	145 (47.9)	20.07 (3.48)	
Age (years) [Mean (SD)=58.74 (5.99)]			<0.001**
50-59	179 (59.0)	20.49 (3.09)	
60-69	109 (36.0)	18.69 (3.24)	
≥70	15 (5.0)	16.60 (3.00)	
Education level			<0.001**
No	60 (19.8)	17.02 (3.05)	
Primary school	190 (62.7)	20.03 (3.00)	
Secondary school or higher	53 (17.5)	21.26 (3.08)	
Marital status			0.197*
Married	240 (79.2)	19.52 (3.33)	
Single/Divorced/Widowed/Separated	63 (20.8)	20.13 (3.27)	
Perceived income sufficiency			0.013*
Insufficient	164 (54.1)	19.21 (3.04)	
Sufficient	139 (45.9)	20.16 (3.56)	
BMI (kg/m^2) [Mean (SD)=23.15 (3.47)]			0.027**
Underweight (<18.5)	22 (7.2)	17.86 (3.27)	
Normal (18.5-22.9)	131 (43.2)	19.53 (3.42)	
Overweight (23.0-24.9)	75 (24.8)	20.25 (3.14)	
Obesity (≥25.0)	75 (24.8)	19.76 (3.18)	
Underlying disease			0.491*
No	165 (54.5)	19.77 (2.93)	
Yes	138 (45.5)	19.50 (3.73)	
Smoking			0.032*
No	221 (72.9)	19.90 (3.30)	
Yes	82 (27.1)	18.98 (3.29)	
Alcohol drinking			0.215*
No	132 (43.6)	19.37 (3.65)	
Yes	171 (56.4)	19.86 (3.03)	
Entering the farm			0.312**
<1 time per month or monthly	24 (7.9)	20.63 (3.59)	
Weekly	147 (48.5)	19.61 (3.35)	
Every day	132 (43.6)	19.51 (3.22)	
Home proximity to nearest farm			0.439**
<300 m	34 (11.2)	19.62 (3.17)	
300 m – 1 km	92 (30.4)	20.01 (3.31)	
>1 km	177 (58.4)	19.46 (3.35)	
Use of household insecticides			0.215*
No	119 (39.3)	19.35 (3.05)	
Yes	184 (60.7)	19.84 (3.47)	

* Independent t-test
** One-way ANOVA

Table 2. Farmers' pesticide use history and active ingredient classification (n=303)

Pesticide	n (%)	WHO Class	Pesticide	n (%)	WHO Class
Insecticide					
Abamectin	300 (99.0)	Ib	Methamidophos	10 (3.3)	Ib
Malathion	25 (8.3)	III	Carbosulfan	9 (3.0)	II
Cypermethrin	23 (7.6)	II	Methomyl	9 (3.0)	Ib
Chlorpyrifos	20 (6.6)	II	Monocrotophos	8 (2.6)	Ib
Carbaryl	16 (5.3)	II	Carbofuran	7 (2.3)	Ib
Herbicide					
Glyphosate	291 (96.0)	III	Diuron	6 (2.0)	III
Paraquat	153 (50.5)	II	Ametryn	3 (1.0)	II
Fungicide					
Carbendazim	300 (99.0)	U	Benomyl	12 (4.0)	U
Thiophanate	19 (6.30)	U	Copper sulfate	3 (1.0)	II
Mancozeb	17 (5.6)	U	Propineb/Maneb	3 (1.0)	U

Ib – highly hazardous; II – moderately hazardous; III – slightly hazardous; U – unlikely to present acute hazard in normal use

Table 3. Percentile of pesticide exposure and Spearman's rank correlation coefficient between pesticide exposure and MoCA score among farmers (n=303)

Pesticide exposure	P10	P25	P50	P75	P90	Spearman coefficient (r_s)	p-value
Lifetime application days	188	340	490	680	1384	-0.145	0.011
PPE score	0.22	0.27	0.46	0.63	0.63	-0.163	0.004
Exposure intensity score	1.27	1.65	2.47	4.01	4.01	-0.184	0.001
Pesticide exposure score	337	650	1327	2247	3144	-0.225	<0.001

Table 4. Mean MoCA scores of farmers classified by pesticide exposure group (n=303)

Pesticide exposure	MoCA (score)	
	Mean (SD)	p-value*
Lifetime application days		0.159
Low exposure group (≤490)	19.91 (3.40)	
High exposure group (>490)	19.38 (3.22)	
PPE score		0.011
Low exposure group (≤0.46)	20.12 (3.35)	
High exposure group (>0.46)	19.15 (3.22)	
Exposure intensity score		0.001
Low exposure group (≤2.47)	20.31 (3.26)	
High exposure group (>2.47)	19.03 (3.27)	
Pesticide exposure score		<0.001
Low exposure group (≤1327)	20.32 (3.33)	
High exposure group (>1327)	18.97 (3.17)	

* Independent t-test

Table 5. Association between pesticide exposure and MoCA score among farmers by linear regression

Pesticide exposure	B	Beta	p-value	95% CI
Lifetime application days (High vs Low)				
Unadjusted model	-0.54	-0.08	0.159	-1.29, 0.21
Adjusted model*	-0.04	-0.01	0.901	-0.73, 0.64
PPE score (High vs Low)				
Unadjusted model	-0.97	-0.15	0.011	-1.71, -0.23
Adjusted model*	-0.75	-0.11	0.037	-1.46, -0.05
Exposure intensity score (High vs Low)				
Unadjusted model	-1.28	-0.19	0.001	-2.01, -0.54
Adjusted model*	-0.97	-0.15	0.007	-1.66, -0.27
Pesticide exposure score (High vs Low)				
Unadjusted model	-1.35	-0.21	<0.001	-2.09, -0.62
Adjusted model*	-0.77	-0.12	0.033	-1.47, -0.06

B – unstandardized coefficients; Beta – standardized coefficients; 95% CI – 95% confidence interval for B
*Adjusted for sex, age in years, educational level, perceived income sufficiency, and BMI

DISCUSSION

The assessment of cognitive function in adult Thai farmers revealed a prevalence of MCI as high as 93.7%, with a mean MoCA score of 19.65, suggesting an increased risk of Alzheimer's disease and dementia. This finding may be partly due to demographic factors such as age and education, which significantly influence cognitive impairment [19, 21, 23, 26], and should be considered when interpreting MoCA scores using cut-off points [33]. Although the farmers had an average age of approximately 59 years, over 80% had completed only primary school or less, which may impact MoCA scores and contribute to the higher prevalence of cognitive impairment. Additionally, with a mean duration of pesticide use of 25 years and 80.2% of participants mixing and spraying pesticides, chronic and intensive pesticide exposure may play a role in cognitive decline. This prevalence is notably higher than in a Korean study, which reported 29.5% MCI among pesticide users, with a mean MoCA score of 24.1 [23]. However, in a Thai study, pesticide applicators had MoCA scores of 21.25 before pesticide application and 17.51 afterward [27]. Another study reported that Thai farmers had more than five times higher odds of cognitive impairment, as measured by the Mini-Mental State Examination (MMSE), compared to non-farmers [26].

Our findings show that MoCA scores were negatively associated with occupational pesticide exposure, including cumulative exposure score, PPE use score, and exposure intensity score, even after controlling for sex, age, education, perceived income sufficiency, and BMI. The lower MoCA scores in the high exposure group may reflect the health effects of pesticides on cognitive function, potentially through mechanisms such as oxidative stress, mitochondrial dysfunction, neuroinflammation, neurotransmitter abnormalities, and intestinal dysfunction [34]. Prolonged pesticide exposure may increase the risk of cognitive impairment, while proper use of PPE, bathing, and changing clothes after pesticide application may help reduce exposure and lower the risk of cognitive decline. Some farmers reported not using PPE, particularly gloves and chemical masks, during pesticide mixing and spraying – key factors in reducing exposure [27, 35]. Farmers rarely use advanced PPE due to tropical conditions, discomfort, poverty, unavailability, and high costs [36]. As a result, farmers may be exposed to significant amounts of chemicals through inhalation and skin absorption, particularly if they do not shower or change clothes immediately after pesticide use. Inadequate self-protection behaviors may, therefore, increase the risk of cognitive impairment and other health effects among farmers. However, pesticide exposure also depends on factors such as mixing and spraying practices, chemical storage, and disposal [35, 37, 38], which were not included in this study.

These findings align with those from several studies. In Korea, the exposed group had a higher prevalence of MCI and lower MoCA scores than the non-exposed group, though no significant difference was found between high and low pesticide exposure groups [23]. Our study, however, detected a significant difference in MoCA scores between high- and low-exposed farmers, which may reflect variations in study areas, population characteristics, and pesticide-related factors. A Thai study found that MoCA scores for pesticide applicators were significantly lower after pesticide application [27]. In Chile, agricultural workers directly exposed to pesticides had significantly lower MMSE scores compared to residents living in agricultural areas with indirect exposure [21]. A 4-year follow-up in France showed a significantly greater decline in MMSE scores among exposed vineyard workers [19], while a study in Costa Rica found that exposed individuals performed worse on the MMSE than non-exposed individuals [24].

Farmers in our study reported using various pesticides, including insecticides like organophosphates (malathion), carbamates (carbaryl), and pyrethroids (cypermethrin); herbicides like glyphosate and paraquat; and fungicides such as carbendazim and maneb. Although some of the pesticides identified in this study have been banned in Thailand, their illegal use persists. The neurotoxicity of these pesticides is supported by evidence linking long-term, low-dose exposure to neurodegenerative diseases, particularly from paraquat, maneb, pyrethroids, and organophosphates [39]. A study among Indonesian farmers found that long-term exposure to organophosphates resulted in significantly lower MMSE scores compared to other pesticides [25]. Similarly, exposure to organophosphates has been linked to cognitive performance in older Mexican Americans [18] and French vineyard workers [20]. In Chile, pesticide exposure, as measured by cholinesterase inhibition (a biomarker for organophosphate and carbamate exposure), was associated with cognitive performance [22]. A Thai study also found that individuals with cognitive impairment had significantly lower blood acetylcholinesterase levels compared to those without cognitive impairment [26]. Furthermore, low-level pyrethroid exposure was linked to cognitive dysfunction in older adults in the US [17], and a positive association was found between glyphosate exposure and impaired visual memory among smallholder farmers in Uganda [29].

Regarding the study's limitations, its cross-sectional design limits the ability to infer causal relationships. Additionally, the non-probability sampling method may result in a sample that is not fully representative of the broader population. The use of a questionnaire to assess cumulative pesticide exposure through farmers' self-reports may introduce recall bias and does not specify pesticide types or account for environmental exposure. Future studies should incorporate biological indicators, such as urine and blood tests, to assess internal pesticide exposure, and consider including farmers with no history of pesticide use to better understand the impact of pesticide exposure on cognitive impairment. For low-educated older adults, a cognitive screening tool such as the MoCA-Basic (MoCA-B) may be more appropriate to address this limitation [40]. Despite these limitations, the study's findings underscore the significant differences in MoCA scores between high- and low-exposure groups among Thai farmers, even when exposure is categorized using an algorithm.

CONCLUSIONS

This study provides evidence that occupational pesticide exposure is associated with cognitive impairment in adult Thai farmers, depending on the level of exposure, including PPE use, personal hygiene practices, and other exposure characteristics. The high prevalence of MCI raises significant concerns about potential health risks. Therefore, cognitive performance should be regularly monitored among farmers for early screening and surveillance of Alzheimer's disease or dementia. Preventive measures should be implemented to reduce the risk of negative health effects from pesticide exposure among farmers.

Acknowledgements

We would like to thank all of the farmers who took the time to participate in the study.

Conflict of interest

All authors declare they have no potential competing interest.

REFERENCES

1. Food and Agriculture Organization of the United Nations (FAO). Pesticides use and trade – 1990–2022. FAOSTAT Analytical Briefs, No. 89. Rome: FAO; 2024. ISSN 2709-006X.
2. Office of Agricultural Regulation. Statistics of hazardous chemicals imported into Thailand [Internet]. Bangkok: Department of Agriculture, Ministry of Agriculture and Cooperatives; 2021 [cited 2022 July 12] Available from: https://www.doa.go.th/ard/?page_id=386.
3. Ong-Artborirak P, Boonchieng W, Juntarawijit Y, Juntarawijit C. Potential effects on mental health status associated with occupational exposure to pesticides among Thai farmers. Int J Environ Res Public Health. 2022;19(15):9654. doi: 10.3390/ijerph19159654.
4. Bassil KL, Vakil C, Sanborn M, Cole DC, Kaur JS, Kerr KJ. Cancer health effects of pesticides: systematic review. Can Fam Physician. 2007;53(10):1704-1711.
5. Cavalier H, Trasande L, Porta M. Exposures to pesticides and risk of cancer: Evaluation of recent epidemiological evidence in humans and paths forward. Int J Cancer. 2023;152(5):879-912. doi: 10.1002/ijc.34300.
6. Gerken J, Vincent GT, Zapata D, Barron IG, Zapata I. Comprehensive assessment of pesticide use patterns and increased cancer risk. Front. Cancer Control Soc. 2024;2:1368086. doi: 10.3389/fcacs.2024.1368086.

7. Daghagh Yazd S, Wheeler SA, Zuo A. Key risk factors affecting farmers' mental health: a systematic review. Int J Environ Res Public Health. 2019;16(23):4849. doi: 10.3390/ijerph16234849.
8. Khan N, Kennedy A, Cotton J, Brumby S. A pest to mental health? Exploring the link between exposure to agrichemicals in farmers and mental health. Int J Environ Res Public Health. 2019;16(8):1327. doi: 10.3390/ijerph16081327.
9. Petit P, Gondard E, Gandon G, Moreaud O, Sauvée M, Bonneterre V. Agricultural activities and risk of Alzheimer's disease: the TRACTOR project, a nationwide retrospective cohort study. Eur J Epidemiol. 2024;39(3):271-287. doi: 10.1007/s10654-023-01079-0 [published correction appears in Eur J Epidemiol. 2024;39(5):569. doi: 10.1007/s10654-024-01116-6].
10. Yan D, Zhang Y, Liu L, Yan H. Pesticide exposure and risk of Alzheimer's disease: a systematic review and meta-analysis. Sci Rep. 2016;6:32222. doi: 10.1038/srep32222.
11. Zaganas I, Kapetanaki S, Mastorodemos V, Kanavouras K, Colosio C, Wilks MF, et al. Linking pesticide exposure and dementia: what is the evidence? Toxicology. 2013;307:3-11. doi: 10.1016/j.tox.2013.02.002.
12. GBD 2016 Dementia Collaborators. Global, regional, and national burden of Alzheimer's disease and other dementias, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet Neurol. 2019;18(1):88-106. doi: 10.1016/S1474-4422(18)30403-4.
13. World Health Organization (WHO). WHO mortality database: Alzheimer and other dementias [Internet]. Geneva: WHO; 2024 [cited 2024 July 12] Available from: https://platform.who.int/mortality/themes/theme-details/topics/indicator-groups/indicator-group-details/MDB/alzheimer-and-other-dementias.
14. Kelley BJ, Petersen RC. Alzheimer's disease and mild cognitive impairment. Neurol Clin. 2007;25(3):577-609. doi: 10.1016/j.ncl.2007.03.008.
15. Finhler S, Marchesan GP, Corona CF, Nunes AT, De Oliveira KCS, de Moraes AT, et al. Influence of pesticide exposure on farmers' cognition: a systematic review. J Neurosci Rural Pract. 2023;14(4):574-581. doi: 10.25259/JNRP_58_2023 .
16. Aloizou AM, Siokas V, Vogiatzi C, Peristeri E, Docea AO, Petrakis D, et al. Pesticides, cognitive functions and dementia: A review. Toxicol Lett. 2020;326:31-51. doi: 10.1016/j.toxlet.2020.03.005.
17. Kim UJ, Hong M, Choi YH. Environmental pyrethroid exposure and cognitive dysfunction in U.S. older adults: the NHANES 2001-2002. Int J Environ Res Public Health. 2021;18(22):12005. doi: 10.3390/ijerph182212005.
18. Paul KC, Ling C, Lee A, To TM, Cockburn M, Haan M, et al. Cognitive decline, mortality, and organophosphorus exposure in aging Mexican Americans. Environ Res. 2018;160:132-139. doi: 10.1016/j.envres.2017.09.017.
19. Baldi I, Gruber A, Rondeau V, Lebailly P, Brochard P, Fabrigoule C. Neurobehavioral effects of long-term exposure to pesticides: results from the 4-year follow-up of the PHYTONER study. Occup Environ Med. 2011;68(2):108-115. doi: 10.1136/oem.2009.047811.
20. Blanc-Lapierre A, Bouvier G, Gruber A, Leffondré K, Lebailly P, Fabrigoule C, et al. Cognitive disorders and occupational exposure to organophosphates: results from the PHYTONER study. Am J Epidemiol. 2013;177(10):1086-1096. doi: 10.1093/aje/kws346.
21. Corral SA, de Angel V, Salas N, Zúñiga-Venegas L, Gaspar PA, Pancetti F. Cognitive impairment in agricultural workers and nearby residents exposed to pesticides in the Coquimbo Region of Chile. Neurotoxicol Teratol. 2017;62:13-19. doi: 10.1016/j.ntt.2017.05.003.
22. Ramírez-Santana M, Zúñiga-Venegas L, Corral S, Roeleveld N, Groenewoud H, van der Velden K, et al. Association between cholinesterase's inhibition and cognitive impairment: A basis for prevention policies of environmental pollution by organophosphate and carbamate pesticides in Chile. Environ Res. 2020;186:109539. doi: 10.1016/j.envres.2020.109539.
23. Kim JY, Park S, Kim SK, Kim CS, Kim TH, Min SH, et al. Pesticide exposure and cognitive decline in a rural South Korean population. PLoS One. 2019;14(4):e0216310. doi: 10.1371/journal.pone.0216310.
24. Steenland K, Wesseling C, Román N, Quirós I, Juncos JL. Occupational pesticide exposure and screening tests for neurodegenerative disease among an elderly population in Costa Rica. Environ Res. 2013;120:96-101. doi: 10.1016/j.envres.2012.08.014.
25. Setyopranoto I, Gofir A, Rahardjo LP, Panggabean AS, Dwianingsih EK, Setyaningsih I, et al. Association of pesticide exposure with cognitive function in farmers. Eur Neurol. 2023;86(5):305-314. doi: 10.1159/000530899.
26. Wongta A, Hongsibsong S, Xu ZL, Chantara S, Pattarawarapan M, Sapbamrer R, et al. The relationship of organophosphate pesticide exposure and cognitive decline among residents of an agricultural area in northern Thailand. J Health Res. 2023;37(6):372-379. doi: 10.56808/2586-940X.1035.
27. Chittrakul J, Sapbamrer R, Hongsibsong S. Exposure to organophosphate insecticides, inappropriate personal protective equipment use, and cognitive performance among pesticide applicators. Front Public Health. 2022;10:1060284. doi: 10.3389/fpubh.2022.1060284.
28. Fuhrimann S, Staudacher P, Lindh C, van Wendel de Joode B, Mora AM, Winkler MS, et al. Variability and predictors of weekly pesticide exposure in applicators from organic, sustainable and conventional smallholder farms in Costa Rica. Occup Environ Med. 2020;77(1):40-47. doi: 10.1136/oemed-2019-105884.
29. Fuhrimann S, Farnham A, Staudacher P, Atuhaire A, Manfioletti T, Niwagaba CB, et al. Exposure to multiple pesticides and neurobehavioral outcomes among smallholder farmers in Uganda. Environ Int. 2021;152:106477. doi: 10.1016/j.envint.2021.106477.
30. Nasreddine ZS, Phillips NA, Bédirian V, Charbonneau S, Whitehead V, Collin I, et al. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. J Am Geriatr Soc. 2005;53(4):695-699. doi: 10.1111/j.1532-5415.2005.53221.x [published

correction appears in J Am Geriatr Soc. 2019;67(9):1991. doi: 10.1111/jgs.15925].
31. Hemrungrojn S. Montreal cognitive assessment (MoCA) [Internet]. Canada: MoCA Test Inc.; 2021. [cited 2024 Sep 8] Available from: https://mocacognition.com.
32. Tangwongchai S, Phannasathit M, Charernboon T, Akkayagorn L, Hemrungrojn S, Phanthumchinda, et al. The validity of Thai version of the Montreal Cognitive Assessment (MoCA-T). Dement Neuropsychol, 2009;3(2):172.
33. Rossetti HC, Lacritz LH, Cullum CM, Weiner MF. Normative data for the Montreal Cognitive Assessment (MoCA) in a population-based sample. Neurology. 2011;77(13):1272-1275. doi: 10.1212/WNL.0b013e318230208a.
34. Wen L, Miao X, Ding J, Tong X, Wu Y, He Y, et al. Pesticides as a risk factor for cognitive impairment: Natural substances are expected to become alternative measures to prevent and improve cognitive impairment. Front Nutr. 2023;10:1113099. doi: 10.3389/fnut.2023.1113099.
35. Kim JH, Kim J, Cha ES, Ko Y, Kim DH, Lee WJ. Work-related risk factors by severity for acute pesticide poisoning among male farmers in South Korea. Int J Environ Res Public Health. 2013;10(3):1100-1112. doi: 10.3390/ijerph10031100.
36. Sapbamrer R, Kitro A, Panumasvivat J, Assavanopakun P. Important role of the government in reducing pesticide use and risk sustainably in Thailand: Current situation and recommendations. Front Public Health. 2023;11:1141142. doi: 10.3389/fpubh.2023.1141142.
37. Kafle S, Vaidya A, Pradhan B, Jørs E, Onta S. Factors associated with practice of chemical pesticide use and acute poisoning experienced by farmers in Chitwan District, Nepal. Int J Environ Res Public Health. 2021;18(8):4194. doi: 10.3390/ijerph18084194.
38. Sookhtanlou M, Allahyari MS, Surujlal J. Health risk of potato farmers exposed to overuse of chemical pesticides in Iran. Saf Health Work. 2022;13(1):23-31. doi: 10.1016/j.shaw.2021.09.004.
39. Baltazar MT, Dinis-Oliveira RJ, de Lourdes Bastos M, Tsatsakis AM, Duarte JA, Carvalho F. Pesticides exposure as etiological factors of Parkinson's disease and other neurodegenerative diseases – a mechanistic approach. Toxicol Lett. 2014;230(2):85-103. doi: 10.1016/j.toxlet.2014.01.039.
40. Julayanont P, Tangwongchai S, Hemrungrojn S, Tunvirachaisakul C, Phanthumchinda K, Hongsawat J, et al. The Montreal Cognitive Assessment-Basic: A Screening Tool for Mild Cognitive Impairment in Illiterate and Low-Educated Elderly Adults. J Am Geriatr Soc. 2015;63(12):2550-2554. doi: 10.1111/jgs.13820.

Received: 06.11.2024
Revised: 09.12.2024
Accepted: 06.02.2025
Published online first: 27.02.2025