MATHEMATICAL MODELLING OF RICE FARMERS’ EXPOSURE TO PESTICIDES WITH ENDOCRINE-DISRUPTING PROPERTIES

by

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A report submitted in fulfillment of the requirements for the degree of
Bachelor of Applied Science (Sustainable Science) with Honours

**FACULTY OF EARTH SCIENCE UNIVERSITI
MALAYSIA KELANTAN**

2021

THESIS DECLARATION

I hereby declare that the work embodied in this Report is the result of the original research and has not been submitted for a higher degrees to any universities and institutions.

………………………………….

Student

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Date : 12 December 2020

I certify that the report of this final year project entitled Mathematical Modelling of Rice Exposure to Pesticides with Endocrine-Disrupting Properties by Saiful Ikhwan Bin Nor Arifin, matric number E17A0106 has been examined and all correction recommended by examiners have been done for the degree of Bachelor of Applied Science (Sustainable Science) with Honors Faculty of Earth Science, University Malaysia of Kelantan

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ACKNOWLEDGEMENT

Firstly, I would like to give this recognition to the Faculty of Earth Science (FSB), Universiti Malaysia Kelantan for allowing me to take the Final Year Project as one of my undergraduate course requirements.

Secondly, highest appreciation and deepest gratitude to my supervisor, Dr Wong Hie Ling for her guidance and assistance, patience, encouragement and support in helping me throughout the completion of my thesis.

I also would like to appreciate the support of my fellow undergraduate students for the support and finally the biggest appreciation to my parents for their endless support and encouragement throughout my study in this course.

Mathematical Modelling of Rice Farmer's Exposure To Pesticides With Endocrine Disrupting Properties

ABSTRACT

This study investigates rice farmers' exposure to pesticides with endocrine-disrupting properties by using mathematical modelling for non-dietary routes of exposure via dermal and inhalation. A total of 13 rice farmers were estimated for their exposure to single active substances applied on a daily basis from June to September 2019, using the Agricultural Operator Exposure Model and the WHO Generic Risk Assessment Model for Indoor and Outdoor Space Spraying of Insecticides and to predict pesticide exposures during mixing/loading and application activities. Then, the estimated exposures to applied active substances on a spraying day were assessed against the no observed adverse effect level of endocrine-disrupting properties for the risk level using hazard quotient (HQ) method. In this study, the 13 selected rice farmers applied 4 – 14 pesticide products with a total of 6 – 19 active substances applied across a whole cropping season. Overall, the estimated exposures were influenced by the use of wettable powder formulation during mixing/loading activities, with overestimation of the risks indicates the need to consider the use of PPE in exposure modelling. There were two applications with HQ values larger than 1 (1.7 and 46.4) because of the use of high toxicity active substances, namely deltamethrin and lambda-cyhalothrin. Study findings indicate the mathematical modelling can be used to monitor pesticide uses and exposures in rice fields, with further refinement deems necessary when data become available.

Pemodelan Matemmatik Kepada Petani Terhadap Pendedahan Racun Serangga Yang Mempunyai Sifat Gangguan Endokrin

ABSTRAK

Kajian ini menyiasat pendedahan petani padi kepada racun perosak dengan sifat-sifat endokrin yang mengganggu dengan menggunakan pemodelan matematik untuk laluan bukan pemakanan pendedahan melalui dermal dan penyedutan. Seramai 13 petani beras dan dianggarkan pendedahan mereka terhadap bahan aktif tunggal yang dipohon setiap hari dari Jun hingga September 2019, menggunakan Model Pendedahan Pengendali Pertanian dan Model Penilaian Risiko Generik WHO bagi Penyemburan Ruang Dalam dan Luar Racun Serangga dan meramalkan pendedahan racun perosak semasa kedua-dua aktiviti percampuran/pemunggahan dan aplikasi. Kemudian, anggaran pendedahan kepada bahan aktif yang digunakan pada hari penyemburan telah dinilai terhadap tahap tiada kesan buruk yang diperhatikan sifat-sifat yang mengganggu endokrin untuk tahap risiko menggunakan kaedah Hazard Quotient (HQ). Dalam kajian ini, 13 petani beras terpilih menggunakan 4 – 14 produk racun perosak dengan sejumlah 6 – 19 bahan aktif digunakan pada keseluruhan musim tanaman. Secara keseluruhan, anggaran pendedahan dipengaruhi oleh penggunaan formulasi serbuk basah semasa aktiviti pencampuran/pemunggahan, dengan penggunaan PPE perlu dipertimbangkan dalam pemodelan. Terdapat dua aplikasi dengan nilai HQ yang lebih besar daripada 1 (1.7 dan 46.4) kerana nilai NO(A)EL yang sangat kecil untuk deltamethrin dan lambda-cyhalothrin. Dapatan Kajian ini menunjukkan pemodelan matematik boleh digunakan untuk memantau kegunaan racun perosak dan pendedahan dalam bidang padi, dengan penetapan lanjut dianggap perlu apabila data tersedia.

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LIST OF ABBREVIATIONS

AOEM	Agricultural Operator Exposure Model
EUROPOEM	European Predictive Operator Exposure Model
PPE	personal protective equipment
NOAEL	no observed (adverse) effect levels
EPA	Environmental Protection Agency
ED	Endocrine disrupting
EDC	Endocrine Disrupting Chemicals
DREAM	Dermal Exposure Assessment Method
WHO	World Health Organization
WHO-PEAM	WHO-predicted exposure assessment models (WHO-PEAM)
ML	Mixing/Loading
AP	Application
PPDB	Pesticide Properties Database

LIST OF SYMBOLS

[]	Bracket
=	Equal
>	Greater Than
<	Less Than
x	Multiply
-	Minus
%	Percentage
bw	Body Weight
Kg	Kilogram
Mg	Milligram
L	Litre

CHAPTER 1

INTRODUCTION

1.1 Background of study

Rice is the staple food that is mainly grown in Southeast Asian countries including Malaysia. Rice comes from the grain in paddy plants, which are almost always protected by pesticides from various crop diseases and pests. Despite the efforts in ensuring high crop yield and food security, incorrect use of pesticides can lead to adverse effects for both human health and the environment (Damalas & Koutroubas, 2016). In pesticide safety, toxicity refers to the capacity of a substance to bring illness or in the worst case scenario (death) while risk is a combination between toxicity and exposure factors (Damalas & Koutroubas, 2016). There are three major types of pesticide toxicities and the respective guideline values for dermal and inhalation exposures as indicated by three signal words displayed on the product labels, namely poison, caution and warning (Table 1.1). Acute toxicity can occur from a single incident exposure. Subchronic toxicity can occur from repeated incidents of exposure over several weeks or months and chronic toxicity occurs due to repeated incidents of exposure for many months or years (Damalas & Koutroubas, 2016).

Table 1.1: Categories of pesticide toxicities and their signal word and dermal and inhalation guideline values (Damalas & Koutroubas, 2016).

Categories	Signal Word	Dermal guideline values (mg kg^{-1})	Inhalation guideline values (mg L^{-1})
I-Highly toxic	poison	0 – 200	0 – 0.2
II-Moderately toxic	warning	200 – 2000	0.2 – 2.0
III-Slightly toxic	warning	2000 – 20000	2.0 – 20
IV-Relatively non-toxic	warning	20000+	20+

Paddy farmers are mainly exposed to pesticides via two major non-dietary routes of exposure, namely dermal contact and respiratory inhalation. The levels of exposure and associated risk are influenced by the duration of exposure, and the level of toxicity for single active substances. Pesticides can cause acute and chronic health effects upon human exposure such as irritation to the eyes, nausea and also diarrhea and also includes endocrine-disrupting effects (Chitra et al., 2006).

According to the National Institute of Environmental Health Science (2019), endocrine disruptors can be defined as the chemicals that can mimic or interfere human body’s hormones and it can be natural or man-made. Endocrine disruptors may lead to the potential of altering the normal function of the human body system (Annette et al., 2015). It can change the body’s normal endocrine functions including the level of hormone, which may in turn significantly affect the developmental and biological effects. Endocrine disruptors can be found in everyday products including plastic bottles, food containers and in pesticides.

Pesticide exposure modelling is a method in which the risk of pesticide exposure is predicted by the use of mathematical models and/or algorithms. Over time, a range of pesticide exposure models have been developed to estimate pesticide exposure and health risk, particularly in developed countries like those in the United States and European Union. For examples, Tier I Rice model from the US EPA, Agricultural Operator Exposure Model (AOEM) and European Predictive Operator Exposure Model (EUROPOEM). These models can be used as an integral part of pesticide registration and authorisation procedures (Kennedy, 2015).

1.2 Problem statement

Farming is among the most hazardous occupations because farmers are most likely to be exposed to a wide range of occupational and health risks due to their pesticides-related work (Kurina et al., 2015). In paddy fields, paddy farmers can be exposed to high levels of pesticides and thus health risks due to a range of factors, including the use of knapsack sprayer, the working behavior involving the use of personal protective equipment (PPE) and the environmental factors under actual field conditions.

In developing countries, knapsack sprayers are indispensable agricultural equipment for pesticide applications particularly in small-scale farming systems, mainly due to farmers' affordability and the ease of sprayer-handling (Sinha et al., 2018). In Malaysia, farmers commonly use knapsack sprayers because of lower maintenance cost and the ease of operating. However, the use of knapsack sprayer may cause higher levels of pesticide exposure compared to the use of mechanical application equipment such as trucks and aerial sprays in the developed countries (Phung et al., 2012). Of a particular concern, higher exposure can be expected due to the direct dermal contact of farmers with pesticides contaminated paddy water while walking in the rice plots.

1.3 Objectives

1. To assess the level of paddy farmers' exposure to pesticides with potential endocrine-disrupting properties across a whole cropping season.
2. To identify the major drivers of farmers' exposure to pesticides in mitigating pesticide risk in rice fields

1.4 Scope of study

This study is limited to paddy farmers' exposure to pesticides via non-dietary routes of exposure comprising the dermal and inhalation routes during pesticide mixing/loading and application activities. The most relevant mathematical models or algorithms are used to predict pesticide daily exposure and associated endocrine-disrupting effects for a total of 13 paddy farmers using pesticide application data that collected from June to November 2019, taking into the total amount of active substances applied on a working day, formulation types and the use of personal protective equipment (PPE). The data that were used are secondary data and some of the application dates needed to be removed because of the missing data.The predicted exposures are then assessed against the no observed (adverse) effect levels (NO(A)ELs) for endocrine-disrupting properties for the level of risk based on the HQ method.

1.5 Significance of study

This study is important to investigate the levels of exposure and thus risk of endocrine-disrupting effects among paddy farmers. Study findings can be used to identify major drivers of pesticide exposure in rice fields, which can be used to improve pesticide risk mitigation measures. This study can be used to identify major gaps of knowledge and major implications for current regulatory risk assessment.

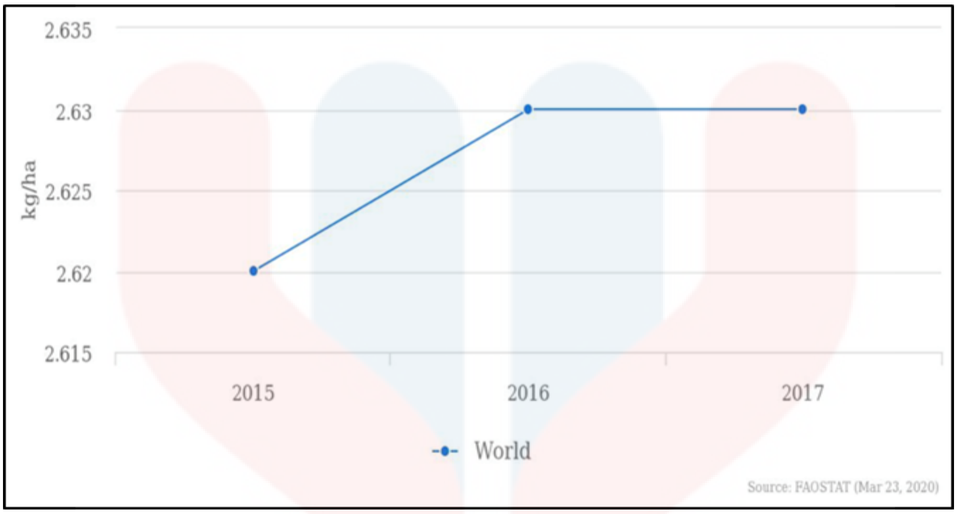
CHAPTER 2

LITERATURE REVIEW

2.1 Pesticide use in paddy field

Pesticide can be described as a single substance or mixture of substances that are used to prevent, destroy, repel and mitigate any pests and crop diseases, including those acting as a plant regulator, defoliant, desiccant and any kind of nitrogen stabilizer (EPA, 2018). In modern agriculture, pesticides are often used extensively to increase the yield quality and quantity while ensuring the global food security due to its cost-effectiveness.

Globally, there are approximately 2 million tonnes of pesticides applied in agricultural activities every year (Sharma et al., 2019), that accounted for around 2.6 kg pesticides applied per hectare between 2015 and 2017 (Figure 2.3). Pesticides are important in the agriculture sector, including paddy plantation as a major crop grown in Southeast Asia (How et al. 2015).



Source: FAOSTAT (Mar 23, 2020)

Figure 2.3 Average pesticide usage per area of cropland across the world (FAOSTAT, 2020)

There are a variety of exposure factors due to the use of knapsack sprayer, including the properties of active substances, formulation types, types of sprayers, the use of PPE, working behavior and also environmental conditions. Gender and age of the knapsack sprayer operator also play an important role in the factors which lead to the risk of pesticide exposure to the operator when handling the knapsack sprayer. Most of the pesticides sprayer were male sprayers (96.7 %) and majority of operators were between 19-28 years of age with only few of them are older than 50 years old of age (Bhattacharjee et al., 2013)

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2.2 Pesticide related endocrine disrupting effects

Endocrine-disrupting (ED) chemicals are compounds in which it alters the normal functioning of endocrine systems that may cause disease or deformity in organisms and their offspring Despite the risks, pesticides are still used widely for agriculture, public areas, homes and gardens. Concerns on Endocrine Disrupting Chemicals (EDCs) are increasing because of their potential impacts on the environment, wildlife and human health (Mckinlay et al., 2008).

Pesticides with endocrine-disrupting properties can cause many health effects, including infertility, breast, testicular cancer, low sperm quality and reduced sperm function (Sifakis et al., 2017).

2.3 No Observed Adverse Effect Level (NOAEL) for endocrine-disrupting properties

According to Dorato and Engeldhart (2005), no observed adverse effect level (NOAEL) is defined as the highest experimental point which has no adverse effect observed. NOAEL is used to predict the adverse events in humans in non-clinical safety testing, identifying the toxic effects in humans and also determining and predicting the dose response pattern by using animal toxicological studies. Nevertheless, the existing toxicological studies for the derivation of NOAELs for dermal and inhalation routes are generally lacking for most pesticides. Therefore, the NOAELs are typically derived using oral toxicity studies and extrapolated for different routes of exposure when needed (Salem and Katz, 2006).

2.4 Mathematical modelling of pesticide exposure in rice fields

Mathematical modelling is often used to predict or estimate human exposure to pesticides due to agricultural activities in developed countries. In rice fields, Baharuddin et al. (2011) proposed the use of the Dermal Exposure Assessment Method (DREAM) to estimate farmers' exposure to pesticides based on inventory and evaluation methods which consist of 33 variables that focused on the effect of dermal exposure, chemical characteristics and protective clothing as a reference for quantitative value of the determinants.

Phung et al. (2019) also proposed the use of the World Health Organization (WHO) Guidelines for Generic Risk Assessment Model for Indoor and Outdoor Space Spraying of Insecticides (WHO 2018) in estimating the paddy farmers' exposure to pesticides applied in rice fields using mathematical algorithms. The study indicated that mathematical modelling can be used to assess pesticide risk in rice fields in developing countries.

CHAPTER 3

MATERIALS AND METHOD

3.1 Pesticide exposure during mixing/loading activities

This study used the secondary pesticide application data for 13 selected paddy farmers that collected from June to November 2019 in Kelantan (1, 5 and 7 farmers from Pasir Puteh, Pasir Mas and Tanah Merah, respectively) as the key input parameter in the Agricultural Operator Exposure Model (AOEM). The AOEM is used to predict occupational exposure to pesticides during mixing/loading tasks because it reflects the current scientific knowledge (Groβkopf et al., 2013). This model is developed to predict acute and longer-term exposure based on the 95th and 75th percentiles. In this study, median exposure algorithms are used to predict the exposure on a daily basis via tank mixing/loading activity (Table 3.1; Wong et al., 2018). The exposure scenario accounts for dermal and inhalation exposures and the total exposure scenarios were used to estimate pesticide exposure with no PPE use via hands and body exposures.

Table 3.1: Median exposure algorithms to predict daily exposure to pesticides while mixing/loading pesticides (Groβkopf et al., 2013; Wong et al., 2018)

TANK ML	$log\ exposure\ = log\ TA$ + [formulation type] + constant
Total hands	$log\ DE$ $_{\text{ML(H)}}$ = 0.71$log\ TA$ + 0.71[liquid]+ 1.31[WP]- 0.34[glove wash] + 2.73
Protected hands	$log\ DE$ $_{\text{ML(Hp)}}$ = 0.39 · $log\ TA$ + 0.71[liquid]+ 1.31[WP] + 1.74[WP]+ 1.02
Total body	$log\ DE$ $_{\text{ML(B)}}$ = 0.71· $logTA$ + 0.24[liquid]+ 1.69[WP] + 2.87
Protected body	$log\ DE$ $_{\text{ML(Bp)}}$ = 0.95 · $logTA$ - 0.05[liquid]+ 2.26[WP] + 0.87
Head	$log\ DE$ $_{\text{ML(C)}}$ = $log\ TA$ + 0.55[liquid]+ 1.31[WP] + 1.56 [no face shield] – 1.07
Inhalation	$log\ IE$ $_{\text{ML}}$ = 0.53 · $log\ TA$ - 0.73[liquid]+ 2.26[WP] + 0.61

Note: DE: dermal exposure, IE: inhalation exposure, HP: hands protected, B: total body, Bp: body protected, C: head, WP: wettable powder formulation

$$Exposure_{ML} = \frac{\left((DE_{ML(H\ or\ Hp)} + DE_{ML(B\ or\ Bp)} + DE_{ML(c)})\times DA_{ML}\right)+(IE_{ML}\times IA_{ML})}{BW\ \times UF} \qquad (1)$$

where BW is the body weight of the operator (kg), DA_{ML} is the dermal absorption factor and IA_{ML} is the inhalation absorption factor. Dermal absorption is adjusted based on proportions of active substance(s) in the formulated products with the factors of 25 and 75 % for >5 and δ5 % of active substance(s), respectively (EFSA, 2012). Meanwhile, inhalation absorption is assumed to be 100% for the worst-case scenarios (Lee et al., 2018). *UF* is the unit conversion factor from μg to mg. The physicochemical properties can be obtained from the Pesticide Properties Database (PPDB, 2020).

3.3.1 Dermal exposure

The model algorithm of the WHO (2018) is used to predict the inhalation exposure during application (IE_{MAX}, mg kg bw^{-1} day^{-1}) as follows:

$$S_{ys}D_{Twa} = \frac{VLH \times C_{spray} \times PPE \times EF \times Abs_p}{BW \times AT} \tag{2}$$

where $S_{ys}D_{Twa}$ is the maximal daily systemic dose (mg kg bw^{-1}), VLH volume of liquids on hands which is 8.2 mL because it is the maximum amount of the liquids on the hands of an adult. C_{spray} is the amount of concentration of the active ingredient in the spray which derived from concentration of the active ingredient in the formulation and its dilution for spraying (mg mL^{-1}). PPE is the protection provided by the PPE in which is assumed for this study is 1.0 for lax standard scenario. Lax standard scenario is where the hands are exposed to the spray during application and spray liquid during washing and maintaining of the spraying equipment. EF can be described as the exposure frequency of the rice paddy farmers. Abs_p is the dermal absorption during spraying. BW is the body weight of the rice paddy farmers and AT is averaging time of the farmers in spraying.

3.3.2 Inhalation exposure

The model algorithm of the WHO (2018) is used to predict the inhalation exposure during application (IE_{MAX}, mg kg bw^{-1} day^{-1}) as follows:

$$IE_{MAX} = \frac{TAR \times RPE \times BV \times ED \times Abs_D}{HSC \times BW} \tag{3}$$

where $SysI_{MAX}$ is the maximal daily systemic dose (mg/kg bw), TAR is the target application rate (mg active substance per m^2), RPE is the protection provided by the respiratory protective equipment (0.1 for the guideline scenario and 1.0 for the lax standard scenario). BV is the breathing volume (m^3/h) and ED is the exposure duration (hours). Abs_D is the absorption from the respiratory tract, HSC is the height of spray cloud and BW is the body weight of the farmer.

3.3.3 Total exposure during on a single spraying day

The total exposure on during an application is the summation of dermal and inhalation exposure as follows:

$$Total\ daily\ exposure\ =\ DE_{MAX} + IE_{MAX} \qquad (4)$$

3.3.4 Risk characterization

The estimated total exposures for individual active substances are assessed based by the respective no observed (adverse) effect levels (NO(A)ELs) for endocrine-disrupting toxicities. The NO(A)ELs are extracted from the established toxicological databases, namely EFSA Draft Assessment Report and Renewal Assessment Report, the Joint meeting on Pesticide Residues of the International Programme on Chemical Safety, the Hazardous Substances Data Bank of TOXNET, the Integrated Risk Information system, the EPA Endocrine Disruptor Screening Program Tier I Screening detection and associated data values (Wong et al., 2019).

Then, the level of risk for single active substance is calculated based on the hazard quotient (HQ) method:

$$HQ = \frac{Total\ daily\ exposure}{NO(A)EL\ for\ endocrine\ disrupting\ effects} \qquad (5)$$

where HQ>1 indicates endocrine-disrupting risk is possible.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Pesticide application in rice fields

Table 4.1 shows the basic information of the 13 selected rice farmers as represented by codes ranging from RF01 to RF13 and their usages of pesticide products and active substances in different crop grown areas across the whole cropping season. In general, the 13 selected rice farmers applied a total of 4 to14 pesticide products (median: 5 products) and 6 to 19 active substances (median: 7 active substances) in different sizes of grown areas (1.6 – 20.2 ha). The median of the total grown area of the crop was also considered because the farmers are facing major exposure during the spraying of the pesticide, drift from the neighboring fields and also the contact with the pesticide residue on the crop (Damalas & Koutroubas, 2016).

Table 4.1: Basic Information on the rice farmers

Rice Farmer (RF)	Total number of pesticide products	Total number of active substances applied	Total grown area (ha)
RF01	8	11	8.1
RF02	6	8	1.6
RF03	6	7	2.6
RF04	4	6	20.2
RF05	4	6	4.0
RF06	10	11	7.3
RF07	5	7	4.0
RF08	5	7	16.2
RF09	5	7	2.8
RF10	5	7	2.4

Table 4.1 (continued)

RF11	5	8	4.9
RF12	7	11	4.5
RF13	14	19	4.5
MEDIAN	**5**	**7**	**4.5**

Table 4.2 shows 32 active substances applied by at least one of the 13 selected rice farmers based on the information on pesticide labels and their physicochemical properties, approval status, type of the pesticide (herbicides, fungicides and insecticides) in accordance with the PPDB (2020), and their NOAEL values for endocrine-disrupting toxicity that extracted from the toxicological databases. Overall, there were 15 of 32 active substances not approved for use based on the PPDB (2020), with the highest number of pesticide types applied were insecticides (16 active substances), followed by herbicides and fungicides (11 and 5 active substances, respectively). This is because insecticides are much easier to purchase and required by the farmers especially in Asian countries (Gianessi, 2014). According to the PPDB, all the 32 applied active substances were scientifically and/or technically evaluated by European Food Safety Authority (EFSA) before the use of active substance is approved by EU (European commission, 2020).

Table 4.2 also shows three active substances with confirmed endocrine-disrupting properties (i.e. deltamethrin, fenitrothion and flubendiamide) and seven active substances with possible endocrine-disrupting properties with NO(A)EL values between 0.001 and 300 mg/kg bw^{-1} day^{-1}. That is, deltamethrin can cause weak estrogenic activity while fenitrothion can cause competitive binding to androgen receptors and the inhibition of estrogens action (Mnif et al., 2011). Meanwhile, flubendiamide and its endocrine-disrupting properties require more thorough search for the respective NOAEL value.

Table 4.2: List of 32 active substances and their status of approval, pesticide type and endocrine-disrupting properties based on the PPDB (2020) and their NO(A)ELs for endocrine-disrupting toxicities

Active substance		**PPDB (2020)**		**NOAEL for endocrine-disrupting toxicity (mg kg bw^{-1} day^{-1})**
	Status of approval	**Pesticide type**	**Endocrine-disrupting properties**	
2,4-D butyl ester (2,4-D)*	Approved	Herbicide	?	15
azoxystrobin	Approved	Fungicide	-	-
aentazone sodium (bentazone)*	Approved	Herbicide	x	-
bispyribac-sodium	Approved	Herbicide	-	-
buprofezin	Approved	Insecticide	x	-
cartap hydrochloride	Not Approved	Insecticide	-	-
chlorantraniliprole	Approved	Insecticide	x	-
chlorpyrifos	Not Approved	Insecticide	?	5.0
cyhalofop-butyl	Approved	Herbicide	-	-
cypermethrin	Approved	Insecticide	?	6.25
deltamethrin	Approved	Insecticide	✓	0.001
difenoconazole	Approved	Fungicide	x	31.3
ethoxysulfuron	Not approved	Herbicide	x	-
fenitrothion	Not approved	Insecticide	✓	30.0
fenobucarb	Not approved	Insecticide	x	-
fenoxaprop-p-ethyl	Approved	Herbicide	x	-
fentin acetate	Not approved	Fungicide	?	-
fipronil	Not approved	Insecticide	?	-
flubendiamide	Approved	Insecticide	✓	-
glyphosate isopropylamine	Approved	Herbicide	x	300
glyphosate-monoammonium (glyphosate)*	Approved	Herbicide	?	300
imazapic	Not approved	Herbicide	x	-
imazapyr	Not approved	Herbicide	-	-

imidacloprid	Approved	Insecticide	-	-
lambda-cyhalothrin	Approved	Insecticide	x	-
MCPA dimethylammonium (MCPA)*	Not approved	Insecticide	-	-
MCPA iso octyl ester (MCPA)*	Not approved	Insecticide	-	-
pymetrozine	Not approved	Insecticide	x	-
thiamethoxam	Not approved	Insecticide	x	-
thiobencarb	Not approved	Herbicide	-	-
tricyclazole	Not approved	Fungicide	-	-

Note:

"*": Active substance not found in PPDB (2020). Alternative active substance is referred to.

"?": Possibly, status not identified

"-": No data found

"x": No, known not to cause a problem

"✓": Yes, known to cause a problem

4. 2 Estimated pesticide exposures on single spraying days

Figures 4.1 and 4.2 show the estimated exposure for the 13 rice farmers during mixing/loading and application activities, respectively. In general, all the farmers had larger dermal exposures ($3.83x10^{-3}$ - 54.2 mg kg bw^{-1} day^{-1}) compared to inhalation exposures ($1.03x10^{-5}$ - 5.31 mg kg bw^{-1} day^{-1}) during both activities across the whole cropping season.

During mixing/loading pesticides, RF06 had the highest total estimated exposure for both dermal and inhalation during mixing/loading activities with $6.42x10^{-1}$ and $3.39x10^{-2}$ mg kg bw^{-1} day^{-1}, respectively (Figure 4.1). This is because wettable powder can lead to larger exposure compared to wettable granule and liquid (Groβkopf et al., 2013).

During application, RF08 had the highest dermal exposure (54.2 mg kg bw^{-1} day^{-1}) whereas RF06 had the highest inhalation exposure (5.31 mg kg bw^{-1} day^{-1}). In Figure 4.2, RF08 have the highest exposure for dermal because RF08 applied more pesticide. Moreover, exposure for a farmer that apply pesticide for days or weeks in a season is higher compared to once a year (Damalas & Eleftherohorinos, 2011).

Figure 4.3 indicates the total estimated exposure expressed in percentage for comparison between the 13 selected rice farmers. The relatively larger estimated exposures during mixing/loading for RF03, RF06 and RF11 were caused by the use of wettable powder formulations, that contributed to the largest inhalation exposure for RF06. Meanwhile, the WHO (2018) algorithms estimate larger exposure than the AOEM (2013) algorithms. While assuming all farmers did not wear any PPE, this may lead to greater risk estimates than the actual risk under field conditions in this study.

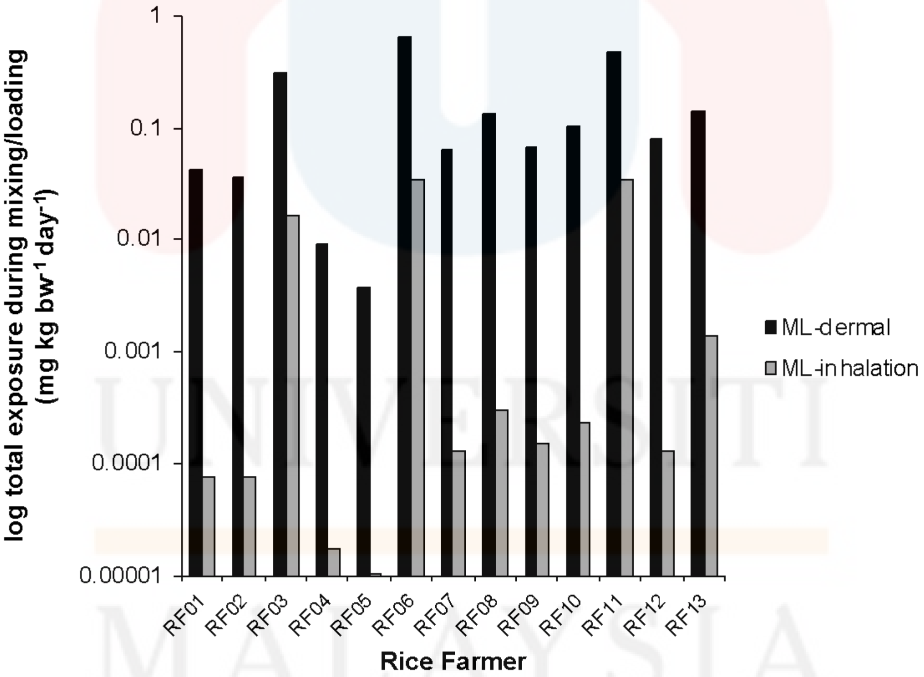

Figure 4.1: Total estimated exposures using the AOEM (2013) algorithms during mixing/loading activities across the whole cropping season

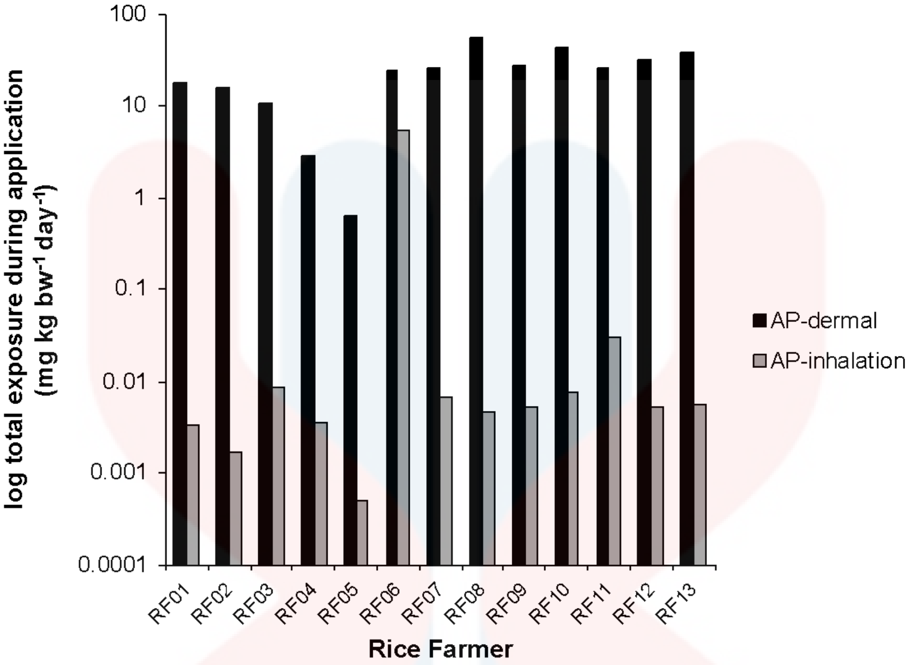

Figure 4.2: Total exposures during application activities that estimated using the WHO (2018) algorithms for the whole cropping season

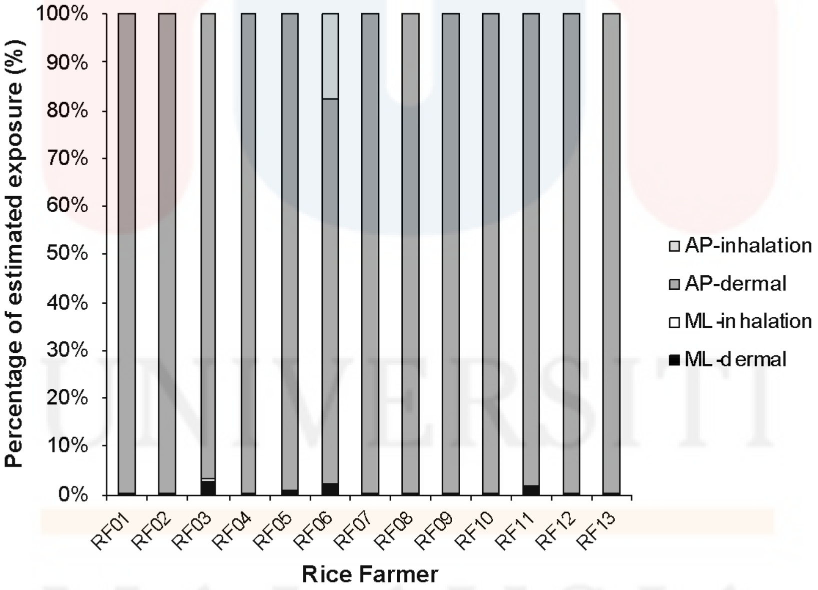

Figure 4.3: Percentage of estimated total exposures for the 13 selected rice farmers across the whole cropping season

4.3 Risk level for endocrine-disrupting properties

Figure 4.4 shows the classification of estimated HQs for single spraying days that had at least one active substance applied by the 13 selected rice farmers across the whole cropping season. Based on the analysis, RF06 had estimated HQ values larger than 1 because of the use of active substance deltamethrin and lambda-cyhalothrin with very small NO(A)EL for endocrine-disrupting properties (0.001 and 0.7 mg kg bw^{-1} day^{-1}, respectively), indicating its possibility to cause high toxicity. Deltamethrin is a substance that can cause deterioration in male reproductive system (Killian et al., 2007).

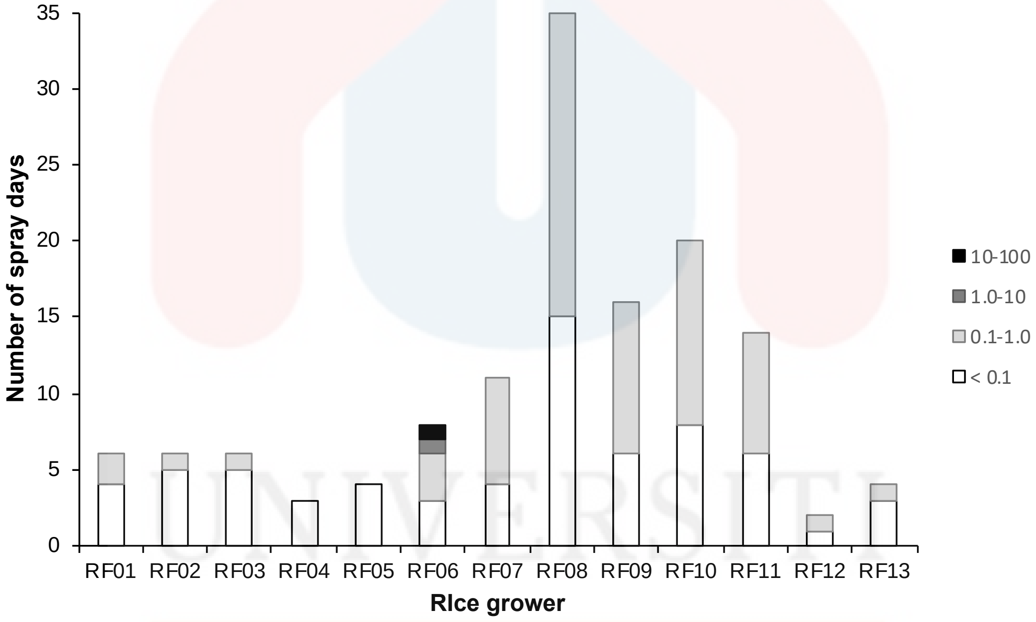

Figure 4.4: Estimated hazard quotients for single spraying days that had at least one active substance applied by the 13 selected rice farmers

4.4 Limitations of the study

Some limitations were encountered in this study including the use of default values in modelling when data are not available, including the lax standard scenario assuming all rice farmers were not wearing any PPE in WHO (2018) model algorithms, but in real situation, some of the farmers wore PPE during mixing/loading and application activities. Thus, future studies can consider the actual use of PPE in pesticide risk assessment. In addition, some pesticide information and labels were missing where the use of alternative products may affect the accuracy of result analysis. There is also a need to improve the data collection method where, missing pesticide application data were excluded from the present study.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study uses mathematical modelling to determine the levels of exposure of rice farmers to pesticides with endocrine-disrupting properties and thus the risk level. Study findings indicate pesticide exposures in rice were influenced by the formulation type such that larger exposures were due to the use of wettable powder during mixing/loading and relatively larger amount of pesticides handled on single spraying days. Meanwhile, the use of PPE among some farmers needs to be adjusted using protection factors to reflect the actual exposure conditions. Overall, the risk of exposure to active substance with endocrine-disrupting properties was due to the very small NOAEL value for deltamethrin, indicating very toxic active substances should be discontinued from accessibility on the markets. Study findings indicate further improvement is required to increase the accuracy of mathematical modelling as potential tool in pesticide regulatory to mitigate pesticide risks in rice fields.

5.2 Recommendations

It is highly recommended that the future study should collect basic information on the rice paddy farmers and the field conditions such as the use of actual usage data rather than the use of recommended application rate. Secondly, future studies can also consider the use of other mathematical models to consider the dermal contact with pesticide contaminated paddy water using the US EPA Tier 1 Rice Model and that of dermal contact with pesticide residues on treated crop using the EFSA (2014) algorithms. Study findings also indicate that rice farmers may require improved awareness of the importance of wearing PPE during mixing/loading and during application activities in mitigating pesticide risks in rice fields.

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