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PROLIFERATION OF DIFFERENT CATEGORIES OF CHEMICAL PESTICIDES AND RESPIRATORY DISEASE RISK FOR FARMERS IN THE NYIRAGONGO HEALTH ZONE IN NORTH KIVU, DRC

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ABSTRACT

The use of pesticides has increased due to their widespread application in agricultural and environmental pest control. There are thousands of categories of pesticides, each with a specific chemical composition and use. Pesticides form a major farm input with many farmers in the Democratic Republic of Congo (DRC) continually applying pesticides to boost their crop production. Some of these pesticides have been banned or restricted but still find their ways into the farmers hands. However, in the Nyiragongo health zone, in North Kivu, thousands of farmers are victims of respiratory poisoning caused by chemical pesticides. The objective of this study, therefore, was to determine the proliferation of different categories of chemical pesticides and respiratory disease risk for 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. Data was collected using a questionnaire, and analyzed using descriptive and inferential statistics. The study established that five chemical pesticides, four insecticides and one insecticide, were significantly associated with the risk of respiratory diseases among farmers in the Nyiragongo health zone in North Kivu. Among these, three pesticides; Carbaryl 85 WP, Deltamethrin, and Deltamethrin presented a significant risk compared to all other pesticides.In addition to the toxicity of chemical pesticides, the risk of disease was exacerbated by poor knowledge and poor pesticide handling practices by farmers. The study therefore recommends the DRC Government improve the policy environment by putting in place provincial mechanisms to fight corruption and customs fraud. Also, there is need for the state services to establish an agricultural monitoring system (agricultural monitors) for permanent support and guidance of farmers in the rational use of chemical pesticides in agricultural areas.

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INTRODUCTION

Pesticides are chemical substances widely used in agriculture to control, prevent or eradicate harmful insects, birds, rodents, bacteria, weeds, among others. The use of pesticides has increased due to their widespread application in agricultural and environmental pest control. There are thousands of categories of pesticides, each with a specific chemical composition and use. The exact number of pesticides can be difficult to determine due to the variety of products, formulations and trade names used in different regions and countries (Géril, 2022). There are three main categories of pesticides, that is; insecticides, herbicides and fungicides. Insecticides are designed to kill or control insects while herbicides are designed to kill or control weeds. Fungicides designed to eliminate fungi. Other pesticides include nematicides (against nematodes) and rodenticides (Tebila, 2020). The efficacy of the pesticides is related to the quality of pesticide application with small droplets, such as aerosols often improving performance. Chemical pesticides are generally toxic to both pests and humans, and the toxicity of a pesticide depends on its function and other factors. For example, insecticides tend to be more toxic to humans than herbicides. The World Health Organization (WHO) classifies acute effects of pesticides based on oral and dermal lethal doses (LD_{50}), which can vary depending on whether the product is in solid or liquid form. Class Ia pesticides are extremely toxic, class Ib pesticides are very toxic, class II pesticides are moderately toxic while class III pesticides are slightly toxic 5. Toxicity category IV is practically non-toxic and not an irritant (WHO, 2007). The same chemical can have different effects at different doses, that is, depending on how much of the chemical a person is exposed to. Toxicity may also depend on the route by which exposure occurs, such as ingestion, inhalation, or direct skin contact (Mabushar *et al.,* 2019). Many agricultural activities such as, storing, mixing, preparing and spraying pesticides, and loading and cleaning spray equipment pose serious pesticide exposure risks. Therefore, agricultural workers are often at risk of being exposed to these toxic substances. Exposure to chemical pesticides refers to people (farmers) coming into direct or indirect contact with a pesticide during its handling, storage or transportation. The latter cause direct effects (symptoms) acute and chronic after prolonged exposure. The degree of exposure is determined by the concentration of the toxic active ingredient, the surface area of skin exposed, the sensitivity of the body, the duration of contact and the frequency of repeated contact. Harmful exposure to chemical pesticides, therefore, implicitly means exposure to pesticides beyond accepted limits and this could have an effect on health. Further, the WHO (2023) estimates the number of poisonings worldwide at 1,000,000 and the resulting deaths at 20,000. Adverse exposure to pesticides can lead to acute and chronic health problems, including temporary acute effects such as eye irritation and excessive salivation. Other reported adverse health effects include burning sensations in the eyes/face, skin irritation, headache, dizziness and respiratory effects. This can lead to respiratory diseases such as asthma and bronchitis as well as dermatitis and chronic diseases such as cancer and reproductive and developmental disorders. Exposure can also affect peripheral nerves, lead to chronic neurobehavioral disorders, and motor dysfunction. Respiratory pathologies in people exposed to pesticides and the association between bronchial asthma and occupational exposure to pesticides have been well documented, mainly in agricultural occupations (Tarbre *et al.,* 2020).

Most of the pesticides sold in the market in most countries are generally legal and safe and can have rewarding effects on pest control when handled and utilized as prescribed by the manufacturer. Unfortunately, however, a number of pesticides existing in the market are illegal and unsafe for use and, therefore, should not even be existing in the shelves in the first place. Most of them, like DDT, are persistent organic pollutants (POPs) that accumulate in the fatty tissues of organisms and cause many health problems. Since the adoption of the Stockholm Convention on POPs in 2001, the manufacture and use of some pesticides has either been banned or strictly limited. However, some of the pesticides banned in Europe end up in the hands of farmers in several countries in Africa. A survey published in September 2020 by the Swiss NGO Public Eye shows that Africa has become one of the main export zones of pesticides banned in Europe (Eye, 2020). Farmers in developing countries are the most disproportionally affected by the products banned for use in industrialized countries which are still sold in these countries (WHO, 2023). The Democratic Republic of Congo is one of the key export destinations of these banned pesticides (Eye, 2020). The absence of strict controls at Congolese borders encourages informal networks that make it possible for the banned products to infiltrate the country. According to a study by SOS FAIM carried out in the DRC in 2021 among market gardeners, in addition to approved products, investigators noted the presence of prohibited products, the most common being Dichlorvos, DDT and Thiodan Endosulfan Sulfate. The product most used by Congolese market gardeners in the Kinshasa region is Thiodan which put the health of farmers and consumers at risk (SOS FAIM, 2021). In the DRC, laws to regulate the use of chemical inputs exist. In addition, a list of banned and approved pesticides (authorized importation) exists with the regulators in the DRC. However, they are poorly implemented leading to loss of control of banned pesticides entering the country. Prohibited products such as Dichlorvos, DDT, Endosulfan and Thiodan circulate the most in the country compared to approved pesticides (SOS FAIM, 2021). Most of these products also come with manufacturers instructions written in foreign languages which mean that farmers are likely to end up not following the manufacturers instructions and, therefore, poorly handling the pesticides leading to adverse exposure and contracting of diseases.

Problem: Majority of the population in the Nyiragongo health zone are peasant farmers and mostly practice market gardening. Over 150,000 tonnes of vegetables are produced per year on small family farms in the Democratic Republic of Congo (DRC) to mainly feed rapidly growing urban populations and quickly provide producers with income (Balasha *et al.*, 2023). Pesticides form a major farm input with many farmers in the country continually applying pesticides to boost their crop production. Some of these pesticides have been banned or restricted but still find their ways into the farmers hands. This coupled with the fact that most farmers use the pesticides hazardously has exposed the farmers to the harmful effects of the pesticides. Random inspection of the pesticide management knowledge and practices reveal that the pesticides are being handled in a risky way by the farmers. Also, evidence from discarded pesticide containers and random interviews with farmers indicate that banned toxic pesticides have found their way to the area further exposing the farmers to more disease risks. Added to this is poor disposal of chemical pesticide containers, which some farmers use for drinking and storing consumables as well as food handling. As a result, many farmers are victims of several repeated symptoms that cause respiratory diseases, thus weakening their health and affecting their productivity. According to the Central Office of the Nyiragongo Health Zone (BCZ/NYIRAGONGO), many farmers coming to consult different health centers present with acute respiratory symptoms (persistent cough, shortness of breath, fever, cold, difficulty breathing and rhinitis) while others are already suffering from asthma, bronchitis; and this, caused by chemical pesticide spraying practices which do not meet international standards. However, from a public health perspective, the admixture of legal and banned chemicals in the country makes it difficult to link specific pesticides with respiratory illnesses among the farmers in the country. This study, therefore, undertook to profile the chemical pesticides used by farmers in the Nyiragongo health zone in North Kivu, DRC and link them to respiratory disease occurrence among famers in the area.

Objective

The objective of the study was to determine the proliferation of different categories of chemical pesticides and respiratory disease risk for farmers in the Nyiragongo health zone in North Kivu, DRC.

LITERATURE REVIEW

Insecticides use for Agriculture: Insecticides are claimed to be a major factor behind the increase in the 20th-century's agricultural productivity (Meriç, 2017). Insecticides are pesticides used to control insects by killing them or preventing them from engaging in undesirable or destructive behaviors. Insecticides are formulated to kill, harm, repel or mitigate one or more species of insect. They include ovicides and larvicides used against insect eggs and larvae, respectively (Sparks *et al.,* 2020). The synthetic insecticides most used by farmers are formulated based on the following active ingredients: profenofos 40% + cypermethrin 4% (24.4%), abamectin 1.8% (9.8%), abamectin 20 g/L + acetamiprid 3% (7%), cypermethrin. 5% (6.1%), cypermethrin 25 g/L (3.9%), dichlorvos 77% EC (2.8%), malathion (1.3%), endosulfan 400 g/L (0.8%) (Purkait *et al.*, 2019). Further, synthetic insecticides can be classified based on their major chemical compounds. These include; Organochlorides, Organophosphates, Carbamates, Pyrethroids, Neonicotinoids, Phenylpyrazoles, Phenylpyrazoles, Butenolides, and Ryanoids/diamides. Insecticides can be classified into two major groups: systemic insecticides, which travel though the plant after uptake; and contact insecticides, which do not (Simon-Delso *et al.,* 2015). Systemic insecticides, after uptake, are distributed systemically throughout the whole plant. When insects feed on the plant, they ingest the insecticide. Systemic insecticides produced by transgenic plants are called plant-incorporated protectants (PIPs).

Contact insecticides are toxic to insects upon direct contact (Adomako *et al.,* 2022). These can be inorganic insecticides, which are metals and include the commonly used sulfur, and the less commonly used arsenates, copper, and fluorine compounds. Contact insecticides can also be organic insecticides, i.e. organic chemical compounds, synthetically produced, and comprising the largest numbers of pesticides used today. Or they can be natural compounds like pyrethrum, neem oil, etc. (Kumar *et al.,* 2021). Insecticides are used in agriculture, medicine, industry and by consumers. Insecticides work in different ways. Some insecticides disrupt the nervous system, whereas others may damage their exoskeletons, repel them or control them by some other means. They can also be packaged in various forms including sprays, dusts, gels, and baits. Because of these factors, each insecticide can pose a different level of risk to non-target insects, people, pets and the environment. Nearly all insecticides have the potential to significantly alter ecosystems; many are toxic to humans and/or animals; some become concentrated as they spread along the food chain (Tooker & Pearsons, 2021). The World Health Organization (WHO) emphasizes that the professional use of insecticides is particularly dangerous and can cause serious illnesses: the most serious acute pesticide poisonings are linked to insecticides (notably organophosphates and carbamates). Among the categories of chemical pesticides used in agriculture, organophosphate insecticides are potentially fatal toxicants in the event of acute poisoning. These poisonings, often voluntary, are frequent, particularly among farmers, in developing countries, with a frequency preventing 3 million poisonings per year worldwide and a mortality of around 200,000 people per year (Gong *et al.* , 2016). Insecticide toxicity can be either acute or chronic. The danger of acute poisoning, during accidental exposure, manifests itself in skin, digestive, respiratory, muscular, nervous and cardiovascular disorders. But there are also risks of chronic poisoning, resulting from frequent and prolonged exposure to low doses. They can cause nervous system disorders, carcinogenic and mutagenic effects, as well as endocrine disruption: the risks induced by direct and/or indirect exposure to insecticides have significant effects on the frequency of certain cancers, neurodegenerative diseases and on fetal development (WHO, 2020).

Fungicides use for Agriculture: A fungicide is any substance, preparation, or organism intended for destroying or controlling any fungal species during production, storage, or distribution of an agricultural commodity or food, in ornamental plants, or in situations endangering the health of animals or humans (Najam & Alam, 2023). Fungicides most used by farmers on farms consist of the following active ingredients: copper oxychloride 50% WP (32.7%), metalaxyl 4% + mancozeb 64% (22%), metalaxyl 80 g/kg + mancozeb. 640 g/kg (14.3%), sulfur 80% (11.3%) and mancozeb 80% (1.8%) (Toe, Idem). The categories of counterfeit chemical fungicides proliferate in agricultural areas since the farmers who market the products are not authorized to do this trade. And yet, import and export permits fall under the jurisdiction of the Ministry of Foreign Trade (Damalas & Eleftherohorinos, 2011). Agricultural workers use several categories of fungicides over the course of an application, a season, and a working life to eliminate fungi that threaten plants in the field (Klaassen & Watkins, 2015). To minimize agricultural losses during harvest and continue to meet growing food demand, farmers use fungicides and insecticides. Although they are recognized for having the advantage of acting on a broad spectrum of pests and improving the quantity and quality of crops, the repeated and poorly controlled use of pesticides leads to resistance from pests and the elimination cultivation auxiliaries, environmental pollution and serious health problems for farmers and consumers (Kouakou *et al.,* 2019). Liquid fungicide cocktails can cause additive or synergistic effects due to toxicological interactions between the different ones (Cedergreen *et al*., 2017). As with insecticides, the main routes of exposure to fungicides are oral, respiratory and dermal. For the general population, the predominant exposure comes from oral ingestion (INSERM, 2013). On the other hand, in the case of agricultural workers, respiratory and skin exposures constitute the main routes of exposure (INSERM, 2013). Concomitant exposure via several routes is also possible among farmers when spraying products intended to eliminate fungi on plants (Fryeuse, undated). A study conducted in Burkina Faso by Toé (2010) found that around 45% of farmers had suffered poisoning linked to the application of fungicides and pesticides, most of which are made with toxic pesticides such as paraquat and l. 'Endosulfan (Thiodan).

Herbicide use for Agriculture: A herbicide product is defined as a preparation having the property of killing plants. The term “weedkiller” is synonymous with herbicide. In crop protection, herbicides are used to control weeds , or weeds , intended to destroy or limit the growth of plants, whether herbaceous or woody. They can be used, depending on their mode of action, pre- or post-emergence (WHO, 2022). In general, herbicides have high acute toxicity to humans because the physiology of humans is very different from that of plants. There are exceptions, however; many can be irritating to the skin as they are often strong acids, amines, esters and phenols. Inhalation of spray mist may cause coughing and a burning sensation in the nasal passages and chest. Prolonged inhalation sometimes causes dizziness. Ingestion will typically cause vomiting, a burning sensation in the stomach, diarrhea, and muscle twitching (Armand, 2020). The use of herbicides considered hazardous is increasingly common in developing countries, particularly in efforts to control disease vectors and pests to improve crop yields. However, it is one of the continents where these toxic products cause the most damage to populations and the environment, particularly in rural regions (Le Bars *et al.,* 2022). In Africa, NGOs from several networks, working with unions and other organizations, have campaigned for years for a global ban on the manufacture and use of the herbicide paraquat. Paraquat, one of the most widely used herbicides in the world, is used by small-scale farmers. It is highly toxic: just one teaspoon is dangerous for humans and can cause respiratory and skin allergies (Lyn, 2017). A study conducted in Burkina Faso in 2010 found that approximately 45% of local farmers had been contaminated by the application of hazardous pesticides, including highly toxic pesticides such as paraquat (Toé, 2010).

Banned pesticides used by farmers: Many of the pesticides they apply to their crops are classified as Class II (moderately hazardous) by the World Health Organization (WHO) although a few others are WHO Class III (slightly hazardous). Some farmers continue to apply persistent or very toxic banned pesticides, including aldrin, dieldrin, endosulfan, lindane, DDT, and methyl bromide and these chemicals have been identified in human fluids, vegetables, and the environment (Fosu-Mensah *et al.* 2022). One of the most toxic chemical insecticides is Endosulfan (also known by its brand names Benzoepin, Endocel, Parrysulfan, Phaser, Thiodan, Thionex). It is produced by the Israeli firm Makhteshim Agan and several manufacturers in India and China. It is an organochlorine insecticide used against aphids, thrips, and beetles, larvae that feed on leaf tissue, mites, borers, cutworms, cotton caterpillar, flies whites and leafhoppers. Endosulfan is a non-systemic insecticide and acaricide with contact and stomach action (Nayak & Solanki, 2021). Since its introduction, endosulfan has shown exceptionally good plant compatibility. Reports about phytotoxic effects are extremely scarce and mostly due to uncontrolled tank mixtures with products which were not recommended for this purpose. In comparison to organophosphates, endosulfan has short Preharvest Intervals in many crops, which offers a safety margin for consumers notably for vegetables.

Endosulfan has, however, been banned or severely restricted in nearly 50 countries in the world following the 2011 Stockholm Convention that became effective in mid-2012 due to its strong toxicity among human and animals and its persistence in the environment. It is for the same reasons that The European Union has proposed registration of Endosulfan on the annex 3 of the Agreement of Stockholm on the POPs has because of his serious impacts on health and the environment. Endosulfan was voluntarily withdrawn from cotton production in West Africa the before the years 1980 and replaced by the pyrethroids (PAN, 2008). In Africa, particularly, the Sahelian Countries and some West African countries have banned the use of Endosulfan products since the year 2007. However, endosulfan (Thiodan) is still widely used in Congolese agriculture by market gardeners despite its ban. It is used on cotton, tobacco, cantaloupe, tomato, squash, eggplant, sweet potato, broccoli, pear, pumpkin, corn, cereals, oilseeds, potatoes, tea, coffee, the cocoa, soy, and others vegetables. In CILSS countries, Endosulfan was mainly used on cotton. Illicit uses in vegetable crops have been reported in several countries of the sub-region. Dichlorodiphenyltrichloroethane (DDT) is an insecticide used widely in control of insects in agriculture and insects that carry diseases. DDT is a colorless, tasteless, and almost odorless crystalline chemical compound, an organochloride. The development of DDT was motivated by desire to replace more dangerous or less effective alternatives. DDT was introduced to replace lead and arsenic-based compounds, which were in widespread use in the early 1940s (Sadasivaiah, Tozan & Breman, 2007). DDT was brought to public attention by Rachel Carson's book *Silent Spring* (Paull, 2013). Originally developed as an insecticide, it became infamous for its environmental impacts. The United States banned the use of DDT in 1972. However, some countries outside the United States still use DDT to control of mosquitoes that spread malaria.

One side-effect of DDT is to reduce the thickness of shells on the eggs of predatory birds. The shells sometimes become too thin to be viable, reducing bird populations. This occurs with DDT and related compounds due to the process of bioaccumulation, wherein the chemical, due to its stability and fat solubility, accumulates in organisms' fatty issues. Also, DDT may biomagnify, which causes progressively higher concentrations in the body fat of animals farther up the food chain (Silva *et al.,* 2019). Human health effects from DDT at low environmental doses are unknown. Following exposure to high doses, human symptoms can include vomiting, tremors or shakiness, and seizures. Laboratory animal studies showed effects on the liver and reproduction. DDT is considered a possible human carcinogen (Costa, 2015). Dithane is broad spectrum fungicide and controls many fungal diseases in field crops, fruits and vegetables etc. It is based on the active ingredient, mancozeb, which belongs to the dithiocarbamates group of compounds. Dithane, a commercial formulation containing 80% Mancozeb, is a broad-spectrum contact fungicide that is utilized to combat fungal diseases in vegetables, fruits, crops and paddy fields (Choudhury & Das, 2020). Mancozeb, one of the ethylene bis (dithiocarbamates) type fungicides, was first introduced to the world market in the 1960s, and its use has been increasing in the 2020s because of its non-selective fungicidal action and inexpensiveness (Macar *et al.,* 2023). The antifungal action of Mancozeb is due to its power to inhibit the sulfhydryl groups of both the amino acids and enzymes in the cells of fungal organisms, leading to the breakdown of respiration, lipid metabolism and ATP production (Sharma *et al.*, 2019). Dithane gives effective control for most of the fungal diseases across crops. The fungicide is a broad-spectrum protectant fungicide labeled for outdoor crops, for turf and ornamental uses or greenhouse grown ornamentals. Optimum disease control is achieved when the fungicide is applied in a regularly scheduled preventative spray program. No reported resistance to Dithane has been reported even after more than 45 years of commercial use. Excellent blend partner and preferred partner of choice for resistance management. Very fine particle size of Dithane give better solubility & spreading on the leaf surface providing better disease protection.

Some adverse effects depending on Mancozeb exposure were reported as visceral diseases, nervous system disorders, skin damage, hormonal dysfunctions, reproductive system abnormalities and genetic defects (Choudhury & Das, 2020). Monitoring studies on Ethylene revealed that Ethylenethiourea, the most active degradation product of Dithane, is the main crucial toxicological risk factor (Asita & Makhalemele, 2009). Mancozeb is the first pesticide banned in the EU because of its endocrine disrupting properties (Arya *et al.,* 2017). Dithane is, however, harmful to humans if absorbed through the skin. It causes moderate eye irritation. Prolonged or frequently repeated skin contact may cause allergic reactions in some individuals. Contact with skin, eyes, or clothing should be avoided. Dichlorvos, an organophosphate, is a predominant pesticide used in domestic insect control in developing countries. Dichlorvos is usually used as a household and agricultural pesticide. Dichlorvos has the molecular formulation C4H7Cl2O3P, molecular weight of 220.98, vapor pressure of 1.2×10^{-2} mmHg at 20 °C, and density of 1.415 g/ml at 25 °C (Budavari, 1998). It is classified by the WHO as a class 1B, "highly hazardous" chemical (WHO, 1992). Dichlorvos is a powerful pesticide designed to effectively eliminate a variety of household pests. The advantage of the organophosphate dichlorvos is that it gives rapid knockdown and with its broad-spectrum activity is used to control sucking and chewing insects and spider mites on a wide range of crops (BCPC 2012 and pers. It kills in less than a minute. Lava is an instantaneous pesticide that instantaneously kills all flying and crawling pests. It kills flies, mosquitos, cockroaches, ants, and other crawling and flying insects quickly and efficiently. It is effective against mushroom flies, aphids, spider mites, caterpillars, thrips, and whiteflies in greenhouse, outdoor fruit, and vegetable crops. Domestically it is used to control insects like bedbugs and cockroaches. It acts against insects as both a contact and a stomach poison.The legal status of Dichlorvos, specifically its ban and restriction varies across various jurisdictions and a uniform ban has not been agreed to worldwide.

Proliferation of Banned Pesticides: According to the World Bank, many developing countries import chemical insecticides to increase agricultural production. But after a while, these products become unusable and dangerous for humans. Today in sub-Saharan Africa, more than 50,000 tonnes of expired insecticides expose the health of farmers to respiratory, skin, eye and nervous poisoning. These pollutants can also cause cancer, respiratory diseases, allergies, reproductive disorders, immune disorders and nervous system damage (World Bank, 2013). According to a study by Jean (2020), certain pesticides such as Curacron, Cypermethrin, Polytrin, Profénofos, Dithane, thiodan and others, banned on vegetables worldwide, are used by certain market gardeners in many countries. Africa and the Democratic Republic of Congo for agricultural purposes. This poses a risk to the health of farmers and consumers (Jean, 2020). The product most used by Congolese farmers is Thiodan. Its success can be explained by its affordable price (in February 2021, two bottles of Thiodan cost 2,000 Congolese francs, or 0.83 euros), a large supply and weak legislation on the importation of toxic products into the DRC. Furthermore, it has even been observed that certain insecticides such as Curacron, Cypermethrin, Polytrin, Profenofos and others, banned on vegetables, are used by certain market gardeners. This poses a risk to their health and that of consumers (the population) (WHO, 2020). The presence of such a banned substance endangers the Congolese people and the Congolese ecosystem.

METHODOLOGY

Context of the study area: This study was carried out in the Nyiragongo health zone, North Kivu Province in the Democratic Republic of Congo. Agricultural activities constitute the economic pillar of the Nyiragongo health zone where more than 85% of households practice agriculture and livestock breeding. Nyiragongo health zone was chosen for this study due to the high prevalence of respiratory diseases in recent years compared to other health zones in the region, and these have been linked to the hazardous application chemical pesticides.

Study design: According to a 2023 report from the Health Information System (SNIS) of the Nyiragongo health zone, respiratory diseases have a prevalence of 8% among farmers in the area. The prevalence of respiratory diseases recorded in the Nyiragongo health zone justifies the choice of the retrospective case-control study design. The case-control study is retrospective because it begins with an outcome and then returns to examining exposures.The case-control study was used to see if exposure is linked to a certain outcome (i.e. recurrent respiratory illness). In this study, the cases therefore included farmers using chemical pesticides who had contracted respiratory diseases, while the control group was composed of farmers using chemical pesticides who had not previously contracted respiratory diseases. Exposure included farmers who inhaled, handled, stayed for a long time in hazardous agrochemicals, while non-exposures included farmers who had not been exposed to hazardous agrochemicals. The researcher had reason to believe that exposure to hazardous chemical pesticides was influenced by the farmers' knowledge and practices regarding the application of chemical pesticides in the region.

Population studied: This study targeted farmers in the Nyiragongo health zone who use chemical pesticides, estimated today at 183,988 farmers. The study included area farmers aged 18 and over because they are responsible for their choices. This included actual farm owners and farmers who are actively involved in daily agricultural activities on their land. The study focused only on farmers actively involved in purchasing and applying chemical pesticides on their farms. This research targeted farmers in the Nyiragongo health zone who had contracted respiratory diseases (cases) and those who had not contracted respiratory diseases (control zone). Exposure was defined as farmers who had prolonged exposures and inhalation of pesticide vapors (exposed) and those who did not have prolonged exposures and inhalation of pesticide vapors (unexposed). The inclusion criteria for the cases and control were; being a farmer from the Nyiragongo Health Zone, having ever used chemical pesticides, resident in the Nyiragongo Health Zone, being an adult, over 18 years old, having contracted a respiratory symptom or illness for the cases, and not reported in people with respiratory illnesses for the control. The exclusion criteria for the cases and the control were; being a farmer from another health zone in North Kivu, farmers who do not use chemical pesticides in Nyiragongo Health Zone, farmers under 18 years of age, and an undeclared case in a health facility in the Nyiragongo health zone. The study also targeted the regulatory actors involved in the implementation of the chemical pesticide control policy in the North Kivu province. These included actors involved in different services in the implementation of the chemical pesticide control policy at the provincial level, namely: 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 the Study of Agronomic Research (INERA), National Sanitation Program (PNA), Provincial Environment Division (DPE), Provincial Health Division (DPS), Civil protection, Peasant organizations of Nyiragongo farmers, Central Health Zone Office (BCZ), Rural development (DR), and Trade.

Determination of sample size: For this case-control study, the sample size was determined among farmers (cases and controls) for the quantitative approach. But also at the level of the actors involved in the implementation of chemical pesticide control policies for the qualitative approach.To determine the sample size for the two groups (cases and controls) of the retrospective case-control study, the study used the formula proposed by *Charan and Biswas* (2013) as follows:

$$n = \frac{r+1}{r} \frac{(P^*)(1-P^*)\left(Z_\beta + Z\alpha_{/2}\right)^2}{(P_1 - P_2)^2}$$

Or;

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.

Qualitative data was collected from 14 state structures responsible for implementing chemical pesticide control policies who were the key informants on pesticide policy monitoring and regulation in the North Kivu Province.

Sampling technique: According to the Health Information System (SNIS) of the Nyiragongo health zone, respiratory diseases have a prevalence of 8% among farmers. Since most of these farmers were diagnosed at some point with respiratory diseases in public health facilities in the region, it was possible to access their data and thus be able to trace them. Their medical records at health facilities in their respective health zones provided the necessary contact details as well as socio-demographic information of the farmers. Systematic random sampling was, therefore, used to select farmers who were diagnosed with respiratory diseases and match them with control group farmers. This ensured that inclusivity and proportionality in sampling was done across all the health zones. Using the farmers' contact information at the hospital, initial contacts were made with the farmers by the researcher where the study's purpose was explained and the inclusion criteria of the farmers in the study was determined. After these were determined, the researcher located physically the first farmer in his farm in Kiziba health zone. After interviewing the first farmer, the researcher was also able to locate other farmers who met the inclusion criteria for controls and cases group in the Kiziba health zone. The process was repeated in other health zones in the area as well. For the policy actors, the study used convenience sampling where individuals were interviewed in different structures or organizations based on their availability.

Data Collection Instruments: The study used two approaches: quantitative and qualitative, and each approach had its specific tools: for the quantitative approach, the *survey questionnaire* was used to facilitate data collection of cases and controls (farmers) in the Nyiragongo health zone. For the qualitative approach, *the interview guide* was used to collect data from key informants in different targeted structures.

Data analysis methods: For the quantitative approach the control cases used two types of analysis, namely univariate analysis and bivariate analysis. Univariate analysis involved frequencies, percentages, means, standard deviations.Bivariate analysis regression approach was used to evaluate the relationship between the dependent and independent variables, the Odds ratio (OR) was subsequently calculated and allowed us to measure the association between the factors of exposure of farmers to chemical pesticides and the respiratory diseases that this exposure causes. For the qualitative approach, the data analysis was carried out at two levels; content analysis and theme analysis.

RESULTS

Categories of chemical pesticides proliferating Nyiragongo health zone in North Kivu: The study sought to determine the categories of chemical pesticides that proliferate in the Nyiragongo health zone in North Kivu in the DRC. The results are summarized as follows:

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 shows that in general, chemical insecticides (N = 515) were used more than chemical fungicides (N = 317). This suggests that the most common pests affecting farmers were insects. However, the heavy use of fungicides also suggests that fungi posed a considerable threat to farmers. In terms of brand, Thiodan was the most commonly used insecticide (66.6%), followed by Lava Dichlorvos 100% EC (27.5%) and Actellic 2% (22.2%).

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
	Tafgor (Dimethoate 40%)	46	15.2	256	84.8
	Sumithion 50 CE	6	2	296	98
	Carbaryl 85 WP	10	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	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

Table 2. Trends in chemical pesticide use between case and control groups

Chemical type	Brand	Rsp.	Case	Controls	Total	Chi square	P-value
Chemical	Thiodane	Yes	129	72	201	48,332	0.000
Insecticides		No	22	79	101		
	Rocket	Yes	14	5	19	4,549	0.033
		No	137	146	283		
	DDT	Yes	ten	2	12	5,554	0.018
		No	141	149	290		
	Deltamethrin	Yes	16	30	46	5.026	0.025
		No	135	121	256		
	Lava Dichlorvos 100% EC	Yes	38	45	83	.814	0.367
		No	113	106	219		
	Tafgor (Dimethoate 40%)	Yes	19	27	46	1,641	0.200
		No	132	124	256		
	Sumithion 50 CE	Yes	4	2	6	.680	0.410
		No	147	149	296		
	Carbaryl 85 WP	Yes	1	9	ten	6,619	0.010
		No	150	142	292		
	Actellic 2%	Yes	35	32	67	.173	0.678
		No	116	119	235		
	Super lace	Yes	6	13	19	2,752	0.097
		No	145	138	283		
	Malathion	Yes	2	4	6	.680	0.410
		No	149	147	296		
Chemical	Ridomil	Yes	14	30	44	6,810	0.009
Fungicides		No	137	121	258		
	Dithane	Yes	149	106	255	46,591	0.000
		No	2	45	47		
	Super Homai 70 WP	Yes	3	9	12	3.124	0.077
		No	148	142	290		
	Benlate	Yes	0	6	6	6.122	0.013
		No	151	145	296		

Table 3. Bivariate analysis of chemical pesticide types and respiratory disease risk

	Wald	Sig.	Exp(B)	95% CI for EXP(B)	
				Lower	Superior
Thiodane	24,086	0.000	20,688	1,595	8,371
Rocket	1,437	0.231	0.105	0.003	4.174
DDT	4.242	0.039	1,662	0.633	4.361
Deltamethrin	0.000	0.997	0.000	0.000	.
Lava Dichlorvos 100% EC	0.543	0.461	1,346	0.611	2,965
Tafgor (Dimethoate 40%)	1,066	0.302	0.198	0.042	0.925
Sumithion 50 CE	0.281	0.596	0.119	0.051	0.279
Carbaryl 85 WP	5,368	0.021	1,898	0.178	20.28
Actellic 2%	0	0.986	0.992	0.41	2.403
Super lace	1,088	0.297	2.1	0.521	8,467
Malathion	0.155	0.693	1,521	0.189	12,245
Dithane	8,955	0.003	4.75	1,712	13,178
Ridomil	0	0.998	0.000	0	.
Super Homai 70 WP	0	0.999	0.000	0	.
Benlate	14,992	0.000	1.82	1,344	2,465

Dithane (84.4%) and Ridomil (14.6%) were the most frequently used fungicides in the region. Thiodan is the dangerous, banned insecticide to which farmers are more exposed in the Nyiragongo health zone. The results also imply that in general, there were fewer fungicide brands than insecticide brands used in the region.

Types of chemical pesticides and unwanted exposure: Subsequently, the study sought to establish trends in chemical pesticide use between cases and control groups in the area. There is some evidence that pesticide use was significantly different between case and control groups, as shown in Table 2.

Chemical insecticides: There were significant differences in the use of Thiodan ($\chi^2 = 48.332$, p = 0.000), Roket ($\chi^2 = 4.549$, p = 0.033) and DDT ($\chi^2 = 5.554$, p = 0.018) between the Cases and control groups with the use of these chemical insecticides tend to be higher among the cases than in the control group. The results show, however, that the chemical insecticides Deltamethrin ($\chi^2 = 5.026$, p = 0.025) and Carbaryl 85 WP ($\chi^2 = 6.619$, p = 0.010) were used more by the control groups than by the case groups and the differences in the use was significantly greater.

Chemical fungicides: Significant differences in the use of chemical fungicides between the case and control groups were also observed. Dithane ($\chi^2 = 46.591$, p = 0.000) was the most commonly used chemical fungicide by the case group compared to the control group. Farmers in the control group tended to use Ridomil ($\chi^2 = 6.810$, p = 0.009) than the case group and the differences in usage were significant. However, Benlate ($\chi^2 = 6.122$, p = 0.013) was only used by the control group and the difference in usage was also significant. There were also differences in the use of the other pesticides listed in Table 4.4, but the differences were not significant.

Banned chemical pesticides: The study found that only five chemical pesticides, three insecticides and two insecticide were significantly associated with the risk of respiratory disease among farmers in the Nyiragongo health zone in North Kivu. Among these, three insecticides; Thiodan, DDT, and Carbaryl 85 WP, had probabilities greater than unity, meaning they were factors of risk of respiratory diseases among farmers in the region. Dithane and Benlate, presented a greater risk than all other fungicides with the risks of respiratory illnesses associated with Dithane being 4.75 times higher among cases than among controls.

Categories of chemical pesticides used and risk of respiratory diseases: The types of chemical pesticides, example chemical insecticides and chemical fungicides. The results revealed that the logistic regression model was statistically significant, $\chi^2(8) = 41.396$, $p < 0.0018$. The model explained 62.4% (Nagelkerke R^2) of the variance in respiratory diseases and correctly classified 81.1% of cases. To determine the actual chemical pesticides increasing the risk of respiratory illness, the odds ratio was calculated and the results summarized in Table 3. The results in Table 3 show that only five chemical pesticides, three insecticides and two insecticide were significantly associated with the risk of respiratory disease among farmers in the Nyiragongo health zone in North Kivu. Among these, three insecticides; Thiodan (OR 20,688, 95% CI 1,595 - 8.371), DDT (OR 1,662, 95% CI 0.633 - 4.361), and Carbaryl 85 WP (OR 1,898, 95% CI 0.178- 20.28), had probabilities greater than unity, meaning they were factors of risk of respiratory diseases among farmers in the region. Dithane (OR 4.75, 95% CI 1.712 - 13.178) and Benlate (OR 1.82, 95% CI 1.344 - 2.465) presented a greater risk than all other fungicides with the risks of respiratory illnesses associated with Dithane being 4.75 times higher among cases than among controls.

DISCUSSIONS

The results revealed that chemical insecticides were used more than chemical fungicides. In terms of brand, Thiodan was the most commonly used insecticide, followed by Lava Dichlorvos 100% EC and Actellic 2%. The results imply that highly banned pesticides such as Thiodan and DDT were also the most commonly used insecticides. However, other banned and dangerous insecticides were also used by farmers in the region. These findings corroborate those of Jean (2021) who found that despite its ban, Thiodan was the insecticide most used by Congolese farmers. Its success can be explained by its affordable price (in February 2021, two bottles of Thiodan cost 2,000 Congolese francs, or 0.83 euros), a large supply and weak legislation on the importation of toxic products into the DRC. The presence of such a substance, banned in Europe, endangers the Congolese people and the Congolese ecosystem. The study found that Thiodan, DDT and Carbaryl 85 WP were the chemical insecticides significantly associated with the risk of respiratory diseases, that is, their use exposed farmers to significant risks of respiratory diseases. The results therefore confirm those of Rinsky *et al.* (2019) whose cohort study demonstrated an increased risk of chronic bronchitis with the use of insecticides such as malathion, carbaryl, pyrethrin, permethrin, lindane, parathion, some of which were identified in the present study, namely malathion and carbaryl. According to Lukwe (2022), some chemical insecticides, including DDT and malathion, have been completely banned and are unsuitable for use for agricultural purposes due to their toxicity. Jems (2020) also lists Thiodan and DDT among the insecticides banned in the DRC. A study by Abong'o et al., (2014) similarly found the evidence of banned pesticides in Kenya. The study established that organophosphates and other banned organochlorine pesticides such as lindane, aldrin and dieldrin were used by farmers (Abong'o et al., 2014).

According to Jean (2021), the continued use of these insecticides poses a significant risk to farmers. Additionally, the p,p'-DDE metabolite of DDT, which has been classified as a possible human carcinogen by the United States Environmental Protection Agency (USEPA 2016), was found in significant concentrations in urine agricultural workers during the investigation conducted by (USEPA 2016). This implies that in addition to respiratory disease risks, DDT could also pose other non-respiratory disease risks that are even more life-threatening. In their previous studies (Kester 2001) as well as Beard (2006) and Klaasseen 2013) reported that OC pesticides tend to accumulate in different tissues and are cancer inducers, endocrine disruptors and exert other toxicological effects. Furthermore, the results revealed that banned highly toxic chemical fungicides, such as Dithane and Ridomil, were commonly used by farmers to control fungus on their farms. The results are consistent with those of Toé (2010) whose study in Burkina Faso revealed that most farmers in this country had suffered poisoning linked to the application of fungicides and pesticides, most of which are made with pesticides toxic substances such as Endosulfan (Tyodan). These results also confirm those of Emeribe *et al.* (2023), whose examination of smallholder farmers' perception and awareness of the public health effects of pesticide use in Edo Central, Nigeria, found that moderately toxic pesticides (class II of the WHO) were commonly used with some cases of highly toxic pesticides (WHO Ib). According to a study by Jean (2020), certain pesticides such as Curacron, Cypermethrin, Polytrin, Profénofos, Dithane and others, banned on vegetables worldwide, are used by certain market gardeners in many African countries and in the Democratic Republic of Congo for agricultural purposes.

The results of the present study also revealed that farmers in both the case and control groups reported that they knowingly used insecticides and fungicides that were already expired. Also according to the results, the use of expired pesticides posed significant risks of respiratory diseases for farmers. These results agree with those of Pascale *et al.* (2020) who found that in African countries, farmers very often use already expired chemical insecticides which present a danger to users with all the consequences on their health. Still according to the FAO (2022), stocks of expired chemical insecticides pose a serious threat to human health and populations in developing countries. Most of them, like DDT, are persistent organic pollutants (POPs) that accumulate in the fatty tissues of organisms and cause many health problems. Since the adoption of the Stockholm Convention on POPs in 2001, the use of some of these products has either been banned or strictly limited. The World Bank (2013) also estimates that more than 50,000 tonnes of expired insecticides are currently available in sub-Saharan Africa and continue to expose farmers' health to respiratory, skin, eye and nerve poisoning. These pollutants can also cause cancer, respiratory diseases, allergies, reproductive disorders, immune disorders and nervous system damage. The study, therefore, find the significant presence of banned pesticides among farmers in the Nord Kivu area. This means that the banned pesticides were still very much present in the international pesticides supply chain and some permeated into the area from the neighboring countries probably suggesting that the problem of banned pesticides was not limited to the DRC alone. This further suggests a lack of international regulatory control or the banned or restricted pesticides and, therefore, inability to completely phase them out from the pesticide supply chain. Imperatively, these chemical pesticides flow from areas of high regulatory control where they are manufactured to areas of weak regulatory control. The mechanism with which they leave their highly regulated manufacturing points to their destination markets, however, remains unclear. However, what is clear is that there remains insufficient cooperation internationally to completely phase out the harmful pesticides from the agrochemical supply chain.

Conclusions and Recommendations

The study concluded that only five chemical pesticides, four insecticides and one insecticide, were significantly associated with the risk of respiratory diseases among farmers in the Nyiragongo health zone in North Kivu. Among these, three pesticides; Carbaryl 85 WP, Deltamethrin, and Deltamethrin presented a significant risk compared to all other pesticides, with the risks of respiratory illnesses associated with Carbaryl 85 WP being 20.7 times higher among cases than among controls. In addition to the toxicity of chemical pesticides, the risk of disease was exacerbated by poor knowledge and poor pesticide handling practices by farmers. The association of respiratory diseases with other chemical pesticides was, however, fortuitous.

The study, therefore, makes the following recommendations arising from the findings and conclusions:

1) To the Government of the Democratic Republic of Congo:

- Improve the policy environment by putting in place provincial mechanisms to fight corruption and customs fraud;
- Capitalize on all international and national regulations on the management and control of chemical pesticides already ratified, by revitalizing the application and surveillance system in different Provinces of the country;
- Establish a national and provincial capacity building program for agents assigned to different services with the mission of implementing chemical pesticide control and management policies.

2) To state services (OCC, IPAEL, DPPV, SNV, SQUAV, IPS, DPS, etc.)

- Establish an agricultural monitoring system (agricultural monitors) for permanent support and guidance of farmers in the rational use of chemical pesticides in agricultural areas;
- Encourage the Congolese Government to propose to the National Assembly the promulgation of regulations on the purchase, transport, storage and application of pesticides by farmers in agricultural areas;
- Become aware of the health problems facing farmers in the North Kivu Province by ensuring effective control of chemical pesticides at border level and monitoring the distribution, marketing, use and management of packaging by farmers in agricultural areas at North Kivu;

3) To farmers in the Nyiragongo health zone

- Use health facilities in the Nyiragongo health zone to be diagnosed with respiratory illnesses caused by exposure to dangerous chemical pesticides;
- Integrate pesticidal plants into their agricultural system for the artisanal production of organic pesticides in order to sustainably fight against poisoning caused by dangerous chemical pesticides.

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