



Dermal Distributions of Pesticide in Agriculture Occupational Settings: A Scoping Review

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KEYWORDS

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ABSTRACT:

Introduction: Agricultural workers are frequently exposed to pesticides and agrochemicals through dermal contact, making dermal exposure assessment a crucial aspect of occupational health and safety.

Objectives: This scoping review explores the different patterns of dermal distribution in agricultural settings and the key determinants influencing exposure levels. Understanding dermal distribution is essential for agricultural workers to improve their awareness of body parts that are at a higher risk of pesticide exposure and to prioritize protection for these areas.

Methods: A search on three databases was done from 2006-2025 using the term occupational, dermal or skin and pesticide exposure. This review will explore on differences in pesticide dermal distribution and the determinants.

Results: Across multiple studies examining dermal pesticide exposure, the lower legs and hands consistently showed the highest exposure particularly in application and mixing/loading tasks with exposure patterns influenced by task type, plant height, and spraying method, such as tractor use. Studies comparing total dermal exposure across various determinants consistently showed that application tasks, taller plant heights, motorized sprayers, and the applicator job role were associated with the highest exposure levels.

Conclusions: This scoping review reveals that hands and lower legs are the most pesticide-exposed body parts in agriculture, underscoring the need for targeted, accessible protective measures especially in low-resource settings to reduce health risks.

1. Introduction

Pesticide was defined by the United States Environmental Protection Agency (US EPA) as any substance that is intended to prevent, destroy, repel or mitigate any pest [1]. Human exposure to pesticides is categorized into three main types: occupational, environmental, and dietary exposures [2]. The most common type of pesticide exposure is occupational. Occupational exposure of pesticides to workers is varied; for instance, agricultural workers are exposed to open plantation fields or greenhouses, exterminators in house pests and factory workers in pesticide industry manufacturing. Occupational exposure is especially significant in epidemiology, as it can occur at levels hundreds of times higher than those experienced by the general population, potentially leading to an increased

risk of certain diseases [3]. Moreover, they also pose significant health risks, causing injury and illness among farmers and farm workers [4].

Agriculture contributes most of the pesticide exposure to the population. In the United States, about 75% of pesticide usage is in agriculture, placing agricultural workers at a significantly higher risk of pesticide exposure than non-agricultural workers between 1998 – 2005 [5]. Among agriculture workers, about 99% of them considered exposed to pesticides, based on a survey in the United States Agricultural Health Study (AHS) [6]. Similar pattern was also shown in other countries, which about 87.6% in Australia, 68% in France and 63% in Norway [7,8]. A similar pattern was shown in lower- and middle-income countries, where a large prevalence of



pesticide use was noted among agriculture workers, with 87.15% in Ethiopia [9].

Dermal exposure played the most important exposure route compared to others. Agricultural workers are primarily exposed through dermal contact [10]. In both mixing/loading and application tasks, inhalation exposure only accounted for less than 1% of the total exposure for agricultural workers [11]. Some studies are even below the detection level [12]. This was consistent even in different agriculture settings and active ingredients. Among open-field farmers, dermal exposure significantly exceeded inhalation exposure, accounting for 93.9-100% of the total exposure [13]. In greenhouse farmers, inhalation exposure constituted only 0.05-0.07% of the total potential operator exposure [14]. Pesticide exposure can lead to both short-term and long-term health effects, depending on the level of exposure and the length of time an individual is exposed [15,16].

Hence, the usage of PPE was crucial to minimize the exposure to the workers. Using personal protective equipment (PPE), selecting the appropriate type of PPE, and following safe handling practices can help minimize the risks associated with pesticide exposure [16,17]. However, the estimate usage of PPE among workers are still unsatisfactory, where it was estimated that about 71.1% workers worn long sleeve trousers, 66.1% worn long sleeve T-shirt and just 40.5% worn gloves [18]. There are multiple factors associated with PPE usage such as health literacy, awareness, income, social norms, attitude, and access to information [17,18].

Several studies had pointed out that communities with higher income had better pesticide safety practices such as wearing full PPE [19,20]. The high cost of personal protective equipment (PPE) poses a significant barrier for farmers in many developing countries, limiting their ability to access and utilize proper protective gear. While some farmers are aware of pesticide safety practices, economic constraints often prevent them from adhering to these safety measures [15,18]. Hence, identifying these high-risk areas allows for more effective protective strategies, such as prioritizing the use of gloves, long sleeves, and face shields, especially in situations where full-body personal protective equipment (PPE) is not available [21]. Furthermore, accurate data on dermal pesticide distribution contributes to improved risk

assessments, helping refine exposure models and safety protocols to better protect agricultural workers [16].

2. Objectives

Therefore, this review aims to identify the patterns of pesticide distribution among agricultural workers and examine the factors associated with exposure. Understanding these patterns is crucial in determining which body parts are at the highest risk of contamination and in developing targeted protective strategies.

3. Methods

The scoping review was carried out following the JBI methodology for scoping reviews and was reported in accordance with the PRISMA-ScR checklist (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) [22,23].

Eligibility Criteria

The scope of this review was established using the PCC framework (Population, Concept, and Context) as the basis for eligibility criteria [22]. The concept encompassed a broad range of non-invasive methodologies for assessing dermal exposure in agricultural occupational settings, along with the specific type of pesticide used. The studies must also at least mention the difference between two body parts exposed during occupational activities. Studies on acute injuries due to pesticide exposure were not included. Studies that used invasive methods to obtain dermal measurement such were also removed. The population in this review were workers who were directly involved in handling pesticides in agricultural setting. The study will be excluded if the population only involves bystanders or exposure due to living nearby the pesticide exposure. The pesticide exposure must occur during occupational activities.

Types of Sources

This review did not include qualitative or narrative-style reviews, editorials, conference abstracts, book chapters, or any documents from the grey literature. The literature search was restricted to the past 20 years, covering the period from 2006 to 2025. Furthermore, due to logistical limitations, only articles published in English were considered.



Search Strategy

An initial search was carried out on the Science Direct to examine the keywords found in the titles, abstracts, and index terms of relevant articles. The literature was explored iteratively to capture a wide range of studies. The comprehensive search strategy implemented in PubMed targeted article titles, abstracts, and keywords, with the search conducted on 1st February 2025:

- Primary topic: (Skin OR dermal OR derm)
AND (Exposure OR loading OR uptake)

- AND topic: (Occupational OR Workplace)
AND (Pesticide)

A similar strategy was applied to Science Direct and Web of Science search strategy. Both searches were confined to the past 20 years (2006-2025) and limited to English-language articles with full-text availability, focusing exclusively on primary research (i.e., excluding reviews). The articles retrieved from both databases were then combined and duplicates were removed.

Study Selection and Data Charting

Reviewers independently screened the retrieved titles and abstracts to identify potentially relevant articles. Subsequently, they obtained and assessed the full text of the selected papers. Any discrepancies were resolved through discussions, and if necessary, A third reviewer was consulted to reach a consensus. The total number of reviews meeting the inclusion criteria was recorded.

A data extraction chart was utilized to collect relevant information. The extracted data included details such as the author, year of publication, country of origin, study aims, population characteristics, country setting, research methodology, measurement tools, and reported outcomes. Additional variables, including study design, objective, study location, study population, sample size, relevance, and key findings, were identified upon a thorough review of the full text. The findings from each article were systematically tabulated, and these results were further analysed and discussed in the discussion section.

Ethics for the study

Ethics for the study was approved by the Medical Research Ethics Committee Universiti Malaysia Sabah with approval code JK Etika 4/(24) 15.

4. Results

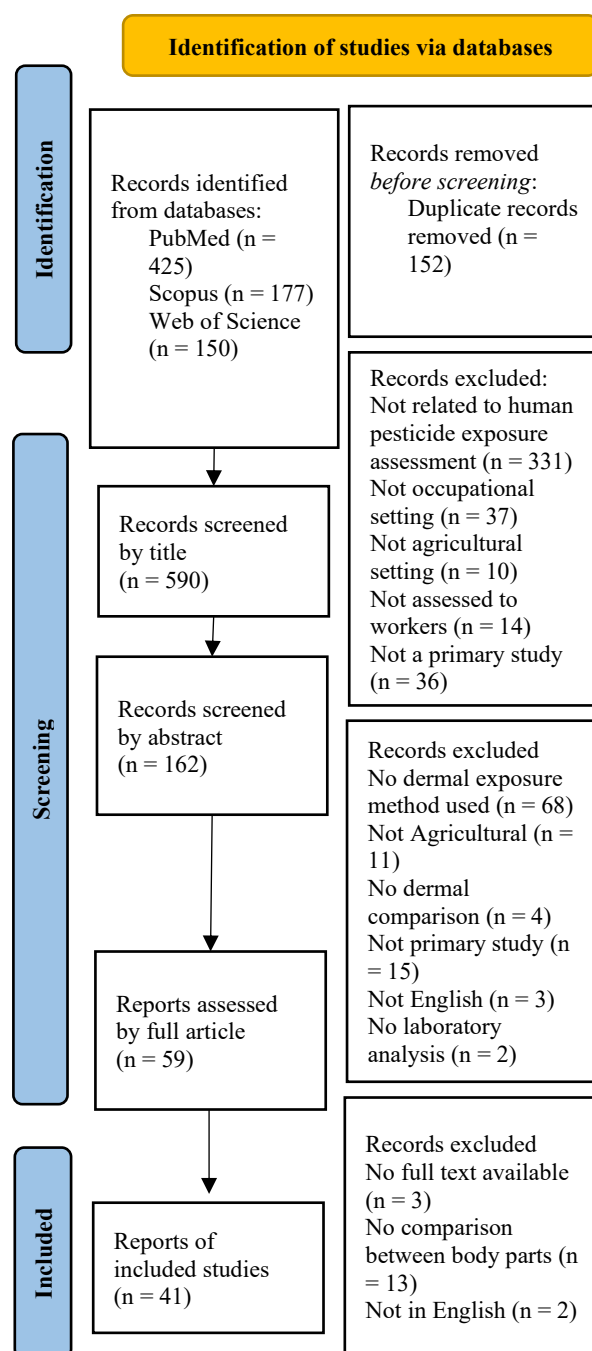


Fig.1 : PRISMA flowchart for dermal distributions of pesticide in agriculture occupational settings



Table 1: Study and dermal sampling details of all qualifying occupational pesticide exposure studies (n = 41)

Author, Year	Unit	Dermal distribution	Author, Year	Unit	Dermal distribution
Chuanjiang et al, 2024 [37]	mg/kg a.i.	Hand and lower leg were statistically significant higher compared to other body parts (p value <0.05) No significant differences between climate regions	Lee et al, 2022 [29]	% of Body parts	Mixing/Loading: Hand (90.4), Front Torso (1.4), Back (1.3), Lower Leg and Rt Thigh (1.0), Pelvis (0.7), Head (0.1) Total: 0.6mg Application: Pelvis (27.3), Upper Leg (16.5-16.3), Lower Leg (11.5-11.1), Front (10.2), Back, Forearm (1.8-2.1), Back (1.7), Upper arm (0.7-0.6), Hand (0.2) Total: 28.6mg
Lee et al, 2024 [12]	µg	Mixing/Loading [Chlorothalonil]: Hands (1645), Chest (356), Back (329), Rt Upper arm (177), Pelvis (148), Rt shin (103), Lt upper arm (101), Others (<100) Total: 3325 Mixing/Loading [Flubendiamide]: Hands (140), (Chest, Back, Upper arm, Forearm, Pelvis, Buttocks, Thigh, Shin (1.25)) Total: 173 Application [Chlorothalonil]: Pelvis (202608), Rt thigh (88341), Buttocks (77245), Chest (56403), Lt thigh (55404), Lt shin (54843), Others (<50000) Total: 647765	Lee et al, 2022 [30]	µg	Mixing/Loading: Hands (153.9), Chest (8.9), Other Body parts (0) Total:0.163mg Application: Rt shin (5621.8), Lt shin (5425.5), Chest (4832.5), Pelvis (3822.2), Rt Upper arm (1725.1), Rt forearm (1271.0), Rt Thigh (1134.0), Lt Upper arm (954.6), Lt Forearm (864.3), Hands (496.3) Total 32.3mg
Lee et al, 2024 [12]	µg	Application [Flubendiamide]: thigh (15803), Lt thigh (15038), Rt shin (13667), Hands (6772), Chest (6509), Lt shin (5859), Others (<5000) Total:93360	Aprea et al, 2021 [27]	Geometric mean (ng / cm ²), Hand wash µg	Spraying: Calf (4.37-13.9), Shin (6.43-10.2), Ant thigh (5.05-10.2), Post thigh (4.71-5.41), Others (<5.0) Total: 1.89 Hand wash: (0.063-0.351) Stapling: Ant thigh (11.7), Shin (6.57), Calf (4.20), Right forearm (3.53), Post thigh (1.50), Others (<1.0) Total:15.4 Hand wash: (0.240-2.01)
Boulanger et al, 2023 [25]	µg	Mixing/Loading: Hands (587.9), Chest (80.8), Forearms (74.5), Thighs (72.9), Legs (71.9), Back (40.5), Arms (9.2)	Bureau et al, 2021 [26]	Percentage of body parts	Application, hands accounted for 49%, Mixing/loading 45%, Spraying 39% and cleaning 38%. Lower legs accounted for 15 to 20% for each task. On harvest days, hand was the most contaminated (38%), followed by forearm, trunk and lower legs (15% each).
Lari et al, 2022 [58]	µg (Mean)	Without PPE: Hand (17.014), Chest (3.755), Face (3.47), Upper and lower arm (2.885), Upper and lower leg (0.519)	Bootsikeaw et al, 2021 [43]	mg/h (GeoMean)	Total Leg (0.82), Back (0.06), Total Arm (0.05), Forehead (0.01) No significant difference between type of spraying device (Manual vs Motorized vs Battery Pump vs High Pressure)
Costa et al, 2022 [59]	ng/cm ²	With PPE: Hand (0.407), Upper and lower arm (0.111), Face + Neck (0.059), Chest (0.054), Upper and lower leg (0.017)			
		Tasks [Application and seedling] For outer layer, Rt and Lt Forearm was the highest, followed by chest, and lastly by bilateral thigh			



An et al, 2019 [47]	µg	Electric backpack sprayers: Back (503), Cap (497.42), Lt Lower Leg (363.45), Rt Hand (358.52), Lt Hand (355.59), Rt Forearm (287.17), Rt Lower Leg (216), Chest (172.68), Others (<170) Total Dermal Exposure: 3613.63 µg	0.5m [Backpack]: Rt shin (14.42), Lt shin (10.77), Chest (10.66), Rt thigh (9.22), Right forearm (3.77), Lt thigh (3.25), Others (<3.0)
		Stretcher-mounted sprayers: Rt Hand (964.69), Lt Hand (707.53), Lt Lower Leg (646.78), Rt Lower Leg (539.5), Lt Thigh (449.57), Cap (396.53), Rt Thigh (282.46), Others (<280) Total Dermal Exposure: 5654.28 µg	0.5m [Handheld]: Rt shin (58.23), Rt thigh (57.29), Lt shin (49.57), Lt thigh (51.06), Lt forearm (0.38), Others (<0.35)
Li et al, 2019 [43]	mg/kg a.i	<80cm: Lower leg (333), Upper leg (89.8), Back (61.9), Chest (29.7), Rt glove (21.4), Lt glove (20.1), Others (<5.0)	1m [Backpack]: Lt shin (44.52), Lt thigh (44.03), Rt shin (43.78), Rt thigh (43.69), Chest (7.53), Rt forearm (7.26), Others (<5.0)
		80-130cm: Forearm (222), Lower leg (207), Upper leg (202), Lt glove (167), Rt glove (165), Upper arm (152), Others (<150)	1m [Handheld]: Chest (50.64), Left forearm (29.17), Right forearm (27.97), Right arm (27.21), Left arm (17.62), Others (<4.0)
Konthonbut et al, 2019 [45]	µg/hr	130cm: Upper arm (358), Forearm (330), Upper leg (225), Back (224), Chest (200), Rt glove (188), Others (<180)	Motorized: Upper leg (9.29), Lower leg (7.27), Back (6.42), Forearm (1.86), Upper arm (1.63), Face (0.66)
		Highest plant was three times higher than the lowest, p value <0.05	Battery Pump: Upper leg (2.72), Lower leg (2.87), Upper arm (0.46), Forearm (0.34), Back (0.25), Face (0.15)
Noh et al, 2019 [46]	µg	Motorized: Legs (38.79), Arms (10.91), Back (3.41), Chest (2.82), Head (1.21)	Imidacloprid [Forward]: Upper body (1420.05), Lower body (321.88), Hands (315.30)
		Without PPE: Arm (76.59), Leg (52.67), Feet (38.79), Glove (5.89), Head (1.74)	Imidacloprid [Backward]: Upper body (119.74), Lower body (39.90), Hands (27.92)
Konthonbut et al, 2019 [45]	µg/hr	Battery Pump: Legs (17.9), Arms (2.56), Back (1.26), Chest (1.08), Head (0.18)	Allura Red [Forward]: Upper Body (2006.47), Lower body (480.87), Hands (465.41)
		With PPE: Leg (17.18), Feet (Boot) (8.93), Arm (5.63), Glove (3.77), Head (0.49)	Allura Red [Backward]: Upper Body (151.23), Lower body (72.16), Hands (22.67)
Rincon et al, 2018 [48]	µg	Arm, Head and Chest dermal exposure were significantly higher in Motorized compared to Battery Pump (p<0.05)	Spray Gun: Lt Foot (83.61), Rt Foot (79.07), Back (19.23), Thigh Rt Back (13.92), Lower Lt Leg (11.13), Head (10.95), Lower Rt Leg (10.72), Others (<10.0)
		Outer clothes: Leg (989.40), Chest (51.55), Hip (43.44), Arm (28.96), Hands (19.39)	Knapsack-stop: Rt Foot (58), Lt Foot (56.46), Rt Upper Arm (33.51), Lt Upper Arm (24.39), Rt Thigh 22.74, Lower Lt Leg (21.66), Chest (20.34), Lt Forearm (13.98), Lt Thigh (12.38), Others (<10.0)
Ilyassou et al, 2018 [49]	µg/cm ²	Inner clothes: Leg (41.54), Hands (19.39), Chest (7.81), Arm (5.32), Hip (5.00)	Knapsack Non-stop: Chest (304.17), Head (282.99), Lt Foot (220.44), Rt Foot (207.56), Rt Forearm (111.57), Rt Thigh (64.28), Lt Thigh (57.02), Lt Lower Leg (43.30), Others (<50.0)
		Mahaboonpeeti et al, 2018 [48]	µg/h (Median)
Cao et al, 2018 [60]	mg/kg a.i. (Mean)		



Gao et al, 2013 [51]	mg/kg	<80cm [Inexperienced]: Lt Glove (3467.72), Lower leg (400.05), Upper Legs (149.55), Back (74.41), Others (<30)	Hines et al, 2011 [53]	µg (Geometric Mean)	Hand (230), Rt Forearm (31), Rt Thigh (24), Lt Forearm (22), Lt thigh (21), Rt Shoulder (11), Chest (10), Lt Shoulder (9.9), Rt Lower Leg (8.9), Lt Lower Leg (7.1)
		[Experienced]: Torso (106.95), Upper Legs (102.07), Lower Legs (84.66), Back (46.40), Others (<40)			Airblast sprayer lead to about 4-5 times more dermal exposure compared to handheld sprayer (p<0.05)
		80-130cm [Experienced]: Lt Glove (229.75), Rt Glove (218.35), Forearm (206.76), Torso (185.13), Upper Legs (174.34), Back (103.25), Lower Legs (62.97), Others (<10)			Ramos et al, 2010 [54]
>130cm [Inexperienced]: Lt Glove (3286.07), Forearm (333.51), Upper Arms (311.21), Lower Legs (251.07), Torso (236.94), Upper Legs (171.45), Back (85.29), Socks (25.96), Cap (24.47), Others (<20)	Deltamethrin: Mix/load (1.55), Application (0.83), Re-entry (0.13)				
Moon et al, 2012 [62]	Proportion of b parts	[Experienced]: Forearm (326.31), Torso (311.52), Rt Glove (268.55), Upper Arms (257.36), Upper Legs (215.85), Lt Glove (191.66), Cap (160.80), Back (146.85), Others (<100)	Apra et al, 2009 [64]	ng/cm ²	On skin: Arm (17.17), Anterior thigh (3.24), Post thigh (2.06), Forearm (1.78), Calf (1.46), Others (<1.5)
		Mixing/Loading: hand 55.8-99% of total exposure compared to forearm			Cloth: Ant thigh (23.20), Chest (9.19), Forearm (6.63), Upper Back (1.02)
Fenske et al, 2012 [41]	mg/cm ² /hour	Application: Thigh, Upper arm, Chest, Hand, Shin	Nuyttens et al, 2009 [42]	mL	Spray gun: Lt Foot (8.42), Rt Foot (3.43), Lt Lower Leg (2.80), Lt Upper arm (1.32), Rt Lower Leg (1.23), Others (<1.0)
		Engineer: Leg (0.149), Arms (0.116), Torso (0.029)			Spray lance forward: Lt Foot (13.86), Lt Lower Leg (8.58), Rt Foot (6.99), Rt Lower Leg (5.43), Rt Upper Leg and Rt Hand (2.15), Others (<2.0)
Lesmes-Fabian et al, 2012 [63]	PDE ratio (10 ⁻⁶)	Technician: Legs (1.62), Torso (0.332), Arms (0.246)	Spray lance backward: Rt Hand (1.95), Lt Foot (1.61), Rt Foot (0.92), Lt Lower Leg (0.57), Others (<0.50)		
		Applicator: Legs (30.1), Arms (6.96), Torso (1.73)	Trolley: Lt Hand (0.82), Rt Hand (0.63), Lt Foot (0.47), Rt Foot (0.25), Others (<0.2)		
Lesmes-Fabian et al, 2012 [63]	PDE ratio (10 ⁻⁶)	HD Nozzle: Rt Leg front (172), Lt Leg Dorsal (149), Lt Leg Front (139), Rt Leg Dorsal (116), Lower Back (72.3), Rt Thigh Front (39.4), Lt Thigh Dorsal (32.5) Rt Thigh Dorsal (32.0), Other (<30)	Fumimatic: Lt Hand (1.63), Rt Hand (1.19), Lt Foot and Head (0.11), Others (<0.1)		
		LD Nozzle: Rt Leg Front (220), Lt Leg Front (208), Lt Leg Dorsal (188), Rt Leg Dorsal (182), Upper Back (67.7), Rt Arm Dorsal (43.9), Rt Thigh Dorsal (43.0), Others (<43)	Fumicar: Rt Hand (1.30), Lt Hand (1.02), Head (0.42), Rt Foot (0.35), Rt Upper Leg (0.23), Lt foot (0.21), Others (<0.2)		



Jurewicz et al, 2009 [65]	Geometric mean ratio	Gloves (2.47), Chest + arm (0.61)
Lebailly et al, 2008 [34]	mg	Mixing/Loading [Rear-mounted]: Glove (83.1), Forearms (30.0), Chest (17.0), Lower Legs (16.3), Thighs (11.3), Other (<5) [Trailer sprayer]: Glove (37.7), Forearm (8.2), Lower Legs (4.9), Chest (3.6), Thigh (1.6), Other (1.0) Application [Rear-mounted]: Glove (36), Forearm (7.0), Chest (4.8), Thigh (4.2), Other (<3.0) [Trailer Sprayer]: Glove (21.6), Lower legs (2.7), Chest (1.7), Others (<1.5)
Baldi et al, 2006 [36]	% body parts	Application [Tractor only]: Hands (49), Head (17.3), Legs (16.0), Others (<10.0) Mixing/Loading [Tractor only]: Hands (56.2), Forearm (13.0), Legs (12.3), Head (10.3), Others (<10.0) Median total contamination [Tractor]: 40.5mg Vineyard workers: Hands (43.3), Legs (18.4), Trunk (14.4), Others (<10.0) Backpack sprayer: Hands (43.9), Arms (21.4), Legs (15.6), Head (10.6), Others (<10.0) Median total contamination [Backpack]: 68.8mg Median total contamination [Vineyard]: 1.3mg
Kuye et al, 2007 [32]	Percentage to Whole body	Mixing/Loading: Hands (90), Feet (70), Torso + Arms + Legs (10) Application: Hands (80), Feet (60), Torso + arms + Legs (20), Face (10)
Choi et al, 2006 [13]	mg/h (mean)	Thigh (12.01), Shin (7.83), Arms (7.55), Hands (6.26), Chest (5.05), Others (<5.0)
Hughes et al, 2006 [66]	mL/h (mean)	Rt shin (24.33), Rt lower leg (16.93), Lt Upper arm (7.5), Back (7.31), Rt Hand (7.26), Others (<6)

The review found 41 studies. Initially, 152 duplicates were removed from multiple databases. Other than that, several studies were excluded due to language, non-occupational, dermal exposure not specifically measured. Only 41 studies were chosen and can be categorized based on type of tasks, type of farm and spraying equipment. The search strategy generated a total of citations, all sourced from electronic database searches. Among these, were duplicates, leaving a set of unique study references. Additionally, relevant references were identified, and their full texts were retrieved and reviewed. Consequently, studies were excluded, while those meeting the review's inclusion criteria were included, as illustrated in Figure 1.

Study Variation Types and Sources

There are substantive variations observed between studies, which generally can be categorized into study objective and level of exposure. Hence, comparing different dermal exposure between different studies was difficult. For instance, the differences of the study objective were type of active ingredient, type of farm, spraying device used, type of tasks involved, and body part assessed. The differences of variables were shown in Table 1.

This review encompassed 15 countries, with the majority of studies originating from Asia (20 out of 41), followed by Europe (13 out of 41), Africa (4 out of 41), North America (1 out of 41), and South America (3 out of 41). Regarding active ingredients, most studies examined various types of pesticides. Specifically, six studies focused solely on chlorpyrifos, while imidacloprid was investigated in three studies. Additionally, chlorantraniliprole and glyphosate were each examined



in two studies. Other studies assessed different combinations of pesticides. In terms of occupational tasks, 39 out of 41 studies evaluated exposure during pesticide application, whereas two studies focused exclusively on harvesting tasks. Among the 39 studies, 18 assessed only application tasks, 11 examined both application and mixing/loading tasks, five investigated application, mixing/loading, and cleaning tasks and other five were application with other type of tasks.

Spraying devices utilized in the studies were categorized into vehicle-based and handheld/backpack devices. Seven studies employed vehicle-based spraying devices, while 32 relied on handheld or backpack sprayers. Two studies did not utilize any spraying devices, as they focused exclusively on re-entry and harvesting exposure. Regarding dermal exposure assessment methods, 17 studies implemented the whole-body dosimeter technique, whereas the remaining 24 studies employed the dermal patch method. For hand dermal exposure assessment, eight studies did not evaluate hand exposure, 23 used glove sampling, nine employed the handwashing technique, and one utilized skin wiping. In terms of farm type, six studies assessed exposure in greenhouse-based farms, two focused on non-food farms (such as gardens and ornamental plant cultivation), and the remaining 33 studies were conducted in food-based farms.

The variation in pesticides, farm types, and application or work methods examined in the studies could have provided valuable insights if quantitative exposure data had been reported consistently. However, this was not the case. Differences in exposure levels were influenced by factors such as the sampling methods used, units of measurement, sample analysis techniques, and the specific body parts assessed. For example, five studies quantified dermal exposure based on the percentage of body surface area contaminated, while one study used the Potential Dermal Exposure ratio. Additionally, the majority of studies reported exposure levels in units of milligrams (mg), milliliters (mL), or micrograms (μg), but with varying derivations. For instance, three studies expressed exposure as $\mu\text{g}/\text{cm}^2$, relating pesticide concentration to body surface area, while four studies used either mg/hour or $\mu\text{g}/\text{hour}$ to quantify pesticide exposure over the duration of task performance. Consequently, the exposure values reported across studies are not directly comparable due to differences in unit types and calculation methods.

Dermal Exposure Body Parts Comparison Within Studies

Since dermal measurement data could not be compared across studies, the analysis focused on identifying potential exposure patterns within individual studies based on body part, farm job, and other work factors. Similar patterns were then explored in other studies. Within each study, exposure levels were compared across all measured body parts to determine which had the highest exposure. Even within each study, several studies categorized the samples based on different determinants such as type of tasks or average plant height and compare between each body parts. Additionally, results were examined to see if similar findings emerged in other studies of the same farm job. Specifically, the body part with the highest average potential dermal exposure relative to the others measured in the same study was identified.

Within each study, the stratification of samples were varied with several studies compared between different tasks or plant height. Comparing all studies, lower legs had the highest potential dermal exposure compared to other body parts in at least one of the determinants studied (24/41) and followed closely by hand with (20/41). However, it should be noted that 8 studies did not measure hand dermal exposure. Other than that, arm had (6/41) studies with highest potential dermal exposure in at least one of the determinants studied, followed by chest with (4/41), pelvis with (2/41) and back with (1/41).

For the determinants, there were specific patterns can be observed. There were 14 studies that categorized and compared the body parts-based type of tasks [11,24-35]. From these studies, 12 studies compared application and mixing/loading, one study compared application versus stapling, and another study compared re-entry versus harvest. From this application versus mixing/loading studies, 11 out of 12 studies found that hand had the highest dermal exposure in mixing/loading tasks compared to other body parts. The other 1 study has combination of few body parts (Torso, upper and lower legs), which had much higher body surface area compared to hands [34]. From these 12 studies, for application, the highest body parts dermal exposure were varied, with 6 studies with hand the highest (6/12), followed by (5/12) for lower legs, 2/12 for pelvis and



1/12 for back. Pelvis and Lower leg were the highest for Chlorothalonil and Flubendiamide respectively in Moon et al study, whereas hand was the highest for apple and lower leg the highest for other type of plants in application tasks in Choi et al study [11,32]. There were 18 studies that assessed application tasks only. From these studies, 14 of the studies had lower legs (or one of its parts) as the highest dermal exposure in at least one of the stratification [12,36-49]. This was followed by hand with (5/18), chest with 4 studies, arm with 3 studies and back with 1 study.

Apart from type of tasks, there were 4 studies done comparing the height of plants and dermal distribution of pesticide exposure, each with different level of specific height comparison. 3 out of 4 of the studies had lower leg as the highest dermal distribution for the lowest height in the study's comparison. For the highest plant height in comparison, 2 of the studies had hand as the highest, 1 had upper arm and another had lower leg as the highest dermal distribution [38,43,49,50].

In these studies, there are 7 studies that used tractor as at least one of the methods of spraying. From these studies, 6 out of 7 had hand as the highest dermal pesticide distribution [25,33-35,51,52], whereas lower leg had only 1 of the study as the highest dermal exposure [30].

Total Dermal Exposure Comparison Based on Determinants

The next category of within-study comparisons focused on research that assessed multiple determinants and reported total body potential dermal exposure. Since total body exposure is particularly relevant for epidemiological studies, these comparisons examined exposure levels across different determinants such as type of tasks, spraying devices, plant height and others.

A total of 12 studies have compared dermal exposure levels across at least two occupational tasks [11,24,25,28-35]. Among these studies, 11 studies found that application task demonstrated the highest level of dermal exposure relative to mixing/loading task. Only 1 study found that mixing/loading task was higher compared to application tasks [53]. Additionally, four studies specifically examined the impact of plant height on total dermal exposure. The findings from all four studies consistently indicated that total dermal exposure increased as plant height increased [38,43,49,50]. Two

studies comparing motorized versus battery pump spraying device, which found that motorized spraying device had significantly higher total dermal exposure compared to battery pump sprayer [44,48]. One study investigated the difference in exposure between different job, and found that applicator had the highest dermal exposure, followed by technician and engineer [40].

5. Discussion

This review examined existing literature on dermal monitoring to identify trends and occupational factors that may influence dermal pesticide exposure among farm workers. A key finding was the considerable variation observed across studies measuring exposure for the same agricultural tasks. This variation was categorized into differences in study focus and reporting, as well as differences in exposure levels, with the former posing the greatest challenge and restricting meaningful data comparisons to within individual studies.

This review examined occupational factors relevant to dermal pesticide exposure assessment in epidemiological research and identified areas requiring further investigation to determine whether and how these factors influence exposure levels. Initial within-study comparisons assessed potential dermal exposure by analysing measurements across different body regions to identify those with the highest relative exposure. These findings were then compared with results from other studies investigating the same agricultural tasks to evaluate consistency. The analysis suggested that specific body regions may be more susceptible to higher levels of potential dermal exposure.

Farmers' hands and lower legs experience the highest levels of pesticide dermal exposure due to direct contact during mixing, loading, and application processes. When farmers prepare pesticide solutions, they often handle concentrated chemicals, increasing the risk of spills and splashes. Since the hands are the primary point of contact with pesticide containers and application equipment, they are disproportionately exposed. Even minor leaks, drips, or residue on gloves or bare skin can lead to significant contamination [54].

The lower legs experience higher pesticide exposure than other body parts due to their constant contact with contaminated surfaces, pesticide runoff, and lack of protective clothing. As farmers walk through pesticide-



treated fields, their lower legs repeatedly brush against residue-covered crops and soil, leading to continuous pesticide transfer onto the skin and clothing. Additionally, pesticides tend to drip and run off crops, accumulating near the ground, which increases deposition on the lower legs compared to upper body regions like the arms or chest [15,54]. Additionally, pesticides tend to drip and run off crops, accumulating near the ground, which increases deposition on the lower legs compared to upper body regions like the arms or chest [55].

Additionally, pesticide application using handheld equipment, such as knapsack sprayers, results in droplets encountering exposed body parts, particularly the hands and lower legs, especially in the absence of protective measures. During spraying, pesticide droplets can drift or splash onto exposed body parts, especially the hands and lower legs. The lower legs are at high risk due to pesticide runoff from crops, soil contact, and direct exposure when working in treated fields. In certain agricultural tasks, such as weeding or transplanting, farmers frequently kneel or walk through pesticide-treated areas, further increasing dermal absorption [54,56].

One of the key limitations of the reviewed studies was the restricted statistical association between exposure determinants and specific body parts. In this review, comparisons were based solely on the highest proportion of dermal exposure observed across different body regions, rather than comprehensive statistical analyses. Additionally, variability in body part measurements across studies further complicated comparisons. For example, some studies measured left and right limbs separately, while others applied different criteria for head coverage assessments. Given the significant variation among studies, it is recommended that future research provide raw exposure data to facilitate more flexible comparisons across different analytical approaches. Furthermore, exposure determinants should be reported with greater detail, including variables such as exposure duration, job type, measurement units, monitoring devices, and specific tasks performed, to enhance the reliability and comparability of findings across studies.

6. Conclusion

This scoping review highlights that hands and lower legs are the most exposed body parts to pesticides in

agricultural occupational settings. Understanding these dermal exposure patterns is crucial for developing effective protective measures. By recognizing the differences in exposure levels across body parts, agricultural workers can implement targeted protective strategies, such as wearing gloves, long sleeves, and facial coverings, even in the absence of full-body PPE. This finding is particularly relevant for lower-income communities where access to comprehensive protective equipment may be limited. Strengthening awareness and accessibility to practical protective measures can significantly reduce pesticide-related health risks among agricultural workers.

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