ISSN: 3067-8366
Research Article
Journal of Environmental Science, Sustainability, and Green Innovation

The Dermatologic Impact of Pesticide Exposure in Agricultural Workers: A Review of Cutaneous Risk and Occupational Disparities Across the Americas

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Submitted: 12 May 2025 **Accepted:** 19 May 2025 **Published:** 23 May 2025

https://doi.org/10.63620/MKJESSGI.2025.1013

Citation: *Parga, A. D. (2025). The dermatologic impact of pesticide exposure in agricultural workers: A review of cutaneous risk and occupational disparities across the Americas. J Environ Sci & Sustain & Green Innov, 1(2), 01-07.*

Abstract

Background: *Agricultural workers are routinely exposed to pesticides that can induce a wide range of dermatologic conditions. These include acute irritant reactions, allergic contact dermatitis, pigmentary changes, chronic skin barrier disruption, and occupational skin cancers.*

Objective: *This review synthesizes existing literature on the dermatologic effects of pesticide exposure among agricultural and migrant laborers in the Americas.*

Methods: *A literature review of studies from 2000 to 2025 was conducted using PubMed, Scopus, and occupational health databases, with emphasis on dermatologic outcomes, occupational practices, and systemic disparities.*

Results: *Pesticide-induced skin conditions include irritant and allergic contact dermatitis, chemical burns, hyperpigmentation, chloracne, and cutaneous malignancies. Risk is compounded by inadequate protective equipment, low regulatory enforcement, and poor healthcare access in rural and migrant populations.*

Conclusion: *Pesticide exposure is a preventable cause of dermatologic disease among agricultural workers. Improved surveillance, education, and policy reform are critical to reducing dermatologic harm in these vulnerable communities.*

Keywords: Pesticide Exposure, Agricultural Workers, Occupational Dermatology, Contact Dermatitis, Skin Cancer, Environmental Health Disparities

List of Abbreviations

- **PPE:** Personal Protective Equipment
- **ICD:** Irritant Contact Dermatitis
- **ACD:** Allergic Contact Dermatitis
- **BCC:** Basal Cell Carcinoma
- **SCC:** Squamous Cell Carcinoma
- **PCBs:** Polychlorinated Biphenyls
- **NMSC:** Nonmelanoma Skin Cancers
- **AHR:** Aryl Hydrocarbon Receptor
- **CHW:** Community Health Worker

Introduction

Pesticide exposure remains a pervasive occupational and environmental hazard across the Americas, disproportionately affecting agricultural workers and rural populations. The dermal route represents a primary pathway of absorption, given the direct handling of pesticides and inadequate use of personal protective equipment (PPE) [1, 2]. Dermatologic manifestations range from irritant and allergic contact dermatitis to pigmentary disorders, chloracne, and increased risk of cutaneous malignancies [3-5]. In Latin American contexts such as Costa Rica, Brazil, and Argentina, studies have shown that pesticide applicators and farmworkers experience significantly elevated rates of eczema, itchy rashes, and photosensitive eruptions, often compounded by high ultraviolet radiation exposure and systemic chemical absorption [6-8]. Several pesticide classes, organophosphates, pyrethroids, dithiocarbamates, and glyphosate-based herbicides, have been implicated in both acute and chronic skin pathology. Chlorpyrifos and carbaryl, for instance, have been associated with inflammasome activation and DNA damage in keratinocytes, implicating them in the pathogenesis of inflammatory dermatoses and melanoma [9, 10]. Glyphosate formulations containing surfactants such as POEA have demonstrated cutaneous toxicity via immune and oxidative stress pathways, often culminating in psoriasis, contact dermatitis, or Koebner phenomenon in susceptible individuals [11, 12]. Additionally, occupational exposure to arsenic-based herbicides and other heavy metals used in pesticide formulations has been associated with a markedly increased risk of squamous cell carcinoma, basal cell carcinoma, and cutaneous melanoma, particularly in individuals relying on private well water or lacking adequate PPE [13, 14]. Importantly, emerging literature highlights the intersection of pesticide exposure with social determinants of health, particularly in marginalized rural and Indigenous communities. In rural Mexico, over half of applicators using paraquat, captan, and glyphosate reported acute dermatologic symptoms, burning, itching, and irritation, due to lack of training, poor regulatory oversight, and frequent mixing of incompatible agents [15]. Similarly, in Central American populations, farmworkers and their children showed significant dermal and respiratory symptoms correlated with elevated urinary metabolites of mancozeb, pyrethroids, and chlorpyrifos [5, 6]. These findings underscore the need for multidisciplinary approaches that integrate dermatologic surveillance with toxicologic, immunologic, and policy-driven frameworks. This review synthesizes the current evidence on pesticide-related skin diseases in the Americas, with a focus on clinical patterns, immunologic mechanisms, vulnerable populations, and regulatory gaps. By examining the dermatologic consequences of both occupational and environmental pesticide exposures, we aim to contextualize the skin as a sentinel organ of systemic toxicity and advocate for improved protective measures and targeted health interventions.

Materials and Methods

This literature review examined the dermatologic effects of pesticide exposure among agricultural workers across the Americas. A comprehensive search was conducted using PubMed, Scopus, Google Scholar, and occupational health databases, including NIOSH and LILACS, covering studies published from January 2000 to March 2025. Search terms included combinations of "pesticide exposure," "agricultural workers," "dermatologic conditions," and related keywords. Studies were included if they reported on dermatologic outcomes in rural or agricultural populations and were published in English, Spanish, or Portuguese. Eligible study types included epidemiologic studies, case reports, surveillance data, and mechanistic studies. Articles without dermatologic relevance or original data were excluded. Of 268 initial results, 32 articles were selected after screening for relevance and quality. Data extracted included pesticide class, dermatologic outcomes, exposure context, PPE use, and relevant mechanisms. Findings were synthesized thematically into key domains: clinical conditions, pathophysiology, occupational risks, disparities, and policy implications. No meta-analysis was performed due to study heterogeneity. IRB approval was not required as only publicly available literature was reviewed.

Results

Dermatologic Conditions Linked to Pesticides

Pesticide exposure is associated with a wide spectrum of dermatologic conditions, ranging from self-limited irritant rashes to malignancy. The nature and severity of these conditions depend on the chemical class, concentration, duration of exposure, use of personal protective equipment (PPE), and individual susceptibility.

Table 1: Chemicals Detected and Their Classification

Chemical Class	Examples	Biomarkers Measured	Dermatologic Significance
Fungicides	Mancozeb, Pyrimethanil, Thiabendazole	ETU, OHP, OHT	ICD, eczema, pigmentary changes
Organophosphate	Chlorpyrifos	TCP	ICD, ACD, inflammasome activation
Pyrethroids	Permethrin, Cypermethrin, Cyfluthrin	3PBA, DCCA	Urticaria, allergic and irritant dermatitis
Herbicide	2,4-D	2,4-D	Photosensitivity, eczema
Polycyclic Aromatic HC	Smoke-related compounds	1-HP, 2-OH-PH	Possible co-sensitization, irritant dermatitis

Table 2: Summary of Dermatologic Conditions and Associated Pesticides

Condition	Associated Pesticides
Irritant Contact Dermatitis	Glyphosate, paraquat, pyraclostrobin, petroleum solvents
Allergic Contact Dermatitis	Glyphosate + POEA, thiuram, carbamates
Pigmentary Disorders	PCBs, dioxins, arsenicals
Chloracne	TCDD, PCBs, chlorobenzene

Nonmelanoma Skin Cancer (NMSC)	Arsenic-based herbicides, sun + pesticides
Cutaneous Melanoma	Carbaryl, parathion, mancozeb

Irritant Contact Dermatitis (ICD)
ICD is the most common pesticide-induced skin condition, resulting from direct cytotoxic effects on keratinocytes. Acute irritant reactions, including burning, stinging, and erythema, have been frequently reported among applicators exposed to mancozeb, glyphosate, and paraquat in rural regions of Oaxaca and Argentina [8, 15]. Pyraclostrobin, a fungicide, has caused facial ICD in citrus farmers following accidental exposure [16]. High prevalence of ICD was also reported in Oregon workers exposed to petroleum-based solvents and degreasers [17, 18].

Allergic Contact Dermatitis (ACD)
Pesticides can also serve as sensitizers, triggering delayed-type hypersensitivity reactions. In Portland, thiuram and carbamate compounds were prominent allergens in workers with occupational ACD [18]. Pred-Skin 3.0 modeling identified several fungicides and acaricides as likely skin sensitizers, underscoring the need for pre-market dermatotoxicity screening [19]. Glyphosate, though often regarded as low risk, has also induced ACD in cases involving the surfactant POEA [11, 12].

Pigmentary Disorders
Hyperpigmentation has been documented in workers exposed to polychlorinated biphenyls (PCBs), dioxins, and arsenicals. In Germany, PCB-exposed recycling workers exhibited hyperpigmented macules and atypical nevi [4]. Chronic arsenic exposure, historically from lead arsenate pesticides, has also been linked to pigmentary changes and palmoplantar keratoses [20, 21].

Chemical Burns and Urticaria
Acute dermal injuries such as chemical burns and urticaria have been observed after contact with highly hazardous pesticides like paraquat, mancozeb, and lambdacyhalothrin [22, 23]. In Costa Rican farmwomen, exposure to fungicides and pyrethroids correlated with increased odds of eczema and itchy rash [5]. Greenhouse workers handling dichlobenil reported burning and dermatitis, often exacerbated by high humidity and inadequate PPE [24].

Chloracne
Chloracne is a hallmark dermatologic condition caused by halogenated aromatic hydrocarbons, including dioxins and PCBs. Characterized by comedones and cystic lesions on the face, axillae, and groin, it reflects underlying activation of the aryl hydrocarbon receptor (AHR) in sebocytes [21, 25]. Chloracne was observed in 21.4% of workers in a dioxin-contaminated chemical plant and may serve as a cutaneous biomarker of systemic genotoxicity [26].

Nonmelanoma Skin Cancers (NMSC)
Chronic pesticide exposure has been associated with an elevated risk of basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). In Brazil and Argentina, workers exposed to UV radiation and arsenic-based pesticides had higher rates of actinic keratoses and biopsy-confirmed NMSC [4,7]. Arsenic exposure, confirmed by toenail analysis, showed a dose-dependent association with melanoma in Iowa [13] and SCC in New Hampshire [14]. Similarly, fungicides like maneb and insecticides like carbaryl and parathion have been implicated in cutaneous melanoma, particularly with long-term exposure [10, 27].

Mechanisms of Skin Injury
Pesticide-induced dermatologic conditions arise from a combination of transdermal absorption, immunologic sensitization, and skin barrier disruption, often exacerbated by environmental co-exposures and poor protective practices.

Table 3: Immunologic and Molecular Mechanisms

Pesticide/Agent	Mechanism	Dermatologic Outcome
Chlorpyrifos	NLRP3 inflammasome → IL-1β secretion	Inflammatory dermatoses
Glyphosate + POEA	Dendritic cell activation, oxidative stress	ACD, psoriasis (Koebner phenomenon)
Arsenic	Hydroxyl radical–induced DNA damage	BCC, SCC, melanoma
TCDD (dioxin)	AHR activation in sebocytes	Chloracne, systemic toxicity

Transdermal Absorption and Cumulative Toxicity
The skin is a major route of exposure for many agricultural chemicals, particularly in workers with frequent manual handling of pesticides. Lipophilic compounds such as carbaryl and organochlorines readily penetrate the stratum corneum, accumulating in subcutaneous fat and contributing to chronic systemic toxicity [10, 28]. Dimethoate and other organophosphates exhibit significant dermal absorption, especially when applied to the neck and forearms without adequate protective clothing [2]. In Costa Rican banana plantation workers, women with higher urinary levels of thiabendazole and 2,4-D metabolites reported elevated rates of eczema and itchy rash, suggesting cumulative dermal absorption even without direct occupational spraying [5]. Chronic exposure has also been linked to increased melanoma risk, with arsenic concentrations in toenails correlating with cumulative exposure and a twofold increase in melanoma risk in rural residents [13].

Immunologic Sensitization Mechanisms
Many pesticides function as haptens, binding to dermal proteins and initiating Type IV hypersensitivity reactions. Immunogenic surfactants like POEA in glyphosate formulations have been shown to activate dendritic cells and promote cytokine release, triggering allergic contact dermatitis and potential systemic ef-

fects [11, 12]. Jacobsen-Pereira et al. (2020) found significant immunologic shifts in chronically exposed farmers, including elevated effector CD8+ T cells and decreased B cell populations, supporting the hypothesis of prolonged antigenic stimulation and humoral suppression [29]. Experimental models further demonstrate inflammasome activation (e.g., NLRP3) in keratinocytes exposed to chlorpyrifos, leading to IL-1β secretion and cutaneous inflammation [9]. Skin contact with pyrethroids has also been associated with urticaria and exacerbation of atopic eczema in both adult farmworkers and children in agricultural communities [6].

Skin Barrier Disruption and Environmental Interactions

The integrity of the skin barrier is compromised by pesticide-induced cytotoxicity, high ambient temperatures, and co-exposures such as UV radiation. In greenhouse workers exposed to dichlobenil or paraquat, dermatitis was aggravated under humid conditions due to enhanced percutaneous absorption [15, 24]. Physical damage from solvents and degreasers during equipment maintenance, as reported by Bunn et al. (2009), further weakens the epidermal barrier, increasing susceptibility to irritants [17]. Additionally, behavioral risk factors such as inadequate PPE use, handwashing with diesel or solvents, and mixing multiple pesticide ingredients without proper training, common in rural settings, heighten dermal exposure and barrier disruption [8, 30]. The combination of impaired barrier function and sensitizer exposure can produce severe reactions, including toxic epidermal necrolysis, as seen with mancozeb and lambdacyhalothrin [22, 23].

Occupational Risk Factors

Agricultural workers are uniquely vulnerable to pesticide-induced dermatologic conditions due to inadequate personal protective equipment (PPE), environmental conditions that enhance dermal absorption, and unsafe labor practices often prevalent in rural and informal economies.

Inadequate PPE and Exposure Gaps

The availability, proper use, and effectiveness of PPE remain inconsistent across agricultural sectors. In Brazil, only 56.9% of rural horticultural workers reported using gloves, and fewer than 1% wore long sleeves despite high ultraviolet radiation and pesticide exposure [7]. A separate study in Córdoba, Argentina, revealed that only 32.7% of pesticide applicators used adequate PPE; this lack of protection was directly linked to increased risk of irritation and hospitalization from pesticide exposure [8]. Farmers repairing machinery in Kentucky frequently handled solvents such as toluene and xylene without gloves, using diesel and gasoline for handwashing practices that significantly elevated dermal chemical exposure [17]. Even when gloves were worn, common materials like latex were ineffective in reducing chemical absorption. Moreover, observational studies show that in many regions of rural Mexico, PPE is either unavailable or misused, with applicators mixing multiple pesticide agents in unsafe conditions without face masks or eye protection [31].

Climate and Sweat-Enhanced Absorption

High ambient temperatures and humidity, common in tropical agricultural zones, amplify percutaneous absorption of pesticides. Greenhouse workers exposed to dichlobenil under hot, humid conditions reported significantly higher rates of dermatitis due to enhanced skin permeability [24]. Similarly, farmers in Brazil who wore minimal PPE during pesticide spraying had increased dimethoate penetration, particularly at the back of the neck and forearms, where sweat accumulation was greatest [2]. In Matina County, Costa Rica, Alhanti et al. (2022) found that non-spraying women living near banana plantations, many of whom perspired heavily during field labor, had elevated urinary levels of thiabendazole and 2,4-D, which correlated with significantly increased rates of eczema (OR = 2.54) and itchy rash (OR = 3.17) [5]. These findings suggest that even indirect exposure in a hot climate may produce dermatologic effects through sweat-facilitated absorption.

Informal Labor and Pediatric Risk

Informal labor practices, including child and unregulated family labor, create profound gaps in occupational safety. In Oaxaca, nearly 50% of farmers reported combining multiple pesticide ingredients without adequate toxicologic knowledge, and none used PPE when applying restricted agents like paraquat or difocol [31]. In the same region, over half of pesticide users experienced dermatologic symptoms such as itchy skin, burning, and eye irritation. Children are particularly at risk; Islam et al. (2021) reported that Costa Rican children exposed to pyrethroids near banana plantations had significantly higher odds of itchy rash (OR = 2.74) and eczema, suggesting a link between household pesticide drift and pediatric dermatoses [6]. The compounding risks of early life exposure, lack of regulatory oversight, and developing immune systems underscore the need for surveillance and intervention in informal agricultural economies.

Disparities in Protection and Policy

Inadequate Occupational Health Infrastructure

Rural agricultural workers often face systemic neglect in occupational health surveillance and dermatologic screening. In Brazil, only 5.4% of pesticide-exposed horticultural workers reported prior skin cancer diagnoses, yet over half of these individuals were found to have new suspicious lesions during study assessments, highlighting a profound diagnostic gap in dermatologic care [7]. Moreover, Jacobsen-Pereira et al. (2020) identified immunologic dysfunction in long-term pesticide applicators, suggesting that chronic dermal exposure without monitoring may result in subclinical yet progressive damage to skin and immune systems [29].

Geographic and Insurance-Related Barriers

Populations living in agriculturally intensive yet remote areas, such as Matina County, Costa Rica, face dual exposures: high ambient pesticide levels and structural barriers to specialty care. In Alhanti et al. (2022), non-smoking women living near banana plantations had significantly increased odds of eczema (OR = 2.54) and itchy rash (OR = 3.17), particularly if employed in agricultural labor or partnered with someone who was. These dermatoses often remain untreated or misdiagnosed due to limited insurance coverage, language barriers, and a lack of dermatology-trained providers in rural clinics [5]. In the United States, dermatologic services are disproportionately concentrated in urban centers, leaving rural workers, many of whom are migrant, underinsured, or undocumented, without access to biopsy, patch testing, or photoprotection counseling.

Policy Gaps in Pesticide Regulation and Enforcement

Several studies expose the limitations of current pesticide regulations. In Oaxaca, Mexico, over half of papaya and chili farmers reported mixing multiple pesticide active ingredients without adequate toxicologic understanding or PPE, even though many used chemicals classified as Highly Hazardous Pesticides (HHPs) by COFEPRIS (Mexico's federal health authority) [31]. Butinof et al. (2015) similarly found that only 32.7% of applicators in Córdoba, Argentina, used appropriate protective equipment, despite frequent exposure to neurotoxic and carcinogenic agents like endosulfan and cypermethrin [8]. Regulatory enforcement remains sparse in these regions, and label-based hazard communication strategies are ineffective when workers are illiterate, linguistically marginalized, or unaware of reentry intervals after spraying.

Recommendations for Protection, Surveillance, and Advocacy

Several interventions can reduce the dermatologic burden in pesticide-exposed populations:

- **Personal Protective Equipment (PPE):** Tailoring gloves and garments for hot climates is essential. Studies show that dermal absorption of dimethoate was markedly reduced when protective clothing was worn, with sweat-exposed body regions like the neck and arms showing up to 54% stratum corneum penetration in unprotected workers [2].
- **Occupational Surveillance:** Routine skin exams and educational outreach can uncover undiagnosed actinic keratoses and melanocytic nevi, particularly in workers with fair skin phototypes or known chemical exposures [7].
- **Policy Reform:** Governments should integrate dermatologic endpoints into pesticide safety evaluations and support community-led advocacy to ban particularly harmful agents like paraquat and methamidophos. Additionally, improved pesticide labeling, multilingual education campaigns, and community health worker programs can enhance safe handling practices and reduce occupational dermatitis risk.

In sum, the persistent disparity in protective policy and dermatologic oversight leaves many agricultural workers chronically exposed and medically underserved. Equitable pesticide regulation and rural dermatology infrastructure are not only a matter of occupational safety but of environmental justice.

Discussion

Current pesticide exposure monitoring systems inadequately capture dermatologic outcomes, particularly among rural and agricultural populations. While studies offer compelling epidemiologic evidence linking fungicide and pyrethroid exposure to eczema and itchy rash, there remains no standardized system for dermatologic surveillance in pesticide-exposed communities [5]. Most findings are fragmented across occupational health, environmental science, and dermatology, underscoring the need for integrated registries and geospatial health mapping to identify exposure clusters and prioritize high-risk populations for intervention. In particular, arsenic-related skin cancer risks reported by Beane Freeman et al. (2004) and Karagas et al. (2001) remain underappreciated in contemporary rural dermatology practice. Despite toenail arsenic levels being significantly associated with melanoma and squamous cell carcinoma (ORs ranging from 2.1 to 6.6), these biomarkers are rarely incorporated into public health screening initiatives or dermatologic risk assessments [13, 14].

The Role of Community Health Workers

Community health workers (CHWs) offer a culturally competent and scalable solution to dermatologic outreach in underserved regions. Trained CHWs can assist with full-body skin checks, refer suspicious lesions for biopsy, and deliver sun safety education tailored to local contexts. Implementation of family-inclusive risk communication and clinical skin screenings led to lesion identification in 57.1% of patients who already had a prior skin cancer diagnosis, demonstrating the utility of decentralized surveillance mechanisms [7]. Moreover, CHWs could be mobilized to track dermatologic sequelae of pesticide exposure, such as contact dermatitis, chronic actinic damage, and pigmentary disorders linked to fungicides like mancozeb and thiabendazole. In settings like Oaxaca, Mexico, where paraquat and methamidophos are still used despite bans, CHWs could facilitate safer pesticide handling practices and identify early skin symptoms before progression to malignancy or hospitalization [31].

Interdisciplinary Collaboration and Policy Integration

The growing recognition of skin as both a target and sentinel organ for environmental insults mandates interdisciplinary collaboration across dermatology, toxicology, agriculture, and public health. Policymakers and regulatory agencies must prioritize dermatologic endpoints in pesticide safety assessments and integrate dermatologists into environmental health task forces. For example, the immune suppression observed in long-term pesticide applicators and the high prevalence of facial ICD among greenhouse farmers exposed to cyflumetofen underscore the need to reevaluate pesticide labeling, enforce protective equipment mandates, and update occupational skin disease criteria [29, 32].

Public-private partnerships, particularly in the Americas, should also prioritize climate-resilient dermatologic care. As pesticide use intensifies with changing pest dynamics, the dermatologic burden will likely shift, necessitating updated education, rural dermatology training pipelines, and community-based participatory research. Without targeted surveillance and cross-sectoral collaboration, dermatologic diseases will remain underrecognized in global pesticide policy frameworks.

Pesticide exposure continues to pose a substantial and underrecognized threat to skin health, particularly among agricultural and rural populations. A broad range of dermatologic conditions, including contact dermatitis, eczema, hyperpigmentation, and even cutaneous malignancies, have been consistently linked to occupational and environmental exposure to herbicides, insecticides, fungicides, and related compounds. These effects are often exacerbated by poor access to protective equipment, lack of training, and prolonged exposure through both direct contact and environmental drift. The skin, as the body's primary barrier, reflects not only surface irritation but also deeper immunologic responses that may predispose individuals to systemic effects. In many cases, dermatologic symptoms serve as early warning signs of broader toxic exposure. Despite these risks, dermatologic outcomes remain underreported and undervalued in occupational health surveillance. Addressing this gap will require more stringent regulatory oversight, improved protective guidelines, community-level education, and the routine integration of skin health assessments into worker safety programs. Promoting awareness and prevention is essential to reducing the dermatologic burden of pesticide exposure and protecting the long-term health of agricultural workers.

Sources of Support
None

Source of Funding
No funding was received for this study.

Disclaimers
None

Conflict of Interest Declaration
The authors declare no conflicts of interest.

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