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Research article

Carbofuran residues in soil and consumption risks among farmers growing vegetables in Ubon Ratchathani Province, Thailand

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Abstract: Farmers in Khi Lek Subdistrict, Muang District, Ubon Ratchathani Province, Thailand have been known to persistently use pesticides, especially carbofuran, in their agricultural fields. This indeed poses a risk to farmers' health and ecosystem. However, there has been no report pointing out this problem. The purpose of this study was to determine carbofuran residues in soil in four villages in Khi Lek Subdistrict, Muang District, Ubon Ratchathani Province, Thailand, where pesticides were widely used for vegetables. The quick, easy, cheap, effective, rugged and safe (QuEChERS) method was used to extract the samples, which were then analyzed utilizing high-performance liquid chromatography with a mass spectrometry detector. The health risks of carbofuran exposure through soil ingestion among 485 farmers were investigated by using the hazard quotient (HQ). The concentration of carbofuran in 10 soil samples was less than 0.01 mg/kg. The overall average of the farmers' daily dose of carbofuran in Villages 5, 8, 9 and 10 ranged from 3.9×10^{-9} mg/kg-day to 5×10^{-9} mg/kg-day, and the hazard quotient (HQ) indicated an acceptable level for health risks. However, this study found that 98.97% of the farmers ate food and 97.53% drank water while farming. As a result of this, they may still be exposed to pesticides. Since the factors contributing to human health risks include the length of exposure, frequency of exposure, and farmer body weight, this study suggests that the government should be concerned because the current pattern of pesticide use still poses an immediate health risk to the farmers. While The farmers should be trained in safe pesticide usage while safe pesticide practice should also be promoted.

Keywords: carbofuran; soil; residues; health risk assessment

1. Introduction

Thailand mostly relies on the use of pesticides to protect crops from insect pests or diseases and improve productivity. Pesticide use has increased almost four-fold over the last 10 years in the Kingdom of Thailand [1]. Organophosphate, carbamate, and pyrethroid insecticides were the most common classes of imported insecticides. For more than 70% of Thailand's population, agriculture is their primary source of income [2]. The significant main effect of organophosphate and carbamate insecticides is the inhibition of acetylcholinesterase in erythrocytes and butyrylcholinesterase in plasma [3].

Carbofuran (Furadan) is a carbamate pesticide used to kill insects. It has been widely utilized and has revealed high levels of environmental pollution. Carbofuran is highly mobile in soil and is soluble in water [4]. The total carbofuran residues in soil were identified for up to 105 days after treatment with a half life of 10.83 days [5]. As a result, it has the potential to contaminate soil, groundwater, and nearby aquatic bodies.

Carbofuran creates anticholinesterase activity. Cholinesterase is a catalyst for acetylcholine hydrolysis [6]. Acetylcholine is a neurotransmitter, and cholinesterase is created to avoid acetylcholine accumulation. When acetylcholine levels are high, it can cause cholinergic manifestations like cramps, increased salivation, lacrimation, and blurred vision [7–8]. Therefore, accidental exposure to carbofuran in humans can result in severe toxicity and death, making it exceedingly harmful [9].

In Thailand, under the Hazardous Substances Act, carbofuran is classified as a Class 3 hazardous material regulated by the Department of Agriculture. Pesticide toxicity was reported in approximately 49,000 to 61,000 cases per year, with a morbidity rate of 76.4 to 96.6 per 100,000 population [10]. According to the findings of Sapbamrer and Nata, occupational pesticide exposure and agricultural tasks among rice farmers in northern Thailand may be associated with increases in respiratory tract and muscle symptoms [11]. In a study conducted by Yongpraderm et al., carbofuran was rated a risk level of 4 to agricultural workers in a village in Nakhon Si Thammarat Province [12]. In addition, according to the Occupational and Environmental Diseases and Health Hazards Report, there were 6,075 cases of toxic effects of pesticides, representing a rate of 10.04 cases per 100,000 population in 2018 and 10,312 cases of pesticide poisoning in 2017, representing a rate of 17.12 cases per 100,000 population [13].

The farmers in Ubon Ratchathani Province, Thailand, are known for producing backyard vegetables such as radishes, chilies, green leafy vegetables, and green onions. Pesticides are imported into the province. According to a study on pesticide imports in 2014, the amounts (in tons) of herbicides, insecticides, and pesticides were 147,375,949.63, 117,645,359.22, and 13,910,544.21, respectively, showing an upward trend. The most often used chemical is a glyphosate-related category of herbicides, followed by insecticides. The study found that the farmers were at high to very high risk of pesticide exposure. In 2015, 40.5% of the farmers were at risk, compared with 38.58% in 2016. In 2014, the rate of pesticide poisoning among the farmers was 21.18 per 100,000 population, compared with 22.08 and 31.02 in 2015 and 2016, respectively [14].

In Khi Lek Subdistrict, Muang District, Ubon Ratchathani Province, there are a total of 1, 630 households in 11 villages where the majority of the inhabitants work in agriculture. In agriculture, carbofuran was used in Villages 5, 8, 9 and 10, where farmers grew vegetables such as chilies, radishes and lettuce. As reported by a study in 2018, 15.83% of the farmers in the area used carbofuran to control insects and nematodes on their crops [15]. Carbofuran has the potential to contaminate soil, which implies that while farmers are working on their farms, it may contaminate their food and drinking water. There are no data on carbofuran's presence in the soil and the consumption risk among farmers in the agricultural area of Khi Lek Subdistrict, Muang district, Ubon Ratchathani Province. The current study's purpose was to evaluate the carbofuran residues in agricultural soil as well as the consumption risks among farmers who may be at risk due to their work in the agricultural fields. A questionnaire was used to identify farmers who might be at risk, and carbofuran residues in soil were determined using the in-house approach based on the QuEChERS with a high-performance liquid chromatography (HPLC Model: 1100) with a mass spectrometry detector. This technique is highly effective in separating multiple complicated chemicals. It has a high potential to provide good results [16].

2. Materials and methods

2.1. Study area

This research is a cross-sectional descriptive study aiming to determine the health effects of exposure to carbofuran through soil intake among farmers between January 2021 and August 2021 in Khi Lek Subdistrict, Muang District, Ubon Ratchathani Province, Thailand (Figure 1). A health risk assessment was undertaken following the guideline of the USA Environmental Protection Agency (EPA).

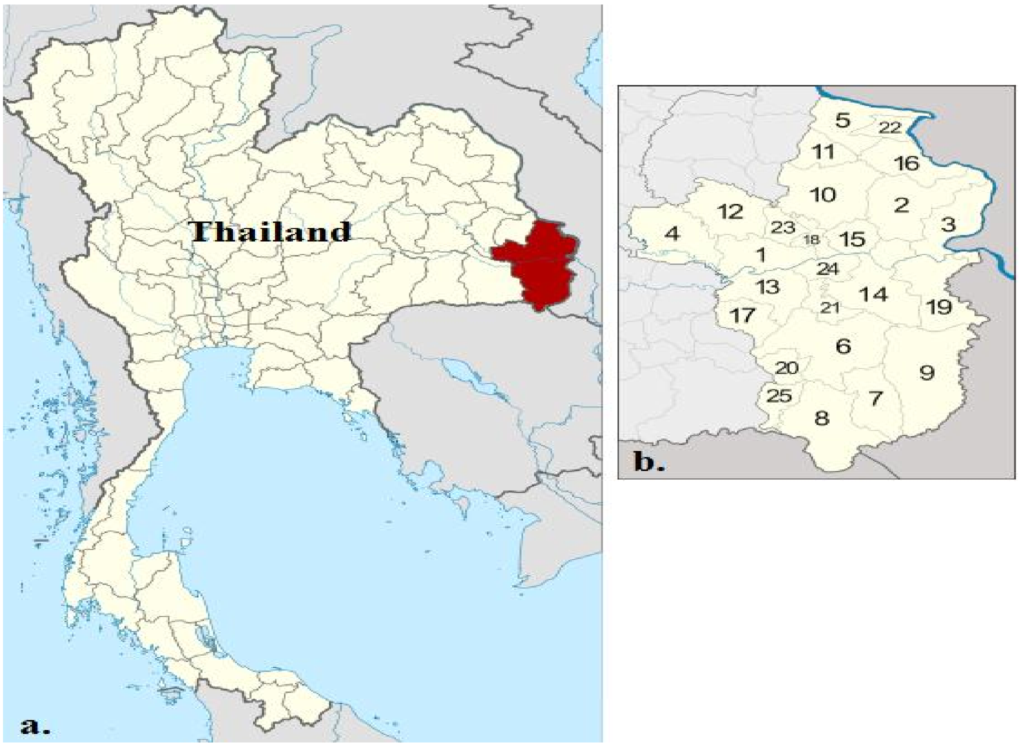

Figure 1. Maps showing the location of the study area: (a.) map of Thailand (the area marked with red color is Ubon Ratchathani Province) and (b.) map of Ubon Ratchathani Province (Area number 1 is Muang District).

2.2. Sampling

Soil samples were gathered using the method of purposive collecting under the recommended guidelines of the Department of Agriculture. The samples were collected from multiple spots on the vegetable plots. A V-shaped hole 7-6 inches deep was dug using a spade or shovel. The first section of the dirt was discarded. Then, a spade or shovel was used to take a 1–2 inch thick slice of soil from the side of the hole. All soil samples from all spots were blended into one sample with a weight of 1 kg, which was then put in containers [17]. A total of 10 soil samples were collected: three from Village 5, two from Village 8, three from Village 9 and two from Village 10.

A total of 485 farmers from 485 households in the four villages who used carbofuran on their farms were asked to fill out a questionnaire.

2.3. Soil sample analysis

A total of 10 samples of topsoil were taken from the agricultural land in Khi Lek Subdistrict. The samples were gathered, placed in Ziploc bags, sorted, and transported to the research laboratory. Carbofuran residues in soil were determined using the in-house approach based on QuEChERS with a high-performance liquid chromatography (HPLC model: 1100) with a mass spectrometry detector. First, a 10 g sample was weighed and carefully mixed with 10 ml of deionized (DI) water. Then, 10 ml of acetonitrile (HPLC) was mixed with 4.00 g of magnesium sulfate and 1.00 g of NaCl. Then the mixture was centrifuged for 10 minutes at 5 degrees Celsius at 3000 rpm. Then, the top 5 ml of the mixture was vacuumed and dried with N-evaporation until it was completely dry. Then, 1 ml of 0.01% of formic acid was added in MeOH: DI (1:1). After that, the extracts were tested for carbofuran using the 1100 HPLC system with a mass spectrometry detector. Calibration curves were linear over the studied range (equivalent to 0.01–0.1 mg/kg) with correlation coefficients of 0.999. The limit of detection (LOD) was 0.02 mg/kg. The limit of quantitation was 0.10 mg/kg. The mean recovery of extractions for carbofuran was 106.93%, with a relative percent difference of 20%. These values were considered acceptable and good results since a recovery range of 70.3%–120% was approved [18].

2.4. *Exposure and health risk assessment*

Exposure through ingestion:

Carbofuran exposure through the oral ingestion of soil was measured. The non-carcinogenic cases were taken in account. Eq 1 was used to calculate the carbofuran human exposure section, whereas Eq 2 was used to calculate the hazard quotient (HQ). The reference dose of carbofuran was 5×10^{-3} mg/kg-day, which may be computed using the following equation:

$$\text{Average daily dose (ADD)} = (C \times CF \times IR \times EF \times ED \times FI) / (BW \times AT) \qquad (1)$$

$$\text{Hazard quotient (HQ)} = ADD/RfD \qquad (2)$$

The values used for calculations are shown in Table 1.

2.5. Data analysis

The descriptive statistics for frequencies and percentage distribution were used to describe information regarding the demographic characteristics, types of vegetables grown, eating habits, and health risk level. For ADD analysis, the results of carbofuran residues were reported not detected (ND) and they were substituted with the $_{1/2}$LOD following the recommendation of the USA EPA (2000) [21].

Table 1. Parameter values for risk calculation.

Parameters	Description	Unit	Value used	References
ADD	Average daily dose	mg/kg-day		
HQ	Hazard quotient	-		
C	Concentration of carbofuran in soil	mg/kg	Data from laboratory analysis	
CF	Conversion factor	kg/mg	10^{-6}	
IR	Ingestion rate	mg/day	100	[19]
EF	Exposure frequency	Days/Year	Individual data from the questionnaire	
ED	Exposure duration	Years	Individual data from the questionnaire	
FI	Fraction ingested from contaminated source	-	1	
BW	Body weight	kg	Individual data from the questionnaire	
AT	Average time over which exposure averaged	Days	ED × 365 days	
RfD	Reference dose	mg/kg-Day	5×10^{-3}	[20]

*Note: Risk Characterization: the hazard quotient (HQ) from Equation (2) was interpreted for two levels of the health risk: HQ < 1 means an acceptable risk for human health; HQ ≥ 1 means an unacceptable risk for human health.

3. Results and discussion

Due to the extensive use of carbofuran by farmers in four villages in Khi Lek Subdistrict, Muang District, Ubon Ratchathani Province, many studies have been conducted; one revealed that 51.18% of pesticide use had unsafe levels of cholinesterase enzyme activity and 48.03% had at-risk levels [22] at which carbofuran may have an impact on the activity of the abnormal cholinesterase enzyme. Although carbofuran is highly mobile in soil and soluble in water, there is no data on its risk of consumption by farmers in agricultural areas. Consequently, this study assessed the risk related to consumption as well as the carbofuran residues in agricultural soil. According to the demographic data, the majority of the farmers were female (56.99%) with an average age of 44.06 years (SD

=8.85), an average weight of 58.76 kg (SD =7.39) and a smoking rate of 22.42%. Chilli was the most widely grown crop (38.47%), followed by radish (26.95%), and 98.97% of the farmers ate food from the packages they had prepared while working. While farming, 92.18% of the farmers drank water from the container they had prepared, and 81.48% of the drinking water came from a shared plastic water cooler (Table 2). Pesticide residues in the soil where the farmers eat and drank may contaminate their food and water, which could have an impact on their health [23].

Table 2. Frequency and percentage of the farmers cultivating vegetables using chemicals in Khi Lek Subdistrict, Muang District, Ubon Ratchathani Province (n = 485).

General information	Frequency	Percentage
1. Gender		
- Male	209	43.09
- Female	277	56.99
2. Age (year), Mean 44.06 (S.D = 8.85)	25–70 year (min to max)	
3. Weight (kg), Mean 58.76 (S.D = 7.39)	40–88 kg (min to max)	
4. Smoke		
- Yes	109	22.42
- No	377	77.57
5. Types of vegetables grown (can answer to more than one type)		
- Chilli	187	38.47
- Radish	131	26.95
- Lettuce	87	17.90
- Kale	27	5.55
- Water spinach	67	13.78
- Cantonese	40	8.23
- Others	14	2.88
6. Eating while farming		
- Yes	481	98.97
- No	5	1.02
7. Eating habits during farming		
- Eat packaged food	486	100.00
8. Drinking water during farming		
- Yes	448	92.18
- No	38	7.81
9. Container for drinking water		
- Personal plastic water cooler	90	18.51
- Shared plastic water cooler	396	81.48

All residual levels in the field were found to be below the limit of detection (0.02 mg/kg) and were replaced with the $_{1/2}$LOD as recommended by the USA EPA (2000) [21] (Table 3). This may be partly attributable to the way soil samples were collected; soil samples were collected using a purposive sampling method when the growing season was coming to an end. According to field tests conducted in Jinan, Shandong province, and Langfang, Hebei province, China, carbofuran can degrade with a half-life of 3.1 and 4.6 days, respectively [24] and only 1.24 days under the humid tropical climate [25]. It is possible that the collected samples were carbofuran-free at the time of research examination. These findings were in contrast to those of Otieno et al. [9] where the concentration of carbofuran residues in soil in Kenya's agricultural farmlands ranged from 0.010 –1.009 mg/kg [26].

Table 3. Average amount of carbofuran residues in Khi Lek Subdistrict, Muang District, Ubon Ratchathani Province by village.

Village	Amount of carbofuran residues (mg/kg)			
	Sample 1	Sample 2	Sample 3	Average
5	0.01	0.01	0.01	0.01
8	0.01	0.01	-	0.01
9	0.01	0.01	0.01	0.01
10	0.01	0.01	-	0.01

According to the results, the overall average of the farmers' daily dose of carbofuran in Villages 5, 8, 9, and 10 ranged from 3.9×10^{-9} mg/kg-day to 5×10^{-9} mg/kg-day, and the farmers in Villages 5, 8, 9 and 10 were at an acceptable health risk (HQ <1) (Table 4). This is in line with the findings of Silipunyo et al., which, evaluating the risk of short-term contact with chemicals, found no risk of toxicity among the consumers who consumed fruits and vegetables in Chiang Mai province [27]. In addition, the study by Prasopsuk et al. indicated that, among the growers of Chinese kales in Khon Kaen Province, Northeast Thailand, who were at risk of being exposed to pesticide residues in soil, the average hazard index (HI) was less than 1, which was considered an acceptable risk level [28]. However, this study found that during their farming, 98.97% and 97.53% of the farmers ate food and drank water, respectively. They may still be exposed to pesticides. As the study of Chaisuwan et al. showed, pesticide use behavior was statistically significant and associated with cholinesterase levels in farmers in high-risk areas [29]. If farmers continue to use pesticides for their vegetables, consume food, drink water, and farm at the same time, they are at risk of being exposed to carbofuran by intake of carbofuran-contaminated food and water as carbofuran is linked to endocrine disruption, reproductive problems, and cytotoxic and genotoxic abnormalities in humans [30]. In addition, according to Tongpoo et al., farmers may become ill, and the most common clinical indications of occupational carbofuran poisoning were nausea and vomiting (82.3%), headaches (56.3%), and miosis (19.8%) [31].

Table 4. Frequency and percentage of health risk of carbofuran exposure through soil intake among farmers (n = 485).

Village	Sample (Person)	ADD (mg/kg-day)	Risk (HQ)			
			Acceptable (HQ < 1)		Unacceptable (HQ ≥1)	
			Frequency	Percentage	Frequency	Percentage
5	155	5.0×10^{-9}	155	100.00	-	-
8	163	4.1×10^{-9}	163	100.00	-	-
9	90	4.8×10^{-9}	90	100.00	-	-
10	77	3.9×10^{-9}	77	100.00	-	-

3. Conclusion

Despite the fact that there was an acceptable level of risk of pesticide exposure, farmers have persistently used pesticides in their agricultural fields. Their pesticide use behavior and consumption of food and water while working puts them at risk. This also happens with farmers in Khi Lek Subdistrict, Muang District, Ubon Ratchathani Province, Thailand. However, no scientific reports have presented this problem. This article is the first scientific report presenting the contamination of carbofuran pesticide in soil and its risk on farmers' health in four villages of Khi Lek Subdistrict where pesticides have been strongly used. The information obtained from this research may be useful for policy planning to help reduce the use of pesticides and promote healthcare among farmers.

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Conflict of interest

The authors declare no conflict of interest.

References

1. Panuwet P, Siriwong W, Prapamontol T, et al. (2012) Agricultural Pesticide Management in Thailand: Situation and Population Health Risk. *Environ Sci Policy* 17: 72–81. https://doi.org/10.1016/j.envsci.2011.12.005
2. National Statistical Office (2020) Labour Statistics 2020 Ministry of Digital Economy and Society, Bangkok. Available from: http://statbbi.nso.go.th/staticreport/page/sector/en/ 02.aspx
3. Hongsibsong S, Kerdnoi T, Polyiem W, et al. (2018) Blood cholinesterase activity levels of farmers in winter and hot season of Mae Taeng District, Chiang Mai Province, Thailand. *Environ Sci Pollut Res* 25: 7129–7134. https://doi.org/10.1007/s11356-015-4916-6
4. Mustapha MU, Halimoon N, Johari WLW, et al. (2020) Enhanced Carbofuran Degradation Using Immobilized and Free Cells of Enterobacter sp. Isolated from Soil. *Molecules* 25: 2771. https://doi.org/10.3390/molecules25122771
5. Ramasubramanian T, Paramasivam M (2018) Persistence and metabolism of carbofuran in the soil and sugarcane plant. *Environ Monit Assess* 190: 538. https://doi.org/10.1007/s10661-018-6926-6
6. Fukuto TR (1990) Mechanism of action of organophosphorus and carbamate insecticides. *Environ Health Perspect* 87: 245–254. https://doi.org/10.1289/ehp.9087245
7. Whitmore C, Lindsay CD, Mike Bird M, et al. (2019) Assessment of false transmitters as treatments for nerve agent poisoning. *Toxicol Lett* 321: 21–31. https://doi.org/10.1016/j.toxlet.2019.12.010

8. Peter JV, Sudarsan TI, Moran JL (2014) Clinical features of organophosphate poisoning: A review of different classification systems and approaches. *Indian J Crit Care Med* 18: 735–745. https://doi.org/10.4103/0972-5229.144017
9. Otieno PO, Lalah JO, Virani M, et al. (2010) Carbofuran and its toxic metabolites provide forensic evidence for furadan exposure in vultures (Gyps africanus) in Kenya. *Bull Environ Contam Toxicol* 84: 536–544. https://doi.org/10.1007/s00128-010-9956-5
10. Tawatsin A, Thavara U, Siriyasatien P (2015) Pesticides used in Thailand and toxic effects to human health. *Med Res Arch* 3: 1–10. https://doi.org/10.18103/mra.v0i3.176
11. Sapbamrer R, Nata S (2013) Health symptoms related to pesticide exposure and agricultural. *Environ Health Prev Med* 19: 12–20. https://doi.org/10.1007/s12199-013-0349-3
12. Yongpraderm M, Yimthian S, Intaramuean M, et al. (2019) Risk rating of pesticide exposure among agricultural workers in a community, Nakhon Si Thammarat Province. *Dis Control J* 45(1):42–53.
13. Bureau of Occupational and Environmental Diseases (2018) Situation report: Diseases and health hazards from work and environment in 2018. Available from: http://envocc.ddc.moph.go.th/uploads/situation2/2561/2561_01_envocc_situation.pdf
14. The Office of Disease Prevention and Control 10, Ubon Ratchathani (2017) The preventive, development, and operations for disease control 2017, in collaboration with the province. Available from: https://odpc10.ddc.moph.go.th/wp-content/uploads/2018/01/20180117_083837.pdf
15. Boonkhao L, Wongsafu S (2020) Health risk assessment of pesticide exposure among vegetable farmers in Khi lek Subdistrict, Muaeng District, Ubon Ratchathani Province. *J Saf Health* 13: 93–106.
16. Zhang C, Deng Y, Zheng J, et al. (2019) The application of the QuEChERS methodology in the determination of antibiotics in food: A review. *Trends Analyt Chem* 118: 517–537. https://doi.org/10.1016/j.trac.2019.06.012
17. Department of Agriculture (2019) Manual for pesticide residue analysis service in plants, soil, water, product quality, agricultural toxic substances, and natural substances. Available from: https://www.doa.go.th/apsrdo/wp-content/uploads//2021/05/-64.pdf
18. Caldas SS, Bolzan CM, Cerqueira MB, et al. (2011) Evaluation of a Modified QuEChERS Extraction of multiple classes of pesticides from a rice paddy soil by LC-APCI-MS/MS. *J Agric Food Chem* 59: 11918–11926. https://doi.org/10.1021/jf202878s
19. Remediation and Redevelopment Division, Michigan Department of Environmental Quality (2015) Soil and Dust Ingestion Rate (IR). Available from: https://www.michigan.gov/documents/deq/deq-rrd-chem-MDEQSoilIngestionRateTSDSRC_527406_7.pdf
20. U.S. Environmental Protection Agency (1987) Integrated Risk Information System (IRIS), Chemical Assessment Summary: Carbofuran; CASRN 1563-66-2. Available from: https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0218_summary.pdf
21. U.S. Environmental Protection Agency (2000) Assigning values to non-detected/non-quantified pesticide residues in human health food exposure assessments. Office of Pesticide Programs. Washington, DC.
22. Boonkhao B, Baukeaw W (2020) Prevalence of abnormal serum cholinesterase among the vegetable farmers in a district in Ubon Ratchathani Province. *Naresaun Phayao J* 13: 59–65.

23. Bhandari G, Atreya K, Scheepers PTJ, et al. (2020) Concentration and distribution of pesticide residues in soil: Non-dietary human health risk assessment. *Chemosphere* 253:126594. https://doi.org/10.1016/j.chemosphere.2020.126594
24. Chen L, Jia C (2013) Degradation and persistence of carbofuran in peanut and soil in field trails as determined by GC-MS. *Adv Mat Res* 807: 1031–1037. https://doi.org/10.4028/www.scientific.net/AMR.807-809.1031
25. Sim SF, Chung LY, Jonip J, et al. (2019) Uptake and dissipation of carbofuran and its metabolite in Chinese kale and Brinjal cultivated under humid tropic climate. *Adv Agric* 5:1–7. https://doi.org/10.1155/2019/7937086
26. Otieno PO, Lalah JO, Virani M, et al. (2010) Soil and water contamination with carbofuran residues in agricultural farmlands in Kenya following the application of the technical formulation Furadan. *J Environ Sci Health Part B* 45: 137–144. https://doi.org/10.1080/03601230903472058
27. Silipunyo T, Hongsibsong S, Phalaraksh C, et al. (2017) Determination of organophosphate pesticides residues in fruits, vegetables and health risk assessment among consumers in Chiang Mai Province, Northern Thailand. *Res J Environ Toxicol* 11: 20–27. https://doi.org/10.3923/rjet.2017.20.27
28. Prasopsuk J, Suwit Laohasiriwong S, Promkhambut A, et al. (2019) Risk Assessment of Pesticide Residues in Soil to Health of Chinese kale Growers in Khon Kaen Province, Northeast Thailand. *Thai Agric Res J* 37:272–285
29. Chaisuwan C, Phornwisetsirikun W, Suwanbongko P (2021) Factors associated with blood cholinesterase enzyme levels of the agricultural workers in Health Region 1. *Chiangrai Med J* 13:137–151.
30. Mishra S, Zhang W, Lin Z, et al. (2020) Carbofuran toxicity and its microbial degradation in contaminated environments. *Chemosphere* 259:127419. https://doi.org/10.1016/j.chemosphere.2020.127419
31. Tongpoo A, Sriapha C, Wongvisawakorn S, et al. (2015) Occupational carbamate poisoning in Thailand. *Southeast Asian J Trop Med Public Health* 46: 798–804.