Preliminary assessment of nursery workers' exposure to applied pesticides

Izzatul Nazirah Kamaruldzaman[1], *Siti Hajar* Ya'acob[1], *Hie Ling* Wong[1*]

[1]Faculty of Earth Science, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia

Abstract. Nursery workers can be exposed to pesticides via skin contact and respiratory inhalation when they mixing/loading pesticide product(s) and applying pesticide solution on a single spraying day. This study investigates how pesticide usage and agricultural practices among nursery workers affect their exposure to and potential health risk of pesticides applied over a 2-month period. Ten workers from different nurseries were involved in both personal interview and questionnaire survey to collect data for exposure modelling purposes. On a single spraying day, individuals' total daily exposure to single active substances ranged from 0.002 to 0.024 mg kg-bw^{-1} day^{-1}, mainly constituted of pesticide exposure during application activities (57.3 – 99.9% of total daily exposure). The total daily exposures were assessed against the respective acceptable operator exposure levels (AOELs) for single active substances. Overall, four nursery workers had at least one active substance application that exceeded the AOEL, indicating health risk is possible. While respondents generally worn long sleeves and long pants as the basic protective measures, the exceedances were likely caused by the usage of hazardous active substance (i.e., cypermethrin) and wettable powder formulation, and improper use of gloves. Future studies can consider the influence of different nursery plants on workers' exposure to pesticides handled.

1 Introduction

A pesticide product contains at least one active substance that is formulated to kill pests or to protect against diseases. Due to large amount of pesticides handled, close contact with pesticides or the treated crops, agricultural workers have a greater risk of being exposed to pesticides and associated health effects than the general public [1]. Despite the inherent toxicity of pesticides, nurseries often rely on the heavy use of pesticides for high-quality flowers, fruits and vegetables, leading to various health risks towards non-target organisms [2].

In general, nurseries can be categorised based on plant categories including fruit plants, vegetable, ornamental plants, flower plants (floriculture), medicinal and aromatic plants, where plants are grown for planting elsewhere and/or for sale purposes. Meanwhile, horticulture is the most related branch of plant agriculture that deals with fruits, vegetables and ornamental plants. The demand for agricultural products had led to an increase in

* Corresponding author: hlwong@umk.edu.my

horticulture production, leading to intensified agricultural practices and increased usage of synthetic pesticides [3]. However, nursery plants are usually grown in confined containers unlike other agricultural areas [4]. This may cause difficulty during pesticide spraying activity, particularly for the case of multirow planting [5], while nursery workers can be exposed to pesticides via dermal and inhalation routes.

A few studies have reported pesticide related health effects due to direct and indirect exposure to pesticides applied at nurseries. A review study conducted by Pereira et al. [6] proposed that pesticide exposures in floriculture production for ornamental purposes were related with a variety of adverse health effects including genotoxicity, neurobehavioral development, congenital malformations, and reproductive disorders. A biological monitoring study conducted by Bolognesi et al. [7] on the levels of micronuclei (MN) in peripheral blood lymphocytes proposed the association between pesticide exposure and the levels of micronuclei based on 107 floriculturists and 61 controls (4.41 +/- 2.14 MN/1000 cells versus 3.04 +/- 2.14; $P<0.001$), suggesting the genotoxic risk is possible. Meanwhile, Nguyen et al. [8] proposed the close living proximity to nurseries (<75 m) as a risk factor for the increased childhood leukaemia (odds ratio (OR): 2.40; 95% confidence interval (CI): 0.99 – 5.82) and acute lymphocytic leukaemia (OR: 3.09; 95% CI: 1.14 – 5.82) based on 5788 childhood leukaemia cases and 5788 controls. To date, scarce studies had quantified non-dietary routes of exposure to and thus risks of pesticides applied by nursery workers, via exposed skin surface and respiratory inhalation.

This study investigates how pesticide usage and agricultural practices may affect nursery workers' exposure to pesticides applied and potential health risks over a 2-month period. To do so, we selected ten nursery workers who handled both mixing/loading and application activities at ten different nurseries, on a voluntarily basis. Both questionnaire survey and personal interview methods were used to collect data on the daily pesticide usage and agricultural practices, where data were analysed using the Agricultural Operator Exposure Model (AOEM) for nursery workers' total daily exposure to applied pesticide active substances across a 2-month period. Then, the estimated total daily exposures to single active substances were assessed against the respective agricultural operator exposure levels (AOELs), where any exceedance indicates health risk is possible. Study findings can be used to identify potential risk factors among the selected nursery workers.

2 Methodology

Personal interview and questionnaire survey methods were used to collect contextual information and pesticide usage from the ten selected nursery workers (August – September 2022) in Negeri Sembilan, Malaysia. Pesticide labels were also collected to gather information on model parameters including the weight of product (assuming 1 litre = 1 kg), name of active substance(s) and the respective percentage weight of weight (% w/w), and formulation type. Biopesticides like wood vinegar and emamectin benzoate were excluded from the present study. The ten selected nurseries were denoted as N01, N02, …. and N10 for ethical purposes.

In Table 1, the AOEM algorithms were used to predict nursery workers' exposure to pesticides while mixing/loading and applying pesticides, using the tank mixing/loading and high crop hand-held application algorithms respectively [9]. The AOEM can simulate pesticide exposure under field conditions via different body parts (hands, body, head) and respiratory inhalation in accordance with the total amount of active substance applied on each spraying day (TA), type of pesticide formulation (liquid, wettable powder and wettable granule), use of personal protective equipment (PPE) (i.e., protected hands and protected

body exposures), and without the use of PPE (i.e., potential hands and potential body exposures).

Table 1. AOEM algorithms for predicting pesticide exposure during mixing/loading (ML) and application (AP) activities via different body parts (hands, body and head) and respiratory inhalation.

Tank mixing/loading (ML)	**Log exposure = αlog TA + [formulation type] + constant**
Potential hands ($DE_{ML(H)}$)	Log DE_H = 0.71log TA + 0.57 [liquid] + 1.55 [wettable powder] – 0.34 [glove wash] + 2.73
Protected hands ($DE_{ML\,(Hp)}$)	Log DE_{Hp} = 0.39log TA + 0.17 [liquid] + 1.74 [wettable powder] + 1.02
Potential body ($DE_{ML(B}$))	Log DE_B = 0.71log TA + 0.24 [liquid] + 1.69 [wettable powder] + 2.87
Protected body ($DE_{ML(Bp)}$)	Log DE_{Bp} = 0.95log TA – 0.05 [liquid] + 1.99 [wettable powder] + 0.87
Head ($DE_{ML(C)}$)	Log DE_C = log TA + 0.55 [liquid] + 1.31 [wettable powder] + 1.52 [no face shield] – 1.07
Inhalation (IE_{ML})	Log IE = 0.53log TA – 0.73 [liquid] + 2.26 [wettable powder] + 0.61
High crop hand-held application (AP)	Log exposure = αlog TA + [culture] + constant
Potential hands ($DE_{AP(H)}$)	Log DE_H = log TA – 0.94 [normal culture] + 4.02
Protected hands($DE_{AP(Hp)}$)	Log DE_{Hp} = log TA – 1.26 [normal culture] + 1.90
Potential body ($DE_{AP(B)}$)	Log DE_B = 0.32log TA – 1.50 [normal culture] + 5.75
Protected body ($DE_{AP(Bp)}$)	Log DE_{Bp} = -1.79 [normal culture] + 4.24
Head ($DE_{AP(C)}$)	Log DE_C = 0.34log TA – 1.18 [normal culture] + 2.87
Inhalation (IE_{AP})	Log IE = 0.74log TA – 0.57 [normal culture] + 2.13

On a single spraying day, the estimated exposure to an active substance handled during mixing/loading activity (Exp_{ML}; mg kg-bw^{-1} day^{-1}) and application activity (Exp_{AP}; mg kg-bw^{-1} day^{-1}) were summed up to predict total daily exposure to the active substance ($Total\ Exp_{a.s.}$; mg kg-bw^{-1} day^{-1}) as follows:

$$Exp_{ML} = \frac{[(DE_{ML(H\ or\ Hp)} + DE_{ML(B\ or\ Bp)} + DE_{ML(C)}) \times DA_{ML}] + (IE_{ML} \times IA_{ML})}{BW \times CF} \quad \text{(Eqn. 1)}$$

$$Exp_{AP} = \frac{[(DE_{AP(H\ or\ Hp)} + DE_{AP(B\ or\ Bp)} + DE_{AP(C)}) \times DA_{AP}] + (IE_{AP} \times IA_{AP})}{BW \times CF} \quad \text{(Eqn. 2)}$$

$$Total\ Exp_{a.s.} = Exp_{ML} + Exp_{AP} \quad \text{(Eqn. 3)}$$

where DA is the fraction of dermal absorption. $DA_{ML}$is 0.25 or 0.75 for pesticide product containing >5% or ≤5% of active substance, respectively [10]. DA_{AP} is 0.75 for the diluted spray solution containing ≤5% of active substance. DA is 0.1 during both ML and AP activities for active substance(s) with log octanol-water coefficient (Log P) <-1 or >4 and molecular weight >500 g mol^{-1} [10]. IA is the fraction of inhalation absorption (default: 1.0), BW is the body weight of the nursery workers (kg), and CF is the conversion factor used to change unit from μg to mg (1000).

Following the exposure modelling, the estimated daily exposure to each active substance was assessed against the respective AOEL that extracted from the Pesticide Properties Databases [11]. AOEL is the regulatory limit used in pesticide authorisation process in accordance with Regulatory (EC) No 1107/2009 [12]. Any estimated daily exposure:AOEL >1.0 indicating possible health risk.

3 Results and Discussion

Table 2 shows the ten selected nurseries had nursery sizes ranged from 0.1 to 0.5 hectares (mean: 0.3 ha) and 2 to 5 spraying days (mean: 4 days) across a 2-month period. Eight of nurseries produced a variety of nursery plants (vegetable, fruit and ornamental plants) while two nurseries produced only fruit plants.

Overall, the ten selected nursery workers had body weights ranged from 40 up to 100 kg (mean: 66 kg). At work, all of them had worn long sleeves and long pants (classified as protected body according the AOEM), five of them worn plastic/rubber gloves (classified as protected hands exposure), and another five worn cotton gloves or no gloves (classified as potential hands exposure). All ten nursery workers had applied 1 – 3 pesticide products (mean: 2 products), comprising insecticides as the most commonly applied products (10 nurseries), followed by herbicides (6 nurseries) and fungicides (4 nurseries) (Table 2).

Table 2. Summary of context information collected from the ten selected nurseries.

Nursery ID	Type of Nursery	Size of nursery (ha)	Total no. of spraying days	No. of pesticide product applied				Protective measures for hands and body	Body weight (kg)
				Insecticide	Herbicide	Fungicide	Total		
NS01	Fruit	0.2	4	1	1	1	3	Plastic gloves, long sleeves & long pants	46
NS02	Variety	0.3	4	1	0	0	1	Cotton gloves, long sleeves & long pants	76
NS03	Fruit	0.2	4	1	0	0	1	Cotton gloves, long sleeves & long pants	72
NS04	Variety	0.2	4	2	1	0	3	Rubber gloves, long sleeves & long pants	55
NS05	Variety	0.5	2	2	0	0	2	No gloves, long sleeves & long pants	55
NS06	Variety	0.5	4	1	1	1	3	Rubber gloves, long sleeves & long pants	80
NS07	Variety	0.5	4	1	1	1	3	Rubber gloves, long sleeves & long pants	40
NS08	Variety	0.5	4	1	1	1	3	Rubber gloves, long	100

								sleeves & long pants	
NS09	Variety	0.1	2	1	1	0	2	Cotton gloves, long sleeves & long pants	80
NS10	Variety	0.1	5	1	0	0	1	Cotton gloves, long sleeves & long pants	60
Mean	**-**	**0.3**	**4**	**1**	**1**	**0.4**	**2**	**-**	**66**

Some of the applied products contain more than one active substance, contributing to a total of eight active substances (i.e., 4 insecticides, 3 fungicides and 1 herbicide) applied by at least one of ten selected nurseries workers, of which mancozeb and propineb were formulated as wettable powders (Table 3). According to the PPDB [11], none of the applied active substances had Log P <-1 or >4 together with molecular weight >500 g mol^{-1} while chlorpyrifos had AOEL value that recently removed from the database; thus, no risk characterisation can be performed (Table 3).

Table 3. Summary of eight active substances that applied by at least one of the ten selected nursery workers based on the collected pesticide labels and the PPDB [11].

No.	**Pesticide label**			**PPDB**		
	Active substance	**Pesticide type**	**Formulation**	**Molecular mass (g mol^{-1})**	**Log octanol- water partition coefficient at pH 7, 20°C (Log P)**	**AOEL (mg kg-bw^{-1} day^{-1})**
1.	Carbendazim	Fungicide	SC[a)]	191.21	1.48	0.02
2.	Carbosulfan	Insecticide	EC[b)]	380.5	7.42	0.005
3.	Chlorpyrifos	Insecticide	EC	350.58	4.7	None allocated
4.	Cypermethrin	Insecticide	EC	416.3	5.55	0.0025
5.	Glyphosate	Herbicide	SL[c)]	169.1	-6.28	0.1
6.	Malathion	Insecticide	EC	330.36	2.75	0.03
7.	Mancozeb	Fungicide	WP[d)]	271.3	2.3	0.011
8.	Propineb	Fungicide	WP	289.80	-0.26	0.018

[a)]SC: suspension concentrate

[b)]EC: emulsifiable concentrate

[c)]SL: soluble liquid

[d)]WP: wettable powder

Figure 1 shows the estimated total daily exposures of the ten selected nursery workers to single active substances applied ranged from 0.002 to 0.024 mg kg-bw^{-1} day^{-1} across the study period, comprising 0.1 – 42.7% of total daily exposure during mixing/loading and that of 57.3 – 99.9% during application activities. The estimated daily exposures were generally lower than 0.01 mg kg-bw^{-1}day^{-1}, with higher exposure estimates due to the use of malathion (0.024 mg kg-bw^{-1} day^{-1}; NS02) and mancozeb (0.01 mg kg-bw^{-1} day^{-1}; NS07) that formulated as wettable powders and no use of gloves for chlorpyrifos (0.013 mg kg-bw^{-1} day^{-1}, NS05) (Figure 1). Studies generally agreed that wettable powders may lead to higher level of pesticide exposure during mixing/loading [9, 12], while PPE is considered as an important safety shield against pesticide exposure [13]. While model inherent assumptions were not considered in the present study, larger number of respondents are needed to establish exposure databases and predictive models [14].

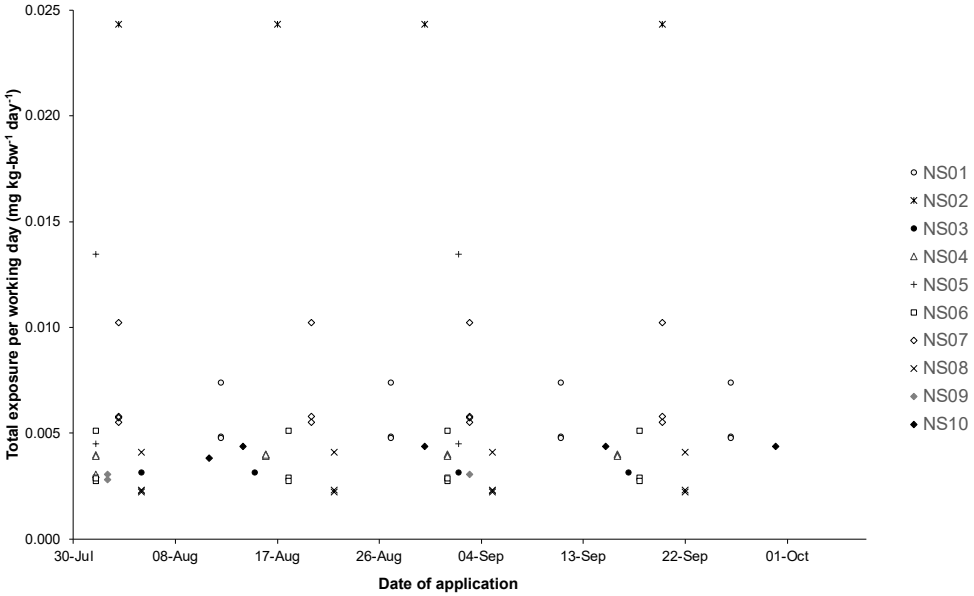

Figure 1. Estimated total daily exposure for single active substance applied by the ten selected nursery workers in August and September 2022.

Figure 2 shows four of the ten selected nursery workers had at least one application of active substance with total daily exposure larger than the respective AOEL value. While chlorpyrifos applications were excluded in risk characterisation due to none AOEL value allocated (Table 3), a total of 16 exceedances were caused by the usage of hazardous cypermethrin with relatively smaller AOEL value (0.0025 mg kg-bw^{-1} day^{-1}; Table 3). Nevertheless, it is useful to note that AOEL values are generally derived based on the oral short-term toxicity study using the most sensitive no observed adverse effect level and associated health endpoints [12].

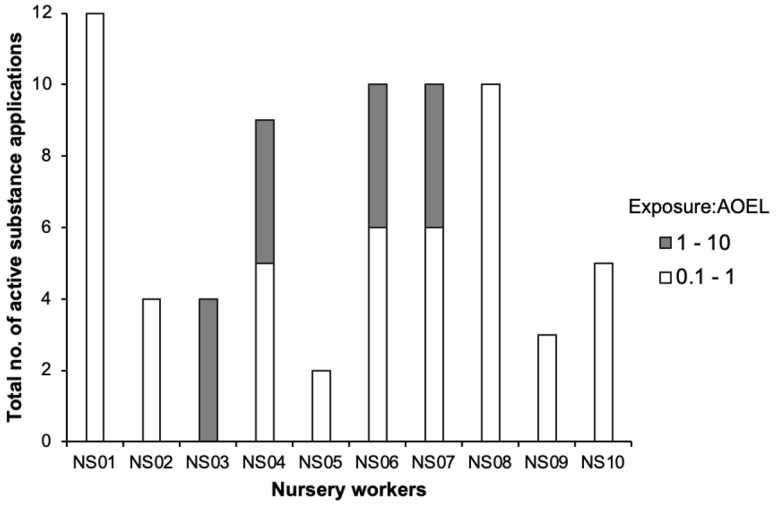

Figure 2. Ratio of the estimated total daily exposure:AOEL for single active substance applications (categorised as 0.1 – 1 and 1 – 10) among the selected ten nursery workers across the study period.

Further studies can consider the influence of different nursery plants on the usage of pesticide, the respective level of exposure and thus health risk, and the potential influences of other risk factors such as equipment and technique, working behaviour, experience, and training [12, 15]. To date, there are no pesticide use monitoring system at the national level [16], while no limits on pesticide usage available for ornamental purposes (e.g., minimum residue level for food and biosafety) where pesticide overuse is possible [6]. Therefore, more studies are required to fully understand pesticide risk among nursery workers.

4 Conclusion

This study indicates the potential pesticide risk factors among the selected nursery workers due to the use of pesticide products that formulated as wettable powders and that contained hazardous active substances, and the use of proper protective measures while handling pesticides. Study findings deem useful as the preliminary assessment on pesticide risk among nursery workers.

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