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Paraquat exposure of backpack sprayers in agricultural area in Thailand

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Abstract

Thai agriculturists heavily used paraquat in agricultural areas to control weed and grasses. This study determined paraquat exposure among backpack sprayers in Thailand and identified determinants of occupational exposure. Breathing zone air and dermal samples were collected from 57 backpack sprayers while spraying. Spot urine samples were collected on the day before spraying, end of spraying event and the next day after spraying. The subjects were interviewed about general demographics, agricultural activities, pesticide application and personal protective equipment used while applying paraquat. Paraquat concentrations in urine samples, air samples and dermal samples were determined by HPLC with a fluorescence detector. The median IQR of urinary paraquat concentrations on the day before spraying, end of spraying event, the next day after spraying were 2.51 (0.81–5.59), 8.23 (3.3–13.73) and 3.48 (1.03–8.19) μg/g creatinine, respectively. Concentrations of air samples and total dermal exposures were 5.15 (2.28–10.12) $\mu g/m^3$and 92.66 (34.37–1647.46) μg/hr, respectively. Use of battery powered backpack sprayer and standing upwind effectively reduced inhalation exposures. Wearing a long sleeve shirt, long pants, boots, latex gloves and balaclava could reduce paraquat concentration on dermal exposure among backpack sprayers.

Keywords

Paraquat; agriculture; inhalation exposure; dermal exposure; Thailand

Introduction

In Thailand, 47% of the land is used for agriculture (National Statistical Office 2016) and 32% of Thais work in agriculture (National Statistical Office 2019). Farmers frequently use

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many pesticides to protect their crops and increase product quality. In 2018, glyphosate, followed by paraquat dichloride, were herbicides imported to Thailand in the largest volumes (Department of agriculture, 2019). Paraquat or gramoxone (1, 1-dimethyl-4, 4-bipyridylium, PQ), is a quaternary ammonium compound. It is a nonselective contact broad-spectrum herbicide used for controlling broad leaf weeds and grasses in agricultural areas such as fruit, rice and vegetable farms, most often in preparation for planting (Krieger 2001; Watts 2011).

In humans, paraquat can enter the body through ingestion, dermal absorption, and inhalation (Watts 2011). In general, Thai farmers use backpack sprayers consisting of a battery backpack sprayer or a motorized backpack sprayer for spraying paraquat in agricultural areas. The sprayers can be exposed dermally during mixing, to the mist of pesticides while spraying or to leakage from the tank of the backpack sprayer during use. Study of dermal exposure to the herbicide among vegetable farmers in Thailand found that vegetable farmers using a two-stroke engine/fan backpack sprayer had higher total body alachlor exposure than those using a battery backpack sprayer (Mahaboonpeeti et al. 2018).

One study of paraquat exposure among backpack sprayers in Costa Rican banana plantations found that the sprayers had health problems such as burning eyes from splashes, nosebleeds, blistering and burns on thighs, hands, testicles, legs and back (Van et al. 1996). Paraquat can affect the central nervous system (CNS) damaging dopaminergic neurons with cell bodies in the substantia nigra, causing neurobehavioral syndrome (Brooks et al. 1999). Paraquat exposure has also been associated with Parkinson’s disease (McCormack et al. 2002; Landrigan et al. 2005; Dinis-Oliveira et al. 2006).

Occupational paraquat exposure assessments have been conducted among sprayers in several countries (Swan 1969; Chester and Woollen 1982; Chester et al. 1993; Van et al. 1996; Lee et al. 2009). However, little has been done in Thailand (Howard 1982; Wongwichit 2010). The objective of this study was to assess paraquat exposure by measuring air samples and dermal samples during spraying event and urinary biomarkers were assessed before spraying day, after spraying event and after spraying day.

Materials and methods

Study population

The subjects were 57 agriculturists who grew several plants such as sugarcane, maize, cassava and rice in Nakhon Sawan province, Thailand and the samples were selected by purposive sampling technique. The subjects were recruited by health promoting hospitals, public health volunteers, provincial public health officers and the local site officer along with a community leader from 2017 to 2018. The site officer visited farmers at their home for recruitment the subjects. One farmer who sprayed paraquat was selected in each household. Inclusion criteria included male or female farmers over 18 years old who sprayed paraquat to kill weeds and had farm work experience of at least one year. Subjects were interviewed to collect general demographics as well as information about agricultural activities, pesticide application and personal protective equipment (PPE) used while working with pesticides.

Data collection

Air sampling—The air sampling method followed the US National Institute of Occupational Safety and Health (NIOSH) 5003 method (NIOSH, 1994) to collect a breathing zone air sample while spraying. The air sampling pump (2 L/min) was connected to a closed two-piece cassette containing 1-μm PTFE membrane filter. After the end of sampling, the cassettes were stored in Ziploc bags at −30 °C until analyzing. The air sampling pump was calibrated at pre and post sampling with a primary calibrator.

Dermal sampling—Dermal exposure was determined using a patch sampling technique. Cotton patches (10 cm × 10 cm) were backed with aluminum foil (11 cm × 11 cm) to prevent contaminating patches. These patches were attached to the skin of backpack sprayers at 11 locations before spraying paraquat (forehead, chest, back, right forearm, left forearm, right upper arm, left upper arm, right thigh, left thigh, right lower leg and left lower leg). After the end of the spraying, the patch samples were immediately placed in plastic bottles. All patch samples were stored at −30 °C until analyzing.

Urine sampling

Spot urine samples were collected the first morning void urine the day before spraying, the end of the spraying event and at first morning void urine the day after spraying. Spot urine samples were collected in 30 ml plastic bottles and stored at −30 °C until analyzing.

Analysis of samples

Air samples—Air samples and field blanks were prepared following the Method 5003 (NIOSH, 1994) and oxidation procedure modification from Tsuchihashi et al. (Tsuchihashi et al. 1988) and Blake et al. (Blake et al. 2002). Air sample filters were transferred to a screwed cap tube and spiked with 50 μl of ethyl viologen (internal standard) at a concentration of 40 μg/ml. After that, 5 ml of de-ionized water was added to each tube and after gentle hand mixing, the sample was sonicated in an ultrasonic bath for 30 min. Three milliliters of the extract solution was placed in a 15 ml centrifuge tube and analyzed using the reported procedure of Konthonbut et al. (Konthonbut et al. 2018). The calibration curve for paraquat was prepared at concentrations of 25,50,100,200,400 ng/ml. The average recovery of paraquat 96.8 to 99.6% at paraquat concentrations of 50 and 200 ng/ml. The coefficients of variation ranged from 1.35 to 5.51% and the detection limit of paraquat in the filter was 5 ng.

Dermal samples—The samples were prepared and the oxidation procedures were modified from Tsuchihashi et al. (Tsuchihashi et al. 1988) and Blake et al. (Blake et al. 2002) with some modification from Mahbub et al. (Mahbub et al. 2010). A Cotton patch was transferred to a 50 ml centrifuge tube. After that, 10 ml of acidic aqueous solvent (0.01 N HCl) was added to each tube and mixed; the sample was sonicated in an ultrasonic bath for 30 min. Three milliliters of the extract solution was placed in a 15 ml centrifuge tube and spiked with 50 μl of ethyl viologen (internal standard) at a concentration of 24 μg/ml and analyzed using the procedure of Konthonbut et al. (Konthonbut et al. 2018). The calibration curve for paraquat was prepared at concentrations of 25, 50, 100, 200 and 400 ng/ml. The average recovery of paraquat 90.4 to 97.2%at paraquat concentrations of 50 and 200 ng/ml.

The between-day assay coefficients of variation ranged from 0.6 to 2.5%. The detection limit of paraquat in dermal samples was 10 ng.

Paraquat concentration of cotton patch samples (μg/hr) was calculated following the US Environmental Protection Agency guidelines (USEPA, 2009). Exposure time (hr) was used to correct dermal exposure calculation (μg/hr). The concentration of paraquat on cotton patch samples was expressed as micrograms of paraquat per square centimeter (100 cm^2) of exposure pad per hour of exposure. After that, the dermal patch concentration (μg/cm^2/hr) was multiplied by the adult body surface areas (USEPA, 2009) to obtain dermal contact exposure as μg/hr. The estimated total dermal exposure was calculated by summing the μg/hr levels for the 11 dermal pad samples taken on each individual.

Urine samples—Urinary paraquat concentrations were analyzed following the modified method of Tsuchihashi et al. (Tsuchihashi et al. 1988) and Blake et al. (Blake et al 2002). The method to analyze paraquat in urine was reported in the study of Konthonbut et al. (Konthonbut et al. 2018). The quality control urine samples containing paraquat (30 and 80 ng/ml) were analyzed together with urine samples. The limit of detection (LOD) of the method was 1 ng/ml.

Data analysis

The data analysis was conducted using SPSS for Window, Version 23 (IBM Thailand Co., Ltd., Bangkok, Thailand). Demographic characteristics, information of cultivation and paraquat use on spraying day and urinary paraquat concentration were described using descriptive statistics. Urinary paraquat concentrations, breathing zone paraquat concentrations and dermal patch samples were reported as the median and the interquartile range (IQR). Due to the high proportion of samples, less than the limit of detection (LOD) resulted in a nonlognormal distribution. For concentrations below the detection limit, we substituted the detection limit by dividing the detection with $\sqrt{2}$ for GSD < 3 or the detection limit divided by two for GSD > 3. Spearman's correlation was used to test the relationship between urinary paraquat concentration and breathing zone paraquat and total dermal paraquat concentration. The Mann–Whitney U-test was used to compare paraquat dermal exposure (median and IQR, μg/hr) at different body locations by two backpack sprayer types (Two-stroke gasoline motor/fan vs. battery pump). To compare urinary paraquat concentrations at the end of the spraying event and the day before spraying, Wilcoxon Signed-Rank test. Linear regression was used to investigate the factors influencing the log(e) of the breathing zone air concentration while spraying using demographics, working conditions and use of PPE

Results

Characteristics of 57 conventional farmers

The characteristics of the 57 conventional farmers are shown in Table 1. Most (70.2%) pesticide applicators were male and most (56.1%) sprayed paraquat in their own farmlands, although many (43.9%) were hired to spray (Table 1). Their ages ranged from 19 to 70, with an average age of 41.6 years; they had worked in agriculture from 1 to 50 years (average

16.3 years) and used pesticides from 1 to 50 years (average 13.8). Most (59.6%) lived near farmland (<1 km) where pesticides were sprayed. Their most commonly reported farm activities were mixing and spraying pesticides and applying fertilizer.

Information of cultivation and paraquat use on spraying day

The spraying period was 6 to 66 min and the average area sprayed was 1049.1 m^2. In addition, the average volume of paraquat solution (SD) was 241.8 (136.9) ml. Most (91.2%) sprayers wore long sleeve shirts but most did not wear long pants (35.1%) or boots (7%) and very few wore gloves (8.8%). For spraying equipment, they generally used motorized backpack sprayers (71.9%) and battery backpack sprayers (28.1%), and 73.7% of sprayers stood upwind while spraying (Table 2).

Inhalation exposure to paraquat

All but one of air sample had detectable levels of paraquat, although the concentrations were all below 8 hr TWA OEL ((OSHA), 2018). The median (IQR) of paraquat concentration in air samples was 5.15 (2.28–10.12) μg/m^3 ranging from 0.09 to 37.3 μg/m^3.

Sprayers using motorized backpack sprayers had a higher median of breathing zone paraquat concentrations (6.28 μg/m^3) than those using battery backpack sprayers (2.32 μg/m^3). A statistically significant difference was found between types of spraying equipment and breathing zone paraquat concentration (Mann–Whitney U-test, $p = 0.006$).

A multiple linear regression model of the log(e) of breathing zone paraquat concentrations (μg/m^3) using a stepwise method was created based on covariates that were significant using univariate analyses. Potential determinants that were investigated included conditions of work (types of sprayer equipment, the position of standing while spraying and duration of spraying), the amount of paraquat used and environmental factors (wind speed). The model showed that use of a battery pump sprayer reduced exposure by a factor of 0.43 in breathing zone paraquat concentrations (μg/m^3) when comparing the use of a motorized sprayer. Standing upwind while spraying reduced exposure by a factor of 0.52 (Table 3).

Dermal exposure to paraquat

Table 4 shows that legs, arms and back were the most exposed body areas. The highest paraquat concentration was found on the leg (median = 29.1 μg/hr) followed by arm (median = 5.77 μg/hr) and back (median = 2.54 μg/hr).

The workers using motorized backpack sprayers had higher paraquat concentrations on several body areas than those using battery backpack sprayers. We found statistically significant differences in median paraquat exposure between the motorized and battery pump backpack sprayers at the arms (10.91 μg/hr vs. 2.56 μg/hr), head (1.21 μg/hr vs. 0.18 μg/hr) and chest (2.82 μg/hr vs. 1.08 μg/hr) ($p = 0.012$, 0.006 and 0.001). For motorized backpack sprayers, the highest median paraquat exposure was at the legs (38.79 μg/hr) followed by arms (10.91 μg/hr) and back (3.41 μg/hr). For battery pump backpack sprayers, the highest median paraquat exposure was also at the legs (17.9 μg/hr), followed by arms (2.56 μg/hr) and back (1.26 μg/hr) (Table 5).

Wearing appropriate clothing and PPE, paraquat exposure to both the arms and legs will be different (Table 6). The results showed sprayers wearing a long sleeve shirt had a lower median of dermal paraquat concentrations on the arms (5.63 μg/hr) than sprayers wearing a short sleeve shirt (76.59 μg/hr). Sprayers wearing long sleeve shirts had 92.7% different from those wearing short sleeve shirts. Sprayers who wore latex gloves had a low median of dermal paraquat concentrations on the arms (3.77 μg/hr) as compared with sprayers not wearing latex gloves (5.89 μg/hr). When sprayers wore latex gloves, the paraquat exposure to the arms of sprayers was different by 35.9%. The results showed that sprayers wearing long pants had a lower median of dermal paraquat concentrations on the legs (17.18 μg/hr) than those wearing short pants (52.67 μg/hr). The paraquat exposure to the legs of sprayers was different by 67.4% when wearing long pants vs short pants. Sprayers wearing boots had a lower median of dermal paraquat concentrations on the legs (8.93 μg/hr) than those not wearing boots (38.79 μg/hr). Therefore, wearing boots had 76.9% difference of paraquat exposure on the legs. The results showed that sprayers wearing a balaclava had a lower median of dermal paraquat concentrations to the face (0.49 μg/hr) than those not wearing a balaclava (1.74 μg/hr). Wearing balaclava had 71.8% difference of paraquat exposure to the face.

Paraquat concentration in urine

Urinary paraquat concentrations were adjusted for urinary creatinine correction and expressed as μg/g creatinine. Many of the urine samples were below the limit of detection; therefore, only the median and IQR are shown in Table 7.

Only the urine sample at the end of the spraying event was significantly higher than the first morning urine sample on the day before spraying (Wilcoxon $p < 0.001$). The first morning urine sample on the day before spraying and the first morning urine sample the next day after spraying did not significantly differ (Wilcoxon $p = 0.064$).

No significant correlations were found between the breathing zone paraquat concentration ($\mu g/m^3$) and urinary paraquat concentration at the end of spraying event (Spearman's correlation = 0.083, $p = 0.539$) and the first morning urine sample the day after spraying (μg/g creatinine) (Spearman's correlation = 0.207, $p = 0.123$). Additionally, no significant correlations were found between the total dermal paraquat exposure and urinary paraquat concentrations at the end of the spraying event (μg/g creatinine) and the first morning urine sample the day after spraying (μg/g creatinine) (Spearman's correlation = 0.22, $p = 0.101$ and Spearman's correlation = 0.153, $p = 0.256$), respectively.

Discussion

The majority of sprayers in this study were male, as has been reported in related studies of occupational paraquat exposure (Swan 1969; Howard 1982; Chester et al. 1993; Lee et al. 2009) mainly due to the strength needed to lift and carry the 25 liters motorized backpack for extended periods. The average sprayers in this study were middle aged, which was similar to related studies in Thailand in that young workers tend to work in the urban industrial sector, not the rural agricultural sector (Kongtip et al. 2018; Mahaboonpeeti et al. 2018).

In this study, the median breathing zone paraquat concentration of 5.15 μg/$m^3$and the highest breathing zone paraquat concentration of 37.3 μg/m^3were much lower than the proposed occupational exposure limit recommended by ACGIH TLV-TWA of 0.05 mg/m^3(inhalable as cation) ((OSHA), 2018).; most likely because the spraying period was short (6 to 66 min) and the area sprayed was small (average 1049.1 m^2).However, our median breathing zone paraquat concentration was higher than related studies. Lee et al. found a geometric mean concentration in Costa Rican farms of 4.75 μg/m^3(Lee et al. 2009). Malaysian plantation workers had an average level of paraquat in air samples of 0.97 and 0.25 μg/m^3in two different locations (Chester and Woollen 1982) and the geometric mean paraquat exposure of knapsack sprayers on banana plantations was 0.6 μg/m^3(Van et al. 1996). Our higher exposure may have occurred because 71.9% of the sprayers in this study used motorized backpack sprayers, while in Costa Rica they used only hand-pressurized backpack sprayers. In addition, differences in environmental factors such as temperature, relative humidity and wind speed could affect inhalation exposures. A study of Baharuddin et al. showed that environmental factors such as wind speed were significantly correlated with inhaled paraquat exposures (Baharuddin et al. 2011). When workers spray paraquat while downwind from a strong wind, paraquat particles could be spread in a large cloud.

The multiple linear regression model showed that the type of spraying equipment and standing upwind while spraying had a significant influence on paraquat concentration in the breathing zone. The use of a motorized sprayer increased paraquat concentrations in the breathing zone more than using a battery sprayer. This could be in part because of the increased capacity (25 liters) compared with that of the battery backpack sprayers (16 to 20 liters). In addition, the motorized sprayers could produce a higher-velocity air stream with a wider range of spray droplets than battery backpack sprayers could (Mahaboonpeeti et al. 2018). Additionally, a motorized sprayer may increase the fraction of respirable particles (Swan 1969). A study on inhalation and dermal exposure to 2, 4-D and paraquat among Malaysian paddy farmers also found that workers using motorized sprayers experienced higher average concentrations of both herbicides than those using manual sprayers (Baharuddin et al. 2011). In our study, most (73.7%) of the sprayers checked the direction of the wind before spraying and stood upwind while spraying. Multiple linear regression showed that standing upwind while spraying could significantly reduce exposures. When the wind is blowing, standing upwind while spraying could reduce paraquat splashes or particles to exposed workers. When workers stood downwind while spraying paraquat, a cloud of paraquat could cover them.

Malaysian plantation workers had total dermal paraquat concentrations at 2.2 mg/hr (inner clothing) and 66.1 mg/hr (outer clothing) (Chester and Woollen 1982). The geometric mean of total dermal paraquat exposure of knapsack sprayers in Costa Rica was 0.5 mg/hr (Van et al. 1996). In this study, the median total dermal paraquat exposure was 92.66 μg/hr. Our total dermal concentration was lower than those studies due to the short spraying times. Malaysian workers sprayed paraquat from 155 to 250 min but our sprayers sprayed paraquat from 6 to 66 min. In our study, the legs were the most exposed body area followed by the arms and back. The highest concentration was found on the legs because workers walked through recently sprayed weeds or walked in the spray mist. Exposure to the legs could be high when the paraquat solution leaked into the worker’s boots. Arm exposure could be

due to workers using their hands to handle the spray nozzle and splashing while preparing paraquat solution or contacting the spray solution when filling the spray tank. Back exposure resulted from leakage of the backpack sprayer. Our results were similar to Van's study reporting that the legs, back and wrists were the most exposed body areas and the exposure of these three parts contributed to 87% of the total dermal exposure (Van et al. 1996).

This study found that motorized backpack sprayers had dermal paraquat concentrations in all exposed areas higher than those using battery pump backpack sprayers. The motorized backpack tank is larger than the battery pump backpack tank so it could apply a higher volume of paraquat. Moreover, the motorized backpack sprayer had a high speed airstream to produce a wider cloud of sprayed droplets (Mahaboonpeeti et al. 2018). Because dermal adsorption may be the major route of paraquat exposure, the use of PPE is important to reduce paraquat exposure. Especially, proper clothing is supposed to considerably reduce dermal exposure. From this study, the majority of workers wore face protection (84.2%) followed by long sleeve shirts (91.2%) and long pants (35.1%) to protect themselves from paraquat exposure during spraying, while gloves, boots and goggles were rarely used.

Related studies have shown that pesticide sprayers, wearing regular clothing to cover their body, could reduce dermal exposure to pesticides. Dermal 2, 4-D and paraquat exposure were significantly negatively correlated with the use of personal protective clothing among Malaysian paddy farmers (Baharuddin et al. 2011). Furthermore, vegetable farmers, wearing long-sleeve shirts and long pants, had significantly lower alachlor concentrations on dermal patches (Mahaboonpeeti et al. 2018). In this study, wearing long sleeve shirts had lower paraquat exposure at the arms when compared with wearing short sleeve shirts. Wearing long pants had lower paraquat exposure at the legs and wearing boots had lower paraquat exposure at the legs.

In the current study, we found the highest frequency of detection for urinary paraquat immediately after the spraying event (82.5%), followed by the next morning void urine after paraquat spraying (63.2%). The lowest frequency of urinary paraquat detection was on the day before spraying (54.4%) and the median concentration of urinary paraquat followed the same pattern. This was similar to a study of occupational paraquat exposure among agricultural workers in large Costa Rican farms; they found the highest number of detectable samples and geometric mean concentration for samples taken on the spraying day followed by the day after spraying and day before spraying (Lee et al. 2009). Paraquat exposure of agricultural workers in large costa Rican farms study showed that urinary paraquat levels before the spraying day were significantly lower than those on the spraying day (Lee et al. 2009). The average ± SD of urinary paraquat level before-spraying day and on spraying day were 2.03 ± 1.92 and 10.65 ± 12.90 μg/24h, respectively. These results are consistent with our study in which urinary paraquat levels at the end of the spraying event were significantly higher than the first morning urinary paraquat levels on the day before spraying.

Moreover, paraquat in urine samples was not detected among knapsack spray operators on banana plantations in Costa Rica before starting work but was found in only two of 28 urine samples taken after work at concentrations of 11 and 22 μg/mmol creatinine (Van et al. 1996). On the other hand, no paraquat was detected in any of the urine samples among

Sri Lankan tea plantation workers (LOD = 0.03 μg/ml (Chester et al. 1993). Malaysian plantation workers exposed to paraquat had average urinary paraquat levels at 0.28 mg/l in 9 of the 19 spray operators. These higher concentrations in urinary paraquat levels than in our study were likely due to the longer spraying duration of Malaysian workers (135–254 min) compared with our subjects who only sprayed paraquat from 6 to 66 min (Chester and Woollen 1982).

Surprisingly, 54.4% of farmers had detectable paraquat in their urine before spraying. This may have been because those working in agricultural areas daily were exposed to paraquat through various agricultural activities. We hypothesized that farmers who take care of their crops daily may be exposed to paraquat through agricultural activities involving the soil, because the half-life of paraquat in soil is up to 20 years (Watts 2011; Kongtip et al. 2017).Urinary paraquat levels were not associated with breathing zone paraquat levels in this study. This result was similar to the study of paraquat exposure of workers in large Costa Rican farms (Lee et al. 2009). This may have been because paraquat is very polar and high soluble in water. When a worker inhales paraquat particles, the particles are deposited and dissolved and in nasal mucous membrane of the upper respiratory tract. Paraquat irritates the mucosal tissue and causes nosebleeds (Krieger 2001); therefore, paraquat particles can pass to the lung and bloodstream at very low concentrations. Moreover, paraquat has low volatility and paraquat particles produced by standard spray nozzles may be too large to be respirable during application, so the main source of exposure may come from dermal exposure (Wesseling et al. 2001).

The relationship between urinary paraquat concentration and total dermal paraquat concentration was not significant due to poor solubility of paraquat in lipids and on the surface membrane of intact skin. Paraquat absorbed through dermal is generally low but skin damage can increase absorption and has led to death among humans (Watts 2011). Paraquat absorption through human skin in vitro is very low; the permeability of human skin is even less than that of the skin of rats, rabbits or guinea pigs (Krieger 2001). Furthermore, this may be caused by aluminum foil attached with cotton patches. Paraquat was deposited on dermal patches during the spraying period. It could not be absorbed through human skin due to the impermeable layer of aluminum foil and the patches represented only a relatively small proportion of the human body region leading to underestimated paraquat dermal exposure.

Conclusion

Based on this study, the type of spraying equipment and standing upwind while spraying were found to be the most critical factors affecting inhalation exposure to paraquat. Wearing long sleeve shirts, long pants, boots, latex gloves and balaclavas can reduce paraquat concentrations on dermal exposure among backpack sprayers. The finding suggested that backpack sprayers should use battery pump backpack sprayers, stand upwind when spraying, and wear proper clothing for protection of paraquat such as long sleeve shirts, long pants and balaclavas to decrease paraquat exposure. These factors will help reduce levels of paraquat in inhalation and dermal exposures of sprayers and protect against paraquat toxicity.

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Table 1.

Demographic characteristics of farmers (n = 57).

Characteristic of Agriculturist	Number (%)
Sex	
Female	17 (29.8)
Male	40 (70.2)
Age (years)	
Mean (SD) 41.6 (14.3) years	
Min - Max (years) 19–70	
BMI	
Mean (SD) 24.5 (4.7)	
Min-Max (16.7 – 41.4)	
Education level	
Uneducated	2 (3.5)
Primary school	25 (43.9)
Junior high school	17 (29.8)
Senior high school or vocational certificate	5 (8.8)
College certificate or high vocational certificate	6 (10.5)
Bachelor degree	2 (3.5)
Occupation	
Farm owner/agriculturist	32 (56.1)
Farm employee	25 (43.9)
Smoking	
Yes (current)	19 (33.3)
No (ex or none)	38 (66.7)
Alcohol consumption	
Yes	44 (77.2)
No	13 (22.8)
Live next to farmland where pesticides are sprayed (<1 km)	
Yes	34 (59.6)
No	23 (40.4)
Income	
Mean (SD) USD 296 (243)	
Min - Max (USD) 60 – 1215	
Cultivating areas (square meters)	
Mean = 81,440, SD = 59,664, Min - Max (6,400–192,000)	
Type of crops	
Sugarcane	32 (56.1)
Rice	15 (26.3)
Cassava	4 (7)
Maize	7 (12.3)
Sesame	8 (14)

Characteristic of Agriculturist	Number (%)
Nut	12 (21.1)
Using pesticide (years)	
Mean = 13.8, SD = 13.1, Min - Max (1–50)	
Working in agricultural field (years)	
Mean = 16.3, SD = 12.9, Min - Max (1–50)	
Agricultural activities	
Apply chemical fertilizer	28 (49.1)
Dig in farm soil	19 (33.3)
Mix pesticide	41 (71.9)
Spray pesticide	57 (100)
Hand-pick weeds	17 (29.8)
Sow	16 (28.1)
Water	10 (17.5)
Harvest	9 (15.8)

Table 2.

Information on cultivation, environmental factors and paraquat use on spraying day.

Parameter	N (%)
Mixing and spraying paraquat	
Paraquat volume (ml) Mean = 241.8, SD = 136.9, Min - Max (80–1000)	
Sprayed area (square meters) Mean =1049.1, SD = 1507.3, Min - Max= 200–9600	
Personal protective equipment usage	
Cloth mask, balaclava or face cloth	48 (84.2)
Latex gloves	5 (8.8)
Boots	4 (7)
Large brim straw hat	9 (15.8)
Spraying equipment	
Battery powered backpack sprayers	16 (28.1)
Motorized backpack sprayers	41 (71.9)
Standing upwind while spraying	
Yes	42 (73.7)
No	15 (26.3)
Duration of spraying	
Mean (SD) minutes 23.9 (11.9)	
Min - Max (minutes) 6 – 66	
Clothes	
Long sleeve shirt	52 (91.2)
Long pants	20 (35.1)
Relative humidity	
Mean (SD) % 78.3 (17.3)	
Min - Max % 41.2 – 97.4	
Wind speed	
Mean (SD) m/s 1.33 (0.6)	
Min -Max m/s 0.36 – 2.8	
Temperature	
Mean (SD) °C 29.1 (3.57)	
Min -Max °C 24.7 –39.2	

Table 3.

Multiple linear regression model using stepwise method for exposure determinants of log(e) breathing zone paraquat concentrations (μg/m^3) among sprayers (N = 57).

Variables	B	*β*	Standard error	Exp (B)	p-value
Constant	2.294		0.278		<0.001 *
Battery Pump sprayer vs. motorized sprayer (1/0)	−0.843	−0.350	0.298	0.43	0.006 *
Standing upwind while spraying vs. standing downwind while spraying (1/0)	−0.658	−0.268	0.304	0.52	0.035 *

p-values were calculated using linear regression,

* p-value <0.05.

Table 4.

Paraquat concentration on dermal sample.

Exposed areas	N	Detection (%)	Median (IQR) μg/hr
Forehead	57	48 (84.2)	0.83 (0.21 – 7.88)
Arms	57	53 (93)	5.77 (2.45 – 45.47)
Legs	57	56 (98.2)	29.1 (9.9 – 360.83)
Back	57	48 (84.2)	2.54 (1.04 – 21.88)
Chest	57	46 (80.7)	1.98 (1.04 – 6.33)
Total dermal exposure	57	57 (100)	92.66 (34.37 – 1647.46)

Table 5.

Comparison of personal paraquat dermal exposure (median, IQR and μg/hr) at different body locations by two types of backpack sprayer (two-stroke gasoline motor/fan vs. battery pump).

Location of attached dermal patches	N	Median (IQR) (μg/hr)		p-value
		Motorized backpack sprayer (n=41)	Battery pump backpack sprayer (n=16)	
Arms	57	10.91 (3.31 – 95.43)	2.56 (1.42 – 11.04)	0.012 *
Legs	57	38.79 (13.21– 347.26)	17.9 (5.79 –2952.48)	0.500
Head	57	1.21 (0.32 – 9.16)	0.18 (0.1 – 0.86)	0.006 *
Back	57	3.41 (1.67 – 21.88)	1.26 (0.39 – 40.24)	0.138
Chest	57	2.82 (1.4 – 10.71)	1.08 (0.4 – 2.08)	0.001 *
Total	57	92.66 (39.39–1055.22)	87.49 (17.27–3958.36)	0.887

* p-values were calculated using Mann-Whitney U-test and significant at $p < 0.05$.

Table 6.

Impact of different clothing items to median paraquat dermal exposures while spraying.

Location of attached dermal patches	N	Personal protective equipment	Median (IQR) (μg/hr)	Difference (%)
Arms				92.7
	52	Long sleeve shirt	5.63 (2.42 – 32.07)	
	5	Short sleeve shirt	76.59 (18.66 – 519.74)	
Arms				
	5	Wearing latex gloves	3.77 (3.23–86.62)	35.9
	52	Not wearing latex gloves	5.89 (2.08 – 46.98)	
Legs				
	20	Long pants	17.18 (5.81 – 322.21)	67.4
	37	Short pants	52.67 (15.09 –395.58)	
Legs				
	4	Wearing boots	8.93 (3.61–11.49)	76.9
	53	Not wearing boots	38.79 (12.69 – 395.58)	
Head				
	26	Wearing balaclava	0.49 (0.21 – 1.98)	71.8
	31	Not wearing balaclava	1.74 (0.19 –9.20)	

% Difference = [1- (long/short)]×100 or [1- (Wearing/Not wearing)]×100.

Table 7.

Urinary paraquat concentrations at three time points: morning void urine the day before spraying, end of spraying activity, morning void urine the next day after spraying.

Parameter	*n* = 57
First morning urine on day before spraying	
Detection frequency (%)	31 (54.4)
Median (IQR) μg/g creatinine	2.51 (0.81 –5.95)
Min - Max (μg/g creatinine)	0.34– 41.78
Median (IQR) ng/ml	1.8 (0.71 –6.05)
Min - Max (ng/ml)	0.71– 16.9
Urine at the end of spraying event	
Detection frequency (%)	47 (82.5)
Median (IQR) μg/g creatinine	8.23 (3.3 – 13.73)
Min - Max (μg/g creatinine)	0.48 – 83.44
Median (IQR) ng/ml	7.9 (4.05 – 16.00)
Min - Max (ng/ml)	0.71– 91.5
First morning urine the next day after spraying	
Detection frequency (%)	36 (63.2)
Median (IQR) μg/g creatinine	3.48 (1.03 – 8.91)
Min - Max (μg/g creatinine)	0.21– 40.95
Median (IQR) ng/ml	3.9 (0.71 – 8.8)
Min - Max (ng/ml)	0.71– 43.1