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ORIGINAL ARTICLE

Exposure and Risk Assessment of Insecticide Methomyl for Applicator during Treatment on Apple Orchard

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Abstract Exposure and risk assessments were conducted to evaluate safety of speed spayer (SS) and power sprayer (PS) used for treatment of insecticide methomyl in apple orchard on the operator. Dermal patches, gloves, socks, and masks were used to monitor the potential dermal exposure, and personal air monitor with XAD-2 resins was used to evaluate the potential inhalation exposure. Validation of methods for limit of detection, limit of quantitation, recovery, reproducibility, linearity of calibration, trapping efficiency, and breakthrough tests were performed to obtain reasonable results for quantitative exposure study of methomyl. During application of methomyl, PS resulted in more dermal exposure than SS. Important contaminated parts of body were upper arms, thigh, chest, shin, hand, forearm, and head for both SS and PS. Exposure rate was 44–176 mL/h. Although the level of inhalation exposure was very low during application, relatively higher level was observed for PS than for SS. During mixing/loading, more dermal exposure occurred by SS than that of PS probably due to drift of wettable powder (WP) formulation. Exposure was mostly observed on hand, and 99.9% of hand exposure to soluble liquid formulation (215 mg) in PS was from spill of liquid formulation on gloves. However, the body exposure ratio to total mixing/loading amount and inhalation exposure during mixing/loading was very low. Margin of safety in risk assessment was much larger than 1 in all cases, indicating low risk.

Keywords exposure · methomyl · orchard · pesticide application · risk assessment

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Introduction

Exposure is generally defined simply as contact of an organism's exterior with a chemical (Crosby, 1988). Human exposure to pesticides can occur during manufacture, mixing/loading, spraying, harvest, and by consumption of chemical-treated crops. During spraying, the representative routes of human exposure are dermal deposition and inhalation (Fenske, 1990). The potential dermal exposure to pesticide sprays can be measured with the patch method (Fenske, 1990) or with the whole body dosimetry method. Insecticide methomyl is a broad spectrum *N*-methyl oxyimidothioate carbamate insecticide with both contact and oral toxicity to control chewing and sucking of *Lepidotera*, *Homoptera*, *Coleoptera* and *Hemiptera* pests in vegetable, orchard, vine, and field crops (Terry and David, 1999). The insecticide acts as a neurotoxic compound by inhibition of cholinesterase enzymes. Its solubility in water is 57.9 g/L (25°C), and is relatively stable to light in field. Methomyl has a low acute (rat, oral 34 mg/kg) and chronic toxicity (2 years for rats 100 mg/kg) in mammals with no evidence of carcinogenicity, neurotoxicity, and mutagenicity. The acceptable daily intake (ADI) value of methomyl is 0.02 mg/kg body weight per day (Tomlin, 2006). Apple is one of the most important fruit in Korea Famers use speed sprayer (SS) or power sprayer (PS) for the application of pesticides in orchard (Hong et al., 2007), and significant exposure to workers and unintended body contamination could also occur. Exposure and risk assessment studies with various pesticides and crop on spray operator were reported recently (Byoun et al., 2005; Choi et al., 2006; Ramos et al., 2010).

However, to our knowledge, there is no previous exposure and risk assessment of methomyl in apple orchard. Methomyl was chosen as a subject pesticide, because it is one of the suspected endocrine disruptors (EDs). Thus, in the present study, dermal and inhalation exposures of applicator to methomyl were investigated during mixing/loading and spraying procedure. Two different formulations, wettable powder (WP) and soluble liquid (SL), and two different application methods (SS and PS) were used to compare their exposure characteristics. Based on the results, risk assessment was conducted by calculating margin of safety (MOS) to ascertain the existing status of exposure of operators to methomyl.

Materials and Methods

Chemicals and Reagents. Methomyl (99.9%) of analytical standard grade was purchased from Riedel-de-Haën (Seelze, Germany). Analytical standard was dissolved in methanol to make concentrated stock solution of 1000 μg/mL. From this stock solution, working standard solutions of 0.1, 1, 5, 10, and 50 μg/mL were prepared by serial dilution with methanol. All solvents were HPLC-grade, and were purchased from Fisher Scientific Korea Ltd (An-sung, Korea). Pesticide formulation used in field study was methomyl 45% WP, methomyl 24.1% SL were purchased from pesticide vendor.

Dermal patches, gloves, socks, and mask. Dermal patches were used for dermal exposure measurement. The patches were made by putting cellulose TLC paper (Whatman 17CHR, 46 × 57 cm, Cat. No. 3017-915, 1 mm thickness, Kent, UK) in the patch pocket (10 cm × 10 cm), which has circular exposure part (50 cm^2). Safety pins were used to attach patches on protective garment (SP protective, KleenGuard, Yuhan-kimberly Korea Ltd, Seoul, Korea). Cotton mask (face exposure; 200 cm^2), cotton socks (feet exposure), cotton gloves (hand exposure) were purchased from local markets.

Personal air monitor and U-shape glass tube. Inhalation exposure was measured using a personal air monitor equipped with an air pump (Gillian Model 224-PCXR7, MSA, Dong Ha Trading Co., Ltd., Seoul, Korea), glass fiber filter (37 mm, SKC, Eighty Four, PA) in open-faced cassette (SKC) and solid sorbent (ORBO™ 609 Amberlite XAD-2 400/200 mg, Supelco Korea Ltd, Seoul, Korea), which traps methomyl in air. The flow rate of personal air monitor was 1 L/min. U-shape glass tube for trapping efficiency test was manufactured by Daejung Chemical (Daejon, Korea).

Fields. The exposure field studies were conducted in an apple orchard at Apple Research Institute in Gunwi-gun, Gyeongbuk. Temperature (18–20°C), relative humidity (50–55%), and wind speed (0 m/s) were obtained from Apple Research Institute by its own anemometer or hygrometer.

Mixing/loading. Workers prepared spray mixture by mixing methomyl WP with water after weighing a specific amount of powder (225 g of WP in 500 L water for SS, and 67.5 g of WP in 150 L for PS). For SL mixture, a specific amount of liquid (120.5 mL of SL in 500 L water for SS, and 36.1 mL of SL in 150 L for PS) was measured with bottle cap (11 mL) and mixed with water in mixing tank. The mixture was stirred mechanically in the case of SS, whereas a long stick was used for stirring in PS.

Application of methomyl. Applicator applied spray mixture to apple trees using PS and SS (SS, TLD ASS-555, Asia Motors, Daegu Metropolitan City, Korea) in field for 20 min. Application with PS was performed by stepping backward and moving the lance up and down. All experiments were repeated three times.

Dermal exposure sampling and calculation. For mixing/loading, 7 dermal patches were attached: head (1), front of neck (1), chest/stomach (1), upper arm (2), and forearm (2). In the case of spraying, dermal patches were attached on 13 parts of body: head (1), front of neck (1), back of neck (1), chest/stomach (1), back (1), upper arm (2), forearm (2), thigh (2), and lower leg (2). Workers wore cotton gloves, cotton socks, and masks. After mixing/loading and spraying, exposure matrices were removed for analysis. The exposure intensity per body part (μg/cm^2) was calculated by dividing the amount of methomyl (μg) on each matrix by the exposed area of the corresponding matrix to give μg/cm^2. Dermal exposure amounts per body part were calculated by extrapolating exposure intensity (μg/cm^2) to the surface area (cm^2) of the appropriate body region (EPA, 1996).

Inhalation exposure sampling and calculation. A glass fiber filter cassette and a XAD-2 resin tube were attached to the breathing zone with clip, and an air pump was fastened on waist by belt. The air flow rate was 1 L/min. After mixing/loading and spraying, XAD-2 resin and filter were removed for analysis. The flow rate of personal air sampler was 60 L/h. The inhalation exposure rate (ng/h) was obtained by dividing the inhalation exposure amount (ng) by work time (h), and extrapolated to light work breathing rate for male (EPA, 1996).

Extraction of methomyl from dermal patches, gloves, socks, mask, and XAD-2 resin. The patches, gloves, mask, and socks were placed into 100- and 500-mL vessels containing 60 and 300 mL of acetone. XAD-2 resin was placed into a 20-mL vial, and 10 mL of methanol was added. After shaking the containers for 1 h on a shaker (Wooju Scientific, Kimpo, Korea), aliquots (20 μL) were analyzed using high performance liquid chromatography (HPLC).

Analytical instrument and conditions. HPLC system (Agilent

1100 series, Palo alto, DE) with VWD (variable wavelength detector) was used for the analysis of methomyl. Methomyl was separated on a Shiseido C_{18} column (240 mm × 4.6 mm, 5 μm particle; Kyoto, Japan) at 40. The mobile phases for pumps A and B were methanol and water, respectively. A gradient system was employed for 15 min at the flow rate of 1.0 mL/min with A:B as follows: initial 0 min, 10:90; 5 min, 50:50; 7 min 50:50; 11 min 10:90; final 15 min 10:90. Injection volume was 20 μL, and elution of methomyl was monitored at 230 nm.

Limit of Determination (LOD) and Limit of Quantitation (LOQ). Aliquots (20 μL) of methomyl standard solution (0.01–1.0 μg/mL) were analyzed for LOD determination before LOQ calculation.

Reproducibility of analysis. Three levels (1 LOQ, 5 LOQ, and 10 LOQ) of methomyl standard solution were analyzed six times by HPLC to calculate coefficient of variation (C.V.).

Standard calibration curve linearity. Various methomyl standard solutions (0.1–10 μg/mL) were analyzed for establishment of calibration curve. After 1 and 3 days of storage, the linearity of the curve was investigated again.

Recovery (Matrix extraction efficiency) test. Three levels (LOQ, 5 LOQ, and 10 LOQ) of standard solution were spiked in patches, gloves, socks, mask, and XAD-2 resin. The analysis was conducted following the method described in the analytical procedure mentioned above.

Field recovery test. A 5 LOQ level of methomyl was spiked on patches, gloves, socks, mask, and XAD-2 resin in apple field. Those matrices were exposed to outdoor for a period of time equivalent to the duration of spray application in order to simulate field study conditions.

Trapping efficiency test. This test was repeated three times by spiking of a standard solution (10 LOQ) on the bottom of U-shape glass tube connected with XAD-2 resin tube, and air was passed through the system at 1 L/min for 4 h for trapping of evaporated methomyl. To determine the volatility of compounds, U-shape glass tube was heated to 70°C. The residue in U-shape glass tube and the amount trapped in XAD-2 resin were analyzed for mass balance.

Breakthrough test. This test was spiked at 10 LOQ level of standard solution in the 1°- resin part before passing air through the tube at 1 L/min for 4 h. Subsequently, 1°- and 2°- resin parts were analyzed separately.

Risk assessment. The potential dermal exposure (PDE) and potential inhalation exposure (PIE) values were obtained by extrapolating corresponding exposure volume per h (mL/h) to 6 (Choi et al., 2006). External dermal exposure (EDE) was obtained based on assumptions of 10% penetration of clothes for dermal exposure (Jensen, 1984). Internal DE (IDE) was obtained after 10% penetration of EDE through skin (Choi et al., 2006). Absorbable quantity of exposure (AQE) value was obtained by adding IDE and PIE values. MOS was calculated by an adaptation of the formula of Severn (Davis, 1984): MOS = (NOEL × BW)/(AQE × SF) where, no observed effect level (NOEL) is 100 mg/kg/day (rat) for methomyl, body weights (BWs) were 70 and 60 kg in human male and female, respectively (Choi et al., 2006), and safety factor (SF) was 100 (Renwick, 2000).

Results and Discussion

Method validation. LOD and LOQ are the criteria of instrumental sensitivity for the analyte (Lee et al., 2009) and were low enough to detect the trace level of methomyl in various exposure matrices (Table 1). Excellent reproducibility (C.V. <1%) indicated that instrument was stable for analysis. The linearity (R^2 >0.99) of calibration curve was also good for 3 days over the range of 0.1–10 mg/L. Matrix extraction efficiency (Recovery) test (Table 2) was used to measure recovery of pesticides from various matrices, whereas field recovery test (Table 3) was conducted in the same manner except spiking pesticide in field,

Table 1 LOD, LOQ, reproducibility and linearity of analysis

LOD	LOQ	Reproducibility (Area)			Linearity (R^2)	
		Level	Average	C.V (%)		
2 ng	10 ng	LOQ	30.9	0.3	Day of preparation	0.9999
		5 LOQ	161.3	0.4	After 1 day	1.0000
		10 LOQ	453.2	0.2	After 3 day	0.9999

Table 2 Extraction efficiency of methomyl from patch, glove, sock, mask, and XAD-2 resin

Recovery ± C.V (%)	Dermal patch	Glove	XAD-2	Mask	Socks
LOQ	93.7±4.7	97.7±0.8	86.0±5.2	87.8±4.2	96.4±1.8
5 LOQ	114.9±0.9	103.3±1.1	118.8±7.4	100.1±1.1	112.7±1.2
10 LOQ	104.1±2.2	93.6±1.2	118.8±7.6	100.1±1.3	116.9±7.1

Table 3 Field recovery of methomyl from patch, glove, sock, mask, and XAD-2 resin

Recovery ± C.V (%)	Dermal patch	Glove	XAD-2	Mask	Socks
5 LOQ	83.3±1.6	80.0±1.5	83.0±9.4	79.4±4.4	99.5±0.8

Table 4 Trapping efficiency and breakthrough test of XAD-2 resin

Test	Treated level	Recovery %		
Trapping efficiency	10LOQ	Residue	Trapped	Total
		1.0	86.0	87.0
Breakthrough	10LOQ	1°-resin	2°-resin	Total
		78.1	2.0	80.1

Table 5 Dermal exposure amount during application of methomyl (20 min)

	WP		SL	
	SS	PS	SS	PS
Total spray volume (L)	500	150	500	150
Total exposure amount (mg)	16.90	9.10	3.50	5.54
Applied a.i.† (g)	146.25	43.875	120.5	36.15
Ratio to applied a.i. (%)	0.012	0.021	0.003	0.015

†a.i. = Active ingredient

because pesticides on various exposure matrices may degrade when exposed to sunlight during application time, storage, and transportation. The recovery result was in the rage of 86.0–118.8% with low C.V. (Table 2), indicating a reasonable extraction efficiency. In field recovery, 79.4–99.5% (Table 3) was obtained, suggesting the losses of pesticides due to transfer, storage, transport conditions, and exposure to light were not significant. Trapping efficiency test is used to measure the efficiency of trapping pesticides by XAD-2 resin. The sum of trapped amount in XAD-2 resin and residual amount on bottom of U-shape glass tube confirmed that XAD-2 resin is effective for trapping methomyl in air (Table 4). Breakthrough test was undertaken for evaluating the adsorption ability of XAD-2 resin to methomyl. The XAD-2 resin tube contain two parts (1°-part and 2°-part) of XAD-2 resin, which are separated by small glass wool. Therefore, when 1°-part is saturated by pesticide, it could escape to 2°-part or out of tube via flow of air. If the amount detected in 2°-part of resin is more than 20% of the residue amount in 1°-part of resin, exposure results do not have reliability in assuming some pesticide escaped from resin. Only 1–2% was detected in 2°-part, and most of pesticides remained on 1°-part of resin, indicating that the first resin part has a good holding capacity. Through those various experiments, which were repeated three times for each validation, the analytical and sampling methods of our study were fully validated.

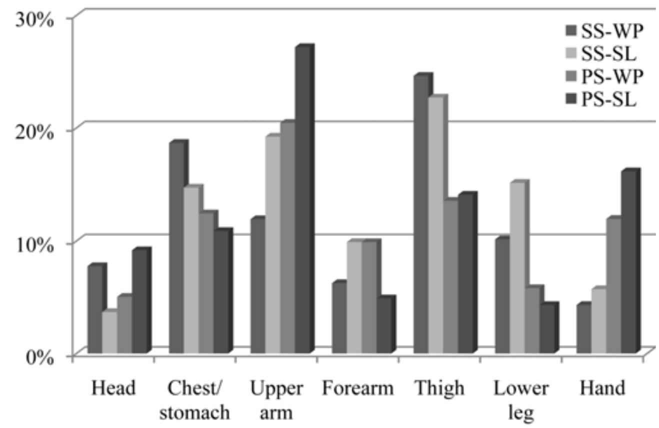

Fig. 1 The dermal exposure ratios (%) during application of methomyl (20 min).

Dermal exposure during spraying of methomyl. Spray volume and the amount of active ingredient (a.i.) for SS were 3–4 times higher than those of PS (Table 5), and the amount of dermal exposure to methomyl was from 3.50 (SL-SS) to 16.9 mg (WP-SS). PS resulted in more exposure than SS when the ratios of dermal exposure amount to active ingredient actually sprayed were calculated (0.003–0.021%), because the applied amount was different depending on formulations and spray machines.

Table 6 Dermal exposure rate (mL/h) during application of methomyl

	WP				SL			
	SS		PS		SS		PS	
	mL/h	(%)	mL/h	(%)	mL/h	(%)	mL/h	(%)
Head	13.69	7.77	4.71	5.04	1.61	3.69	6.34	9.18
Front of neck	1.22	0.69	0.92	0.98	0.03	0.06	0.56	0.82
Back of neck	1.23	0.70	0.45	0.48	0.91	2.09	0.26	0.37
Chest/stomach	32.89	18.67	11.58	12.40	6.40	14.69	7.52	10.89
Back	24.27	13.77	17.38	18.62	0.72	1.66	6.77	9.81
Face	0.89	0.50	0.27	0.29	0.23	0.52	0.16	0.22
Upper arm	20.95	11.89	19.09	20.45	8.38	19.23	18.77	27.19
Forearm	11.03	6.26	9.25	9.90	4.32	9.91	3.38	4.90
Thigh	43.39	24.63	12.62	13.52	9.89	22.70	9.70	14.06
Lower leg	17.89	10.15	5.43	5.81	6.59	15.12	2.97	4.31
Feet	1.15	0.65	0.55	0.59	2.00	4.59	1.46	2.11
Hand	7.60	4.32	11.12	11.91	2.49	5.72	11.14	16.14
Total	176.18	100.00	93.36	100.00	43.58	100.00	69.02	100.00

Table 7 Inhalation exposure during application of methomyl (20 min)

	WP		SL	
	SS	PS	SS	PS
Exposure amount (μg)	2.5	2.9	5.6	4.9
Applied a.i. (g)	146.3	43.9	120.5	36.2
Ratio to applied a.i. (%)	1.7×10^{-6}	6.6×10^{-6}	4.6×10^{-6}	1.4×10^{-5}

Table 8 Dermal exposure amount during mixing/loading of methomyl

	WP		SL	
	SS	PS	SS	PS
Body (mg)	5.45	0.05	0.06	0.11
Hands (mg)	1.28	1.86	0.78	214.92
Total (mg)	6.73	1.91	0.84	215.03
Hand ratio (%)	19.0	97.6	92.5	99.9
Applied a.i. (g)	146.25	43.88	120.50	36.15
Ratio to applied a.i. (%)	4.6×10^{-3}	4.3×10^{-3}	7.0×10^{-4}	5.9×10^{-1}
Ratio to applied a.i. (%) - except hand	3.7×10^{-3}	1.1×10^{-4}	5.2×10^{-5}	3.0×10^{-4}

Exposure rate was about 44–176 mL/h (Table 6), and important contamination parts of body were upper arm, thigh, chest, lower arm, hand, forearm, and head for both SS and PS (Fig. 1). In PS, upper arm and hand showed more exposure than that of SS probably due to spraying by hand. For SS, more exposure was observed in chest, thigh, and lower arm, because the driver sprayed pesticide by sitting on the chair of SS. Ramos et al. (2010) also reported that PS operator had a higher relative exposure on forearm and hand.

Inhalation exposure during spraying of methomyl. Personal air monitoring devices (Choi et al., 1996) have been used to characterize inhalation exposures. In the present study, inhalation exposure was observed at 2.5–5.6 μg, and higher exposure (about 2 times) was observed for PS than for SS (Table 7). The ratio to total application amount was within the range of 1.7×10^{-6}–1.4×10^{-5}%, which is too low.

Dermal exposure during mixing/loading of methomyl. Because upper front body is usually exposed to pesticide in mixing/loading procedure, dermal patches were attached on head (1), front of neck (1), chest (1), upper arm (2), and forearm (2). In WP, more dermal exposure occurred than that of PS probably due to drift of powder of WP formulation (Table 8). Most of the exposure was observed on hand (19.0–99.9% of total exposure), as expected, due to the direct contact with pesticides during opening of an envelope or bottle and pouring of pesticides powder or liquid into the container to formulate a suspension. Krieger et al. (1992) reported that hands receive one to three orders of magnitude more exposure per unit area than other regions of the body. Furthermore, 99.9% hand exposure of about 215 mg for SL formulation in the case of PS is from spill of liquid formulation on gloves. Thus, workers need to take precautions to prevent contamination of hand during measuring of specific volume of liquid. However, the body exposure ratio to total mixing/loading amount was also very low (5.2×10^{-5} – 3.7×10^{-3}%).

Table 9 Inhalation exposure during mixing/loading of methomyl

	WP		SL	
	SS	PS	SS	PS
Exposure amount (μg)	0.50	0.60	0.20	N.D.
Applied a.i. (g)	146.25	120.50	43.88	36.2
Ratio to applied a.i. (%)	3.4×10^{-7}	5.0×10^{-7}	4.6×10^{-7}	-
dermal exposure (mg)	6.73	1.92	0.84	215.03
Ratio to dermal exposure (%)	0.007	0.031	0.024	-

† N.D. = Not Detected

Table 10 Calculation of MOS for application of methomyl

	WP		SL	
	SS	PS	SS	PS†
PDE (mg/4h/day)	202.95	42.05	109.34	2285.30
EDE (mg/4h/day)	20.29	4.21	10.93	228.53
IDE (mg/4h/day)	2.03	0.42	1.09	22.85
PIE (μg/4h/day)	29.59	67.79	35.36	58.38
AQE (mg/day)	2.06	0.49	1.13	22.91
MOS (male)	76.2	144.2	114.5	49.7

† Including mixing/loading

Inhalation exposure during mixing/loading of methomyl. During mixing/loading inhalation exposure was observed at about 10^{-7} level without significant difference between formulation and spray techniques (Table 9).

Risk Assessment. Risk, different from 'hazard' (the potential to produce harm) measures the magnitude of the hazard by probability of its occurrence. Risk assessment, the process for defining just how dangerous a particular substance is to ourselves and our environment, involves four overlapping components: (1) hazard identification, (2) dose-response evaluation, (3) exposure evaluation, and (4) risk characterization (Crosby, 1998).

MOS formula, proposed by Severn (1984), was used in the present work to calculate the safety status of work conditions for the applicator of pesticides. The MOS is a better indicator than the PDE, because it establishes a comparative frame, generating an indicator that allows comparisons under very different field situations including, among others, different application techniques and different plants height (Ramos et al., 2010). If MOS is <1, the working condition is considered to be low risk (Machado-Neto et al., 1998; Hughes et al., 2006).

For the calculation of MOS, inhalation exposure during mixing/loading and application, and dermal exposure during mixing/loading (except SL-PS) were not considered, because the values were too low to be integrated for calculation. Dermal and inhalation exposures during application and dermal exposure during mixing/loading (SL-PS; significant hand exposure) were considered for MOS evaluation. PDE in the present study is defined as "the total amount of pesticide coming in contact with the protective clothing or work clothing, whereas EDE refers to "the amount of pesticide coming into contact with bare (uncovered) skin and the fraction transferring through protective and work clothing, which is therefore available for percutaneous absorption.” IDE is used for determining the amount of pesticide which penetrated through the skin so that is available for the biochemical or toxic action. IDE of methomyl during application ranged from 0.42 to 22.85 mg/4h/day and PIE was 29.59–67.79 μg/4h/day. Therefore, AQE is calculated by adding of IDE and PIE to be 0.49 (WP-SS)–22.91 (SL-PS) mg/day. MOS determined using NOEL, AQE, BW, and SF was much higher than 1 in all cases (Table 10), indicating that the spraying condition was of less risk.

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