ORIGINAL ARTICLE

Dermal Exposure to Pesticides among Sprayers in Different Agriculture Subsectors in Malaysia: Observational Method using DREAM

Nurulain Mustafa Udin[1,2], Sharifah Norkhadijah Syed Ismail[2,3], Vivien How[2], Emilia Zainal Abidin[2]

1 Department of Environmental Health, Universiti Teknologi MARA, Malaysia
2 Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400, UPM Serdang, Malaysia
3 Institut Pengajian Sains Sosial (IPSAS), Universiti Putra Malaysia, , 43400, UPM Serdang, Malaysia

ABSTRACT

Introduction: An assessment of dermal exposure to pesticide mixtures among sprayers was made as a function of crop type, in four agricultural subsectors in Malaysia. Methods: The potential and actual dermal exposures for 160 pesticide sprayers performing pesticide spraying task were estimated by using Dermal Exposure Assessment Method (DREAM). Results: Results showed that there was significant difference between nationality ($p<0.001$), highest education ($p<0.001$), monthly income ($p=0.002$), body mass index ($p<0.001$) and smoking habit ($p<0.001$) distributions of sprayers in different agriculture subsectors. Various types of pesticides were used by respondents, where class II (moderately hazardous) and class III (slightly hazardous) pesticides were the most frequently used pesticides. There was a significant difference in both tPDE ($\chi^2 = 118.093$, $p<0.001$) and tADE ($\chi^2 = 84.980$, $p<0.001$) between different agricultural sectors, where the prominent high tPDE was observed among paddy pesticide sprayers (151.39 ± 22.64 DU) while lowest exposure was recorded among oil palm plantation sprayers (47.67 ± 18.47 DU). Conclusion: Based on DREAM exposure categories, majority of the pesticide sprayers (68.9%) working in paddy farming were exposed in low dermal exposure while 26.7% of respondents were exposed to moderate exposure. Pesticide sprayers in other agriculture sectors were exposed to very low to low exposure level. Dermal exposure distributions on body parts were varied between sectors, influenced by several factors such as crop type, height, and spraying methods.

Keywords: Potential Dermal Exposure, Pesticides, Dermal Exposure Assessment Method (DREAM)

Corresponding Author:
Sharifah Norkhadijah Syed Ismail, PhD
Email: norkhadijah@upm.edu.my
Tel: + 603-97692643

INTRODUCTION

Malaysian agriculture sector continued to expand with a contribution of 8.9% to the Gross Domestic Product (GDP), indicating that agriculture sectors are contributing to the national economic development, particularly the rural economy (1). Increasing demand in agriculture production yield will result in continual used of the pesticide mixtures in Malaysian farming sector. Human particularly farm workers are expose to mixture of pesticides through three routes, which are inhalation, oral ingestion and dermal uptake. However, the most common route for human pesticide exposure is through dermal (2-5). According to conceptual model of dermal exposure developed in literature, transport of pesticide mass from its sources to the skin surface occurred through three main mechanisms, which are emission, deposition and transfer (6).

Pesticide exposure has been associated with various disease including cancer, leukemia, hormone disruption, hypersensitivity as well as respiratory diseases such as asthma and allergies (7). In Malaysia, previous study reported that health effects such as skin itchiness were detected among 42.9% farmers (60 of 140 pesticide handlers) working in paddy fields (8). Health screening among farmers in Kelantan reported the respondents with hypercholesterolaemia (83%), systolic hypertension (41.9%), hyperglycaemia (32.8%) and anaemia (24.2%), suggested to be associated with lack of PPE application during pesticide handling (9). Besides, 14.5% of farmers (of 4,531 farmers) growing vegetables, flowers, and fruits in Cameron Highlands also experienced symptoms of pesticide poisoning (10). Although dermal exposure assessment is vital in providing information on the level of exposure risk faced by the pesticide sprayers is often an expensive and complicated task.

Therefore, this study was intended to assess the dermal exposure risk by using semi-quantitative assessment (DREAM) during the pesticide application task on different agricultural settings. Application of DREAM in assessing exposure offers a relevant and practical option for easy-to-use, quick, cost effective and less time-consuming method. The subsectors involved in this study were paddy (*Oryza sativa*), vegetables, cocoa (*Theobroma cacao*) and oil palm (*Elaeis guineensis*). This study focused on these subsectors due to Malaysian farming systems such as vegetables, fruits, paddy and palm oil plantations involve usage of variety of pesticides (11). This study provides an improved understanding of pesticide sprayer exposure from different agriculture background as fundamental basis for occupational health protection.

Dermal Exposure Assessment Method (DREAM) has been widely used to assess dermal exposure in agriculture and industrial sector. It was suggested to be the most appropriate model due to its structure in which the determinants cover most of the characteristic present in farming systems in developing countries (8,12,13). Previous studies have evaluated the reliability and validity of the DREAM method by focusing on a broad range of exposure scenarios and types of dermal exposure (i.e., solids, liquids, vapors). The method indicates good to excellent inter-observer agreement with inter-class correlation coefficients, ranging from 0.68 to 0.87 for total dermal exposure estimates (14). Besides, DREAM estimates from six exposure surveys were compared with dermal quantification data by estimating the Spearman correlation coefficient, and it was found ranging from 0.19 to 0.82 (15). This indicates small to large positive correlations as suggested by Cohen (1988) (16).

MATERIALS AND METHODS

Study population

This study was conducted among 160 pesticide sprayers from different agriculture sectors, where a total of 45 (28%) pesticide sprayers were paddy farmers, 34 (21%) were vegetable farmers, 51 (32%) were cocoa farmers, and 30 (19%) were oil palm plantation sprayers. The inclusion factors in the subject selection were the male pesticide sprayers with the age of 21 and above. Fig. 1 shows the four sampling locations, purposively selected from the list of registered agricultural farms under Local Agricultural Office, due to their high production yield. The procedures, approaches used and involvement of respondents in this study have been approved by the Ethic Committee for Research Involving Human Subjects of Universiti Putra Malaysia (JKEUPM)FPSK (EXP15) P096. Informed consent was obtained from all individuals before the interview, which included the research objectives, procedures, and privacy in data handling.

Questionnaire

Data collection was carried out through face-to-face interview with participants based on structured questionnaire. Interviews that took approximately 15

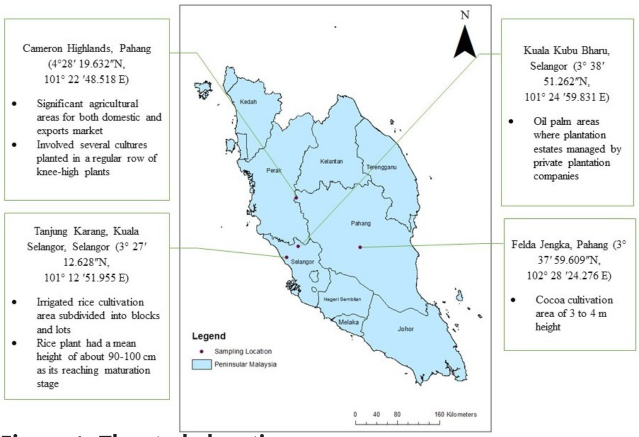

Figure 1: The study locations

minutes were carried out after farmers had finished their daily work to avoid disruption during their work time. Information on socio-demographic background such as gender, age, monthly income, marital and education status of the respondents were identified. Another section required farmers to give an indication of pesticides usage in their plantation, such as the types of pesticide (trade names).

Dermal Exposure Assessment Method (DREAM)

Observations were performed on the day pesticides were applied by sprayers, under their respective way of spraying and protective clothing. Dermal exposure was estimated from each question constructed and answer options were given a priori assigned value determined from an algorithmic scale. Evaluation of exposure for pesticide mixing, loading and application was carried out by assessing the sum of exposure on 9 different body parts (BPs) which are head, upper arms, lower arms, hands, torso front, torso back, lower body parts, lower legs and feet. Potential dermal exposure (PDE) is exposure on the whole body, which was the sum of exposure on clothing layer and uncovered skin. PDE was estimated from an algorithm using pre-assigned default values for variables in Table I. All pesticide sprayers used either solid or liquid form of pesticide with water as solution factor, active ingredients of 1-90% and boiling temperature of 50-150°C for liquid form.

Actual dermal exposure (ADE) represent exposure on the skin only (Eq. 8), which was estimated from an algorithm using pre-assigned default values for variables in Table I. Then, the results were summed up to produce DREAM score of total actual dermal exposure (tADE) (Eq. 12). Scores were then predefined into seven categories as highlighted in summary of DREAM evaluation in Fig. 2.

Statistical analysis

Data was analyzed by using univariate and bivariate analysis, using IBM SPSS version 21.0 and Microsoft Excel. Descriptive statistics such as mean, standard deviation (SD) and range (minimum and maximum) values were presented for continuous variables, while categorical variables were presented by frequency,

Table I: Variables for Potential Dermal Exposure (tPDE) and Actual Dermal Exposure (tADE) estimation

Variables	Description	
Potential Dermal Exposure (PDE)		
PDE_{BP} = Emission (E_{BP}) + Deposition (D_{BP}) + Transfer (T_{BP})	The potential exposure estimate (PDE_{BP}) for a certain body part is the sum of dermal exposures caused by three different routes: Emission (E_{BP}) (Eq. 2), Deposition (D_{BP}) (Eq. 3), and Transfer (T_{BP})	(Eq. 1)
$E_{BP} = P_{E.BP} \times I_{E.BP} \times E_I \times E_{RE}$	Emission	(Eq. 2)
$D_{BP} = P_{D.BP} \times I_{D.BP} \times E_I \times E_{RD}$	Deposition	(Eq. 3)
$P_{E.BP}$ 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. 4)
$P_{T.BP}$	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 x C x EV	Intrinsic emission: physical and chemical characteristics of liquid pesticide	(Eq. 5)
PS	Physical state	
C	Concentration	
V	Viscosity	
$PDE_B = \Sigma_{BP=1-9} PDE_{BP}$	The potential dermal exposure (PDE_B) estimates for the whole body were calculated for each respondent by summing individual body part values	(Eq. 6)
$tPDE = \Sigma_{BP=1-9} (BS_{BP} \times PDE_{BP})$	Before summing results in weighted total potential dermal exposure (tPDE), each body parts were weighed by its body surface factor (BS_{BP})	(Eq. 7)
BS_{BP}	Body surface factors for head (0.69), upper arms (0.67), forearms (0.53), hands (0.47), torso front (1.22), torso back (1.22), lower body parts (2.43), lower legs (1.15) and feet (0.63)	
Actual Dermal Exposure (ADE)		
$ADE_{BP} = PDE_{BP} \times O_{HA/BP}$	ADE_{BP} was calculated for each body part by multiplying the potential exposure with its clothing protection factor (ranging from 0.03 to 1) for hands (O_{HA}) (Eq. 9) or for other body parts (O_{BP}) (Eq.10)	(Eq. 8)
$O_{HA} = M \times PFM_{HA} \times RF \times GC \times GD \times UG \times URF \times BC$	Clothing protection factor for hands	(Eq. 9)
$O_{BP} = M \times PFM_{BP} \times RF$	Clothing protection factor for other body parts	(Eq. 10)
M	Type of material covering skin	
PFM	Protection factor of clothing material	
RF	Clothing replacement frequency	
GC	Connection of gloves to clothing of arms	
GD	Percentage of task duration gloves were worn	
UG	Usage of second pair of gloves	
URF	Replacement frequency of second pair gloves	
BC	Barrier cream usage	
$ADE_B = \Sigma_{BP=1-9} ADE_{BP}$	Actual dermal exposure estimates for whole body (ADE_B) were calculated by summing individual body part values	(Eq. 11)
$tADE = \Sigma_{BP=1-9} (BS_{BP} \times ADE_{BP})$	Total actual dermal exposure (tADE) was calculated by multiplying actual dermal exposure for each body part (ADE_{BP}) with its body surface factor (BS_{BP})	(Eq. 12)
BS_{BP}	Body surface factors for head, upper arms, lower arms, hands, torso front, torso back, lower body parts, lower legs and feet	

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

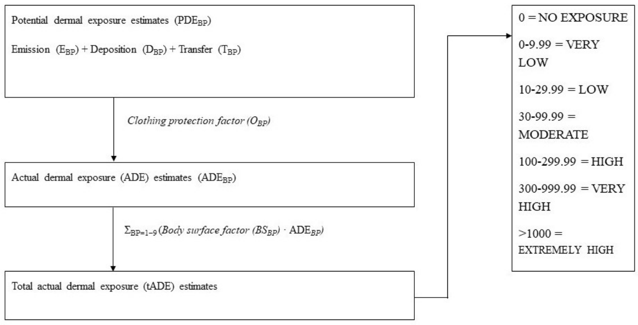

Figure 1: Summary of the evaluation model of DREAM

percentage (%) and graph. The Kruskal-Wallis and Chi-square test was used to identify the difference between agriculture sectors for continuous and categorical data, respectively. The significance level used for all statistical test was $p<0.05$.

RESULTS

Socio-demographic characteristics

Socio-demographic characteristics of pesticide sprayers are shown in Table II. All of respondents were male in the age of 21 to 69 and predominantly married (83.1%, N=133). Overall, a majority of the pesticide sprayers in all agriculture sectors were Malaysian (83.8%, N=134), with 75.0% were Malay, and the remaining were foreign workers (16.9%), Indian (4.4%) and Chinese (3.7%). The findings showed significant differences between nationality ($p<0.001$), highest education ($p<0.001$), monthly income ($p=0.002$), body mass index ($p<0.001$) and smoking habit ($p<0.001$) distributions of sprayers in different agriculture subsectors. There were highest percentage of local pesticide sprayers in cocoa plantation (100%, N=51) compared to other farming sectors. Besides, almost all of them (92.2%, N=47) received secondary education compared to other group of pesticide sprayers.

In terms of monthly income, pesticide sprayers in oil palm plantation received the lowest income (MYR 0-1000) (63.4%, N=19) compared to the other three sectors. There was higher percentage of oil palm pesticide sprayers having normal body mass index (BMI) (93.4%, N=28) compared to pesticide sprayers in paddy, vegetable and cocoa farming. Meanwhile, highest percentage of pesticide sprayers in cocoa plantation (72.5%, N=37) reported smoking. Respondents were considered as active smokers if they smoke more than 5 cigarettes per day during at least one year.

Type of pesticides used among respondents

Various chemicals have been used among respondents, where Table III summaries the most commonly used pesticides with active ingredients and its hazard classification by World Health Organization. WHO has issued the pesticide classification according to health hazard, ranging from extremely hazardous to unlikely to present acute hazards. The respondents

Table II: Socio-demographic characteristics of the respondents (N=160)

Variables	Paddy N=45	Vegeta-ble N=34	Cocoa N=51	Oil palm N=30	Total	χ^2	p value
	n (%)						
Age							
21 – 29	3 (6.7)	7 (20.6)	14 (27.5)	3 (10.0)	27 (16.9)		
30 – 39	7 15.6)	10 (29.4)	25 (49.0)	4 (13.3)	46 (28.7)		
40 – 49	5 (11.1)	13 (38.2)	8 (15.7)	8 (26.7)	34 (21.2)		
50 – 59	20 (44.4)	4 (11.8)	4 (7.8)	11 (36.7)	39 (24.4)		
60 – 69	10 (22.2)	0 (0)	0 (0)	4 (13.3)	14 (8.8)		
Nationality						25.236	<0.001**
Malaysian	40 (88.9)	21 (61.8)	51 (100)	22 (73.3)	134 (83.8)		
Non-Malaysian	5 (11.1)	13 (38.2)	0 (0)	8 (26.7)	26 (16.2)		
Marital status						1.276	0.735
Single	6 (13.3)	7 (20.6)	10 (19.6)	4 (13.3)	27 (16.9)		
Married	39 (86.7)	27 (79.4)	41 (80.4)	26 (86.7)	133 (83.1)		
Highest education						40.925	<0.001**
Illiteracy	1 (2.2)	0 (0)	0 (0)	1 (3.3)	2 (1.3)		
Primary education	12 (26.7)	7 (20.6)	2 (3.9)	15 (50.0)	36 (22.5)		
Secondary education	30 (66.7)	22 (64.7)	47 (92.2)	10 (33.3)	109 (68.1)		
Tertiary education	2 (4.4)	5 (14.7)	2 (3.9)	4 (13.3)	13 (8.1)		
Monthly income (MYR)[a]						20.518	0.002*
Low	26 (57.8)	7 (20.6)	25 (49.0)	19 (63.4)	77 (48.1)		
Interme-diate	2 (4.4)	7 (20.6)	2 (3.9)	1 (3.3)	12 (7.5)		
High	17 (37.8)	20 (58.8)	24 (47.1)	10 (33.3)	71 (44.4)		
Body mass index (BMI) (kg/m^2)						27.176	<0.001**
Normal	24 (53.3)	21 (61.8)	18 (35.3)	28 (93.4)	91 (56.9)		
Over-weight	15 (33.3)	9 (26.5)	22 (43.1)	1 (3.3)	47 (29.4)		
Obese	6 (13.4)	2 (5.9)	10 (19.6)	1 (3.3)	19 (11.9)		
Smoking habit						23.601	<0.001**
Yes	30 (66.7)	14 (41.2)	37 (72.5)	7 (23.3)	88 (55.0)		
No	12 (26.7)	20 (58.8)	13 (25.5)	20 (66.7)	65 (40.6)		
Quit smoking	3 (6.7)	0 (0)	1 (2.0)	3 (10.0)	7 (4.4)		

χ^2= Chi-square test comparing between agriculture sectors
[a]Low=0-1000 MYR, Intermediate=1,001-1,200 MYR, High=Above 1,200MYR
* significant at *p*<0.05
** significant at *p* <0.001

in paddy field used a total of 15 different pesticide products, followed by 14 products used by sprayers in cocoa farming, 12 products in vegetables farming and 3 products in oil palm plantation, comprising herbicides, insecticides and fungicides. Of all products, herbicides that contain glyphosate as the active ingredient such as Roundup, Ammo Supre and Ken-up were used by respondents for application to all crops. In addition, product with glufosinate-ammonium such as Basta, was also commonly applied by pesticide sprayers in paddy, vegetable and cocoa farm.

Respondents in paddy and vegetable farming used insecticide containing lambda-cyhalothrin and chlorantraniliprole such as Karate and Preyathon. Besides, insecticide with chlorpyrifos and cypermethrin (Naga 505) were also applied on paddy and cocoa plantation. Of all pesticides used by the farm sprayers, chlorpyrifos, malathion and dimethoate were insecticides from organophosphate class. Respondents in paddy and vegetable farming used Antracol formulation in common for fungi control which contains propineb as its active ingredients, while thiram (Ancom thiram 80) is being used by pesticide sprayers in oil palm plantation.

Dermal exposure estimations from DREAM

Descriptive statistics of potential and actual dermal exposure for each agriculture sectors are shown in Table IV. Statistical analysis found that there was a significant difference in tPDE between different agricultural sectors, where the prominent high exposure was observed among paddy pesticide sprayers (χ^2 = 118.093, p<0.001), while lowest exposure was recorded among oil palm plantation sprayers. The total potential dermal exposure (tPDE) among paddy pesticide sprayers was 151.39 ± 22.64 DU, followed by pesticide sprayers in cocoa plantation (108.07 ± 35.78 DU), vegetable farm (55.13 ± 16.76 DU) and oil palm plantation (47.67 ± 18.47 DU). High tPDE indicates high total pesticide exposure on both working clothes and uncovered skin of pesticide sprayers.

Kruskal-Wallis H test showed that there was a statistically significant difference in total actual dermal exposure (tADE) between different agricultural sectors (χ^2 = 84.980, p<0.001). Almost similar pattern of exposure was recorded with tPDE, where the highest tADE was estimated among pesticide sprayers in paddy field (26.70 ± 8.72 DU), followed by cocoa plantation sprayers (14.93 ± 7.10 DU), oil palm plantation sprayers (9.84 ± 8.79 DU) and vegetable farm sprayers (6.74 ± 5.04 DU). Higher tADE indicates higher exposure on skin of pesticide sprayers.

The total actual exposure (tADE) were categorised into the dermal exposure categories (Fig.3). Majority of the pesticide sprayers working in paddy fields has low dermal exposure (68.9% of respondents) while 26.7% of respondents were exposed to moderate exposure. Meanwhile, majority of the pesticide sprayers in cocoa plantation were in low exposure (68.6% of respondents) and very low exposure (27.5% of respondents). Two-third of oil palm plantation sprayers were exposed to

Table III: Commonly used pesticides in study area

	Herbicides			Insecticides			Fungicides		
Plantation	Active Ingredient	C	Trade names	Active Ingredient	C	Trade names	Active Ingredient	C	Trade names
Paddy	Paraquat	II	Paraquat, Gramoxone, Kopi-O	Lambda-cyhalothrin	II	Karate	Propineb	U	Antracol
	Glyphosate	III	Ecomax, Ammo Supre	Lufenuron	O	Match	Isoprothiolane	II	Fujione
	Glufosinate-ammonium	II	Basta	Chlorantraniliprole + Thiamethoxam	U	Virtako			
	Diuron	III	Diuron	Chlorpyriphos + Cypermetherin	II	Naga 505			
				Malathion	III	Malathion			
				Chlorantraniliprole	U	Prevathon			
Vegetable	Glyphosate	III	Roundup	Cyromazine	III	Trigard 75WP	Azoxystrobin	U	Amistar
	Glufosinate-ammonium	II	Basta	Lambda-cyhalothrin	II	Karate	Propineb	U	Antracol
				Deltamethrin	II	Decis	Triforine	U	Saprol
				3,5-dibromo-4-hydroxybenzonitrile	O	Maestro			
				Flubendiamide	O	Takumi			
				Chlorantraniliprole	U	Prevathon			
Cocoa	Paraquat	II	Paraquat	Deltamethrin	II	Decis, Deltam	-		-
	Triclopyr	II	Garlon	Dimethoate	II	Logor			
	Glyphosate	III	Roundup, Ecomax, Ken-up, Ammo Supre	Chlorpyrifos + Cypermethrin	II	Naga 505, Dragon 505			
	Metsulfuron-methyl	U	Ally	Cypermethrin	II	Kencis			
	Glufosinate-ammonium	II	Basta						
Oil palm	Glyphosate	III	Roundup, Ally, Ken-up	Cypermethrin	II	N	Thiram	II	Ancom Thiram 80

C = Index classification of active ingredients by WHO (2009)
Ia = Extremely hazardous; Ib = Highly hazardous; II = Moderately hazardous; III = Slightly hazardous; U = Unlikely to present acute hazard in normal use, O = Not classified
N= Not specified by respondents

Table IV: Descriptive statistics of potential (PDE) and actual dermal exposure (ADE) (in Dermal Unit, DU)

Body parts	Potential dermal exposure (PDE)				Actual dermal exposure (ADE)			
	Paddy N=45	Vegetable N=34	Cocoa N=51	Oil palm N=30	Paddy N=45	Vegetable N=34	Cocoa N=51	Oil palm N=30
	Mean (SD)				Mean (SD)			
Hands	15.76 (3.22)	23.70 (5.84)	13.45 (9.32)	17.39 (3.33)	10.77 (7.09)	3.89 (4.86)	2.11 (3.35)	6.48 (8.52)
Head	19.78 (4.31)	0.23 (0.58)	7.32 (10.10)	0.39 (0.84)	1.78 (0.39)	0.06 (0.16)	2.38 (3.60)	0.33 (0.76)
Upper arms	19.55 (4.10)	1.05 (1.54)	9.34 (12.56)	1.05 (0.95)	1.76 (0.37)	0.09 (0.14)	0.84 (1.13)	0.09 (0.8)
Forearms	17.08 (3.76)	1.76 (1.49)	7.68 (8.10)	2.64 (2.55)	1.54 (0.34)	0.16 (0.13)	0.80 (0.76)	0.24 (0.23)
Torso front	45.50 (7.38)	1.08 (1.27)	8.42 (3.67)	0.48 (0.60)	7.54 (4.89)	0.09 (0.11)	1.26 (1.01)	0.06 (0.06)
Torso back	4.83 (1.66)	2.33 (6.07)	8.44 (3.77)	5.32 (5.16)	0.43 (0.15)	0.21 (0.55)	0.76 (0.34)	0.48 (0.46)
Thigh	22.63 (0.22)	6.78 (6.90)	38.92 (11.08)	8.07 (6.89)	2.24 (1.75)	0.59 (0.63)	5.47 (3.48)	1.05 (1.56)
Lower legs	4.02 (1.39)	12.16 (8.17)	9.09 (8.12)	8.04 (6.63)	0.36 (0.13)	1.09 (0.73)	0.82 (0.73)	0.72 (0.60)
Feet	2.24 (0.80)	6.06 (4.25)	5.42 (4.45)	4.27 (3.67)	0.28 (0.18)	0.55 (0.38)	0.49 (0.40)	0.38 (0.33)
Mean total dermal exposure	151.39	55.13	108.07	47.67	26.70	6.74	14.93	9.84
SD total dermal exposure	22.64	16.76	35.78	18.47	8.72	5.04	7.10	8.79
Range total dermal exposure	79.97–169.09	26.34 – 111.23	52.19 – 258.83	22.42 – 102.00	8.88 – 44.36	2.56 – 22.19	7.73 – 37.81	1.09 – 29.73
Significant difference (between sectors)	118.093 (<0.001**)				84.980 (<0.001**)			

Kruskal Wallis Test
**Significant at level p<0.001

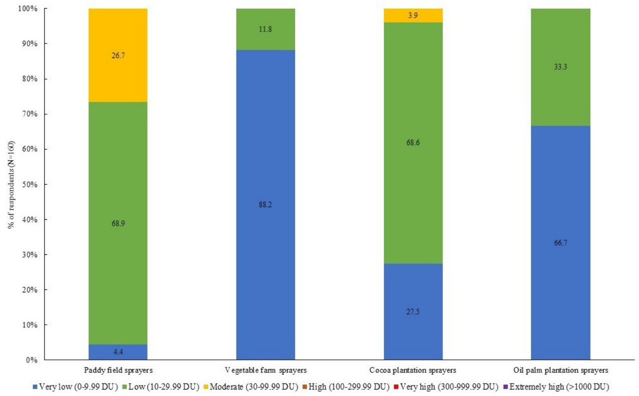

Figure 3: Categories of pesticide dermal exposure among pesticide sprayers

very low (66.7% of respondents) and low pesticide exposure (33.3% of respondents). Similarly, majority of respondents in vegetable farming have very low exposure (88.2% of respondents). None of the respondents in any agriculture sector fell in high, very high and extremely high exposure categories.

DISCUSSION

Socio-demographic characteristics

This study inclusively involved male respondents as they dominated agriculture sector in Malaysia with over 70 percent of employed persons compared to female (1). This gender bias can also be observed in several studies involving pesticide dermal exposure assessment in Malaysia and internationally, where number of male respondents were much higher than female (17,18). A majority of the pesticide sprayers in all agriculture sectors were Malaysian, in line with the percentage of citizens employed persons in agriculture sector of 62.7% (19). Most of the respondents in all other sectors received secondary education, except for half of oil palm workers, where they received primary education. Respondents were less likely to attend higher education mainly due to their involvement in family based traditional tenure of agriculture land. Nearly half of respondents earned an income of less than MYR 1000, which was the minimum monthly wage in Malaysia announced as one of the Government's policy instruments through New Economic Model (NEM). Overall, more than half of pesticide sprayers in this study were reported smoking. Pesticide exposure risk among sprayers tend to increase from unsafe working habit of smoking while working (20,21).

Type of pesticides used among respondents

WHO has issued the pesticide classification according to health hazard, ranging from unlikely to present acute hazards to extremely hazardous. Based on index classification of active ingredients by WHO (2009), we found that class II (moderately hazardous) and class III (slightly hazardous) pesticides were the most frequently used pesticides, whereas no pesticides registered as extremely hazardous (Class Ia) or highly hazardous (Class Ib) were used by the respondents (22). The formulations contain glyphosate as active ingredient were commonly used by respondents for application to all crops, due to the herbicides that provide nonselective, post emergent control of annual and perennial weeds, as well as its relative safety for humans and animals (23,24).

The most common insecticides used by pesticide sprayers in this study were lambda-cyhalothrin, chlorantraniliprole and cypermethrin. Besides, respondents also used insecticides from organophosphate class (i.e. chlorpyrifos, malathion and dimethoate). Organophosphate pesticides function by irreversibly inactivating the acetylcholinesterase, which is essential for nerve function in insects, other animals as well as human (25). Owing to this fact, organophosphate pesticides have been banned in several countries due to its toxicity (26).

Compared to neighboring countries, it is reported that about one third of the pesticides imported into Thailand in 2010 were class I and class II pesticides (27). Besides, there has been increased use of class I pesticides in Vietnam (28). This suggest that Malaysian farmers were not as exposed to class I pesticides as neighboring countries. However, efforts to minimize exposure towards class II and III pesticides should also be carried out due to its negative effects on human health and environment.

Dermal exposure estimations from DREAM

Exposure among paddy field sprayers obtained in this study was higher than exposure to 2,4-D reported in previous study which was 45.67 ± 20.33 DU (8). This may be due to several factors affecting dermal exposures such as PPE usage, spraying equipment used and environmental factors. However, the findings in this current study were comparable to DREAM estimates for insecticides spraying in grape farming, where tPDE and tADE were 153 ± 2.5 DU and 25 ± 2.8 DU, respectively (15).

One of the relevant factors contributed to significant difference in tPDE for each farming sector is the geometry and size of the target plant. The amount of pesticides contaminated sprayer's skin and clothing in this study was greatly influenced by these variables. In this study, pesticide sprayers in paddy field have more contact frequency with dense foliage of rice plants, compared to other crops. Previous quantitative study on imidacloprid application reported highest dermal exposure in the green pepper field (9.5 mg) compared to other crop fields of cucumber (3.1 mg), apple (2.9 mg) and paddy (1.7 mg), which was attributed to the greatest contact frequency with very dense foliage of green peppers (29). Difference in target plants' height can also be observed in this current study, as it influences the way of pesticide spraying and potential exposure. Generally, higher target plants may contribute to higher potential dermal exposure risk (5,30,31). For instance, vegetable farmers sprayed their vegetable cultures that were planted in a regular row of knee-high height of 0.4 to 0.7 meter and oil palm plantation sprayers carried out selective spot weeding to remove weeds from ground covers. Meanwhile, paddy field sprayers sprayed to the rice plant with mean height of about 0.9 meter. Therefore, lower potential dermal exposure among vegetable and oil palm plantation sprayers may be due to their way of spraying as they have to spray downwards, compared to paddy field sprayers which sprayed up to abdomen height to adequately cover the rice plant.

The finding was in line with quantitative study assessing dermal exposure in different maize height where the total PDE values reported were 27.8, 90.6, and 462.1 mL h−1 for pesticide applicators sprayed in 61.8 cm, 108 cm and 212 cm average maize height, respectively (32). Besides, study determined the PDE to deltamethrin among operators in maize farming with mean height of 2.0 m and broccoli of knee-high plant reported the mean PDE value for maize was 258.4 mL h-1 while for lower crop, the exposure was 139.4 mL h-1 (33). This is due to larger exposure on upper body parts of maize sprayers as they have to spray upwards and downwards about shoulder height to knee height, compared to broccoli which only sprayed downwards.

Previous study has adopted DREAM to assess dermal exposure, found that tADE for insecticides spraying in grape farming was 25 ± 2.8 DU (14). Study among paddy farmers in Kerian, Perak, Malaysia estimated dermal exposure to 2,4-D and paraquat of 45.67 ± 20.33 DU and 46.76 ± 20.07 DU, respectively (8). Meanwhile, dermal exposure (tADE) among potato farmers in the highlands of Colombia was 359.0 DU (13). Higher tADE indicates higher exposure on the skin of pesticide sprayers. Therefore, tADE was greatly influenced by level of clothing protection, determined by protective clothing usage including type of material covering the skin, protection factor of the clothing material, and the replacement frequency of particular clothing.

In this current study, high tADE among paddy sprayers can be explained by low protection in hands, which they had the lowest frequency of gloves usage compared to sprayers in other farming sectors. Moreover, inappropriate use of PPE was observed during the study such as usage of protective clothing unsuitable for prevention of exposure to pesticide droplets. The findings seem to be consistent with study reported highly inadequate usage of gloves and other PPE including goggles, coveralls, boots and mask among rice farmers in Tanjung Karang, Selangor, Malaysia (18). Furthermore, paddy field sprayers reported using gloves that were not well-connected to the clothing of their arms, especially when the gloves were not worn properly or they wore short-sleeve shirt. These may cause penetration of spray solution through seams contributing to pesticide exposure on the skin. In contrast, lower tADE among pesticide sprayers in vegetable and oil palm plantation was related to appropriate usage of gloves which well-connected to the long-sleeve shirt worn. The findings further support that inappropriate usage of gloves and other PPE will not adequately protect the sprayers' body parts (34).

Besides, it was discussed earlier that majority of paddy field sprayers did not practice frequent gloves replacement, where they reported change the gloves weekly or monthly. Previous study found that even though workers worn the gloves during work, they will no longer provide protection for the hands if it were reused for multiple times (35). Furthermore, gloves that are infrequently replaced could become a source of exposure on the hands, due to pesticide that had made their way inside the gloves from frequent removal and reuse on the contaminated hands.

CONCLUSION

It can be concluded that tPDE values between different agricultural sectors were significantly different ($p<0.001$) where the highest exposure was among paddy field sprayers (151.39 ± 22.64 DU), followed by sprayers in cocoa plantation, vegetable farm and oil palm plantation. PDE were varied between sectors influenced by several factors such as crop or weed type and height and spraying methods. Almost similar pattern of pesticide exposure level was obtained for tADE where it was largely depending on protective clothing used by the pesticide sprayers, including type of material and its protection factor, as well as the replacement frequency. Findings of this study suggest for an excessive work protection plan or awareness program to highlights the use of protection measures such as gloves, coveralls and boots, since the exposure is significant among the sprayers and influenced by many other uncontrollable factors.

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