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Original Article

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Evaluation of Dermal Exposure to the Herbicide Alachlor Among Vegetable Farmers in Thailand

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Abstract

Vegetable farmers applying the herbicide alachlor may be highly exposed through dermal contact when spraying. Dermal patches were attached to 10 locations on the farmers' skin when they mixed and applied alachlor in vegetable farming areas in Thailand. Measurements were made on farmers using either a backpack sprayer with a 2 stroke gasoline motor and fan or a battery operated pump. Forty-seven vegetable farmers in Bungphra subdistrict of Thailand participated in this study. Both motorized and battery pump backpack sprayers wearing long-sleeve shirts had significantly lower alachlor concentrations on the dermal patches under their long-sleeve shirts compared to those who wore only short-sleeve shirts, regardless of the sprayer type. Moreover, sprayers wearing long pants had significantly lower alachlor concentrations on dermal patches placed under the pants on the lower legs than those wearing short pants, regardless of the sprayer type. The highest estimated alachlor exposures were found on the upper legs (median = 9.29 μg/h) for those using a 2 stroke engine/fan backpack sprayer and on the lower legs (2.87 μg/h) for those using the battery operated pump backpack sprayer. The estimated total body alachlor exposures of applicators using the 2 stroke engine/fan backpack sprayer (219.48 μg/h) were significantly higher than those using the battery operated pump backpack sprayer (15.50 μg/h). Using long-sleeve shirts as personal protection reduced alachlor exposures for the arms 97–99% and wearing long pants reduced alachlor exposure to the legs for 81–99%. Thus, training about the protection provided by clothing choices would be one step in improving the health and safety of Thai farmers.

Keywords: Alachlor; agriculture; battery pump backpack sprayers; motorized backpack sprayers; personal protective equipment; pesticide; vegetable farmers

Introduction

In Thailand, many types of pesticides are used to protect crops and to increase yields (Panuwet *et al.*, 2012). As reported by the Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, Thailand, 78% of pesticides imported were herbicides followed by 10% fungicides and 8% insecticides in 2016 (Office of Agricultural Economics, 2016). Alachlor, an herbicide in the chloroacetanilide group, is commonly used as a pre-emergent herbicide to control grasses and broadleaf weeds on agricultural farmland (Hayes and Law, 1991). In 2016, 700,817 kg alachlor was imported into Thailand (Department of Agriculture, 2016). Alachlor was classified as B2 Carcinogen (probable human carcinogen) by United States Environmental Protection Agency (US EPA) (United States Environmental Protection Agency, 1998). Studies in animals found ataxia, muscle tremors, hyperactivity, dyspnea, lethargy, and convulsions from acute exposures. Chronic exposures in animals have produced toxicity in the liver, spleen, kidneys, iris, lung, and tumors in the lung, stomach, thyroid, and nasal turbinates (California Environmental Protection Agency, 1997; United States Environmental Protection Agency, 1998; Environmental and Occupational Health, 2003). In humans, exposures were reported to produce symptoms such as headaches, memory loss, and stammering and direct contact with alachlor was linked with skin sensitization (Bloomfield, 2017), but the research of human health effect has been limited. The incidence of cancer among alachlor applicators in the Agricultural Health Study was evaluated and found a possible association between alachlor application and incidence of lymphohematopoietic cancers (Lee *et al.*, 2004). In addition, the mean relative telomere length of alachlor applicators decreased significantly with increased life time days of alachlor use after controlling for confounding factors (Hou *et al.*, 2013).

In developing countries, farmers commonly apply pesticides with backpack sprayers that are comprised of a 2 stroke gasoline motor and fan or a battery operated pump or a manual hand pump as shown in Fig. 1. While spraying, the applicators can be exposed dermally to the equipment leaking or spray mist of pesticides. The motorized backpack sprayer uses a gasoline engine to drive a pump and a centrifugal fan. It was hypothesized that applicators who use the motorized backpack sprayers may have higher dermal exposure than those using a battery operated pump sprayers, due to the wider spray range of the motorized applicators (Bayer CropScience, 2015).

In tropical developing countries, sprayers usually do not wear proper personal protective equipment to protect themselves from pesticide exposure. This is because the personal protective equipment is expensive, the weather is hot and humid, and they may not recognize the risk of pesticide exposure through dermal contact. A study of Nicaraguan farmers using backpack sprayers found that wearing long pants provided significant protection to the legs from pesticide contamination (Blanco *et al.*, 2005). The aims of this study are to evaluate worker dermal exposures using two types of backpack sprayers and to compare the protection provided by different types of clothing.

Figure 1. Type of spraying equipment: (a) 2 stroke gasoline motor and fan, (b) a battery operated pump and (c) a manual hand pump.

Material and methods

Study population

The study took place in Bungphra subdistrict, Phitsanulok province, Thailand. We recruited 47 vegetable farmers who planted a variety of vegetables such as kale, Chinese cabbage, morning glory, coriander, spring onions, cucumber, yard long bean, and who sprayed alachlor herbicide to kill weeds on their farms. This study was approved by the Ethics Committee at Mahidol University. The vegetable farmers were interviewed about farm characteristics, planting activities, pesticide use patterns, and their health problems.

Dermal patch sampling

Cotton cloth (10 × 10 cm) was washed with deionized water and dried naturally before assembly. It was sewed on top of an aluminum foil pad (11 × 11 cm) at the edge. The aluminum foil pads were attached on the bare skin of sprayers with adhesive tape at 10 locations, including the forehead, upper back, right upper arm, left upper arm, right forearm, left forearm, right upper leg, left upper leg, right lower leg, and left lower leg as shown in Fig. 2. The cotton patches were placed under any work clothing worn by the sprayer such as long pants, long-sleeve shirts, hat, balaclava, or other cloth wrapped around the face and boots. In some cases, the cotton patches were open to the air if the sprayer wore a short-sleeve shirt, short pants, no head/face covering or no boots. The researcher observed the process of mixing and spraying of alachlor and recorded the personal protective equipment and clothing worn as well as the type of backpack spraying used. After spraying, the researcher, wearing latex gloves, collected the patch samples using forceps, and placed each in a capped amber glass bottle which was stored in a bio freezer at −45°C till analysis.

Analysis of dermal patch samples

Chemical reagents

Alachlor and dimethachlor (internal standard) were obtained from Sigma-Aldrich (Singapore). Hexane (AR grade) and acetone (AR grade) were purchased from Merck (Germany). Ultrapure water was obtained from a Milli-Q system (Millipore, Bedford, MA, USA).

Analysis of dermal patch samples

The analysis method for alachlor on dermal patches was modified from Sanderson *et al.* (Sanderson *et al.*, 1995); they extracted alachlor from gauze patches using hexane with 81% recovery. In this study, we extracted the cotton patches with hexane and acetone (1:1 by volume) and used dimethachlor as an internal standard.

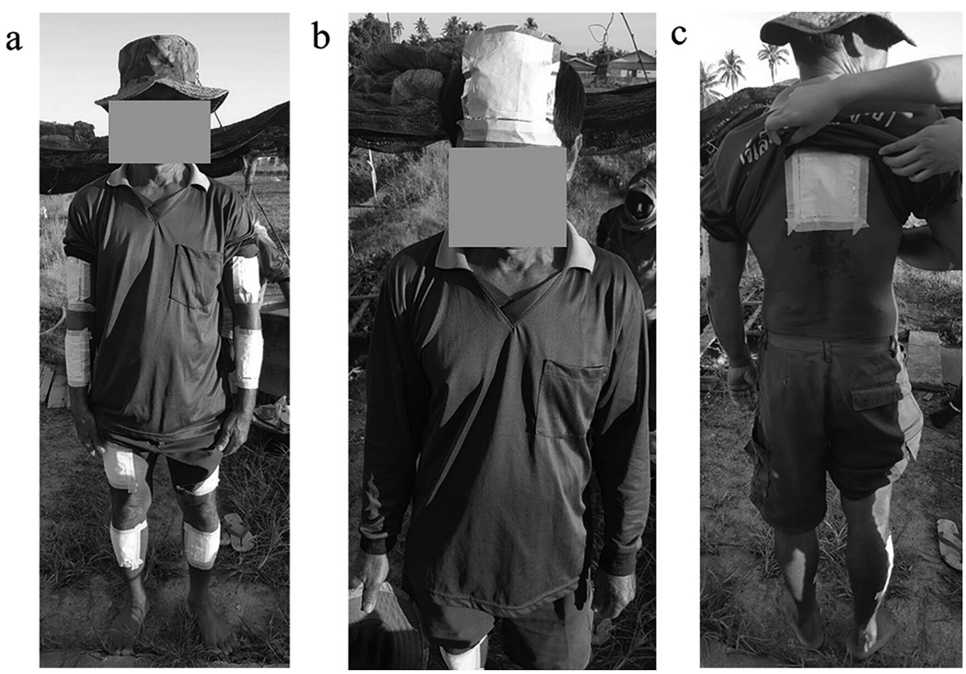

Figure 2. The cotton patches were placed on bare skin of subjects at 10 locations, right and left upper arms, forearms, upper legs, and lower legs in 2a, forehead in 2b, and back in 2c.

The calibration curve of alachlor was set up at 0.0125, 0.025, 0.05, 0.125, 0.25, 0.5, 1.0, 1.5, and 2.0 µg/ml in hexane and acetone (1:1) with dimethachlor (1 µg/ml) as internal standard. Linear calibration curve was found between peak area ratio of alachlor/internal standard and alachlor concentrations with correlation coefficient (r^2) of 0.999. The detection limit (LOD) of alachlor was 2 ng/ml. The recoveries of alachlor concentrations were ranged from 93.3 to 99.7% with relative standard deviation (RSD) of less than 3 at alachlor concentrations of 0.5 to 1.5 µg/ml, respectively. This was an improvement in recovery to that reported by Sanderson *et al.* (1995) of 81%.

The cotton patches were placed in a screw cap tube with 10 ml hexane: acetone (50:50), sealed with parafilm, and then sonicated in an ultrasonic bath for 20 min. One milliliter of extracted solution and 20 µl of internal standard (50 µg/ml of dimethachlor) were placed in a 2-ml amber auto-sampler vial and analyzed by an Agilent 7890A gas chromatography (GC) equipped with an Agilent 5975C mass spectrometer (MS). The GC/MS conditions were as follows: HP-5MS column (30 m × 250 µm i.d.), splitless injection, the inlet temperature of 280°C. The temperature of the column was initiated at 50°C for 1 min, then raised at 10°C/min to 200°C, 3°C/min to final temperature at 230°C, and postrun at 280°C for 4 min. The electron multiplier voltage was set at 70 eV relative to the standard autotune and the data were acquired in the selected ion monitoring (SIM) mode. Helium was used as a carrier gas at a flow rate of 1.0 ml/min with a run time of 30 min. The retention times of alachlor and dimethachlor were 19.9 and 19.4 min, respectively. The quantitation ions were 160, 188, and 269 for alachlor and 134 and 197 for dimethachlor (Internal standard).

The concentration of alachlor on each patch sample (µg/h) was calculated following the United States Environmental Protection Agency guidelines (United States Environmental Protection Agency, 2009). First, the alachlor concentration found on the dermal patch (µg) was divided by the patch area (100 cm^2) and the spraying duration (hours). Then, the dermal patch concentration (µg/cm^2/h) was multiplied by the standard adult body surface area (Fig. 3) (United States Environmental Protection Agency, 2009) to obtain dermal contact exposure as µg/h. The calculation was done for each patch area individually. The individual dermal area concentrations were then summed to obtain the total dermal exposure (µg/h). We did not collect exposure on the chest of subject because subjects felt uncomfortable removing their shirts, and some of the subjects were women.

Data analysis

The data analysis was performed using SPSS (version 18; PASW Statistics Base 18). Descriptive statistics were used to summarize and describe the alachlor concentrations. Alachlor

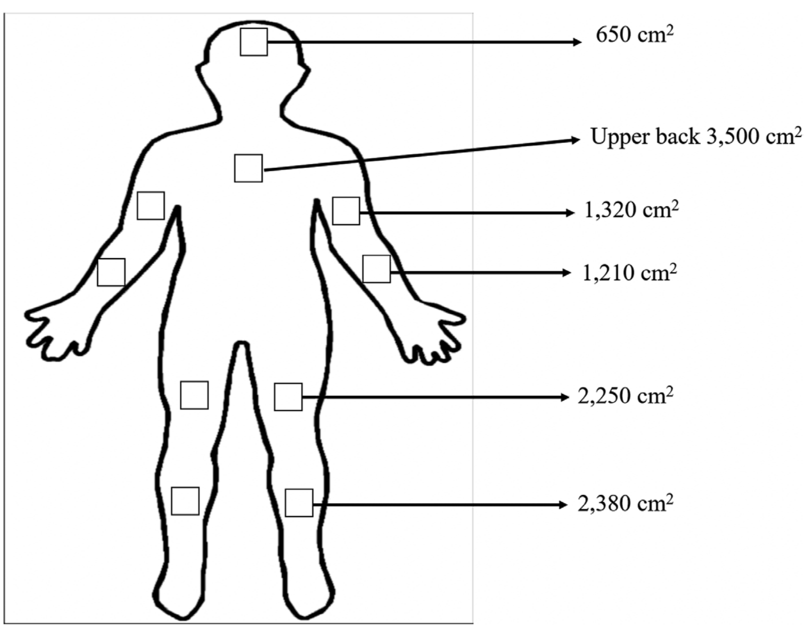

Figure 3. Standard adult body surface areas at forehead, upper backs, right and left forearms, upper arms, upper legs, and lower legs (United States Environmental Protection Agency, 2009).

concentrations on the cotton patches were more log-normally than normally distributed. Therefore, a non-parametric test (Mann–Whitney *U*-test) was used to compare the exposures of motorized backpack sprayers and battery pump backpack sprayers. In addition, linear regression using the log of the patch alachlor concentrations was used to evaluate the factors influencing the sprayers' exposure to alachlor.

RESULTS

Characteristics of sprayers

Of the 47 vegetable farmers who participated in this study, the most common method of applying alachlor herbicide was the use of a 2 stroke gasoline engine/fan (motorized) backpack sprayer (48.9%, n = 23), followed by battery operated pump backpack sprayer (36.2%, n = 17). Less commonly used were a manual pump backpack sprayer (8.5%, n = 4) and a high-pressure pump sprayer, which uses a tank car with compressor and a long hose (6.4%, n = 3). The median total dermal exposure concentrations of manual pump backpack sprayers and high-pressure pump sprayers were 20.51 and 17.23 µg/h, respectively. These exposure levels were similar to the battery pump backpack sprayer. However, the applicators using motorized backpack sprayers had significantly (P = 0.008) higher median total dermal exposure concentrations of 219.48 µg/h compared to the battery pump backpack sprayers (15.50 µg/h). Due to the small numbers for the manual pump and high-pressure pump the remainder of this paper focuses on understanding the factors that might explain the differences in dermal exposures between the motorized and battery pump backpack sprayers.

Significantly more motorized backpack sprayers were male (91.3%), than battery backpack sprayers (53%) (P = 0.009). However, there were no significant differences between the groups in age, education, farm ownership, financial condition, smoking, work clothing, and alcohol consumption (Table 1).

Both motorized and battery pump backpack sprayers have been working in the agricultural fields for many years (15–41) and using pesticides for many years (10–36) and there were no significant differences between these groups. However, with regard to mixing and spraying alachlor, the volume of alachlor (median 40 l versus 26 l) and the farm area sprayed (median 0.16 hectare versus 0.08 hectare) were significantly higher for the motorized backpack sprayers. Since the amount of time spent spraying was not significantly different, this suggests that the rate of application and therefore the air concentration during spraying is likely different between these two groups (Table 1).

Dermal exposure to alachlor

Dermal exposure was determined when applicators mixed and sprayed alachlor. For the arms, the work clothing worn by motorized and battery pump backpack sprayers was found to reduce alachlor exposures (Fig. 4). The motorized backpack sprayers wearing long-sleeve shirts had significantly lower median alachlor concentrations (10.45 versus 1.49 µg/h) for both upper arms compared to those with short-sleeve shirts (P = 0.047). For battery pump backpack sprayer group, no significant difference was found for median alachlor concentration for the upper arms. However, for the forearms, the motorized backpack sprayers wearing long-sleeve shirts had significantly lower alachlor concentrations on both forearms than those with short-sleeve shirts (291.52 versus 1.69 µg/h; P = 0.004). The battery pump backpack sprayers wearing long-sleeve shirts also had significantly lower alachlor concentrations on both forearms than those with short-sleeve shirts (22.36 versus 0.21 µg/h; P = 0.029). There was no significant difference between use of a balaclava or not for either type of spraying machine (Fig. 4).

For the upper legs, there was no significant difference in median alachlor dermal exposure for the upper legs by pant type for either type of spraying equipment because both short and long pants cover the thigh. For the lower legs, the motorized backpack sprayers wearing long pants had significantly lower alachlor concentrations than those wearing short pants (899.1 versus 5.6 µg/h; P = 0.037). In addition, the battery pump backpack sprayers wearing long pants also had significantly lower alachlor concentrations than those wearing short pants (43.42 versus 1.34 µg/h; P = 0.011). No statistically significant difference in median alachlor concentrations was found for sprayers wearing boots or not for either type of backpack sprayer (Fig. 5). However, the boots covered the patches on the lower legs, and therefore wearing boots was often done in conjunction with long pants which were found to reduce the exposure of the lower legs.

Wearing work clothing can decrease dermal alachlor exposure for both the arms and legs for both motorized and battery pump backpack spray types (Table 2), because the forearm exposure was decreased over 99%, when wearing a long-sleeve shirt. The total alachlor exposure of the arms of applicators using motorized and battery pump backpack sprayers were decreased by 99.2 and 97.0%, respectively. The lower leg exposure of applicators wearing long pants was decreased by 97.0–99.4% and the total alachlor dermal exposure of the legs of applicators using motorized and battery pump backpack sprayers was decreased by 99.2 and 81.3%, respectively.

Table 1. Characteristics of vegetable farmers comparing motorized backpack sprayers and battery pump backpack sprayers.

Parameter	Motorized backpack sprayers (n = 23)	Battery pump backpack sprayers (n = 17)	P-value
Gender, n (%)			
Male	21 (91.3)	9 (52.9)	0.009*
Female	2 (8.7)	8 (47.1)	
Age, mean (SD)	49.70 (7.39)	51.24 (11.43)	0.528
Education level, n (%)			
Primary school	15 (65.2)	12 (70.6)	0.583
Secondary school	7 (30.4)	3 (17.7)	
High vocational certificate	1 (4.3)	1 (5.9)	
Bachelor degree or over	-	1 (5.9)	
Own farmland, n (%)	22 (55)	17 (42.5)	1.000
Level of income sufficiency, n (%)			
Sufficient with savings	9 (39.1)	5 (29.4)	0.875
Sufficient without savings	8 (34.8)	8 (47.1)	
Not sufficient without debt	1 (4.3)	-	
Not sufficient with debt	5 (21.7)	4 (23.5)	
Tobacco consumption, n (%)			
Never	15 (65.2)	12 (70.6)	0.520
Past	1 (4.3)	2 (11.8)	
Current	7 (30.4)	3 (17.6)	
Alcohol consumption, n (%)			
Never	6 (26.1)	8 (47.1)	0.480
Past	2 (8.7)	1 (5.9)	
Current	15 (65.2)	8 (47.1)	
Working in agricultural field, mean (range) (years)	20.0 (15.0–35.0)	34.0 (19.5–41.0)	0.096
Using pesticides, mean (range) (years)	20.0 (10.0–35.0)	23.00 (10.50–36.00)	0.941
Process of mixing and spraying alachlor, mean (range)			
Alachlor volume used (l)	0.40 (0.23–0.60)	0.30 (0.15–0.40)	0.088
Volume sprayed (l)	40.0 (26.0–60.0)	26.0 (17.5–45.0)	0.025*
Number of tanks sprayed	2.0 (1.5–3.0)	2.0 (1.0–2.0)	0.081
Duration sprayed (min)	32.0 (27.0–50.0)	29.0 (16.0–50.0)	0.411
Farm area sprayed (hectare)	0.16 (0.08–0.24)	0.08 (0.05–0.13)	0.047*
Work clothing, n (%)			
Cloth mask	6 (26.1)	-	-
Disposable mask	-	1 (5.9)	-
Balaclava	17 (73.9)	10 (58.8)	0.314
Long-sleeve shirt	21 (91.3)	15 (88.2)	1.000
Short-sleeve shirt	2 (8.7)	2 (11.8)	1.000
Long pants	17 (73.9)	13 (76.5)	1.000
Short pants	6 (26.1)	4 (23.5)	1.000
Goggles	1 (4.3)	-	-
Latex gloves	2 (8.7)	3 (17.6)	0.634
Boots	12 (52.2)	9 (52.9)	0.962
Plastic apron	3 (13.0)	-	-

P-values were calculated using χ^2 test and the Mann–Whitney U-test.
*P-value < 0.05.

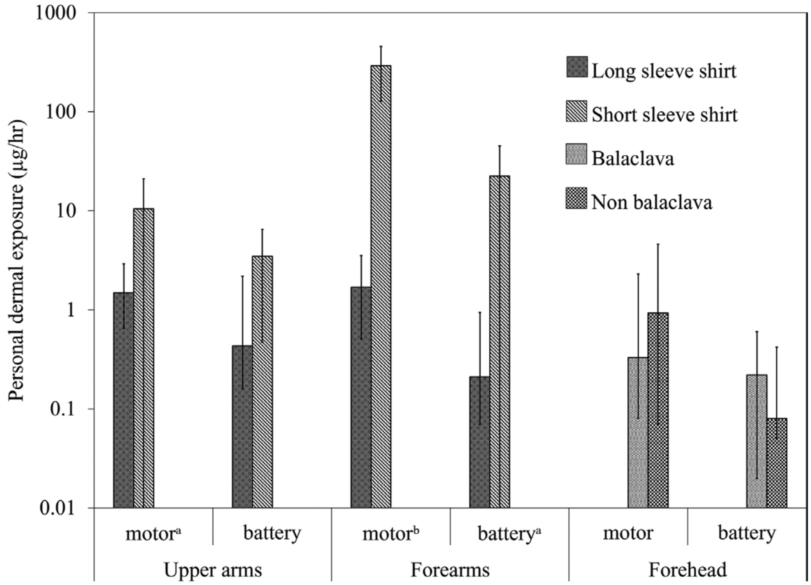

Figure 4. Comparison of alachlor dermal exposure (median and IQR, µg/h) on the upper parts of the body with and without clothing worn as personal protective equipment by backpack sprayer type (2 stroke gasoline motor/fan versus battery pump). If number of samples is two, we used mean and standard deviation. *Significant difference using the Mann–Whitney *U*-test. [a]*P*-value < 0.05, [b]*P*-value < 0.01.

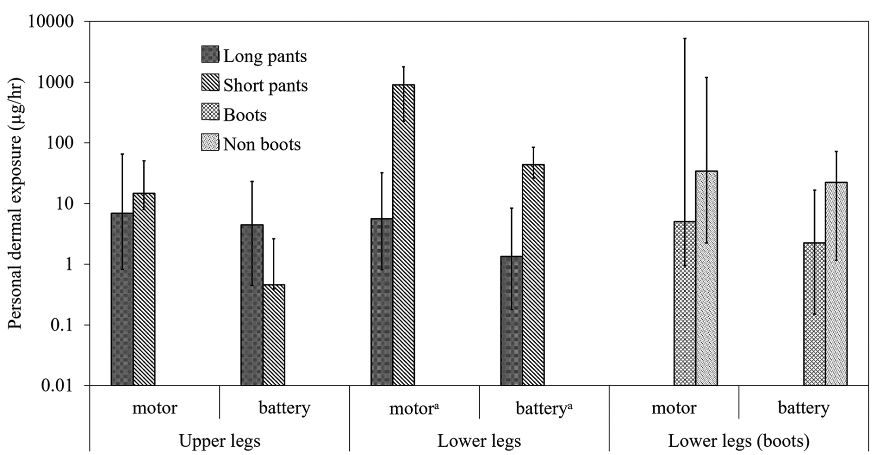

Figure 5. Comparison of alachlor dermal exposure (median and IQR, µg/h) on the lower parts of the body with and without clothing worn as personal protective equipment by backpack sprayer type (2 stroke gasoline motor/fan versus battery pump). *Significant difference using the Mann–Whitney *U*-test. [a]*P*-value < 0.05.

The total median alachlor exposure concentration of motorized backpack sprayers (219.48 µg/h) was significantly higher than that of battery pump backpack sprayers (15.50 µg/h) ($P = 0.008$) (Fig. 6 and Table 3). There were significant differences in median alachlor exposure between the motorized and battery pump backpack sprayers at many body locations including forearms (1.86 versus 0.34 µg/h), upper legs (9.29 versus 2.72 µg/h), and back (6.42 versus 0.25 µg/h) ($P = 0.030$, 0.031, and 0.002), respectively (Fig. 6 and Table 3). For motorized backpack sprayers, the highest median alachlor exposure was at the upper legs (9.29 µg/h), followed by lower legs (7.27 µg/h) and back (6.42 µg/h). For battery pump backpack sprayers, the highest median alachlor exposure was also at the lower legs (2.87 µg/h), followed by the upper legs (2.72 µg/h) and upper arms (0.46 µg/h).

Table 2. Impact of different clothing as personal protective equipment to reduce median alachlor dermal exposures while spraying.

Location of attached dermal patches	Personal protective equipment worn	Median (IQR) (μg/h)		Reduction (%)	
		Motorized backpack sprayer	Battery pump backpack sprayer	Motorized backpack sprayer	Battery pump backpack sprayer
Arms					
Total upper arms	Long-sleeve shirt	1.5 (0.7–2.9)	0.4 (0.2–2.2)	88.2	87.6
	Short-sleeve shirt	10.5 (14.9)*	3.5 (4.3)*		
Total forearms	Long-sleeve shirt	1.7 (0.5–3.5)	0.2 (0.1–0.9)	99.4	99.1
	Short-sleeve shirt	291.5 (231.5)	22.4 (32.0)		
Total arms	Long-sleeve shirt	2.50 (1.1–7.0)	0.8 (0.3–4.8)	99.2	97.0
	Short-sleeve shirt	302.0 (246.4)	25.8 (27.7)		
Legs					
Total lower legs	Long pants	5.6 (0.8–32.0)	1.3 (0.2–8.4)	99.4	97.0
	Short pants	899.1 (226.2–1786.8)	43.4 (26.0–84.0)		
Total legs	Long pants	8.0 (4.4–83.0)	8.5 (1.1–30.8)	99.2	81.3
	Short pants	972.3 (243.0–1798.5)	45.3 (27.2–84.4)		

*If $n = 2$ used mean and range.
% Reduction = [1 − (long/short)] × 100.

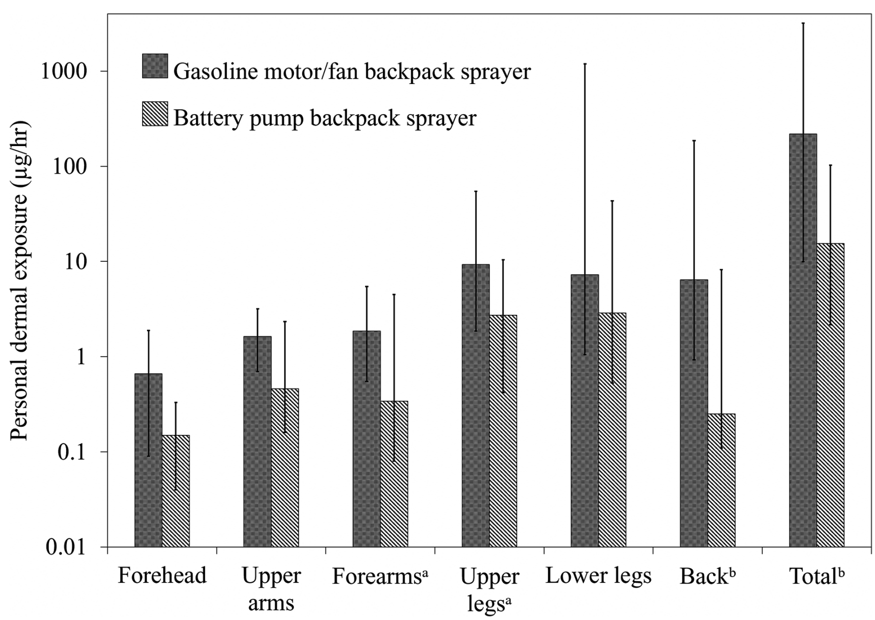

Figure 6. Comparison of personal alachlor dermal exposure (median and IQR, μg/h) at different body locations by backpack sprayer type (2 stroke gasoline motor/fan versus battery pump). *Indicates significant difference using the Mann–Whitney *U*-test. [a]*P*-value <0.05, [b]*P*-value < 0.01.

A multiple linear regression model was performed to predict the log(e) of total dermal exposure concentration (μg/h) using demographic, working condition, and work clothing factors that were significant in univariate models. Only using battery pump spraying equipment versus motorized sprayer (1/0) and wearing long pants versus short pants (1/0) were significant predictors of total dermal exposure concentration in the univariate models. When put in a multivariate model, they both remained significant and the interaction effect was non-significant.

Table 3. Comparison of personal alachlor dermal exposure (median and IQR, µg/h) at different body locations by backpack sprayer type (2 stroke gasoline motor/fan versus battery pump).

Exposed areas	Motorized backpack sprayers (*n* = 23)	Battery pump backpack sprayers (*n* = 17)	*P*-value
	Median (IQR) µg/h	Median (IQR) µg/h	
Forehead	0.66 (0.09–1.88)	0.15 (0.04–0.33)	0.057
Arms			
Left forearms	0.47 (0.20–3.55)	0.10 (0.04–0.82)	0.024*
Right forearms	1.12 (0.27–2.07)	0.10 (0.04–2.15)	0.028*
Total forearms	1.86 (0.55–5.45)	0.34 (0.08–4.51)	0.030*
Left upper arms	0.91 (0.32–1.87)	0.11 (0.05–1.36)	0.013*
Right upper arms	0.57 (0.12–2.08)	0.24 (0.04–0.65)	0.021*
Total upper arms	1.63 (0.70–3.18)	0.46 (0.16–2.33)	0.061
Legs			
Left upper legs	3.55 (0.52–6.92)	0.46 (0.16–2.38)	0.030*
Right upper legs	4.79 (0.61–14.87)	1.02 (0.21–7.44)	0.063
Total upper legs	9.29 (1.85–54.79)	2.72 (0.42–10.41)	0.031*
Left lower legs	3.42 (0.41–311.62)	1.46 (0.14–8.24)	0.116
Right lower legs	5.46 (0.64–297.90)	2.29 (0.35–34.36)	0.091
Total lower legs	7.27 (1.05–1188.71)	2.87 (0.53–43.42)	0.078
Backs	6.42 (0.93–186.60)	0.25 (0.11–8.22)	0.002**
Total dermal exposure	219.48 (9.99–3,193.34)	15.50 (2.16–102.82)	0.008**

P-values were calculated using the Mann–Whiney *U*-test.
**P*-value <0.05, ***P*-value < 0.01.

The R^2 of model was 0.35 (Table 4) and showed that use of battery pump resulted in a reduction of 91% in the total dermal exposure concentration, while use of long pants resulted in a reduction of 94% in the total body dermal exposure concentration. Together, they resulted in a reduction of 99% in the total body dermal exposure concentration to a geometric mean concentration of 8.76 µg/h.

Table 4. Multivariable linear model for exposure determinants of log(e) of total dermal alachlor exposure concentration (µg/h) among Thai vegetable farmers.

Variables	β	R^2	*P*-value
Model		0.352	<0.001
Constant	7.37		<0.001
Battery Pump sprayer versus motorized sprayer (1/0)	−2.38		0.004
Long pants versus short pants (1/0)	−2.82		0.003

Discussion

Considering total dermal exposure, motorized backpack sprayers had the highest median dermal exposure, followed by manual pump backpack sprayers, high-pressure pump sprayers, and battery pump backpack sprayers. The manual pump and high-pressure pump sprayers were rarely used in this population, but should be investigated in the future. High-pressure pump sprayers are expensive, difficult to use, need assistance from family members due to the huge mixing tank, compressor, and very long hose. The advantage of the high-pressure pump sprayer is it is more feasible to use on large agricultural areas. The manual backpack sprayers are convenient for a very small agricultural area, because they have a small tank (10–20 l) and are light weight, but the sprayer has to control the speed of spraying by themselves.

Most applicators in this study were men who did many activities on the farm such as driving a tractor, tillage, applying chemical fertilizer and pesticides. On the other hand, women were more likely to do farm activities such as sowing, hand picking pests, watering, and harvesting. Men in this study mixed and sprayed alachlor more often than did women (75 versus 25%). Other studies have also found that men had more responsibility for planting and pesticide application than women, whereas women did more household work, taking care of children, elderly and disabled (Wang *et al*., 2017). In this study, more men used motorized backpack sprayers (91.3%) than women (8.7%), but there was little gender difference for the battery powered backpack sprayers (52.9% men and 47.1% women).

For motorized backpack sprayers, the highest median alachlor exposure was at the combined upper legs (9.29 µg/h), followed by the combined lower legs (7.27 µg/h) and back (6.42 µg/h); these values were irrespective of wearing short or long pants. For battery pump backpack sprayers, the highest median alachlor exposure was also at the combined lower legs (2.87 µg/h), followed by the combined upper legs (2.72 µg/h) and combined upper arms (0.46 µg/h); these values were irrespective of wearing short or long-sleeve shirts and short or long pants. This study revealed that motorized backpack sprayers had significantly higher dermal exposures than those using battery pump backpack sprayers. Applicators using backpack sprayers may be exposed to higher alachlor concentrations for several reasons: (i) motorized backpack sprayers applied more alachlor volume (l) to more area (hectares) over the same median spray time; so, it is likely that airborne concentrations were higher; (ii) the high speed airstream produced by the centrifugal fan of the motorized backpack sprayer results in a cloud of sprayed droplets that can have a 12–15 m horizontal range and up to 10 m vertical range. On the other hand, the horizontal spraying range of a battery operated pump sprayer is only 1–2 m wide (Bayer CropScience, 2015); (iii) the vibration and older age of many backpack sprayers may have contributed to more spillage onto the back (and therefore the higher dermal exposures on the back for motorized sprayers).

Since the rates of clothing use as personal protective equipment were similar, that is not a likely explanation for the higher dermal exposures of motorized backpack sprayers. Most of the applicators whether they used a motorized or battery operated sprayer wore long-sleeve shirts (91 and 88%, respectively), long pants (74 and 77%, respectively), and boots (52 and 53%, respectively). Thai farmers showed higher use of long-sleeve shirts than workers spraying pesticides in the vineyards in France, 35% of whom had bare forearms, but both groups were similar in terms of leg exposure (27% of French farmers had bare lower legs versus 25% of Thai farmers) (Baldi *et al.*, 2006). Agricultural workers in the Ahmednagar district of India reported higher use of 'a cloth on face' (81%), gloves (67%), and fewer with bare feet (35%)(Singh and Gupta, 2009). Personal protective equipment designed for chemical exposure protection was rarely used by the Indian applicators, such as goggles (2%), disposable mask (2%), cloth mask (15%), gloves (12%), and plastic apron (2%). A study of maize farmers in Northern Thailand found that they did not use gloves, mask, and goggles when they applied herbicide. Moreover, some of them used a wool hat as a replacement for mask and goggles (Wongwichit *et al.*, 2012). Another study on small-scale farmers in rural Phitsanulok in northern Thailand reported that the farmers mostly used mouth and nose cover (64.2%) following by gloves (41.5%), boots, and long-sleeve shirts (21.1%), respectively (Plianbangchang *et al.*, 2009).

Using work clothing to cover the body could reduce dermal alachlor exposure among pesticide applicators. Sprayers in this study mostly wore work clothing made of cotton or cotton mixed with polyester. Long-sleeve shirts reduced exposures by over 99% at the forearms regardless of backpack sprayer type. Wearing long pants reduced alachlor exposure for the lower legs 97–99%. However, a comparison of the penetration between cotton clothing and protective Tyvek coveralls found that the penetration factor of cotton clothing was ranged from 11.2 to 26.8%, whereas the Tyvek penetration factor was less than 2.4%. (Vitali *et al.*, 2009). Similar findings were reported by Aprea *et al.*, 2005. To prevent dermal exposure, protective clothing should be made of non-woven fabrics because these clothing provide more protection, have good air permeability, and high water vapor permeation (Kim *et al.*, 2015). However, the cost and availability of such clothing makes it currently an impractical recommendation for most farmers in Thailand.

The multiple linear regression model revealed that the choice of spraying equipment and wearing long pants had a significant impact on total dermal exposure rate. Wearing long-sleeve shirts was not significant in the total dermal exposure model, because the arms contribute less to the total exposure than the legs (Fig. 6). The multiple regression model showed that using long pants decreased total body dermal exposure by 94%. Culumpang and colleagues also found that pesticide (parathion-methyl) exposures were decreased 96–98% when the farmers wore a long-sleeved cotton polyester shirt and thick polyester long trousers (Calumpang, 1996). One concern in recommending use of clothing to reduce pesticide exposures is possible contamination when changing clothing and possible contamination when using it again without washing (Schneider *et al.*, 1999). Alternatively, washing contaminated clothing with other family clothes could transfer that contamination to other family members including children (Issa *et al.*, 2010).

Conclusion

This study shows that to reduce dermal exposures to alachlor and other pesticides, farmers should use battery pump backpack sprayers, check the sprayers before use to minimize leakage onto the back and at a minimum wear long-sleeve shirts and pants when spraying. Ideally, farmers should be provided information about the potential health hazards of herbicides and the benefits of wearing clothing for protection from exposure. Moreover, herbicide suppliers should provide an informational leaflet together with the herbicide to inform the user about the hazards and precautions to take during use and when donning and doffing of contaminated clothing to prevent skin contamination.

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