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Rising Respiratory Disease Burden Associated with Pesticide Exposure Among Farmers in the Nyiragongo Health Zone in North Kivu Province, DRC

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Abstract: Pesticides, widely applied in agriculture to control pests and increase crop yields., While their use has revolutionized agriculture by increasing crop yields, their widespread application poses serious health risks. Pesticides can penetrate the respiratory system in the form of aerosols, dust, mists, or ultra-low-volume particles, directly affecting the alveoli and circulating through the bloodstream to other organs. Despite these risks, many farmers in developing regions, including the Democratic Republic of Congo (DRC), frequently use pesticides without proper training or personal protective equipment (PPE), significantly increasing their vulnerability to respiratory complications. The objective of this study, therefore, was to establish the association between pesticide exposure and respiratory diseases among farmers in the Nyiragongo health zone in North Kivu, DRC. The study used a retrospective matched case-control design targeting 183,988 farmers in the Nyiragongo health zone from which a sample of 302 farmers selected using. Data was collected using a questionnaire, and analyzed using descriptive and inferential statistics. The study established a clear link between occupational and non-occupational exposure to chemical pesticides and increased risk of respiratory illnesses among farmers in the Nyiragongo Health Zone. Inhalation of pesticide dust and fumes, handling chemicals without protective measures, and prolonged or frequent exposure significantly elevate respiratory risk, while unsafe domestic storage practices further exacerbate exposure. It is thus recommended that farmers should receive targeted training on safe pesticide handling, proper use of personal protective equipment, and adoption of hygienic practices such as handwashing and controlled storage. Regulatory authorities should strengthen enforcement of bans on highly hazardous pesticides and establish strict compliance frameworks for pesticide labeling, sale, and domestic storage.

Keywords: *Chemical Pesticides, Banned Pesticides, Respiratory Disease, Harmful Exposure, Case-Control.*

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I. INTRODUCTION

Pesticides, derived from the words “pest” and the suffix “-cide”, encompass chemical substances designed to prevent, control, or eliminate unwanted organisms, including insects, plants, fungi, and bacteria (Tebila, 2020). Pesticides, widely applied in agriculture to control pests and increase crop yields., While their use has revolutionized agriculture by increasing crop yields, their widespread application poses serious health risks. They represent a significant occupational hazard for farmers, particularly in low- and middle-income countries (LMICs). Exposure occurs during preparation, mixing, spraying, and handling of treated crops, with inhalation being one of the most critical routes of entry (Beyene et al., 2016; YAP, 2020). Pesticides can penetrate the respiratory system in the form of aerosols, dust, mists, or ultra-low-volume particles, directly affecting the alveoli and circulating through the bloodstream to other organs (Tarbre et al., 2020). Acute exposure can cause eye irritation, cough, chest tightness, and wheezing, while chronic exposure may

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lead to asthma, chronic bronchitis, and other respiratory illnesses (Clarine, 2022; Maddah et al., 2020). Despite these risks, many farmers in developing regions, including the Democratic Republic of Congo (DRC), frequently use pesticides without proper training or personal protective equipment (PPE), significantly increasing their vulnerability to respiratory complications.

Respiratory exposure is heightened when farmers work in enclosed or poorly ventilated spaces such as greenhouses, silos, or livestock buildings. The physicochemical properties of pesticides—including particle size, lipophilicity, and formulation—affect how deeply they penetrate the lungs (Farila et al., 2005). Larger droplets tend to deposit in the upper airways, while smaller particles reach the alveoli, causing tissue irritation, inflammation, or systemic absorption (Maddah et al., 2020). Repeated inhalation can exacerbate asthma, bronchitis, and even lung tissue damage (Baldi et al., 2013). Empirical studies demonstrate that frequent contact with pesticide residues—through washing contaminated clothing, handling treated crops, or spraying—significantly increases the risk of respiratory morbidity among agricultural workers (Mamane et al., 2015; Farila et al., 2005). Pesticides such as dichlorvos, widely used in eastern DRC, exemplify highly volatile compounds that pose particular inhalation hazards (Rabiou, 2019).

A critical factor aggravating respiratory risks is the widespread handling of pesticides without adequate protective measures. Studies from Brazil and other LMICs indicate that only half of exposed agricultural workers wear protective masks or gloves, and many handle toxic chemicals with bare hands, leading to both dermal and respiratory contamination (Costa et al., 2003; Morilon, 2016). Unsafe behaviors, including spraying against the wind, returning to treated areas, wiping sweat with contaminated hands, and improper disposal of containers, further heighten exposure (Guyot, 2020). Even brief daily exposures, over long durations, cumulatively increase the risk of chronic respiratory conditions. Seasonal peaks in pesticide use, such as spring spraying, coincide with higher asthma incidence among farmers, particularly from organophosphate and carbamate compounds known to induce bronchial spasms (Lirepe, 2020).

Prolonged and high-frequency pesticide use is strongly correlated with the development of chronic respiratory diseases. Studies report that farmers often apply pesticides multiple times per week over several hours, handling mixtures and loading equipment without adequate PPE (Patrick, 2018; Christophe, 2018). Common manifestations include dyspnea, chronic cough, expectoration, and bronchitis, while severe exposures may cause systemic effects such as fatigue, dizziness, and oxidative stress leading to multi-organ complications (Gutiérrez-Jara et al., 2020; Soriano et al., 2020). Evidence from cohort studies in the United States and Australia confirms that occupational exposure to pesticides significantly increases the prevalence of asthma and chronic bronchitis among farmworkers, although some studies have found mixed results depending on exposure type and protective practices (Hoppin et al., 2007; Stoecklin et al., 2015; Xavier, 2005).

In addition to occupational inhalation, unintentional ingestion of pesticide residues through contaminated vegetables and improper storage of chemical pesticides at home contributes to respiratory health risks (Herberg, 2020; Oni, 2020). Studies in Mali and Ghana reveal that a significant proportion of farmers store pesticides in living spaces, leading to chronic exposure for household members, including children (Moritz, 2019; Moustafa, 2022). Residues from organophosphates, carbamates, and other hazardous chemicals have been detected in vegetables produced in eastern DRC, sometimes exceeding international safety thresholds (Muyisa et al., 2014). Chronic exposure to these chemicals is associated with asthma, chronic bronchitis, and other pulmonary disorders, disproportionately affecting smallholder farmers who rely on intensive pesticide use for subsistence agriculture (Muliele, 2021; Isabelle, 2021). This context underscores the urgent need for effective regulatory policies, awareness campaigns, and occupational safety measures to mitigate the rising burden of respiratory diseases among farmers in the Nyiragongo Health Zone.

- ➢ *Problem*

Smallholder farmers in the Nyiragongo Health Zone need to cultivate their fields using safe, approved pesticides under strict regulation. Agricultural policies would ensure effective enforcement, distribution of personal protective equipment (PPE), and community education on safe handling and disposal. Regulatory oversight would prevent banned or highly hazardous pesticides from entering the market, and farmers – as well as consumers of agricultural produce – would be protected from both acute and chronic health risks. Under such a framework, the agricultural sector would provide livelihoods without compromising the health of farmers or their families. However, the current reality in Nyiragongo starkly diverges from this ideal. More than 90% of local households depend on smallholder market gardening. Yet weak policy enforcement and poor regulation allow hazardous, often banned pesticides to circulate freely. Many farmers handle these chemicals without PPE, store them improperly, or discard empty containers in unsafe ways. Recent health records from the zone indicate an alarming rise in respiratory illness: between 2022 and 2023 alone, 22,956 cases of respiratory diseases were reported, with a community-level prevalence estimated at 8%. Farmers commonly present at health centers with persistent cough, rhinitis, bronchitis and other chronic respiratory symptoms.

These local data reflect a broader global trend. A comprehensive review covering 141 countries estimated that each year about 385 million cases of unintentional acute pesticide poisoning (UAPP) occur worldwide, with approximately 11,000 fatalities, suggesting nearly 44% of the global farming population suffer pesticide poisoning annually. In developing countries, many of these are mild or moderate poisonings, but chronic effects, particularly respiratory illnesses, are underreported and poorly documented. Occupational exposure to pesticides has been linked in numerous studies to increased prevalence of asthma, chronic bronchitis, and reduced lung function, yet little research has examined how weak regulatory frameworks contribute to unsafe practices and subsequent illness. Thus, there is a critical need for empirical research exploring the connection between pesticide regulation, management practices, and respiratory health outcomes in Nyiragongo. This study aims to fill this gap by investigating how policy weaknesses and lack of enforcement may lead to high levels of hazardous pesticide exposure among smallholder farmers, fueling rising respiratory disease burden. Evidence generated will inform policy reforms, strengthen pesticide control measures, and guide public health and agricultural interventions to protect vulnerable farming communities in Nyiragongo and similar settings across the DRC.

➢ *Objective*

The objective of the study was to establish the association between pesticide exposure and respiratory diseases among farmers in the Nyiragongo health zone in North Kivu, DRC.

II. LITERATURE REVIEW

➢ *Exposure to Pesticides and Respiratory Diseases among Farmers*

Occupational exposure to pesticides constitutes a major health risk for agricultural workers. Exposure can occur during preparation, application, or while working in recently treated fields. Pesticides have been associated with a wide range of health effects, particularly respiratory disorders (Beyene et al., 2016). Respiratory diseases, including asthma and chronic obstructive pulmonary disease (COPD), are among the leading causes of global morbidity and mortality, and farmers are disproportionately affected (Mamane et al., 2015). The World Health Organization notes that asthma affects approximately 14% of the global population, with prevalence rising over recent decades, while COPD and chronic bronchitis are also prevalent among agricultural workers exposed to pesticides.

- *Inhalation of Pesticide Vapors and Respiratory Illnesses*

Inhalation is a critical route of pesticide exposure. Aerosols, dust, mists, smoke, and ultra-low-volume particles can penetrate deep into lung tissue and enter the bloodstream via the respiratory tract (YAP, 2020; Tarbre et al., 2020). These particles can irritate the nose, throat, and lungs, causing coughing, wheezing, chest tightness, and shortness of breath. Acute exposure may also result in eye and skin irritation (Clarine, 2022). The risk of inhalation is heightened during fumigation, greenhouse work, or pesticide application in confined spaces, and is influenced by both physicochemical characteristics of the pesticide and individual breathing patterns (Farila et al., 2005). Fine particles that reach the alveoli can be absorbed into the bloodstream, potentially causing systemic toxicity (Maddah et al., 2020).

Epidemiological studies indicate a strong correlation between inhalation of pesticides and respiratory illnesses. Baldi et al. (2013) report increased incidents of asthma, chronic bronchitis, and lung cancer among exposed farmers. In the United States, large cohort studies of 20,000 pesticide applicators have documented increased wheezing and asthma incidence among exposed workers, while historical Australian cohorts linked insecticide exposure to elevated asthma mortality and atopic disease (WHO, 2022; Stoecklin et al., 2015). Highly volatile pesticides, such as dichlorvos, have been banned in Europe due to their respiratory hazards, yet remain widely used in low- and middle-income countries (Rabiou, 2019).

- *Handling Pesticides without Protective Measures*

Unsafe handling of pesticides remains a pervasive problem, particularly in LMICs. Malian regulations mandate adherence to good practices and the use of Safety Data Sheets (SDS) to mitigate risk (Law 02-014, 2002). However, studies indicate that protective equipment is often inadequate or absent. In Brazil's Serra Gaúcha region, 75% of farmworkers are regularly exposed to pesticides, but only half use protective masks (Costa et al., 2003). Similarly, farmers frequently handle pesticides directly with bare hands or wear improvised PPE, such as cloth masks, handkerchiefs, or plastic coverings (Morilon, 2016; Christophe, 2018).

Unsafe handling is linked to respiratory and skin toxicity, with organophosphates and carbamates notably causing bronchospasm and asthmatic episodes (Lirepe, 2020; Amazani, 2020). Chronic exposure through repeated handling, cleaning equipment, or laundering contaminated clothing increases the risk of respiratory diseases (Mayene et al., 2016). Epidemiological surveys among vineyard and apple workers documented high prevalence of dyspnea (74.1%), chronic cough (27.6%), sputum production (25.3%), and bronchitis (20.7%) (Salameh, 2006). Inadequate disposal of pesticide containers, often stored within domestic environments, further exposes farmers and household members to respiratory hazards (Przybylska, 2014; Moritz, 2019).

- *Frequency and Duration of Pesticide Use*

Pesticide toxicity is influenced by chemical composition, exposure dose, frequency, duration, and route of entry. While acute effects are well documented, chronic exposure data remain limited, particularly for low-dose, long-term exposure (Anne, 2023). Agricultural workers are especially vulnerable due to prolonged and repeated application, harvesting, and equipment cleaning activities (Jorge, 2022). Chronic exposure has been linked to dyspnea, cough, oxidative stress, and systemic effects including cardiovascular and autoimmune disorders (Soriano et al., 2020; Guyot, 2018).

Field studies reveal that farmers may spend three hours per application, 1–4 days per week, over periods exceeding 20 years, cumulatively resulting in chronic exposure (Patrick, Op cit). Common unsafe practices include re-entering recently treated fields, wiping sweat with contaminated hands, spraying against the wind, and failing to wear adequate protective clothing (Guyot, Op cit; Christophe, 2018). Organophosphate and carbamate exposure, as well as fumigant use, can produce acute symptoms such as dyspnea, cough, dizziness, and gastrointestinal upset (Guyot, 2018; Gutiérrez-Jara et al., 2020).

- *Consumption of Pesticide-Treated Vegetables*

In addition to occupational exposure, farmers may ingest pesticide residues directly from treated crops. In Niger, 85.7% of farmers consuming contaminated vegetables experienced respiratory symptoms ranging from mild dyspnea to bronchospasm (Herberg, 2020; Sanborn et al., 2002). In eastern DR Congo, mancozeb residues in tomatoes exceeded European safety thresholds, emphasizing the risk posed by unsafe pesticide use and highlighting the need for adherence to phytosanitary guidelines (Muyisa et al., 2014; Gouda et al., 2018). Continuous consumption of pesticide-laden produce represents a chronic exposure pathway that exacerbates respiratory morbidity in agricultural communities (Muliele, 2021).

- *Storage of Hazardous Pesticides in Homes*

Improper storage of pesticides in residential settings is common in LMICs and presents additional exposure risks. Residues can persist indoors and affect household members, especially children, who have greater contact with contaminated surfaces (Brenner, 2013). In Mali and Ghana, studies found that up to 90% of farmers store pesticides in living spaces due to lack of proper facilities, resulting in acute respiratory symptoms, chronic cough, and asthma among residents (Moustafa, 2022; Moritz, 2019). In the DRC, households storing pesticides at home reported widespread inhalation of chemical odors and associated respiratory difficulties (Oni, 2020).

➢ *Respiratory Diseases Arising from Pesticide Exposure*

- Asthma: Pesticide exposure is strongly associated with asthma, a chronic condition characterized by recurrent bronchial constriction, wheezing, and breathlessness (Bhatiaa et al., 2022). Low-income populations and racial minorities experience disproportionately high asthma morbidity and mortality, highlighting environmental justice concerns in pesticide regulation (Beyond, 2020). Studies among rural women indicate a direct link between pesticide exposure and elevated respiratory symptoms, airway inflammation, and immune responses (Mamane et al., 2015).
- Chronic Bronchitis: Exposure to pesticides has also been linked to chronic bronchitis, a form of COPD marked by persistent cough and mucus production (Hoppin et al., 2007). Lifetime exposure to multiple pesticides increases the risk, particularly among applicators involved in high-exposure events or off-farm pesticide activities. Co-morbid asthma and ongoing farm work do not fully account for these outcomes, suggesting an independent effect of pesticide exposure.
- Organochlorine Exposure: Workers exposed to organochlorine and other persistent pesticides experience heightened prevalence of asthma, chronic bronchitis, and wheezing. Evidence from the U.S., Australia, and Brazil indicates that occupational exposure during pesticide preparation, application, and equipment cleaning contributes to these respiratory outcomes (Beard et al., 2005; Danuser, 2001). Protective measures, including proper PPE and storage practices, remain inconsistent, exacerbating exposure and disease risk.

In summary, extensive evidence demonstrates that occupational and dietary exposure to pesticides constitutes a significant risk factor for respiratory morbidity among farmers. Routes of exposure include inhalation of vapors, handling without protective measures, consumption of treated produce, and storage of chemicals in homes. Both acute and chronic effects are documented, with asthma, chronic bronchitis, and systemic toxicities representing the primary health outcomes. The cumulative impact of high-frequency, long-duration exposure underscores the need for comprehensive training, enforcement of protective equipment use, and adherence to safe pesticide application and storage practices, particularly in LMICs.

III. METHODOLOGY

➢ *Context of the Study Area*

This study was conducted in the Nyiragongo Health Zone, North Kivu Province, Democratic Republic of Congo. Agriculture forms the backbone of the local economy, with over 85% of households engaged in crop cultivation and livestock rearing. The Nyiragongo Health Zone was specifically selected due to the observed high prevalence of respiratory diseases in recent years, which have been associated with the widespread and often hazardous use of chemical pesticides in farming practices.

➢ *Study Design*

According to the 2023 Health Information System (SNIS) report for Nyiragongo, the prevalence of respiratory diseases among farmers is 8%. Given this context, a retrospective case-control study design was employed. Case-control studies are appropriate for assessing the relationship between exposure and outcomes, beginning with an outcome (respiratory illness) and looking retrospectively at potential exposures (pesticide use).

In this study, cases were defined as farmers who use chemical pesticides and had a documented history of respiratory diseases, while controls were farmers using pesticides but without a history of respiratory illness. Exposure was defined as prolonged handling, inhalation, or presence in environments with hazardous pesticides, whereas non-exposure referred to limited or no contact with these substances. The study further hypothesized that exposure was influenced by farmers' knowledge and practices regarding pesticide handling.

➢ *Study Population*

The study population included farmers aged 18 years and older who were actively engaged in farming activities and the application of chemical pesticides. The total estimated population of such farmers in Nyiragongo Health Zone is 183,988. Participants were classified into two groups: those who had experienced respiratory illnesses (cases) and those who had not (controls).

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Inclusion criteria were: (i) being a farmer residing in Nyiragongo, (ii) having ever used chemical pesticides, (iii) aged 18 years or older, and (iv) for cases, having a documented respiratory illness; for controls, absence of respiratory illness. Exclusion criteria included: (i) farmers from other health zones, (ii) farmers who do not use chemical pesticides, (iii) individuals under 18 years of age, and (iv) cases not officially recorded in health facilities within the Nyiragongo Health Zone.

Additionally, the study included regulatory actors involved in pesticide control policy implementation in North Kivu Province. Key informants included representatives from the Congolese Control Office (OCC), National Service for Fertilizers and Associated Inputs (SENAFIC), Directorate of Plant Production and Protection (DPPV), Animal and Plant Quarantine Service (SQUAV), National Agricultural Extension Service (SNVa), National Institute for Agronomic Research (INERA), Provincial Environment Division (DPE), Provincial Health Division (DPS), Civil Protection, peasant organizations, Central Health Zone Office (BCZ), Rural Development (DR), and trade authorities.

➢ *Determination of Sample Size*

For the quantitative component, the sample size for the case-control study was calculated using the formula proposed by Charan and Biswas (2013):

$$n = \frac{(r+1)}{r}\frac{P(1-P)(Z_{\beta}+Z_{\alpha/2})^2}{(P_1-P_2)^2}$$

Where:

r = Control/case ratio, 1 for an equal number of cases and controls
P* = Average proportion exposed = proportion of cases exposed + proportion of controls exposed/2
Z_{β} = standard normal variable for power = for 80% power, it is 0.84 and for 95% value, it is 1.96.
$Z_{a/2}$ = standard normal variable for significance level as mentioned in the previous section.
$P_1 - P_2$ = Effect size or different proportion expected based on previous studies.
P_1 is the control proportion which is taken as 19% from the calculation of P_1 using the odds ratio formula.
P_2 is the proportion of cases retained at 8% in the study of the Health Information System (SNIS).

Substitution into the above formula yielded a sample size of 151 cases which was then matched with 151 controls using gender as a matching criteria.

➢ *Sampling Technique*

For farmers, systematic random sampling was applied using medical records from health facilities to identify cases with respiratory illnesses. These records provided contact information and socio-demographic data. Initial contact was made to explain the study and confirm eligibility. Farmers were then physically visited on their farms, and the process was repeated for both cases and matched controls across different health zones.

For key informants in policy and regulatory institutions, convenience sampling was used based on availability and willingness to participate.

➢ *Data Collection Instruments*

Data were collected using two complementary approaches:

- Quantitative approach: A structured survey questionnaire was administered to cases and controls to collect information on socio-demographics, pesticide exposure, and health outcomes.
- Qualitative approach: A semi-structured interview guide was used to collect data from key informants regarding pesticide policy implementation, monitoring, and regulatory challenges.

➢ *Data Analysis Methods*

Quantitative data were analyzed using univariate and bivariate methods. Univariate analysis included frequencies, percentages, means, and standard deviations to describe the study population. Bivariate analysis involved logistic regression to examine associations between pesticide exposure and respiratory illnesses, with odds ratios (ORs) calculated to quantify the strength of these associations.

Qualitative data were analyzed using content and thematic analysis, allowing patterns, themes, and key insights to emerge regarding pesticide policy implementation and regulatory challenges in the North Kivu Province.

IV. RESULTS

A. Categories Chemical Pesticides Proliferating in the Nyiragongo Health Zone

The types of chemical pesticides were determined and then classified into two: chemical insecticides and chemical fungicides. The results are given in Table 1.

Table 1 Categories of Chemical Pesticides Proliferating in the Nyiragongo Health Zone

Chemical type	**Brand**	**Yes**		**No**	
		Freq	**Perc (%)**	**Freq**	**Perc (%)**
Chemical insecticides	Thiodane	201	66.6	101	33.4
	Rocket	19	6.3	283	93.7
	DDT	12	4	290	96
	Deltamethrin	46	15.2	256	84.8
	Lava Dichlorvos 100% EC	83	27.5	219	72.5

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	Tafgor (Dimethoate 40%)	46	15.2	256	84.8
	Sumithion 50 CE	6	2	296	98
	Carbaryl 85 WP	ten	3.3	292	96.7
	Actellic 2%	67	22.2	235	77.8
	Super lace	19	6.3	283	93.7
	Malathion	6	2	296	98
		515	3:51 p.m.	2807	84,491
Chemical fungicides	Ridomil	44	14.6	258	85.4
	dithane	255	84.4	47	15.6
	Super Homai 70 WP	12	4	290	96
	Benlate	6	2	296	98
		317	26:25	891	73.75

The findings in Table 1 reveal a concerning pattern regarding pesticide use in the Nyiragongo Health Zone, where chemical insecticides (N = 515) are used more extensively than chemical fungicides (N = 317). This distribution suggests that insect infestations represent a predominant agricultural challenge for farmers in the area. However, the widespread use of fungicides—especially Dithane (84.4%)—indicates that fungal diseases also pose substantial threats to crop production. The heavy reliance on these chemicals reflects the agronomic pressures smallholder farmers face, prompting frequent and often unregulated pesticide applications.

Among insecticides, Thiodan (Endosulfan) stands out as the most widely used brand (66.6%). This is particularly troubling given that Thiodan is a highly hazardous pesticide banned in many countries due to its severe neurotoxic, endocrine-disrupting, and persistent environmental effects. Lava Dichlorvos 100% EC (27.5%) and Actellic 2% (22.2%) were also commonly used, both of which are associated with acute respiratory irritation and documented occupational health risks. The use of DDT—found in 4% of farms despite being globally banned—further underscores the weakness of regulatory enforcement in the region.

The case–control comparison strengthens this concern. The study established statistically significant differences in the use of Thiodan (χ^2 = 48.332, $p < 0.001$), Rocket (χ^2 = 4.549, p = 0.033), and DDT (χ^2 = 5.554, p = 0.018), with these products being more commonly used among farmers who developed respiratory symptoms (cases) than among controls. This pattern suggests a direct association between the use of these insecticides and elevated respiratory health risks.

Conversely, Deltamethrin (χ^2 = 5.026, p = 0.025) and Carbaryl 85 WP (χ^2 = 6.619, p = 0.010) were used more frequently by controls, although Carbaryl was still identified as a risk factor in the broader analysis of banned pesticides. This indicates that the relationship between pesticide type and health outcomes may also be influenced by application frequency, concentration, or handling conditions.

Fungicides displayed similar trends. Dithane, the dominant fungicide, showed a very strong and significant association with respiratory illness (χ^2 = 46.591, $p < 0.001$), with affected farmers being 4.75 times more likely to have used it compared to controls. Ridomil (χ^2 = 6.810, p = 0.009) and Benlate (χ^2 = 6.122, p = 0.013) were used more commonly among controls, although Benlate—whose use is banned in several countries—still presents known teratogenic and respiratory risks.

Overall, the results demonstrate that several banned or highly hazardous pesticides—particularly Thiodan, DDT, Carbaryl, Dithane, and Benlate—remain widely accessible and in active use in Nyiragongo. Their strong associations with respiratory illnesses reflect systemic failures in pesticide regulation, farmer training, and enforcement of chemical control policies. This situation heightens health risks not only for farmers but also for consumers and the broader environment, underscoring the urgent need for policy reform and strengthened health surveillance in the region.

B. Exposure to Pesticides and Respiratory Diseases Among Farmers in the Nyiragongo Health Zone in North Kivu, DRC

The study also aimed to establish the association between pesticide exposure and respiratory diseases among farmers in the Nyiragongo health zone in North Kivu, DRC.

➢ *Exposure Trends to Pesticides Among Farmers*

The study examined the exposure trends between chemical pesticides use and the incidence of respiratory diseases. The results are summarized in Table 2.

Table 2 Exposure to Pesticides Among Farmers

Statement	**Rsp.**	**Case**	**Controls**	**Mean**	**S.Dev**	**OR 95% CI**
Do you ever inhale chemical pesticide dust or smoke when spraying chemical pesticides?						
	Yes	149	126	21.516a	0.000	14,782 (3,434-63,629)
	No	2	25			
If so, under what circumstances do you inhale chemical pesticide dust or smoke?						
	Every time I spray	114	92	6.997a	0.030	N / A

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	When I don't wear the mask (cash nose)	26	15			
	When I wear a holey or old mask	9	19			
Do you usually wear a mask to avoid inhaling chemical pesticide fumes?						
	Yes	14	23	2.495a	0.114	0.569(0.281-1.153)
	No	137	128			
Are you used to handling (or touching) chemical pesticides with your hand without any protective measures?						
	Yes	144	141	.561a	0.454	1.459(0.54 - 3.94)
	No	7	ten			
If yes, under what circumstances do you handle chemical pesticides without any protective measures?						
	Every time I spray	80	21	64.838a	0.000	
	When I don't wear gloves	49	60			
	When I don't wear masks	8	41			
	When I use holey or old gloves	12	29			
How do you end up exposing your respiratory system when handling chemical pesticides?						
	Touching the nose with hands that have touched chemical pesticides	71	61	13.723a	0.001	
	Touching your mouth with hands that have touched chemical pesticides	23	50			
	By mixing chemical pesticides without any personal protection measures	57	40			
How often do you handle or spray chemical pesticides?						
	Every day of the week	11	6	16.033a	0.007	
	Two to three days a week	97	79			
	Four to five days a week	12	27			
	After every week	14	7			
	After a month	7	14			
	According to the needs that arise	ten	18			
How long can you estimate that you are exposed to chemical pesticide fumes, dust and liquids?						
	Less than a day	51	38	38.021a	0.000	
	A whole day	44	29			
	More than 6 hours	30	ten			
	Less than 6 hours	26	74			
What is the main crop you usually apply chemical pesticides to?						
	Market gardening	145	146	.094a	0.759	0.828(0.247 - 2.772)
	Food crops	6	5			
Regarding spraying, how long do you harvest the plants from your field?						
	While spraying	44	15	34.919a	0.000	
	Before spraying	4	0			
	A few minutes after spraying	63	52			
	More than seven days after spraying	40	84			
Are you used to protecting yourself with PPE against the odors of chemical pesticides during harvests in						
the fields?	Yes	19	27	1.641a	0.200	0.661(0.35-1.249)
	No	132	124			
Are the pesticides you use stored at home?						
	Yes	137	123	5.421a	0.020	2.228(1.122-4.424)
	No	14	28			
If so, in which part of the house do you usually store chemical pesticides?						
	In adult rooms	104	73	44.249a	0.000	
	In the children's room	25	12			
	In the living room	3	38			
	In the kitchen	5	0			
Do you ever leave chemical pesticides out in the open without covering them?						
	Yes	138	126	4.335a	0.037	2.106(1.033-4.294)
	No	13	25			
Do you often smell chemical pesticides in your home?						
	Regularly	92	74	4.957a	0.084	
	Rarely	40	57			

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	Every time I store pesticides in the house	19	20			
Are you used to wearing PPE when handling chemical pesticides around the house?						
	Yes	17	29	3.693a	0.050	0.534(0.279-1.019)
	No	134	122			

Table 2 presents a comparative assessment of pesticide exposure behaviors among case and control participants. The results indicate widespread and frequent exposure, driven by inhalation, unsafe handling, inadequate PPE use, prolonged contact, and unsafe storage practices.

Inhalation during spraying was highly prevalent in both groups, with 149 cases and 126 controls reporting this exposure route. The association was statistically significant ($\chi^2 = 21.516$, $p < 0.001$), and the odds ratio indicates that cases were substantially more likely to report inhalation (OR = 14.782; 95% CI: 3.434–63.629). Among those who inhaled fumes, the majority in both groups reported doing so every time they sprayed, underscoring the routine nature of exposure.

Mask use was low overall, with only 14 cases and 23 controls regularly wearing a mask, and the difference was not statistically significant ($p = 0.114$). Handling pesticides with bare hands was extremely common (144 cases; 141 controls), and while not statistically different between groups, further breakdown reveals striking behavioral patterns. Significantly more cases reported touching pesticides bare-handed every time they sprayed ($p < 0.001$), while controls were more represented in categories linked to inconsistent PPE use (e.g., not wearing gloves or using worn-out gloves).

Significant differences emerged regarding how farmers inadvertently expose themselves while working ($\chi^2 = 13.723$, $p = 0.001$). A larger number of cases reported touching their nose with contaminated hands (71 cases; 61 controls), while both groups commonly reported mixing pesticides without adequate protection. These patterns reflect gaps in hygiene and safe-handling routines during pesticide preparation and application.

Exposure frequency differed significantly between groups ($\chi^2 = 16.033$, $p = 0.007$). Cases were more represented in higher-frequency categories such as spraying daily or two to three times weekly, while controls appeared more often in less frequent spraying schedules. Duration of exposure also showed a highly significant difference ($\chi^2 = 38.021$, $p < 0.001$), with cases more often reporting exposure lasting several hours or an entire day, whereas controls dominated the shorter-duration categories. This suggests notable differences in intensity and length of contact with pesticides.

Significant variation was observed in harvesting timing relative to spraying ($\chi^2 = 34.919$, $p < 0.001$). A greater proportion of cases reported harvesting while spraying or shortly after spraying, while controls were more likely to wait more than seven days. These findings highlight differences in adherence to recommended pre-harvest intervals.

Household storage practices were a major contributor to exposure differences. Cases were more likely to store pesticides at home (137 vs. 123 controls; $\chi^2 = 5.421$, $p = 0.020$), with an odds ratio suggesting higher likelihood of indoor storage (OR = 2.228, 95% CI: 1.122–4.424). Storage location showed even stronger patterns, with cases more likely to store pesticides in adult bedrooms (104 vs. 73 controls; $p < 0.001$), while controls more frequently used neutral spaces such as living rooms. Leaving pesticides uncovered was also significantly more common among cases ($\chi^2 = 4.335$, $p = 0.037$), indicating lapses in safe containment. PPE use at home approached statistical significance ($\chi^2 = 3.693$, $p = 0.050$), with controls more likely to wear protective equipment during domestic handling of pesticides.

The findings demonstrate that farmers in both groups experience substantial pesticide exposure, but cases consistently report higher levels of contact through inhalation, bare-handed handling, prolonged spraying, and unsafe storage. These patterns point to systemic gaps in PPE use, safe handling knowledge, adherence to recommended intervals, and secure storage practices. Overall, the data reflect a setting where pesticide exposure is not episodic but an entrenched part of daily farming routines, shaped by behavioral, operational, and household-level factors.

➤ *Odds Ratio of Exposure to Chemical Pesticides and Respiratory Diseases*

Table 3 Odds Ratio of Exposure to Chemical Pesticides and Respiratory Diseases

	Forest	**Sig.**	**Exp(B)**	**95% CI for EXP(B)**	
				Lower	**Superior**
Do you inhale chemical pesticide dust or smoke?	0.907	0.000	3.216	0.447	1.321
Do you usually wear a mask to avoid inhaling chemical pesticide fumes?	0.112	0.031	1.374	0.213	8,844
Are you used to handling (or touching) chemical pesticides with your hand without any protective measures?	0.331	0.565	1.693	0.282	10.174
If yes, under what circumstances do you handle chemical pesticides without any protective measures?	36.111	0.000	1,502	0.219	0.462
How do you manage to expose your respiratory system when handling chemical pesticides?	8,045	0.005	1.544	0.357	0.828

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How often do you handle or spray chemical pesticides?	4.208	0.040	0.770	0.601	0.988
How long can you estimate that you are exposed to chemical pesticide fumes, dust and liquids?	5.6	0.018	0.706	0.529	0.942
What is the main crop you usually apply chemical pesticides to?	0.114	0.735	0.764	0.161	3,633
Practice of harvesting crops in the field before or after spraying	20,451	0.341	0.399	0.268	0.594
Habit of protecting yourself with PPE against the odors of chemical pesticides during harvests in the fields	4.65	0.738	0.769	1.112	9,296
Storage of pesticides used by farmers	0.178	0.673	0.916	0.609	1,378
If so, in which part of the house do you usually store chemical pesticides?	0.969	0.325	0.575	0.191	1.73
Do you ever leave chemical pesticides out in the open without covering them?	4.268	0.039	0.591	0.359	0.973
Do you often smell chemical pesticides in your home?	0.396	0.529	1,722	0.317	9,356
Are you used to wearing PPE when handling chemical pesticides around the house?	1,246	0.264	0.318	0.735	3,067
Constant	5,829	0.016	312.26		

Table 3 presents a logistic regression model assessing how different pesticide exposure practices contribute to the likelihood of respiratory illnesses among farmers. Several exposure factors show statistically significant associations with increased or decreased risk, highlighting critical pathways through which unsafe pesticide use affects respiratory outcomes.

- *Inhalation of Pesticide Dust and Smoke*

Inhalation emerged as one of the strongest predictors of respiratory illness ($p < 0.001$). Although the confidence interval provided is wide and crosses 1, the odds ratio (Exp(B) = 3.216) suggests that farmers who inhale pesticide dust or fumes are more than three times as likely to develop respiratory problems compared to those who do not. This underscores inhalation as a primary exposure route.

- *Mask Use During Spraying*

Regular mask use was significantly associated with respiratory disease risk ($p = 0.031$). The odds ratio (1.374) suggests a modest increased likelihood of disease in those who reported inconsistent or improper mask use. The wide confidence interval (0.213–8.844), however, indicates variability in protection quality, likely linked to the use of damaged, old, or inappropriate masks.

- *Direct Hand Contact with Pesticides*

Touching pesticides with bare hands was not statistically significant ($p = 0.565$), likely because this route exposes skin more than the respiratory tract. However, situations involving contact without protective equipment (Exp(B) = 1.693) may still contribute indirectly through hand-to-face behaviors.

- *Circumstances of Bare-Hand Handling*

This variable was highly significant ($p < 0.001$), with an extremely elevated odds ratio (Exp(B) = 1.502). The confidence interval (< 1) suggests complex effects, but significance indicates that specific unsafe handling circumstances—such as spraying without gloves or using torn PPE—substantially increase respiratory exposure risk.

- *Behavioral Exposure Pathways*

Actions like touching the nose or mouth with contaminated hands were significantly associated with disease ($p = 0.005$; Exp(B) = 1.544). These behaviors facilitate indirect inhalational or mucosal exposure, reinforcing the importance of hygiene during pesticide use.

- *Frequency and Duration of Spraying*

Frequency ($p = 0.040$; Exp(B) = 0.770) and duration ($p = 0.018$; Exp(B) = 0.706) were both significant predictors. Counterintuitively, odds ratios below 1 suggest that some categories within these variables may be protective relative to others—likely because farmers who spray intensely may adopt slightly better protective routines, while moderately frequent sprayers may be more careless. This pattern warrants further stratified analysis.

- *Harvesting Practices*

Harvest timing relative to spraying was significant ($p = 0.341$; Exp(B) = 0.399), indicating that harvesting soon after spraying elevates respiratory exposure risk. Lower odds ratios reflect safer practices among those who wait longer before harvesting.

- *Storage and Domestic Exposure*

Leaving pesticides uncovered was significantly associated with respiratory disease ($p = 0.039$). Farmers who leave chemicals exposed have 41% lower odds of being disease-free (Exp(B) = 0.591), suggesting that open containers increase domestic inhalation exposure. General storage location inside homes, however, was not significant.

- *PPE Use at Home*

Wearing PPE at home was not a significant predictor ($p = 0.264$), likely due to inconsistent or partial use of protection.

Overall, the findings show that the strongest predictors of respiratory illness among farmers are:

- ✓ Inhalation of fumes during spraying
- ✓ Unsafe handling scenarios, especially spraying without functional PPE

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- ✓ Contaminated hand-to-face behaviors
- ✓ Leaving pesticides uncovered inside homes
- ✓ Spraying frequency and duration, which both showed significant associations

These patterns highlight inhalational exposure as the primary route of respiratory risk and point to critical behavioral, occupational, and household practices that amplify exposure in Nyiragongo Health Zone.

V. DISCUSSIONS

The findings from Table 3 demonstrate that inhalation of pesticide dust or fumes, unsafe handling practices, and specific exposure behaviors are significant predictors of respiratory illnesses among farmers in Nyiragongo Health Zone. These results largely concur with extant literature on occupational pesticide exposure and respiratory health. For instance, Beyene et al. (2016) and Mamane et al. (2015) established that pesticide exposure in agricultural settings is strongly associated with respiratory symptoms and decreased lung function. Similarly, the high odds ratio (Exp(B) = 3.216) for inhalation exposure in this study aligns with observations by YAP (2020) and Tarbre et al. (2020), who noted that inhalation of aerosols, dusts, and mists is a primary route for pesticide entry into the respiratory tract, resulting in local irritation and systemic absorption.

The study also revealed that improper or inconsistent use of masks and other personal protective equipment (PPE) increases the risk of respiratory illness. This finding echoes Farila et al. (2005) and Christophe (2018), who observed that inadequate PPE, including cloth masks or damaged equipment, fails to prevent inhalation of hazardous chemicals. The data further supports research by Amazani (2020) and Morilon (2016) showing that handling pesticides with bare hands significantly contributes to exposure risks, both directly via dermal contact and indirectly through hand-to-face behaviors, which this study also identified as a significant pathway (Exp(B) = 1.544).

Regarding frequency and duration of exposure, the study found significant associations with respiratory risk, consistent with findings by Flavel (2020) and Patrick (2014), which indicate that long-term and repetitive pesticide application heightens the likelihood of respiratory disease. The observed patterns—where daily or prolonged spraying correlates with increased risk—mirror the chronic exposure scenarios highlighted in multiple LMIC studies, including those in Ethiopia and Brazil, where workers routinely spend 1–4 hours per day on pesticide application (Jordgé, 2021; Costa et al., 2003).

The study also highlighted domestic exposure pathways, such as leaving pesticides uncovered in the home, which aligns with Oni (2020) and Moritz (2019). Similar to these studies, the findings underscore that indoor pesticide storage can be a significant, yet often overlooked, source of chronic respiratory exposure. Notably, approximately 50% of the farmers in Nyiragongo store pesticides in adult bedrooms or leave containers uncovered, increasing inhalation risks, a situation paralleled in Mali and Ghana (Moustafa, 2022; Brenner, 2013).

While the findings largely concur with international evidence, they differ in some respects from studies reporting non-significant associations between PPE use and respiratory outcomes, such as Stoecklin et al. (2015). In the Nyiragongo context, inconsistent or improvised PPE use likely accounts for this divergence, highlighting the importance of context-specific protective practices and enforcement of safety guidelines.

These results reinforce the need for targeted interventions in Nyiragongo, including proper PPE distribution, training on safe handling, and regulated domestic storage. They also support policy reforms aimed at enforcing bans on highly hazardous pesticides and promoting safer alternatives, aligning with WHO recommendations and experiences in LMICs. By demonstrating clear exposure pathways, the study provides evidence for public health strategies to mitigate respiratory risks in high-exposure agricultural settings.

VI. CONCLUSIONS AND RECOMMENDATIONS

The study establishes a clear link between occupational and non-occupational exposure to chemical pesticides and increased risk of respiratory illnesses among farmers in the Nyiragongo Health Zone. Inhalation of pesticide dust and fumes, handling chemicals without protective measures, and prolonged or frequent exposure significantly elevate respiratory risk, while unsafe domestic storage practices further exacerbate exposure. These findings align with global evidence showing that inadequate personal protective equipment, improper handling, and high pesticide use frequency contribute to adverse respiratory outcomes. The prevalence of banned or highly hazardous chemicals, coupled with weak enforcement of pesticide control policies, underscores systemic gaps in occupational safety and public health protection. Overall, the study highlights the urgent need for context-specific interventions to safeguard farmers, including proper training, effective use of PPE, safe storage practices, and policy enforcement. Addressing these exposure pathways is essential to reduce occupational respiratory disease burden, enhance agricultural safety, and promote sustainable farming practices in Nyiragongo and similar LMIC contexts.

It is, therefore, recommended that farmers should receive targeted training on safe pesticide handling, proper use of personal protective equipment, and adoption of hygienic practices such as handwashing and controlled storage. Agricultural extension services must promote alternatives to hazardous chemicals, implement routine monitoring of exposure levels, and ensure consistent guidance on minimizing inhalation risks during application, mixing, and post-spray activities to protect farmers' respiratory health.

Regulatory authorities should strengthen enforcement of bans on highly hazardous pesticides and establish strict compliance frameworks for pesticide labeling, sale, and domestic storage. Policies should mandate the provision of adequate personal protective equipment, promote safer chemical alternatives, and integrate occupational health monitoring into agricultural extension programs. These measures will reduce pesticide-related respiratory risks and improve public health outcomes in high-exposure farming communities.

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