ORIGINAL ARTICLE

Distribution of Pesticide Emission, Deposition and Transfer Among Pesticide Sprayers in Malaysian Agriculture Subsectors

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ABSTRACT

Introduction: Extensive use of pesticides appears to be one of the issues that affect the future roles of the agricultural economy, due to occupational disease and poisoning cases associated with pesticide exposure. Emission, deposition and transfer are three main routes involved in transporting pesticide from its sources to the skin surface. This current study was aimed to analyze the distribution of dermal exposure to pesticide on body parts. **Methods:** A total of 160 pesticide sprayers working in paddy, vegetable, cocoa, and oil palm plantations participated in this study. Dermal Exposure Assessment Method (DREAM) was used to evaluate dermal exposure to pesticide caused by emission, deposition and transfer routes. The Kruskal Wallis Test was used to identify the differences on exposure routes between agriculture sectors. **Results:** There was significant difference of total exposure through emission, deposition and transfer among sprayers in different farming sectors ($p<0.001$). Pesticide sprayers in paddy fields have the highest pesticide exposure through deposition (144.31 ± 30.23 DU) and transfer (30.54 ± 1.19 DU), particularly on upper body parts. Meanwhile, vegetable pesticide sprayers were exposed the most on lower body parts, caused by deposition of spray droplets from low crop spraying. Emission found to contribute the least of the total exposure among pesticide sprayers in all agriculture sectors, which may indicate less occurrence of major leaks, splashes and spills during pesticide spraying. **Conclusion:** This study provides insights of exposure assessment, where intervention strategies could be developed with priority given for exposure reductions from relevant exposure routes.

Keywords: Emission, Deposition, Transfer, Pesticide distribution

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INTRODUCTION

Pesticides can be defined as substance used to prevent, destroy, repel or mitigate any pests including harmful organisms such as insects, animals, weeds and microorganisms (1). They were usually classified based on target organisms into herbicides, fungicides, insecticides, nematicides, rodenticides and bactericides. Besides, a pesticide can also be categorized into its chemical structure such as organophosphorus, organochlorine, phenoxy acid, urea and pyrethroids, as well as type of health hazard involved. Extensive use of pesticides appears to be one of the issues that might influence the future roles of the agricultural economy in Malaysia (2). Pesticide exposure has been associated with occupational diseases and poisoning cases such as leukemia, cancer, hypersensitivity, and hormone disruption, as well as respiratory diseases such as asthma and allergies (3).

Agricultural workers are exposed to pesticide through three main pathways which are inhalation, ingestion and dermal contact (4-6). Dermal contact is the most common route of exposure comprising about 60% of total pesticide exposure (7-9). Besides, incidents related to dermal absorption accounted for more than 90% of pesticides poisoning cases (10). After several fatalities due to pesticide dermal absorption, dermal exposure assessment has received more attention. One of the approaches to assess dermal exposure is Dermal Exposure Assessment Method (DREAM). It is a questionnaire-based measurement approaches, provides the semi-quantitative output, easy-to-use, less time consuming and cost effective (11).

DREAM has been used to assess dermal exposure in agriculture and industrial sector. It was developed according to conceptual model of dermal exposure that suggested the occurrence of pesticide transport from its sources to the skin surface through emission, deposition and transfer routes (11). The model was reported to be an appropriate model due to its determinants that cover most of the characteristic present in previous case study (12-14). For instance, DREAM was applied to assesses dermal exposure in potato farming in Colombia as well as Malaysian paddy farming, hence applying this method in agriculture sub-sectors in Malaysia was intended to avoid generalization of exposure level due to dermal exposure that depends on several factors.

Emission occur when pesticides contaminated worker's skin or clothing by direct release from exposure sources, such as splashes and spills, immersion of hands or other body parts onto liquid in the tank or powder-form pesticides. Deposition is the process where pesticide particles mainly of aerodynamic diameter below than 100 µm (i.e. vapours and mist) are transported from air onto worker's body. Meanwhile, transfer occurs when workers come into contact with surfaces such as floor and worktables, or working tools and equipment that have been contaminated with pesticide (15).

Exposure route is one of the factors strongly influenced the pesticide exposure among farm workers. Therefore, this study was designed to analyze and compare exposure distribution on different body parts caused by emission, deposition and transfer. Findings of this study provide insights of exposure assessment to improve understanding on pesticide dermal exposure routes on different agriculture settings. Then, intervention strategies could be developed with priority given for exposure reductions from relevant exposure routes. This study involves pesticide sprayers working in paddy farming, vegetables, cocoa and oil palm plantation due to the subsectors that used varieties of pesticides (16).

METHODS AND MATERIALS

Study population

The study was conducted in four agricultural farms registered under Local Agricultural Office as described in Table I. 160 participated pesticide sprayers comprised of 45 paddy farmers (28%), 34 vegetable farmers (21%), 51 cocoa farmers (32%), and 30 oil palm plantation sprayers (19%). The respondents were the male pesticide sprayers with the age above 21, with working experience as pesticide sprayers for at least 2 years to ensure familiarity and experience in pesticide handling. Informed consent was obtained from all respondents, which include explanation on research objectives, procedures, and privacy in data handling.

Table I. The description of study locations

Sampling location	Coordinate	Area description
Tanjung Karang, Kuala Selangor, Selangor	3° 27' 12.628"N 101° 12 '51.955 E	The area with population of 39857 people, where the Malays dominated rice cultivation The third largest area of paddy field in Peninsular Malaysia. (Mohd Fuad et al., 2012)
Cameron Highlands, Pahang	4° 28' 19.632"N 101° 22 '48.518 E	Most vegetable farming takes place between 900 and 1400 m It has a mild temperature of 14–24 °C throughout the year with average rainfall of 2660 mm
Felda Jengka, Pahang	3° 37' 59.609"N 102° 28 '24.276 E	One of the main area of new cocoa cultivation development program in Peninsular Malaysia for both estates and smallholders
Kuala Kubu Bharu, Selangor	3° 38' 51.262"N 101° 24 '59.831 E	Plantation estate managed by government agency, with land area more than 50 ha exclusively cultivated with oil palm and employing people to manage different tasks Planting density was 138-143 palms per hectare (Azhar et al., 2012)

The study which involved pesticide sprayers in paddy farming was conducted at a rice farming villages located in Tanjung Karang, Kuala Selangor, Malaysia. It is located in North West Selangor Integrated Agriculture Development Area (37,833 ha), which is one of the most productive granary areas in the country with average paddy yield of 6.28 tons/ha (17). Meanwhile, the oil palm cultivated area in Malaysia has increased to 5.74 million hectares in 2016, compared to 5.64 million hectares in previous year, with 138,831 hectares planted area in Selangor (18). Respondents were chosen among pesticide sprayers in oil palm cultivation area in Kuala Kubu Bharu, Selangor. Meanwhile, cocoa cultivation sector contributed 19.5% to the Malaysia's GDP, and the production of cocoa beans increased by 5.6% in 2016 compared to 2015 (19). This study included respondents among cocoa pesticide sprayers in Jengka, Pahang. For vegetable farmers, respondents from agriculture area in Cameron Highlands, Pahang was selected. Cameron highlands is one of the most important vegetable cultivation area in Malaysia, with total land area about 71,218 ha. Vegetable cultivation occupy the largest fraction (50%) of the 5500 ha of agricultural area in Cameron Highlands.

Dermal Exposure Assessment Method (DREAM)

DREAM was used to evaluate dermal exposure to pesticide among the pesticide sprayers caused by emission, deposition and transfer routes. The method consists of inventory and evaluation algorithm parts (15). In the inventory part, structured questionnaire was

Table II: Field characteristics and application characteristics during the sampling

	Paddy	Vegetable	Cocoa	Oil palm
Field				
Plant height (cm)	90-100	40-70	400	<60[c]
Plant density[a]	very dense[b]	dense	dense	dense
Application				
Application method	Motorized mist blower	Manual knapsack sprayer	Hand-carried thermal fogger	Manual knapsack sprayer
Flowrate (L/min)	2-4	0.6-0.7	0.1-0.7 (with oil)	0.6-0.7
Droplet size (µm)	50-100	100-400	20	100-400

[a] The density at which plants are planted in a cultivated plot, based on row and plant spacing
[b] Based on Choi et al., 2013
[c] Target pest height (weed)

constructed to obtain general information and dermal exposure determinants from interview and observation. Each questions were given an answer options with respective priori assigned exposure default values determined from algorithmic scale (11).

Observations were performed on a day of pesticide spraying carried out by respondents. Respondents were observed performing pesticide mixing, loading and spraying in their regular way. Table II showed the field characteristics (i.e. plant height and density) and spraying applications used by the farmers (i.e. application method, flow rate and droplet size). The evaluation part of DREAM involves estimation of dermal exposure from an algorithm. Evaluation of potential dermal exposure (PDE) was carried out for 9 different body parts (BPs). The exposure was evaluated on the head, upper arms, lower arms, hands, torso front, torso back, lower body parts, lower legs and feet. PDE is exposure on respondents' clothing and uncovered skin, estimated through emission (EBP) (Eq. 1), deposition (DBP) (Eq. 2), and transfer routes (TBP) (Eq. 3), as summarized in Table III. The Kruskal Wallis Test was used to identify the significant differences on emission, deposition and transfer variables between agriculture sectors.

Table III. Variables for dermal exposure estimation through emission, deposition and transfer routes

Variables	Description	
$E_{BP} = P_{E.BP} \times I_{E.BP} \times E_I \times E_{RE}$	Emission	(Eq. 1)
$D_{BP} = P_{D.BP} \times I_{D.BP} \times E_I \times E_{RD}$	Deposition	(Eq. 2)
$P_{E.BP}$ and $P_{D.BP}$	Frequency of emission and deposition on clothing and uncovered skin	
$I_{E.BP}$ and $I_{D.BP}$	Amount of pesticide on clothing and uncovered skin from emission and deposition	
$T_{BP} = P_{T.BP} \times I_{T.BP} \times E_{RT}$	Transfer	(Eq. 3)
$P_{T.BP}$	Frequency of pesticide contact with surfaces or tools	
$I_{T.BP}$	Contamination level of contact surface	
ER_E, ER_D and ER_T	Exposure route factors for emission, deposition and transfer	$E_{RE}=3$, $E_{RD}=1$, and $E_{RT}=1$
$E_I = PS \times C \times EV$	Intrinsic emission: physical and chemical characteristics of liquid pesticide	
PS	Physical state	
C	Concentration	
V	Viscosity	

Adapted from Van Wendel de Joode et al. (2003)

RESULTS

Exposure estimates through emission, deposition and transfer was presented in Table IV. There was statistically significant difference of total exposure through emission, deposition and transfer among sprayers in different farming sectors ($p<0.001$). In terms of total emission, cocoa pesticide sprayers had the highest exposure (29.31 ± 48.97 DU) and paddy pesticide sprayers had the lowest (6.38 ± 5.35 DU). Paddy farmers had the highest exposure (144.31 ± 30.23 DU) and oil palm pesticide sprayers had the lowest exposure of deposition (13.99 ± 8.71 DU). For exposure caused by transfer, oil palm pesticide sprayers had the highest total transfer exposure (39.45 ± 10.98 DU) and cocoa pesticide sprayers had

Table IV. Mean and standard deviation of exposure estimates through emission, deposition and transfer (in Dermal Unit, DU)

Exposure routes		Paddy N=45	Vegetable N=34	Cocoa N=51	Oil palm N=30	χ^2 (*p*-value)
Total emission	Mean	6.38	19.38	29.31	12.51	24.736 (<0.001**)
	SD	5.35	12.21	48.97	11.71	
	Range	0.90-18.90	8.10-45.90	0.00-270.00	2.70-54.00	
Total deposition	Mean	144.31	29.17	64.46	13.99	13.619 (<0.001**)
	SD	30.23	13.08	16.09	8.71	
	Range	48.60-155.40	10.20-66.60	24.30-125.10	2.10-30.60	
Total transfer	Mean	30.54	32.86	10.49	39.45	123.790 (<0.001**)
	SD	1.19	4.04	4.33	10.98	
	Range	29.10-31.50	30.00-44.40	9.00-40.80	30.60-93.60	

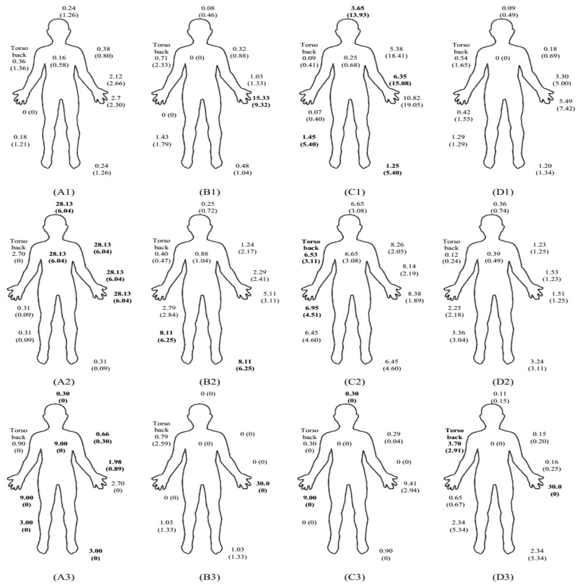

Fig. 1. Dermal exposure estimates through emission (1), deposition (2) and transfer route (3) among pesticide sprayers in (A) paddy, (B) vegetable, (C) cocoa and (D) oil palm plantation

the lowest (10.49 ± 4.33 DU).

Potential dermal exposure for each body parts (PDEBP) caused by emission, deposition and transfer route was presented in Fig. 1. There was significant difference in potential exposure through emission route on hands, where vegetable farmers have significantly highest exposure (*p*<0.001) compared to other farming sector. Meanwhile, cocoa pesticide sprayers exposed the most on those body parts through emission on several body parts (i.e. head, forearms, lower leg and feet) compared to other agriculture sectors (*p*<0.001).

For exposure caused by deposition, the potential exposure estimates also showed significant differences between different farming sectors (p<0.001). Paddy farmers have the highest exposure on upper body parts (i.e. hands, head, forearms, upper arms, torso front), while vegetable farmers have significantly highest exposure (*p*<0.001) on lower body parts (i.e. lower leg and feet) compared to other farming sector. The results of PDE_{BP} caused by transfer route showed significant differences in potential exposure estimates on all body parts between different agriculture sectors (*p*<0.001). Through contact with contaminated surfaces, paddy farmers exposed the most on several body parts (i.e. head, upper arms, forearms, torso front, thigh, lower legs and feet). Meanwhile, vegetable and oil palm pesticide sprayers have significantly higher exposure (*p*<0.001) on hands compared to other farming sector, while cocoa pesticide sprayers exposed the most on thigh.

DISCUSSION

During the exposure assessment, most of farmers in all agriculture sectors were unlikely exposed to pesticide through emission. This indicate less occurrence of major leaks, splashes and spills observed during pesticide spraying activity. However, there were some repeated exposure observed among farmers on their hands and forearms. Relatively higher exposure on hands and forearms may be attributed by accidental splashing or spills during pesticide mixing and loading processes, as well as exposure to spray leakage during holding the trigger valve on the lance, as reported in several studies (20-23). Previous study reported differences in hands exposure among respondents, ranging from 3.1% to 15% of the total exposure, explained by worker carelessness and poor maintainance of spraying equipment, causing accidental spill and the leak in the sprayer lance (22).

In this study, highest pesticide deposition among paddy farmers were contributed by constant exposure to large amount of pesticides on upper body parts (i.e. hands, head, upperarms, forearms, and torso front), and occasional exposure to small amount of pesticide on lower body parts throughout the spraying activity. The farmers sprayed up to their abdomen height to ensure adequate coverage of the 90-100 cm height rice plants. This may cause occurrence of pesticide drift resulting to off-target contamination on paddy farmers' upper body region, consistent with findings in several studies (22,24). The influence of crop type and height (i.e. maize, broccoli, green pepper, cucumber, paddy, apple) on dermal exposure and its distribution has been previously studied (25,26). Moreover, body size and posture during spraying were suggested as factors that greatly influenced the difference in frequency, amount and distribution of pesticide contamination in particular agriculture. For instance, farmer with shorter height have to lift the spraying machine to higher position, causing contamination on their upper body part (27).

Difference droplet size from spraying equipment used is one of the factors which influence the pesticide drift, eventually increasing the exposure (28). In this study, cocoa plantation sprayers were exposed repeatedly with medium amount of pesticide on all body parts. Medium amount of exposure was rated mainly due to smaller pesticide droplets (less than 20 μm) generated from thermal foggers used by cocoa sprayers that are prone to displacement by wind and lessen the contamination on the body.

In contrast, vegetable farmers have greatest exposure (accounts for 45% of total exposure) deposited on lower body parts (i.e. lower legs and feet), due to deposition of spray droplets from low crop application and spraying technique factor. In addition, hand pressure spraying represents highest dermal exposure due to the proximity of the nozzle to the farmers' lower body parts (29). Previous literatures reported exposure on the lower body parts ranged from 62% to 82.6% from the total PDE (29,30). Significant exposure on lower body parts has been described in previous study, reported potential exposure for legs during fungicide application in vineyards was about 2.3 times higher than exposure on upper body parts (31).

This study found that paddy farmers were constantly contaminated with small to medium amount of pesticide through transfer route, which was direct contact with contaminated surfaces on lower body parts (i.e. thighs, lower leg, feet). The findings are consistent with several studies reported highest level of pesticide exposure (51.2−78.8% of total exposure) on lower body part (thighs and shins) of paddy field sprayers (24,25). It is suggested that the exposure was attributed by contamination through greatest contact frequency when farmers walked through the sprayed dense plants (24-26,32).

Vegetable and oil palm plantation sprayers were exposed with large amount of pesticides on the hands. Exposure among vegetable farmers might be due to farmers handling the hose connected to a pump machine and manually operated lance, where the hose contaminated by pesticide on the treated crops and the soil. Furthermore, hand exposure can be related to common practice of farmers adjusting and clearing the lance and nozzle contaminated with pesticide. There were also contamination occurred during handling pesticide containers, where small drops of concentrated pesticide spilled and transferred to workers' hand. Exposure from pesticide contaminated tools and spraying equipment has been reported in several studies (21,33,34). Meanwhile, cocoa pesticide sprayers recorded significantly higher exposure on thigh, particularly due to contact with hand-carried thermal fogger.

CONCLUSION

Paddy farmers having highest pesticide exposure through deposition and transfer, particularly on upper body parts (i.e. head, forearms, upper arms, torso front), due to pesticide drift resulting to off-target contamination on paddy farmer's body. Besides, they were also exposed to contamination through contact frequency as farmers walked through the sprayed dense rice plants. Meanwhile, vegetable farmers expose the most on lower body parts caused by deposition of spray droplets from low crop spraying. Emission found to contribute the least to the total exposure among pesticide sprayers in all agriculture sectors, which indicate less occurrence of major leaks, splashes and spills during pesticide spraying. Therefore, findings of this study provide further understanding and insights of exposure assessment, where intervention strategies could be developed with priority given for exposure reductions from relevant exposure routes.

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