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THE USE OF AGROCHEMICALS AND THEIR IMPACT ON THE HEALTH OF FARMERS IN NIGERIA

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ABSTRACT

Background: The continuous loss of food, fibers, and other agricultural commodities in the farm world due to weed and pest diseases has created a lot of financial burden to the farm owners, contributing to food insecurity in Nigeria. To solve these agricultural problems, farmers have resorted to the use of agrochemicals to increase their production, a trend that poses a significant risk to public health. Sadly, the widespread use of these agrochemicals has remained unchecked, leading to contamination of the soil, water, and air, exposing the farmers to potentially toxic substances that negatively affect their health.

Objectives: This review examines the trends in the use of agrochemicals in Nigeria and the impact of these agrochemicals on farmers' health.

Methods: Google Scholar, Web of Science, Springer Link, Wiley Online Library, and Mendeley were the scientific databases searched. The keywords searched for were "agrochemicals", "farmers", "exposure routes", "occupational hazards", "PPEs", "pesticides", "fertilizers", and "farmers' health". About seventy-three literature were obtained and screened down to forty based on six criteria.

Results: This review revealed the impact of agrochemical exposure on the health of farmers in Nigeria. It showed the common routes of exposure and the associated acute and chronic health effects. Case studies from Nigerian farming communities are discussed to underscore the severity of the issue.

Conclusion: While the use of agrochemicals has greatly increased the level of agricultural productivity and food security in Nigeria, it does pose serious health risks due to improper handling, unawareness, and lack of protection among farmers.

Keywords: Pesticides, Fertilizers, Exposure Routes, Occupational Hazards, Personal Protective Equipment (PPE)

INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO) states, "agriculture is a crucial sector in numerous economies and its advancement is vital for alleviating poverty, enhancing food security, and fostering sustainable economic growth" (FAO, 2017). This quote demonstrates unequivocally how agriculture may help address some of the major issues facing the globe today, including environmental sustainability, unemployment, poverty, and hunger. Agriculture is considered to be a critical factor in economic growth, given its potential to relieve poverty and enhance food security in this regard.

However, the Agricultural sector is largely proliferated by the use of hazardous agrochemicals. Farmers' incorrect use of these chemicals has further exacerbated the situation. Soil contamination due to high interactions with agricultural chemicals has implications on the health of people. Agrochemicals are of concern to all Nigerians because they contain toxic chemicals, which are harmful to the farmers who are the ones with direct exposure. These chemicals contribute to a wide range of health problems, from acute poisoning to chronic diseases such as cancer or neurological disorders (Issa, 2023). This situation is exacerbated by the widespread non-usage of protective measures such as PPE and poor education and training. Other preventive measures, such as education, proper handling of the pesticides, and enforcement of laws by the authorities, go a long way in addressing

such risks.

METHODS

Techniques

Five credible scientific databases—Google Scholar, Web of Science, Springer Link, Wiley Online Library, and Mendeley—were used to do an extensive literature search. Finding pertinent peer-reviewed publications about the application of agrochemicals and their effects on farmers' health was the main goal of the search.

Logic of Search Terms:

Using Boolean operators, the following keywords were employed both singly and in combination to guarantee the retrieval of pertinent literature: "agrochemicals," "farmers," "exposure routes," "occupational hazards," "PPEs," "pesticides," "fertilizers," and "farmers' health." For instance, to expand the search while keeping it relevant, terms like "pesticides" OR "fertilizers" and "agrochemicals" AND "farmers' health" were employed. This method made it possible to find literature that addressed various aspects of the usage of agrochemicals and the health risks that go along with them.

Timeline and Screening Procedure

The database search yielded an initial total of 73 articles. Over the course of four weeks, these were screened twice. Initially, abstracts and titles were examined to weed out redundant or unnecessary research. Second, to make sure that only papers with high relevance and methodological clarity were kept, full-text screening was carried out using six preset criteria.

Risk of Bias Assessment:

Studies were assessed for potential sources of bias during the full-text screening phase, even though no formal risk of bias instrument was used. Studies with well-defined procedures, sufficient sample numbers, and reliable data sources were preferred. Research with methodological flaws, inadequate information, or conflicts of interest was either disqualified or given careful consideration.

REVIEW FINDINGS

Agrochemicals

A chemical product utilized in agriculture is called an agrochemical. Agrochemicals are basically used to improve crop yields and control the population of agricultural pests (Minni, 2023). Agrochemicals are substances that are used in agriculture to enhance the quality and the productivity of the crops. Agrochemicals are the products that were invented to assist the farmers to increase their crops and protect the crops from malicious organisms. More often they consist of pesticides, fertilizers, insecticides, herbicides and so on. They are used as soil conditioners, acidifiers, nutrients and also serve to combat diseases caused by bacteria, fungi, pests and viruses, thus improving agricultural productivity and safety. Factors such as balanced use, optimal dosage, appropriate application methods, and timing help ensure increased agricultural productivity. They cause an increase in the status of production stores plants, protect crops against pests and diseases, but they are harmful to the environment and health when poorly applied (Ministry of Health and Environment, 2024).

Pesticides

Any material used to eliminate, deter, or manage specific types of plants or animals deemed pests is referred to as a pesticide. A pesticide is defined as any substance or combination of substances used to prevent, destroy, or control any pest. This encompasses unwanted plant or animal species that harm food production, processing, storage, transportation, or marketing, as well as wood and wood products, animal feed, vectors of human or animal disease, and substances that can be administered to animals to manage insects, arachnids, or other pests on or in their bodies. The term also includes chemical products that act as desiccants, defoliants, plant growth regulators, thinning agents, or prevent the premature falling of fruits. Additionally, it refers to chemicals applied to crops before or after harvest to prevent deterioration during transport and storage (FAO, 2002). Pesticides are utilized in both home and industrial settings and are available worldwide (Dabady and Tulk, 2015).

Pesticides are a crucial tool in modern agriculture that enable significant increases in food production while protecting crops from a wide range of pests. They constitute an integral input in this field, accounting for nearly a third of the world's agricultural produce (Liu et al., 2002). Pesticides are also utilized to manage urban pest populations, including cockroaches, termites, and rodents, as well as in non-crop areas

to control invasive species and unwanted vegetation. However, in recent years, concerns about the effects of these chemicals on human health have risen significantly. Exposure to hazardous levels can occur when pesticides are misused or when adequate protective measures are not implemented, leading to a variety of adverse health effects. Acute poisoning is the most common issue and has been identified as a major public health problem in the developing world (Kishi and Ladou, 2001).

Pesticide is a general class of chemicals intended to control or destroy pests. They are very varied in their physical, chemical, and functional characteristics. Synthetic pesticides, manufactured by man, are usually categorized under three broad classes: by mode of entry, by function and the type of pest they target, and by chemical composition.

Mode of Entry

Systemic: Example: Imidacloprid (used in insecticides) is absorbed by plants and distributed throughout their tissues. It protects the plant from pests like aphids and termites by poisoning them when they feed on the plant

Contact: Example: Pyrethroids, such as permethrin, are insecticides that kill pests like mosquitoes and flies on direct contact. Full coverage of surfaces is necessary for effective control

Stomach: Example: Boric acid is one of the common stomach poisons for pests like ants and cockroaches. When ingested, it interferes with their digestive system, leading to poisoning.

Fumigants: Example: Methyl bromide is a fumigant used in the destruction of pests in stored grains, fruits, and vegetables. It emits toxic gases that pests inhale, leading to poisoning

Repellents: For example, DEET (N, N-diethyl-meta-toluamide) is an active ingredient commonly used in repellents against mosquitoes. It creates an unpleasant barrier for the pests, preventing them from approaching or feeding without actually killing them.

The classification of pesticides by mode of entry is necessary because it aids in selecting the best control method for specific pests and ensures efficiency and specificity in pest management. This approach reduces resistance, minimizes environmental impact, and generally enhances effective pest control. Their application is critical for managing pests to protect crops; however, classification is equally vital for efficient pest control. (Yadav & Linthoingambi, 2024).

Classification Based on Chemical Structure

Pesticides are classified as organic pesticides and inorganic pesticides. Organic pesticides are defined as those that are based on chemicals having carbon as the basis of their molecular structure, oxygen, phosphorus, or sulfur may be included in their molecules, along with being complex compounds that do not normally dissolve in water. Organic pesticides can be separated into further subdivisions as follows: natural organics and synthetic organics. Natural organics are obtained from the plant base, like the example of rotenone and pyrethrum, while synthetic organic pesticides-or modern pesticides produced chemically, for example, DDT, permethrin, malathion lindane. Comparatively inorganic pesticides are simpler compounds, crystalline, environmentally stable; usually dissolve readily in water compared with earlier types of chemical pesticides, which are inorganic and included materials such as sulfur and lime. (Koli and Sonu 2019). Also, the pesticides belong to four major families: organochlorines (OCs), organophosphates (OPs), carbamates, and pyrethroids (Sarath Chandran, Thomas, & Unni, 2019).

Organochlorines

Organochlorines are among the earliest synthetic organic pesticides and are classified as persistent organic pollutants (POPs) due to their enduring presence in the environment, tendency to bioaccumulate, and chronic toxic effects, even at low doses (Loganathan, 2012). These pesticides have been widely used to control disease vectors, such as those causing malaria and dengue, as well as for agricultural purposes. They target the central nervous system by interfering with sodium (Na^+) and potassium (K^+) ion channels on neuronal membranes. This interference can lead to repeated nerve firing, resulting in seizures, respiratory arrest, or even death. Common organochlorines include DDT, lindane, chlordane, and dieldrin. While these chemicals were effective, their application has been banned or restricted in many countries due to their significant environmental and health impacts (Pushpendra Koli et al., 2019). Organochlorine pesticides are highly persistent in the environment and bioaccumulate in the food

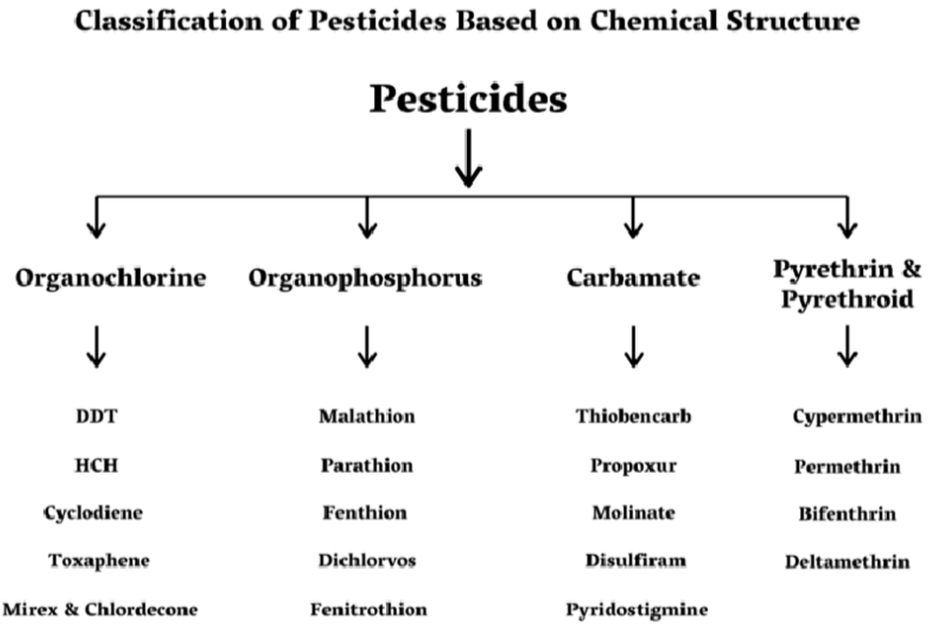

Fig 1: Classification of pesticides based on their chemical structure (Source: Singhal et al., 2021)

chain, posing long-term ecological and health risks. Historically, they were used for pest control and to combat disease vectors like mosquitoes, but many are now prohibited or limited due to their harmful effects (USEPA, 2024).

Organophosphorus

Organophosphates are pesticides derived from phosphoric acid. They belong to a diverse group of chemicals that effectively control a wide range of pests, weeds, and plant diseases due to their multifunctional properties. These compounds primarily act as acetylcholinesterase inhibitors, disrupting neurotransmitter transmission across synapses (Sorgob & Vilanova, 2002). This disruption prevents nerve impulses from passing through the synapse, leading to rapid contractions of voluntary muscles, paralysis, and, ultimately, death. Some commonly used organophosphate insecticides include parathion, malathion, dichlorvos, diazinon, and glyphosate.

A characteristic feature of these compounds is the covalent binding of carbon with phosphate, where the C–P bond is replaced by one of the four C–O–P bonds in the phosphate ester. The direct C–P linkage is chemically and thermally inert in organophosphate compounds, allowing them to withstand harsh conditions such as chemical hydrolysis, photolysis, and thermal decomposition better than analogous compounds with more reactive (N–P), (S–P), or (O–P) linkages (Narenderan et al., 2020).

Organophosphate pesticides have significantly increased crop yields and agricultural output, and developing nations are increasingly adopting their use. For example, Iran, the world's leading producer of pistachios, uses these pesticides to manage pests in orchards. These pesticides can be categorized as slow-acting resistance chemicals, are biodegradable, and have minimal environmental pollution (Sorgob & Vilanova, 2002).

Organophosphate pesticides are widely used in agriculture to control pests on crops such as turf, cotton, and sugarcane. Among the organophosphates used to combat pests are diazinon, fenthion, temephos, parathion, profenofos, chlorpyrifos, and malathion. They typically consist of esters, thiol esters, or acid anhydride derivatives of phosphorus-containing acids. These pesticides affect the human nervous system by phosphorylating the hydroxyl group at the active site of the acetylcholinesterase enzyme, inhibiting the enzyme at nerve endings (Sorgob & Vilanova, 2002).

Symptoms of exposure include loss of reflexes, diarrhea, vomiting, salivation, excessive sweating, agitation, respiratory failure, ataxia, hyperglycemia, convulsions, acute pancreatitis, and even death (Narenderan et al., 2020). Due to the serious health hazards associated with these pesticides, especially for farm workers who may be frequently exposed, proper protection and care during application are essential.

Carbamates

Carbamate pesticides are organic chemicals derived from carbamic acid and are widely used in agriculture to control various pests, including insects, fungi, and nematodes. Some well-known carbamates include carbaryl, carbofuran, and methomyl (Wood et al., 2013). Chemically, carbamates are similar to organophosphates; however, they differ in their origins because organophosphates are derived from phosphoric acid, while carbamates originate from carbamic acid (Tijani et al., 2020).

Carbamates inhibit the cholinesterase enzyme, which is responsible for breaking down acetylcholine at synapses. This inhibition leads to an accumulation of acetylcholine, resulting in continuous stimulation of nerves, muscle paralysis, and potentially the death of the pest (Arias et al., 2015).

Carbamate poisoning in humans resembles organophosphate poisoning and can lead to symptoms such as muscle twitching, excessive salivation, vomiting, convulsions, and, in severe cases, respiratory failure and death (Gonzalez et al., 2013). However, carbamates are generally considered to be less persistent in the environment compared to organophosphates and organochlorines because they degrade more quickly, posing a lower risk for long-term environmental contamination. This characteristic makes carbamates a better alternative for integrated pest management due to their biodegradability and reduced ecological impact (Wood et al., 2013).

Despite their lower persistence in the environment, carbamates can have significant toxic effects on human health if they are not handled properly or if exposure occurs during application. For this reason, the use of carbamates in agriculture is regulated to limit exposure and mitigate adverse health consequences for farm workers and consumers (Arias et al., 2015). Additionally, carbaryl, a member of the carbamate class of pesticides, has been shown to act as a ligand for the hepatic aryl hydrocarbon receptor, a transcription factor involved in the mechanism of dioxin toxicity. There is also evidence that carbamate pesticides can cause neurobehavioral effects (Wesseling et al., 2002), increase the risk of dementia (Lin et al., 2015), and are associated with non-Hodgkin lymphoma (Zheng et al., 2001).

Fertilizers

Fertilizers are substances that improve the growth and productivity of plants. They improve the natural fertility of the soil or replace chemical elements taken from the soil by previous crops. (fact check, Encyclopedia Britannica, accessed November 2024). They are usually applied to the soil or directly to the plants to restore the nutrient levels and improve their health and productivity.

Fertilizers exist in multiple forms, including granules, liquids, and powders, and can be either organic or synthetic. Organic fertilizers are primarily natural substances derived from animal waste, meat processing byproducts, and moist combinations of insoluble materials; they also come from plant sources like compost and biosolids (Saweda O. L- T, et al., 2014). Inorganic fertilizers can be synthesized using chemical compounds such as nitrogen, phosphorus, and potassium combined in various formulations to meet different plant requirements (Alzain et al., 2023).

Synthetic or Inorganic Fertilizers

Inorganic Fertilizers include industrially synthesized fertilizers. Modern synthetic fertilizers are composed mainly of nitrogen, phosphorus, and potassium and they can be classified as Nitrogenous fertilizers (Urea, DAP, NH_4NO_3 & etc.), Phosphorus fertilizers (super phosphate, triple phosphate, $(NH_4)_3PO_4$, Nitro phosphate & etc.) and Potassium fertilizers (KCl, K_2SO_4, KNO_3 & etc.) These inorganic fertilizers come in water-soluble and granular forms, making application easy and economical for wide usage. (Abate, 2023).

Types of Inorganic Fertilizers

Nitrogen Fertilizers: Nitrogen is one of the most essential macronutrients for plants. It is commonly supplied through sources such as urea, ammonium nitrate, and calcium ammonium nitrate. However, excessive nitrogen can lead to leaf burn or environmental contamination, so it's crucial to adhere to recommended application rates to prevent these issues (Abate, 2023).

Nitrogen Fertilizers with Inhibitors: This category includes urease and nitrification inhibitors, which help minimize nitrogen loss through volatilization or leaching. These fertilizers are environmentally friendly and maintain crop productivity (Alzain et al., 2023).

Phosphorus Fertilizers: Examples include single superphosphate (SSP) and triple superphosphate (TSP), which gradually release phosphorus, allowing plants to absorb it steadily throughout the season (Abate, 2023).

Fig 2: Synthetic Fertilizers (Source: Usry, 2012)

Potassium Fertilizers: Potassium chloride (KCl) and potassium sulfate (K2SO4) are widely used to enhance plant disease resistance and overall vigor. These fertilizers are vital for maintaining balanced nutrient availability (Abate, 2023).

Secondary Nutrient Fertilizers: Calcium, magnesium, and sulfur are typically applied through gypsum, lime, or kieserite to address specific nutrient deficiencies (Abate, 2023).

Micronutrient Fertilizers: These provide essential trace elements, including zinc, iron, and boron, which are necessary for plant growth. Special formulations can be tailored to meet the specific requirements of different crops (Alzain et al., 2023).

Inhibitors: Nitrification and urease inhibitors play a significant role in reducing greenhouse gas emissions and minimizing nitrate leaching into water bodies. These innovative fertilizers align well with the principles of sustainable agriculture (Alzain et al., 2023).

Usage of Agrochemicals

Excessive agrochemical use refers to the quantitative application of synthetic chemicals, including synthetic fertilizers, pesticides, and herbicides, into soils for increased crop yields or pest control in a way that is beyond the required amount. Economic gains in the short run, lack of training in sustainable alternatives, and access constraints to safer or environmentally friendly practices are some of the factors that motivate the approach (Jones and Taylor, 2018). Agrochemicals are used profusely by farmers in Nigeria, mainly because of pressures to produce high yields under market demands. The excessive use of agrochemicals has been seen mainly from the point of view of economic benefits: reducing the total cost of production and increasing the yield of crops. Less attention is paid to environmental and health impacts (Chen et al., 2023). Several studies have highlighted that the alarming levels of agrochemical residues in soil, water, air, agricultural products, and even in human blood and adipose tissue pose serious risks to the ecosystem and public health (Ahmed et al., 2020). The massive application of inorganic fertilizers in many parts of the world contributes to the accumulation of dangerous pollutants in the soil, such as arsenic (As), cadmium (Cd), fluorine (F), lead (Pb), and mercury (Hg). which are responsible for further deterioration of soil health and ecosystem pollution (Kumar et al., 2019).

Route of Agrochemical Exposure Among Farmers

Exposure can be defined as the contact of an organism with a measurable chemical, physical or biological agent that affects health. This can include variables or factors on a wide spectrum, from the molecular level to the social and political environment. Of course, there are many specific chemical, biological or physical agents that can be transmitted through the environment (air, water, food, soil) (LaMorte, 2019). However, exposure can also be considered more broadly to include the social contacts, cultural practices, regulations, policies and laws that people live with on a daily basis. These elements are also potentially important

The route of exposure includes:

Dermal Exposure

Dermal exposure is the most common route of exposure to agrochemicals among farmers. This occurs when chemicals come into contact with the skin during:

Mixing and loading: Farmers usually handle concentrated agrochemicals during preparation (Gilden et al., 2010).

Application: Agrochemical spraying may result in drift landing on exposed skin.

Accidental Spills: Agrochemicals are most vulnerable to being absorbed through direct skin/ clothing contamination during any accident while mixing and applying them, especially the highly toxic kinds like paraquat or organophosphate.

Post-application exposure: Residues on treated plants, soil, or equipment can be transferred to the skin.

Factors that increase dermal absorption include cuts, abrasions, and high humidity, which enhance the penetration of chemicals into the skin (Nicolopoulou-Stamati et al., 2016).

Inhalation Exposure

Farmers may inhale agrochemical fumes, vapors, or aerosols, especially during the application. Risk is increased under the following conditions:

The use of fine sprays or mists: These may remain suspended in the air and be inhaled.

High temperatures: These raise the volatility of chemicals.

Poor ventilation: Airborne particles may be trapped in enclosed environments such as greenhouses. Spraying in windy conditions can lead to inhalation of toxic concentrations.

Post-Application Contact: Entering treated fields too soon after spraying increases the risk of dermal absorption or inhalation.

Inhalation exposure may lead to respiratory and systemic toxic effects, depending on the chemical involved (Levin et al., 2004).

Oral Exposure

Oral exposure occurs less frequently but is particularly hazardous when it happens. It may occur through:

Accidental ingestion: This can be by farmers eating, drinking, or smoking without washing their hands after handling the chemicals.

Contaminated food and water: Agrochemicals contaminate the drinking water or food supplies via runoff or residues. Inadequate waiting periods after the spraying of pesticides result in their residues on food crops. When these are consumed, they cause toxic exposure (Nicolopoulou-Stamati et al., 2016).

Ocular Exposure

Eyes are most vulnerable during the process of spraying or mixing because splashes or droplets in the air result in direct contact with chemicals. Eye exposure to agrochemicals may cause irritation, burns, or even long-term damage (Levin et al., 2004).

Secondary or Environmental Exposure

Farmers may also face secondary exposure indirectly through contaminated environments:

Soil and water contamination: Agrochemicals can leach into surrounding ecosystems.

Residue on clothes: Washing clothes used for application incompletely can also lead to chronic low level exposure.

Health Impact of Agrochemical Exposure on Farmers

The improper and excessive use of agrochemicals has become a significant issue for farmers in Nigeria. This problem stems from a lack of awareness, training, and resources for the safe application of these chemicals. Many farmers apply agrochemicals without fully understanding their potential hazards or the recommended guidelines for usage. Misunderstandings lead to over-application, poor mixing, and inadequate disposal of empty chemical containers, often stemming from the belief that more application will yield better results.

Additionally, the presence of counterfeit or poorly labeled products with unknown toxicities exacerbates the situation, exposing farmers to chemicals that may be more dangerous than they realize. Agricultural workers frequently carry pesticide residues home on their clothes and bodies, posing risks to their families. This phenomenon, known as "home exposure," can negatively affect children and other family members (Anjaria & Vaghela, 2024).

These unsafe practices result in prolonged and repeated exposure to harmful chemicals, often without adequate protection. The hot and humid climate in Nigeria, combined with farmers working in sweat-soaked clothing, increases the absorption of chemicals through the skin. Such conditions make both acute and chronic health effects of agrochemical exposure not only likely but all too common.

Figure 3: Farmer spraying agrochemicals without PPE, exposing himself to potential health risks. (Source: Chege & Bundi, 2019)

Acute Poisoning

Acute poisoning due to agrochemicals results from the exposure of an individual to high dosages of pesticides or fertilizers within a very short period, causing an immediate toxic effect. Farmers, agricultural workers, and people in rural areas are highly vulnerable because of occupational exposure, poor practices in handling, and lack of protective equipment. Agricultural workers and pesticide applicators are at increased risk of acute poisoning. They work directly with agrochemicals and may be exposed to high concentrations. Symptoms of acute poisoning can range from: mild skin irritation; eye irritation to more serious effects, such as nausea, vomiting, diarrhea, difficulty breathing, dizziness, and in extreme cases, respiratory distress or death (Anjaria & Vaghela, 2024).

Chronic Health Effects

Cancer

Some agrochemicals, including certain pesticides and herbicides, are classified as known or suspected carcinogens. Long-term exposure to these substances, even at low concentrations, can increase the risk of cancer in agricultural workers (Anaduaka et al., 2023). Research has established a strong link between agrochemicals and the development of cancer in both children and adults. Individuals with close exposure to pesticides are at a heightened risk of developing various malignancies, including leukemia, Burkitt lymphoma, neuroblastoma, Wilms tumor, non-Hodgkin lymphoma, soft tissue sarcoma, as well as cancers of the ovaries, lungs, stomach, colon, bladder, and rectum (Polanco Rodriguez et al., 2017).

Chronic, low-dose exposure is particularly concerning, as it may lead to prenatal and early postnatal changes in children. A recent study (Hernández & Menénde, 2016) suggested that pesticides could play a role in the development of childhood and adult leukemia, the most common type of cancer in children. This potential link may involve interactions with DNA enzymes, such as topoisomerase II, as well as DNA damage caused by oxidative stress. Among the mechanisms through which pesticide exposure may cause cancer, it has been reported that these chemicals can compromise the immune system, leading to chronic inflammation and elevated production of inflammatory chemokines and cytokines (Corsini et al., 2013).

Respiratory Effects

In addition to skin absorption and ingestion, inhalation is another route by which agricultural workers can be exposed to synthetic agrochemicals. These exposures are thought to cause or exacerbate adverse respiratory symptoms in these workers.

A publication last year examined the relationship between occupational exposure to synthetic pesticides among agricultural workers and respiratory symptoms. In this study, Buralli et al. (2018) examined the prevalence of respiratory disorders in a group of family farmers (n = 82) who were exposed to multiple pesticides

from an early age (Buralli et al., 2018). The occurrence of cough, nasal allergies, hay fever, shortness of breath, and chest tightness was noted more often when farmers were engaging in agricultural activities compared to off-seasons. However, due to the small sample size, the confidence intervals around these estimates were wide and rarely reached statistical significance. The authors reported significant associations between lung function, as assessed by various spirometry variables, and self-reported pesticide exposure. Although limited by the lack of an unexposed control group, the results of this study suggest an association between pesticide exposure and respiratory symptoms and impaired lung function.

Neurological disorders

Exposure to certain agrochemicals has been associated with neurological disorders. Organophosphate pesticides, for example, have been linked to cognitive and motor deficits, particularly in children (Rossetti, Stoker, & Ramos, 2020).

Although there is no consensus on the causal role of agrochemicals in the development of neurodegenerative disorders, increasing evidence has shown a link between occupational and environmental exposure to these toxicants and the development of neurological diseases (Wilks, 2016). Among these diseases, Parkinson's disease (PD), Alzheimer's disease (AD), and amyotrophic lateral sclerosis (ALS) appear to be most closely related to the neurotoxic effects of pesticides. Discovered by James Parkinson in 1817, PD is clinically characterized by the appearance of progressive tremor, rigidity, and akinesia, the severity of which gradually increases with age (Elbaz & Moisan, 2016). AD is the most common form of dementia, the most prominent features of which are a slow onset with progressive loss of the ability to learn, retain, and process information, apraxia, agnosia, progressive loss of executive functions, and behavioral changes. ALS is also a progressive disease, leading to spastic tetraparesis or paraparesis with increasing lower motor neuron sign.

Reproductive problems

Some agrochemicals are endocrine disruptors, meaning they can interfere with people's hormonal systems. This can lead to reproductive problems, including reduced fertility and developmental problems in children. (Said, 2023).

The association between occupational and environmental exposure to agrochemicals has been widely evaluated, and studies have shown that exposure to pesticides can impair fertility in both men and women (Kumar, 2004). Studies focusing on the association between pesticide exposure and reproductive harm. A study conducted in Ontario examined the link between exposure to pesticides on farms and miscarriage. The authors observed a moderate risk of early miscarriage for preconception exposures to phenoxyacetic acid, triazines, and any herbicides. They also noted that preconceptional exposure to a different class of pesticides, thiocarbamates and glyphosate, was associated with an increased risk of late-term miscarriage. On the other hand, a study conducted on a population of women working in greenhouses found no significant association between pesticide exposure and the occurrence of preterm birth, spontaneous abortions, and congenital malformations (Jurewicz et. al., 2008).

In male subjects, exposure to pesticides can affect sperm quality, sperm parameters (concentration, morphology, motility), blood sex hormone levels, or testicular structure. Jurewicz and Hanke have shown a mean decrease in sperm count in men who worked in greenhouses for more than ten years (Jurewicz & Hanke, 2007). A comparative study conducted in Venezuela by Miranda-Contreras et al. analyzed sperm quality in farmers exposed to pesticides, showing significant changes in key sperm characteristics in exposed subjects, such as decreased sperm concentration, reduced motility, and changes in the sperm membrane (Jurewicz & Hanke, 2007). Pyrethroids can cause sperm aneuploidy. Organophosphates and carbamates can affect sperm quality and sex hormones, increasing blood levels of thyroid-stimulating hormone (TSH) and luteinizing hormone (LH) (Radwan et al., 2015).

Cardiovascular Disease

Ultrafine particles from agrochemicals have the potential to cause peripheral arterial disease (PAD), also known as peripheral vascular disease (PVD). The development of PVD occurs due to the narrowing of the arteries that supply blood to the heart and brain. This narrowing is often caused by ultrafine particles or fatty acids accumulating in the bloodstream. The consequences of this disease can include various infections, tissue death, or coronary artery disease (Allon et al., 2005). These blockages can result from ultrafine particles becoming lodged in blood circulation paths, leading to

atherosclerosis (Lloyd-Jones et al., 2010). PAD is associated with high rates of cardiovascular morbidity and mortality in many countries. In addition to conventional risk factors, organochlorine pesticides (OCs) have been linked to the onset of PAD. Consequently, other confounding factors may heighten the risk of cardiovascular disease, as discussed earlier. Moreover, recent studies using data from the National Health and Nutrition Examination Survey (NHANES) have shown a positive association between OC pesticide concentrations and self-reported cardiovascular disease among agricultural workers (McDermont et al., 2004).

Peripheral artery disease is connected to two body systems: the integumentary system and the cardiovascular system. This relationship presents a challenge, as intensive studies have established a close link between the skin and agrochemicals. The integumentary system serves as a pathway for absorbing agrochemical particles, resulting in agricultural workers being exposed through multiple routes. The ultimate effect of this exposure enters the circulatory system, potentially causing blockages that can lead to cardiovascular disease.

Air pollutants with an aerodynamic diameter of PM2.5, along with other confounding factors such as hypertension, obesity, stress, and smoking, have been associated with an increased risk of myocardial infarction (MI), stroke, arrhythmia, and worsening heart failure shortly after exposure in susceptible individuals (Gress et al., 2015). The distribution of ultrafine air particles from agrochemical residues has been linked to endothelial dysfunction and vasoconstriction, which contribute to prothrombotic and coagulative changes in blood pressure. This can lead to systemic inflammatory and oxidative stress reactions, autonomic dysfunction, arrhythmia, and the progression of atherosclerosis. As a result, there is a significant relationship between agrochemical residues and PM2.5. Ultrafine particles can penetrate and travel through various blood vessels, ultimately reaching the cardiac system and causing blockages in blood flow. Such blockages to the heart can lead to additional health problems, potentially resulting in death from cardiovascular disease. Agrochemical particles are recognized as a potential hazard to biological systems, causing palpitations and/or heart block, increasing blood pressure, and potentially leading to sudden death. Furthermore, certain agrochemicals can indirectly affect normal heart function.

Kidney damage

Exposure to agrochemicals is increasing among farmers, particularly in rural areas where safety precautions are often neglected. Organophosphates, commonly used in herbicides and pesticides, put a significant number of farmers at risk, especially since most do not wear proper personal protective equipment (PPE). This lack of protection raises the risk of kidney damage, with many farmers displaying signs of kidney dysfunction. Additionally, the practice of reusing agrochemical containers for storing household items further increases exposure to toxic substances within the family environment, as noted by Magomya & Yaro (2021).

A fundamental issue is that farmers have limited knowledge about the risk factors for chronic kidney disease (CKD). Many remain unaware of workplace safety practices, including the importance of PPE, despite the presence of both traditional and non-traditional risk factors. It is crucial to provide health education and advocacy to local community leaders and farmers' associations. Establishing well-equipped health centers and improving access to safety resources in farming communities will help reduce risks and, ultimately, the prevalence of CKD among these communities.

Risk Factors for Agrochemical Exposure

Inadequate Personal Protective Equipment: Many farmers, especially in developing regions, do not use adequate personal protective equipment (PPE) like gloves, masks, and goggles. The farmers in most areas cannot afford proper protective equipment, due to the cost factor, or for discomfort, or because of lack of training.

Poor Storage Practices: Storing chemicals in unsafe or non-labeled containers increases accidental exposure. Poor storage near food and water supplies results in accidental ingestion of agrochemicals (Gilden et al., 2010).

Poor Labeling: Improperly labeling or storing agrochemicals in food and drink containers will increase the possibility of accidental ingestion, particularly by children or the untrained.

Leaking Containers: In cases of damage or leakage, containers can contaminate storage areas and expose workers who come into contact with the chemicals (Gilden et al., 2010).

Limited Knowledge and Training: Misuse or ignorance of handling practices heightens exposure risks. Farmers are usually ignorant of the safe handling of agrochemicals and risks involved, thus leading to unsafe practices (Nicolopoulou-Stamati et al., 2016).

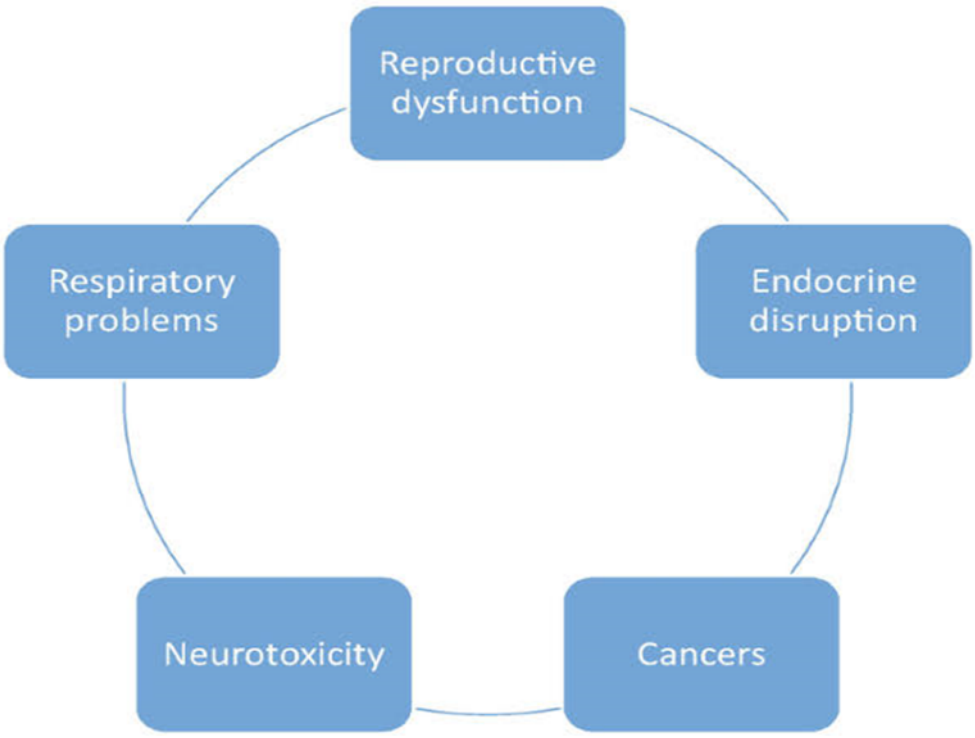

Fig 4: Chronic Effects of agrochemicals on farmers' health (Source: Buralli et al., 2018)

Environmental Conditions: The amount of wind, heat, and humidity at the time of the pesticide application enhances the chance of pesticide exposure through dermal absorption and inhalation (Levin et al., 2004).

Vulnerable Populations to Agrochemical Exposure

Farmers: Agrochemicals are mainly used by farmers, who choose what and when to apply with a view of crop protection from pests, diseases, and weeds; enhancement of soil fertility; and other purposes. They also buy and apply these chemicals on their farms as well as manage their use to maximize crop output at the same time, minimizing health risks and environmental effects.

Farm owners: Farm owners may not necessarily apply agrochemicals, but they ensure regulatory compliance in their operations and training of farm workers on safe handling. They further ensure that proper storage and disposal of agrochemicals are practiced.

Harvesters: Though harvesters do not usually handle agrochemicals directly, they are likely to be exposed to residues on crops during harvesting. Agrochemical application timing is very crucial to ensure the safety of crops for harvest and consumption. Improper protective measures put harvesters at risk.

Field workers: Most of the field workers are directly involved in the application of the agrochemicals, which may involve spraying pesticides or applying fertilizers. If not properly trained or protected, exposure to noxious chemicals could lead to a variety of health problems among the field workers, including skin irritation, poisoning, or respiratory problems.

Growers: Just like farmers, growers are the ones involved in applying agrochemicals to their crops. However, they may also be responsible for ensuring that crops are treated appropriately to prevent pest infestations and diseases that could impact the crop's growth and quality.

Packers: Packagers hardly deal directly with agrochemicals but can be exposed to residues, which may be left on the produce at harvest. They have to follow some safety precautions to minimize exposure to these chemicals while handling, packaging, or storing crops.

Graders and Sorters: Graders and sorters may inspect crops for quality and, if proper washing or residue management techniques are not followed, are at risk of exposure to the agrochemical residues. Their role in ensuring that only safe, chemical-free produce reaches the market is important.

Agrochemical handlers (mixers, lasers, cleaners and sprayers): They are in direct contact with the preparation and application of the agrochemicals.

They mix, load, clean, and apply these chemicals on the crops. They are highly exposed to toxic substances, and the nature of their work calls for strict adherence to safety, including putting on protective clothing and equipment to avoid poisoning or contamination.

Case Studies in Nigeria

CKD and Exposure to Agrochemicals among Nigerian Farmers (Case 1)

Problem Statement

Magomya and Yaro's research work points to the high prevalence of CKD among rural farmers in Nigeria. The problem is entwined with both the exposure to agrochemicals and ignorance of risk factors of CKD.

Farmers' Practices

Herbicides and pesticides were commonly used by farmers, 70% without protective gear. Besides that, many of them took NSAIDs, alcohol, and concoctions of herbs, which added to the risks.

Effects

Markers of kidney damage were prevalent; these included proteinuria, 29.7%, and reduced eGFR, 33.9%. The conditions were compounded by inadequate healthcare facilities and safety practices.

Lessons Learnt

The risk of CKD can be minimized through awareness campaigns and access to healthcare in rural areas. The government should focus on safety training and the establishment of medical facilities in farming settlements.

Pesticide Safety Practices in Rivers State, Nigeria (Case 2)

The Problem

Farmers in Rivers State face significant risks due to improper handling of pesticides. Many households store agrochemicals in unlabeled containers, which are often reused for food and other items. Additionally, the lack of personal protective equipment (PPE) and insufficient safety training further heighten the dangers of pesticide exposure (Udoh & Gibbs, 2022; Raimi, 2021).

Practices of Farmers

Storage Practices: Farmers often stored pesticides within their homes and reutilized agrochemical containers in their homes for food. This unsafe practice persisted in spite of known risks (Udoh & Gibbs, 2022).

Use of PPE: Only 2% of farmers followed the recommendations for the use of PPE. Many used substitute cloth face coverings for respirators and wore contaminated clothes home, exposing family members to harmful chemicals (Ugwu et al., 2015; Sosan & Akingbohungbe, 2009).

Agrochemical Handling: In practice, farmers rarely followed the guidelines on pesticide labels due to illiteracy and lack of training. The most commonly used pesticides were atrazine, chlorpyrifos, and paraquat dichloride (Udoh & Gibbs, 2022).

The impact

Health Effects: Farmers reported developing skin irritation, respiratory problems, and poisoning. In one notorious incident, 24 children and adults died after consuming a food prepared with fertilizer, which had been mistakenly taken for food additive (Raimi, 2021; Udoh & Gibbs, 2022).

Youth Vulnerability: In farming households, children from 3 months to 22 years were commonly exposed either through the use of chemicals in agricultural work or from second-hand exposure. (Udoh & Gibbs, 2022)

Environmental Impact: Poorly disposed of waste pesticide containers degraded environmental quality, with negative impacts on soil and water. (Ugwu et al. 2015).

Lessons Learnt

Community-Based Education: Initiatives like those by Norina Farms, training 160 families on the safe handling of pesticides and giving out PPE, proved that localized, family-centered educational programs can be quite effective (Udoh & Gibbs, 2022).

Access to PPE: Overcoming economic and availability challenges is highly crucial for improving safety practice adoption (Sosan & Akingbohungbe, 2009).

Involvement of Youth and Families: Training of whole households ensures that there is sustainability in the use of safe practices, thereby reducing intergenerational transfer of unsafe methods (Udoh & Gibbs, 2022).

Perception of Health Hazards Associated with Agrochemical Use in Adamawa State, Nigeria (case 3)

The Problem

Farmers in Adamawa State are exposed to a lot of health risks due to frequent exposure to agrochemicals. While the use of pesticides among farmers is widespread, little knowledge on hazards and safety practices exists among them, leading to both acute and chronic health conditions. Lack of education and access to protective equipment further heighten these risks (Magomya et al., 2021; Raimi, 2021).

Practice among Farmers

Agrochemical Usage: Farmers in Adamawa commonly use pesticides without following label instructions or safety precautions due to illiteracy and lack of awareness.

Inadequate Protection: The use of personal protective equipment (PPE) is rare, with most farmers relying on makeshift alternatives, such as handkerchiefs or bare hands, while handling chemicals (Magomya et al., 2021).

Storage and Disposal: A large number of farmers store pesticides in their homes or reuse the containers for domestic purposes, creating a high risk of accidental exposure. Inappropriate disposal methods, such as the dumping of chemicals in nearby water sources, further exacerbate environmental hazards.

Effects

Health Impacts: Farmers reported symptoms such as skin irritation, respiratory problems, dizziness, and nausea after the use of agrochemicals. Other long-run effects include chronic illnesses and reduced productivity that were also noted (Raimi, 2021).

Environmental Contamination: It has been observed that unsafe disposal practices have contaminated water bodies and soil, which has adversely impacted human health and the agricultural productivity of late (Magomya et al., 2021).

Lessons Learnt

Awareness and Training: Awareness programs are critically needed to make farmers understand the risks associated with improper use of agrochemicals and the importance of protective measures.

Access to PPE: Ensuring better availability and affordability of PPE will contribute to minimizing exposure risks.

Policy Enforcement: Stringent regulations in terms of sale, distribution, and use of agrochemicals, accompanied by mechanisms for enforcement, would ensure that compliance with safety standards is observed.

Mitigation Strategies for Safe Agrochemical Use

Agrochemicals should be made available only to those who have been tested and trusted by means of education and license.

Education and Awareness

Reduction of agrochemical exposure can be achieved only with proper education and awareness. The majority of farmers in Nigeria are uninformed about the risks involved and safe handling. Educating farmers and agricultural workers about the risks associated with the use of agrochemicals and training them in sustainable agricultural practices can lead to a more judicious use of these chemicals. Awareness programs can highlight the importance of non-target species in the agricultural ecosystem and promote alternative pest control methods. Workshops, campaigns, and the distribution of educational materials regarding the understanding of the local language should be provided. Extension services should be involved actively in teaching farmers integrated techniques of pest management and use of agrochemicals that reduce health risks.

Use of Personal Protective Equipment

PPE involves gloves, goggles, masks, and protective clothes that greatly reduce direct exposure to chemicals. However, since most farmers in rural areas of Nigeria cannot afford PPE or find it unsuitable for the hot climate, the government and NGOs should be able to subsidize PPE and make it more comfortable for tropical regions. Farmers should be allowed easy access to PPE at an affordable price.

Regulation and Policy Enforcement

Regulatory measures: Governments and regulatory agencies play a crucial role in mitigating the effects of agrochemicals. This may include the registration and approval of agrochemicals based on rigorous risk assessments, restrictions on the use of certain chemicals, and the creation of buffer zones to protect sensitive habitats from crop displacement.

Agrochemical production, distribution, and use must be strictly controlled. Relevant agencies of state, such as NAFDAC and SON, have to

ensure that only acceptable and approved agrochemicals are offered for sale in the market. Regular inspection, information labeling of the product, and imposition of fines may lead to better practices. Restrictive use or ban on hazardous agrochemicals can reduce health risks.

Conclusion

The increased use of agrochemicals has significantly boosted agricultural productivity and food security in Nigeria; however, it also presents serious health risks due to improper handling, lack of awareness, and insufficient protection among farmers. Chronic exposure to various agrochemicals can lead to health issues such as respiratory problems, skin disorders, neurological impairments, and even chronic systemic diseases. The lack of enforcement by regulatory bodies, coupled with inadequate education for farmers and insufficient monitoring, exacerbates these risks. It is essential to find a balance between enhancing agricultural growth and ensuring the health and safety of farmers by promoting sustainable and safe farming practices.

Conflict of Interest: The authors declare that there is no conflict of interest.

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