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PESTICIDE RESIDUES IN NIGERIAN FOOD GRAINS: A THREAT TO FOOD SECURITY

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Abstract

The ubiquitous use of synthetic pesticides in agriculture has a multidirectional impact on human and animal health and, to a large extent, on environmental quality. The residues of these toxic chemicals in foods remain a serious threat to the international trade of agricultural products and public health worldwide. Both direct and indirect exposure to pesticide residues in primary or derived agricultural products pose a potential public health risk. Several epidemiological and animal studies have shown positive correlations between exposure to pesticide residues and numerous health implications, including damage to the central and peripheral nervous systems, cancer, allergies and hypersensitivities, reproductive disorders, and immune system disruption. Nigeria, like other developing countries, has established pesticide laws and regulatory authorities that are concerned with the regulation, manufacturing, formulation, importation, exportation, advisement, sales, distribution, use, and registration of pesticides in Nigeria. However, despite the existing laws and regulatory agencies, pesticide residues in foods remain a major challenge in Nigerian agricultural produce. These must not be unconnected with poor legislation and lack of enforcement of the existing legislation, lack of collaboration among agencies, limited testing facilities and resources, poor monitoring and attention of medical practitioners, and inadequate knowledge and awareness among farmers and the general public. Therefore, this article aimed to review the laws and legislations on pesticides in Nigeria, their accumulation in cereal grains, impact on human health, incidence of poisoning, challenges, and preventive techniques for sustainable agricultural practice and food safety.

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Introduction

Pesticides are now seen as one of the driving forces for increasing agricultural productivity worldwide (Odoh et al., 2024; Munir et al., 2024). As the world population continues to grow exponentially, especially in some Asian, African, and Caribbean countries, increasing agricultural activities and improving food quality to meet the growing food demand are highly advocated (Tudi et al., 2022). Underdeveloped and developing countries are faced with limited advanced agricultural machinery and technical know-how that would boost food production and safety (Asiah et al., 2019). Chemical fertilizers and pesticides are compelled to achieve desired crop protection and increase food production.

Moreover, the existence of known and emergence of new crop diseases that amount to high losses of tons of thousands of food crops are highly significant in both developed and developing countries. A large amount of food has been reported to be lost even after the crops have been harvested due to pests that usually attack stored food crops, especially in tropical countries (Akinneye et al., 2018). This has necessitated the use of chemical pest control aimed at minimizing these losses worldwide. In fact, more than 1100 pesticides are currently used in various combinations of different concentrations and at strategic stages of crop growth and in-stores to prevent, destroy, repel, or mitigate the effects of such pests' activities (Akinneye et al., 2018; Oshatunberu et al., 2023). Large quantities of grains are preserved each year using synthetic pesticides as farmers and traders alike await better prices. This particular practice can increase the accumulation of pesticide residue in stored grains.

Pesticide residues in cereals in Nigeria, as in many other countries, are a significant concern for food safety and public health. Cereal crops such as maize, rice, millet, sorghum, and wheat are staple foods in Nigeria, and pesticides are commonly used to protect these crops from pests and diseases (Oguntade et al., 2020; Jummai et al., 2023). However, improper or excessive use of pesticides can lead to harmful residues remaining on or in cereal grains, posing potential health risks to consumers (Grewal et al., 2017). Both direct and indirect exposure to pesticide residues in primary or derived agricultural products pose a potential public health risk.

The pesticides applied to food crops in the field can leave potentially harmful residues that may interact with the plant surfaces, be exposed to atmospheric environment, and be washed off during rainfall. Pesticides may be absorbed by the plant surface (waxy cuticle and root surfaces) and enter the plant transport system (systemic) or stay on the plant surface (contact). Pesticides that enter plant tissues may be transformed (metabolized) or sequestered in the tissues to form pesticide residues (Odoh et al., 2024).

Several epidemiological studies have shown positive correlations between exposure to pesticide residues and numerous health implications (Ahmad et al., 2024). However, occupational exposure tends to be significantly higher than that ingested by the general population via food consumption (Tudi et al., 2022).

The toxicity of these residues also largely depends on their chemical properties, concentration, and exposure duration (Ansari et al., 2024). The mechanism of toxicity of most pesticides, including organophosphate, organochlorine, and related pesticides, involves binding to the enzyme acetylcholinesterase, which disrupts nerve function, resulting in paralysis and consequent death (Grewal et al., 2017; Tudi et al., 2022). Acute toxicity manifestations include urination, diarrhea, diaphoresis, lacrimation, excitation of the central nervous system, and salivation. Chronic exposure includes damage to the central and peripheral nervous systems, cancer, allergies and hypersensitivity, reproductive disorders, and immune system disruption (Tudi et al., 2022; Ansare et al., 2024; Ahmad et al., 2024). . Therefore, this article aimed to review the laws and legislations on pesticides in Nigeria, their accumulation in cereal grains, impact on human health, incidence of poisoning, challenges, and preventive techniques for sustainable agricultural practice and food safety.

Pesticide Regulation and Standards

Like other developing countries, Nigeria has established pesticide laws and regulatory authorities. The regulation, manufacturing, formulation, importation, exportation, advisement, sales, distribution, use, and registration of pesticides in Nigeria are controlled by six main organizations: the Federal Ministry of Environment (FME), the Federal Ministry of Agriculture and Rural Development (FMARD), the Federal Ministry of Health (FMH), the National Agency for Food and Drug Administration and Control (NAFDAC), and the Federal Ministry of Labor and Productivity (FMLP). The existing legislative tools are: Federal Ministry of Agriculture and Rural Development (1988); National Policy on the Environment (1989); FEPA Decree 58 of 1988 as amended by Decree 59 of 1992 and 1999, but complemented by rules and regulations such as FEPA S.1.5 and S.1.9 dealing with the disposal and distribution/use of pesticides; NAFDAC Decree 15 of 1993, as amended by Decree 19 of 1999; and Pesticide Registration Regulation of 2021. NAFDAC is empowered to regulate the production, formulation, importation, exportation, sales, distribution, use, and registration of pesticides in Nigeria;

The Factories Acts 1990 of the FMLP's Factories Inspectorate Division; The Harmful Waste (Special Criminal Provisions, etc.) Decree 42 of 1988 of the FME and the Nigerian Agricultural Policy (1988). The general pest control objectives in the existing (1988) agricultural policy for Nigeria are to: Control, and/or eradicate and maintain good surveillance of the major economic pests whose outbreaks are responsible for large-scale damage/loss to agricultural production and provide protection to man and animals against vectors of deadly diseases. No. 65 of 2014 is enshrined with the power to protect human health and the environment from the harmful effects of hazardous chemicals, pesticides, and other agrochemicals; promote safety in their use; control the import, export, sales, and handling of hazardous chemicals; and contribute to the sustainable development of agriculture and environmental conservation. In 2020, Nigeria's imports alone (147,477 tons) exceeded the total imports of Southern Africa (87,403 tons) and North Africa (109,561 tons), as shown in Figure 1.

However, most of the pesticides circulating in Nigerian markets are imported from Europe, including those banned in their exporting or manufacturing countries. Surprisingly, European law allows companies to continue to produce, export, and sell banned pesticide products to countries with weaker human health and environmental laws, such as Nigeria (Omohwovo et al., 2024). Thus, the use of these banned pesticides was the brain behind the rejection of Nigeria's agricultural products in some markets, including the EU and the US.

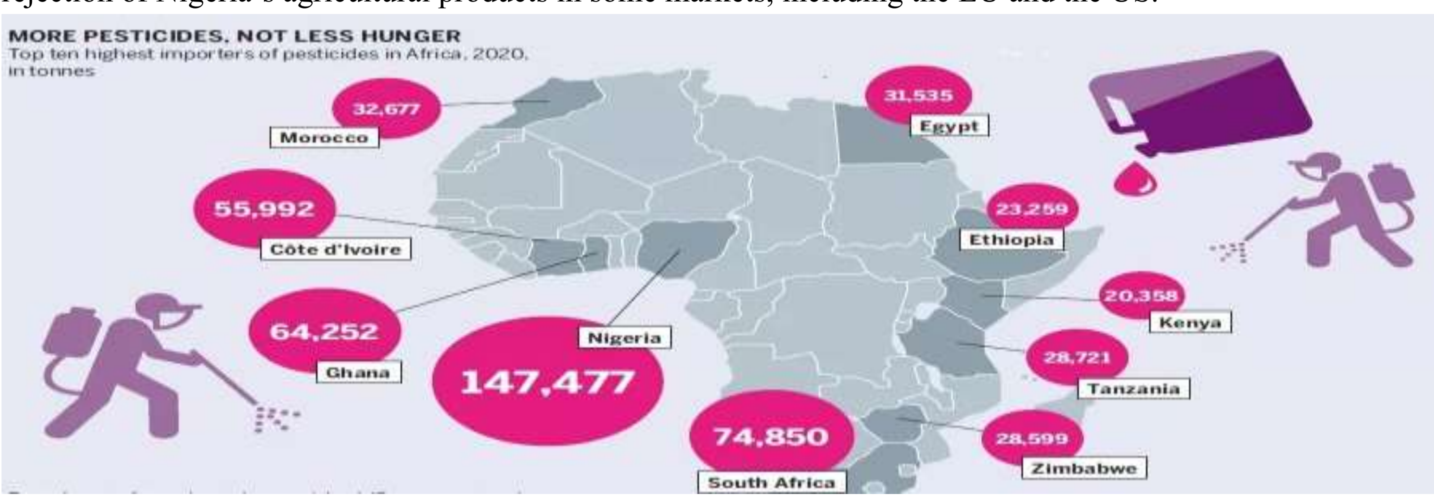

Figure 1: African countries with high pesticide importation. Adapted from the Pesticide Atlas, 2022.

Maximum Residual Limits (MRLs) are the maximum allowable concentrations of pesticide residues (mg/kg) that are legally and toxicologically accepted by the Codex Alimentarius Commission, EU, WHO, and FAO on or in food products and animal feeds (FAO/WHO, 2018). The values represent the highest residue concentration that is expected if the crop is treated with pesticides (Yeung et al., 2018). Therefore, determining this parameter in agricultural products is highly necessary in attaining food safety, enforcement, and control compliance with nationally authorized pesticides laws on commodities moving in international markets (Yeung et al., 2018; Zikankuba et al., 2019). Nigeria has adopted MRLs for pesticides from the Codex limits or those of the importing country.

In a survey conducted by the Food and Agriculture Organization of the United Nations in 109 countries about the safety and effectiveness of pesticide regulation. The survey reveals that the United Kingdom, the Netherlands, and the USA had 150, 120, and over 700 pesticide regulators, respectively. These figures have probably increased over the last 12 years. However, the same 2013 survey found that 77% of low- and middle-income countries had only one or two staff responsible for pesticide regulation (Figure 2). These pesticide regulators are often faced with many problems, including very limited resources and low capacity that make it difficult for them to effectively discharge their responsibilities.

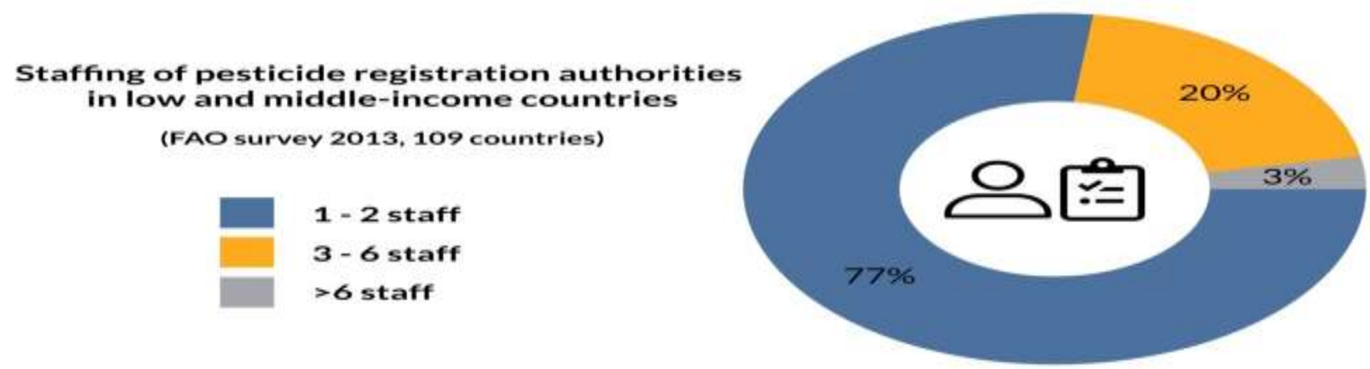

Figure 2: Number of regulatory staff in low- and middle-income countries

Adapted from [the Pesticide Registration Toolkit] *of the Food and Agriculture Organization of the United Nations*

International Conventions and Treaties that Nigeria is Significant

The Bamako Convention on Hazardous Wastes

The Convention was adopted in 1991 by 51 African countries at the Conference of Environment Ministers in Bamako, Mali, and came into force in 1998. It was established to protect human and environmental health by prohibiting the importation of hazardous waste into Africa, minimizing and controlling the trans-boundary movement of waste within Africa, and ensuring that waste is disposed of in a friendly environment.

The Stockholm Convention on Persistent Organic Pollutants

It is a global treaty to which Nigeria is a member. The Convention was adopted in Stockholm, Sweden, on May 22, 2001. It was established to protect human health and the environment from highly dangerous and long-lasting chemicals produced by different industries. The convention aimed to restrict and eliminate their production, use, trade, release, and storage, as well as outright banning and destruction of 12 POPs, 9 of which are pesticides (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, and toxaphene).

International Code of Conduct for Pesticide Distribution and Use

The Code of Conduct, which was established and adopted in 1985 by the Food and Agriculture Organization of the United Nations (FAO) Conference and revised in 2002, is aimed at promoting sound pesticide management practices that minimize potential risks to human and animal health and the environment.

Rotterdam Convention

The Rotterdam Convention on the Prior Informed Consent on Certain Hazardous Chemicals and Pesticides in International Trade is a global treaty. The convention was adopted in February 2004 and aimed to protect public health and the environment. It also aimed to help participating countries make informed decisions about potentially hazardous chemicals that might be shipped to them and to facilitate communication of these decisions to other countries. The Convention requires exporting countries to respect the decisions of importing countries.

Types of Pesticide Residues Found in Cereal Grains in Nigeria

Several reports have indicated that farmers in Nigeria use various pesticides to manage pests and diseases in cereal crops. These include insecticides, herbicides, rodenticides, fungicides, and antimicrobials. The improper and overuse of these chemicals resulted in the accumulation of pesticide residues in the harvested cereals. Moreover, different researchers had documented the most common types of pesticide residues found in Nigerian grains.

A study conducted in Rivers State, Nigeria, showed that approximately 23 different pesticide residues were detected in cereal grains (rice, maize, beans, and ground nut), which included organochlorine > herbicides > fungicides > organophosphates. The results further indicated a high incidence of pesticide residues in grain legumes and cereals sold in the major markets in the state (Egbecho et al., 2019). Oguntade et al. (2020) reported considerable concentrations of different pesticide residues in millet, maize, and beans sold in major commercial markets in Kwara State, Nigeria. All the nine (9) samples (100%) analyzed contained hexadecanoic acid with mean values value of 21.07, 33.06, and 13.38 in millet, maize, and beans, respectively. Hexadecanoic acid and methyl ester were found to have mean values of 4.43, 7.95, and 5.43 in millet, maize, and beans, respectively. Moreover, 9, 12 octadecanoic acid with mean values of 9.41, 19.10, and 4.57 in millet, maize, and beans, respectively.

Modupe et al. (2023) reported high specific contamination of pesticide residues in grains purchased from several markets in southwest Nigeria. Seventeenth (17) out of the total 24 pesticide residues detected, were above the MRLs set by the EU or FAO/WHO. This study documented higher concentrations of organo-chloride and organo-phosphate pesticides in grain samples analyzed in southwest Nigeria. Studies have shown that organochloride pesticides are frequently used by grain merchants and farmers in Nigeria.

A study conducted in the North-Central geopolitical region of Nigeria (Benue, Plateau, Kogi, Nasarawa, Kwara, Niger, and the Federal Capital Territory Abuja) indicated that 23 pesticide residues, including organochlorine insecticides, dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyldichloroethane (DDD), fungicides (etridiazole, chloroneb), and herbicides (simazine, atrazine) were detected in cowpea samples (Ekhuemelo, 2023). The pesticide residues detected in cowpea grains ranged from 72.67 mg kg^{-1} in samples from Kogi State to 159.67 mg kg-1 in samples from Plateau State, which were above the allowable limit of 20 mg kg^{-1}.

Similarly, maize and bean samples were collected from the grain markets of Iware, Jalingo, and Zing in Taraba State, Nigeria, and were analyzed for 11 organochlorine compounds (delta lindane, alpha lindane, beta lindane, gamma lindane, heptachlor, aldrin, heptachlor epoxide, endosulfan I, P, P′–DDE, endrin, endosulfan II, P, P′–DDD, P, P′–DDT, and methoxyclor). All the samples contained high concentrations of pesticide residues far above the RU standard (Abare-Jen, 2023). Similarly, Barau et al. (2023) reported ten (10) pesticide residues in different concentrations in maize, rice, millet, and sorghum samples randomly collected from farmers' fields in three (3) LGAs of Taraba North. The residual contaminations were in the following order: carbofuran (21%) > carbofuran (14%) > dichlorvos (12%) > t-nonachlor (11%) > heptachlor (10%) > HCB > g-chlordane all (9%) > DDT (7%) > endosulfan (6%) > aldrin (1%).

High concentrations of organochlorine pesticide residues have been reported in cereals and legumes sold in Anambra State, South-eastern Nigeria (Omokpariola et al., 2023). Organochlorine pesticide residues varied from 0.048 to 0.298 mg/kg in beans, BDL to 0.398 mg/kg in cowpea, 0.018–0.337 mg/kg in maize, 0.023–0.375 mg/kg in millet, 0.058–0.415 mg/kg in sorghum, and 0.045–0.442 mg/kg in rice. The highest endosulphan II concentration (0.442 mg/kg) was detected in rice, followed by aldrin (0.415 mg kg^{-1}) in sorghum and endosulphan II (0.40 mg/kg) in sorghum.

Sosan et al. (2018) reported several OCP residues in maize samples from open markets and stores in Ile-Ife and Ondo, Southwestern Nigeria. The percentage occurrence of the residues ranged between 20% and 100%, with levels exceeding Maximum Residue Limits (MRLs). The mean concentration of ƛ-HCH, Endosulfan II and Endrin aldehyde were 0.118, 0.592, and 1.039 mg kg^{-1}, respectively, in the maize samples collected from the open markets in Ile-Ife. However, high concentrations of Heptachlor epoxide were detected in maize samples from open markets and stores in Ondo (13.622 and 18.642 mg kg^{-1} respectively).

Moreover, a different study was conducted on pesticide residues in maize grains stored in Bassa, Bokkos, Jos–North, and Mangu Local Government Areas of Plateau State. The study revealed significant concentrations of Dichlorvos T. and aluminum phosphide in all maize samples analyzed with aluminum phosphide and atrazine above the EU/WHO permissible limit of 0.01 and 0.05 ppm, respectively (Atsen et al., 2021).

Fadina et al. (2021) reported high concentrations of organochlorine pesticide residues in cowpea grain samples collected from markets in Ibadan, Oyo State, Nigeria. Endosulfan had the highest mean concentration of 0.7500 mg/kg. Varying concentrations of pesticide residues such as aldrin, carbofuran, g-chlordane, chlorpyrifos, dichlorobiphenyl, dichlorodiphenyltrichloroethane (DDD), DDT, dichlorvos, endosulfan, heptachlor, hexachlorobenzene (HCB), isopropylamine, lindane, t-nonachlor, and profenofos were detected in cereals (rice, millet, and maize) and legumes (soybean) from open markets in Nsukka and Enugu, both in Enugu State within the Southeast geopolitical zone of Nigeria (Omeje et al., 2021). Oladapo et al. (2022) collected different samples of rice from markets and malls in Lagos and Ibadan in Southwestern Nigeria and analyzed them for pesticide residues. Their findings indicated that the concentrations of lindane isomers ranged from 0.00 $mg.kg^{-1}$ to 0.13 $mg.kg^{-1}$, Heptachlor ranged between 0.02 $mg.kg^{-1}$ and 0.18 $mg.kg^{-1}$ whereas the concentration ranges of endosulphan and endrin aldehyde were 0.03-0.40 $mg.kg^{-1}$ and 0.00-0.16 $mg.kg^{-1}$ respectively. The levels of dichlorodiphenyltrichloroethane (DDT) and its derivatives ranged between 0.13 and 0.23 $mg.kg^{-1}$, whilst methoxychlor had 0.08 $mg.kg^{-1}$ in rice. Some pesticide residues were detected far above the maximum residue levels (MRLs) prescribed by the Food and Agricultural Organization/World Health Organization and the European Union.

Samples of brown beans purchased from different markets in Lagos State were analyzed for organophosphate and carbamate pesticide residues (Ogah et al., 2011). All the bean samples contained residues of one or more organophosphate or carbamate pesticides. The mean concentrations ranged from 19.4 to 455.9 μg/kg. More than 10% of the samples contain pesticide residues above maximum residue limits (MRL). The estimated total diet intake (ETDI) for dichlorvos exceeded its maximum permitted intake (MPI) by 131%.

Olajide et al. (2024) examined the incidence, dietary exposure, and risk characterization of some Nigerian-banned organochlorine and organophosphate pesticides in rice, cassava, maize, and beans marketed in the state of Kogi, Nigeria. The residues detected in order of decreasing incidence were methoxychlor, α-chlordane, γ-chlordane, endosulfan II, dieldrin, aldrin, p,p'-DDE, Δ-BHC (hexachlorobenzene), endrin aldehyde, p,p'-DDD, lindane, p,p'-DDT, and endosulfan sulfate. Methoxychlor and α-chlordane had the highest incidences of 46.88% and 31.25%, respectively, whereas lindane, p, p'-DDT, and endosulfan sulfate had the lowest incidence (3.13% in each case). The health risk assessment indicated that the estimated percentage of tolerable daily intake of aldrin and dieldrin far exceeds the safety threshold. Moreover, the hazard index revealed that Δ-BHC (hexachlorobenzene), lindane, aldrin, dieldrin, and methoxychlor had high concentrations with the potential to induce chronic toxicity.

Beans (Phaseolus vulgaris) and green peas (Pisum sativum) were purchased from the Eke Awka market in Anambra State, and their residual pesticides were evaluated (Dike-Iheanyi et al., 2024). The findings of their study showed that all the samples contained pesticide residues (isopropylamine was the most prevalent). The pesticide residues in beans have the highest isopropylamine concentration (0.094 ± 0.001%). Pesticide residue contents were analyzed from bean samples consumed in Port Harcourt, Rivers State, Nigeria. The results of the study showed 17 different pesticide residues in all bean samples. The concentrations of 2, 4-Dichlorophenoxyacetic acid (2, 4-D) and 2, 2-dichlorovinyl dimethyl phosphate (DDVP) were detected in all bean samples and at levels above the MRL of the European Union (EU), except in the iron bean samples. Similarly, glyphosate was detected in all samples at concentrations above the MRL of EU. However, the concentrations of carbofuran (0.43±0.03 mg/kg), Endosulphan (0.18±0.01 mg/kg), HCB (0.62±0.10 mg/kg) Profenos (0.55±0.04 mg/kg) and t-nonachlor (0.32±0.00 mg/kg) decreased significantly to 0.23±0.10 mg/kg, 0.09±0.01 mg/kg, 0.31±0.01 mg/kg, 0.38±0.01 mg/kg, and 0.22±0.00 mg/kg respectively after the iron beans was Parboiled (Kalu et al., 2023).

Kasarachi et al. (2024) investigated pesticide residue levels in cowpea (Vignaunguiculata L. Walp) grains sold in four major markets in Anambra State, Nigeria: Awka, Nnewi, Ekwulobia, and Onitsha. Varying concentrations of different pesticide residues were detected in all the samples across the locations, with some samples exceeding the safety limits established by international health agencies. Olutona and Aderemi (2019) evaluated organochloride pesticide residue levels in food crops from selected markets in Ibadan, Oyo State, Nigeria. The study revealed that cowpea in Oje had the highest level of OCPs with dieldrin (20.14 ± 0.28), aldrin (7.81 ± 0.13), γ-benzene hexachloride (0.24 ± 0.11), pp-DDE (1.23 ± 0.16), endrin (1.82 ± 0.14), endosulfan II (16.90 ± 0.00), pp-DDT (1.82 ± 0.78), endrin CHO (12.89 ± 0.14), and endosulfan (13.49 ± 0.13), whereas beans from Bodija had the lowest value of OCPs with dieldrin (0.99 ± 0.0), endosulfan II (1.02 ± 0.01), and endrin CHO (1.66 ± 0.12), which are all above the maximum residue limits.

Samples of bean (Phaseolus vulgaris) were collected in both field and storage facilities in six local government areas (Bama Biu, Damboa, Gubio, Maiduguri Metropolitan, and Monguno) of Borno State, Nigeria, and analyzed for pesticide residues (Obida et al., 2012). Dichlorvos, endrin, and DDT were found in both field samples (pre-storage) and stored samples (post-harvest). Lindane, diazinon, and aldrin were only detected in the pre-storage samples. The concentrations of pesticide residues in the bean samples analyzed are in the following order: endrin > DDT > dichlorvos. Arowora et al. (2020) investigated the nutritional composition and pesticide residue levels in samples of cereal grains (wheat, sorghum, millet, and maize) sold in the Wukari market, Taraba State, Nigeria. The results showed that the concentrations of organochlorine residues (aldrin, heptachlor, lindane, and methoxychlor) were slightly higher than the maximum residue limits of the European Council.

Table 1: Pesticide Residues Detected in Nigerian Wheat Grains

Authors	Types of detected pesticide residues	State

Olajide et al. (2024)	methoxychlor, α-chlordane, γ-chlordane, endosulfan II, dieldrin, aldrin, p,p'-DDE, Δ-BHC (hexachlorobenzene), endrin aldehyde, p,p'-DDD, lindane, p,p'-DDT, and endosulfan sulfate	Kogi
Dike-Iheanyi et al. (2024)	Isopropylamine	Anambra
Odoh et al. (2024)	Delta lindene, alpha lindene, beta lindene, gamma lindene, heptachlor, aldrin, heptachlor epoxide, endosulfan I, P, P′–DDE, endrin, endosulfan II, P, P′–DDD, P, P′–DDT, and methoxyclor	Taraba
Kasarachi et al. (2024)		Anambra
Ekhuemelo, 2023	Dichlorodiphenyltrichloroethane (DDT), Dichlorodiphenyldichloroethylene (DDE), Dichlorodiphenyldichloroethane (DDD), Etridiazole, Chloroneb, Simazine, and Atrazine	Benue, Plateau, Kogi, Nasarawa, Kwara, Niger, and Abuja
Abare-Jen, 2023	Delta lindene, alpha lindene, beta lindene, gamma lindene, heptachlor, aldrin, heptachlor epoxide, endosulfan I, P, P′–DDE, endrin, endosulfan II, P, P′–DDD, P, P′–DDT, and methoxyclor	Taraba
Barau et al. (2023)	Carbofuran, dichlorvos, t-nonachlor, heptachlor, HCB, g-chlordane, DDT, endosulfan, and aldrin	Taraba
Bando et al. (2023)		Taraba
Omokpariola et al. (2023)	endosulphan II, and aldrin	Anambra
Modupe et al. (2023)	A total of 24 organo-chloride and organo-phosphate pesticide residues	Several markets in southwest Nigeria
Jummai et al. (2023)		Taraba
Kalu et al. (2023)	2,4-Dichlorophenoxyacetic acid (2,4-D), 2,2-dichlorovinyl dimethyl phosphate (DDVP), glyphosate, endosulfan, HCB, t-nonachlor, and proxenos	Rivers
Oladapo et al. (2022)	Endosulphan, endrin aldehyde, heptachlor, dichlorodiphenyltrichloroethane (DDT) and its derivatives, and methoxychlor	Lagos and Oyo

Omeje et al. (2021)	Aldrin, carbofuran, g-chlordane, chlorpyrifos, dichlorobiphenyl, dichlorodiphenyldichloroethane (DDD), dichlorodiphenyltrichloroethane (DDT), dichlorvos, endosulfan, heptachlor, hexachlorobenzene (HCB), isopropylamine, lindane, t-nonachlor, and profenofos are the following:	Enugu
Atsen et al. (2021)	Dichlorvos, aluminum phosphide, and atrazine	Plateau
Fadina et al. (2021)	organochlorine pesticide residues endosulfan	Oyo
Arowora et al. (2020)	Aldrin, heptachlor, lindane, and methoxychlor	Taraba
Oguntade et al. (2020)	Hexadecanoic acid, methyl ester, octadecanoic acid	Kwara State
Olutona and Aderemi, 2019	dieldrin, aldrin, γ-benzene hexachloride, pp-DDE, endrin, endosulfan II, pp-DDT and dieldrin	Oyo
Egbecho et al. (2019)	Chlordane alpha (cis), DDT 0P-, hexachlorobenzene, methoxychlor, endosulphan-alpha, endosulphan-sulfate, DDE O P, DDT PP- BHCs, octachlorostyrene, captan, chlorothalonil quinozene, tecnazene, hexazinone, simazine, cyanazine	
Sosan et al. (2018)	ƛ-HCH, Endosulfan II and Endrin aldehyde and Heptachlor epoxide	Ondo
Obida et al. (2012)	Lindane, diazinol, and aldrin	Borno

Incidence of Pesticide Poisoning in Nigeria

Pesticide poisoning is one of the worlds's greatest public health burdens. Ellie Roger a Communication and Development Officer for Center for Pesticide Suicide Prevention (CPSP) in her speech to mark World Health Day 2024 stated that some root causes of pesticide poisoning. The burden can be traced back to the so-called Green Revolution project, which began in the mid-twentieth century, when new agricultural technologies were introduced that consequently increased global food production. Additionally, during this period, new plant strains, chemical fertilizers and irrigation systems, and pesticide use were spread worldwide. Roger (2024) reported that every year, 385 million people (i.e., 44% of the world's farming population) are poisoned in the course of their work, with an estimated 11,000 people sadly losing their lives. Housséni *et al*. (2018) reported that over three million (3,000,000) pesticide poisoning episodes occur globally each year, with at least 300,000 deaths and 99% occurring in developing countries.

In Nigeria, pesticide residues in food have been responsible for several food poisoning and death cases (Shaibu, 2008), and these cases have been attributed to the indiscriminate use of chemicals in food products. Udoh and Gibbs (2022) reported that many agricultural households in Nigeria rely on chemical fertilizers and pesticides. In 2015, the European Union banned the importation of Nigerian beans due to outrageous concentrations of dichlorvos pesticide in the beans. Moreover, the EU noted that other chemicals, such as chlorpyrifos, cyclothrin, dimathoate, trichlorophon, and omethoate, were discovered in high concentrations in Nigeria's dried beans. In fact, the dichlorvos concentrations ranged between 0.03 and 4.60 mg/kg in most of the rejected beans when the acceptable maximum residue level was 0.01 mg/kg. Pesticide poisonings are becoming regular in Nigeria. In

2020, over 270 people died due to contamination with the highly hazardous pesticide endosulfan in a rural community river in Benue State. Surprisingly, a huge number of similar HHPs (already banned) are circulating in Nigerian markets.

Okon (2018) reported the death of six people in Adamawa State after eating ‘moi-moi,” a local delicacy prepared from beans. In November, four family members in Ilorin also died, and others were hospitalized after a meal of ‘amala’ (a local delicacy prepared from dried yam flour. In 2018, three family members, including a pregnant woman in Bayelsa, died after eating a dinner contaminated with pesticides (Okon, 2018). Moreover, in August 2017, five people in Anambra State were reported to have died after eating jollof rice. In September of that same year, six people of the same family and a neighbor died after eating leaf porridge, known as ‘fate’ in Shinkafi, Zamfara State. Bawa et al. (2016) reported 32 poisoning outbreaks in Gombe State, Nigeria, from 2005 to 2014. An outbreak involved a boarding institution in which two hundred and sixty-seven students presented with symptoms after food ingestion. In the Isua-Akoko area of Ondo State, four out of a 9-member family died after eating yam flour treated with pesticides (Olulakin et al. 2015). In the same state, the WHO (2015) reported the mysterious deaths of at least 18 people in the town of Ode-Irele, where 23 people presented with symptoms including headache, weight loss, blurred vision, and loss of consciousness.

Pesticide-related illnesses, including mental impairment and reproductive problems, have been reported in some communities in southwestern Nigeria. The cases were common among agricultural workers who were regularly exposed to pesticides. Similarly, cases of pesticide poisoning have been reported in some families in the Kwara and Kano states of northern Nigeria (Adedoyin *et al*., 2008: Adeleke, 2009). In 2011, six family members died after eating moin-moin prepared from suspected poisoned beans. Ikpesu and Ariyo (2013) and many people of Bekwarra Local Government Area of Cross River State were hospitalized after eating moin-moin and beans (Ikpesu and Ariyo, 2013).

In Yassharu village of Kafur LGA in Katsina State, a significant number of people suffered from pesticide poisoning after eating maize preserved with pesticides (Ikpesu and Ariyo, 2013). Shuaibu (2008) reported pesticide poisonings: in Cross River State, about 112 people were hospitalized, and 2 people died after eating moin-moin and beans contaminated with significantly high levels of carbamates, fenitrothion, and chlorpyrifos. In Gombe State, over 120 students at a public school were hospitalized after eating a meal containing a high concentration of lindane. In 2004, high concentrations of carbofuran pesticide residues were detected in several batches of noodles manufactured in Nigeria, which may have resulted in 23 reported cases of vomiting and one death (Olurominiyi and Emily, 2011).

Health Implications

In modern agriculture, chemical pesticides are indispensable in promoting crop yield and food security. However, the extensive use of these chemicals in agriculture and other sectors poses significant risks to the environment, animals, and human health. The persistent nature and bioaccumulative properties of these chemicals exert great deterioration on the quality of air, water, and soil, hence causing negative impact on animals, humans, and food safety (Zhou et al., 2025). Moreover, to boost agricultural production and maintain subsistence livelihoods, farmers in developing countries are left with no option but to use pesticides to control pests and diseases. Direct and indirect human exposure to pesticides is now becoming a serious problem worldwide. The entire world population is at risk of exposure to these chemicals and their consequent adverse effects (Ali et al., 2018; Tudi et al., 2022). The problem is seriously affecting people in developing countries and high-risk groups in other countries, possibly due to excessive utilization, unsafe practices, insufficient education and training, inadequate power over external force and internal policy, and poor public health system (Phung et al., 2012; Carvalho, 2017

Lovison et al., 2022). Therefore, the toxicity of the pesticides largely depends on their chemical properties, concentration, and duration of exposure; hence, they are classified based on the degree of toxicity, as shown in Table 2.

Table 2: Pesticide Classification based on the Degree of Toxicity

Types	Level of toxicity	Oral	Dermal
Class Ia	Extremely hazardous	<5	<50
Class Ib	Highly hazardous	5-50	50-200
Class II	Moderately hazardous	50-2000	200-2000
Class III	Slightly hazardous	>2000	>2000
Class IV	Unlikely to present acute	5000 and above	

Approximately 385 million cases of unintentional, acute pesticide poisonings, 220,000 deaths, and 750,000 chronic diseases occur annually worldwide (Boedeker et al., 2020; Tudi et al., 2022). Boedeker et al. (2020) reported that approximately 44 % of farmers worldwide are poisoned by pesticides. In April 2023, more than 20 million Nigerians were reported to be living with chronic kidney diseases. That is more than 10% of the citizens living with kidney diseases. The same survey of small-scale women farmers showed that pesticide-active ingredients such as paraquat and butachlor are capable of causing kidney diseases and cancer. Scientists at several Nigerian universities argue that dangerous pesticides and other agrochemicals are contributing to the rising rates of cancer, which kills as many as 79,000 Nigerians a year. Therefore, chronic exposure to pesticides has been implicated in many diseases, including damage to the central and peripheral nervous systems, diabetes, cancer, allergies and hypersensitivities, reproductive disorders, and immune system disruption (Figure 3).

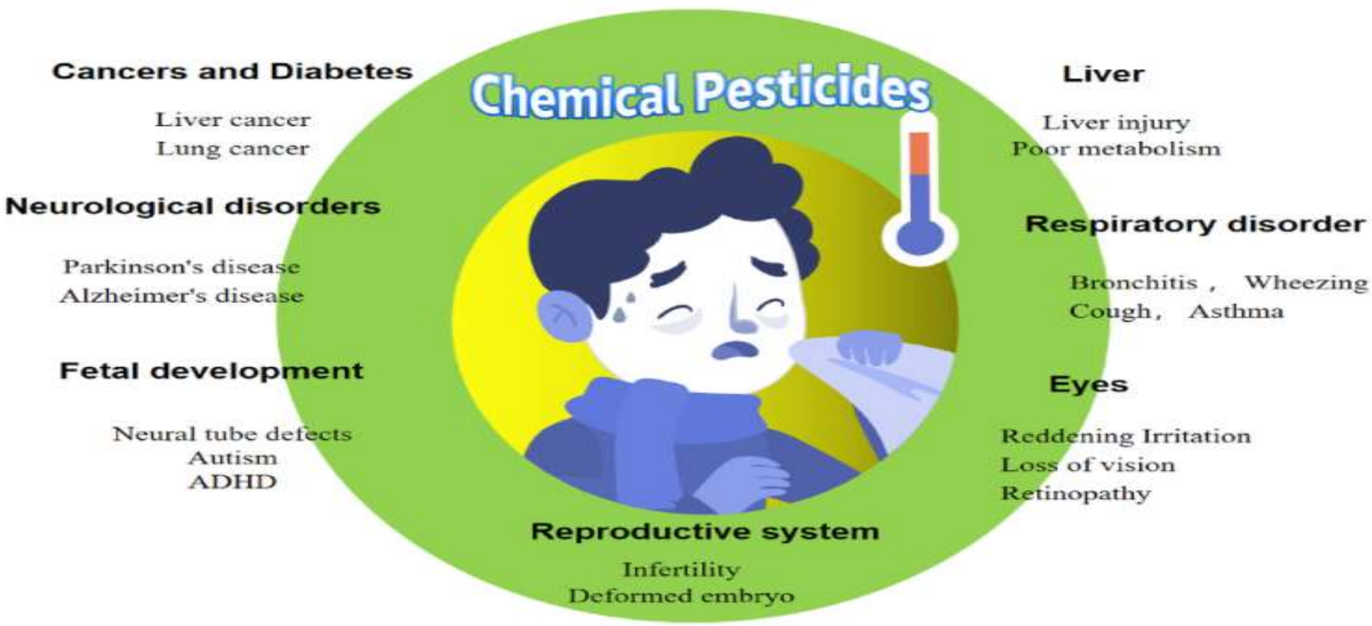

Figure 3: Diseases Related to Pesticide Toxicity. Adapted from Zhou et al. (2025)

Cancer

The association between pesticides and cancer incidence has long been observed and has become a serious concern. Pesticides remain an essential feature of modern-day agriculture that invariably contribute to cancer risk. Epidemiologic studies have observed a significant link between pesticide exposure and cancer risk (Gerken et al., 2024). A hospital-based case-control study conducted in Chinese women found a strong association between exposure to organochlorine pesticides (PCBs, p,p′-DDT, and p,p′-DDE) and breast cancer risk (Huang et al., 2019).

High incidences of urinary bladder carcinomas and low incidences of kidney pelvis papillomas and carcinomas have been observed in rats exposed to high doses (2500 ppm) of diuron (Da Rocha et al., 2014). Mathur et al. (2008) assessed the influence of organochlorine pesticides in 100 females suffering from cervical, uterine, vaginal, and ovarian cancers from Jaipur, India. The results indicated significantly higher concentrations of organochlorine pesticide residues in all patients with cancer than in the control group. In a prospective cohort of 57,311 licensed pesticide applicators in the United States, enrolled from 1993 to 1997, 20,646 applicators were reported to have used crop herbicide (Imazethapyr) and 2,907 developed cancers by 2004 (Koutros et al., 2010). Similarly, another study conducted in East China indicated that exposure to pyrethroid pesticides was linked with an increased risk of childhood brain tumors (Chen et al., 2016).

Several animal and epidemiological studies have shown strong positive associations between parental and childhood exposure to pesticides and the risk of CBT. Greenop et al. (2013) investigated whether exposures to pesticides before pregnancy, during pregnancy, and during childhood were associated with an increased risk of childhood brain tumor from 10 pediatric oncology centers in Australia. Their findings indicated that preconception pesticide exposure and possibly exposure during pregnancy are strongly associated with an increased risk of CBT. Moreover, different pesticides were reported to increase several types of cancers such as childhood leukemia (Mancin et al., 2023), adult leukemia (Rafeeini et al., 2023; Cavalier et al., 2022), laryngeal cancer (Bravo et al., 1990), kidney/liver cancer (Rios et al., 2020; Prudente et al., 2018), eye cancer (Thompson et al., 2022), and colorectal cancer (Gerken et al., 2024).

Diabetes

Several animal and epidemiological studies have linked pesticide exposure to diabetes and glucose deregulation. Pesticides have been reported to disturb glucose homeostasis by generating reactive oxygen species (ROS), which leads to oxidative stress, lipotoxicity, inflammation, acetylcholine (ACh) accumulation, and gut microbiota dysbiosis. Among the three major categories of pesticides, the association between insecticide use and diabetes was more implicative in the literature (Wei et al., 2023). Data extracted from NHANES (2013-2016) indicated a significant association between glyphosate exposure and an increased risk of T2DM in the general adult population (Li et al., 2023). Zhao et al. (2023) reported that occupational exposure to OPs was associated with a significantly increased risk of DM in occupational populations.

A case–control study was conducted involving 130 subjects with non-glucose intolerance (NGT), 130 with pre-diabetes, and 130 with recently diagnosed T2DM in the age group of 30-70 years. Among all recruited subjects consuming pesticide-contaminated groundwater, 42% had T2DM, 38% had pre-diabetes, and the remaining 20% were found normal. The levels of β-HCH, p,p'-DDE, and o,p'-DDT were higher in the pre-diabetes and T2DM groups than in the NGT group. Thus, the study reveals that the elevated OCP levels may contribute to an increased risk of T2DM development after a certain period of exposure (Tyagi et al., 2021). Daniel et al. (2018) reported that diabetes mellitus is associated with higher p,p'-DDE and β-HCH concentrations in Tamil or Telugu South Asians.

Significant concentrations of 4-nitrophenol, 3-phenoxybenzoic acid, 2,4-dichlorophenoxyacetic acid (2,4-D), 3,5,6-trichloro-2-pyridinol, 2,2-bis(4-chlorophenyl)-1,1-dichloroethene, and hexachlorobenzene were also detected among youth with diabetes in the United States. Exposure to these pesticides was also associated with impaired beta-cell function and poorer glycemic control (Kaur et al., 2020). Data derived from the 1999–2004 National Health and Nutrition Examination Survey (NHANES) 1999-2004 indicated high concentrations of p,p'-

DDT (>0.086 ng/g) and p,p'-DDE (2.99-7.67 ng/g) among Mexican Americans and strongly associated with diabetes nephropathy (Everett et al., 2017).

Respiratory diseases

Exposure to pesticides increases the incidence of respiratory pathologies, such as asthma, lung cancer, and chronic obstructive pulmonary disease [COPD]—or chronic bronchitis. The respiratory system is essential to human survival, regulating gas exchange (oxygen-carbon dioxide) in the body to balance the normal function of acid and base tissue cells. A plethora of evidence from both animal and epidemiological studies has confirmed a significant association between pesticide exposure and respiratory diseases.

Horne et al. (2024) observed a significant association between living near pesticide applications and more wheezing symptoms among children in a rural community of Imperial Valley near the US–Mexico border. Maternal exposure to pyrethroid insecticides used for indoor residual spraying (IRS) in malaria-endemic areas increased the risk of asthma and other respiratory allergy symptoms among preschool children in Limpopo, South Africa (Elsiwi et al., 2024). Islam et al. (2023) reported that data extracted from the Infants' Environmental Health Study in Costa Rica showed that exposure to pyrethroids used at residential houses and agriculture caused children's respiratory outcomes of 39% cough, 20% wheeze, 12% asthma, and 5% LRTI. Moreover, in a large population-based study (116 375 participants) in the UK, occupational exposure to pesticides was found to be associated with the risk of COPD (De Matteis et al., 2021). Exposure to pesticides was reported to be highly correlated with respiratory pathologies, such as asthma, chronic obstructive pulmonary disease, and lung cancer. Numerous studies have implicated exposure to pesticides with a significantly increased incidence of respiratory diseases (Tarmure et al., 2020).

Neurological disorders

The nervous system is an integral part of the human body and includes the brain, spinal cord, and a vast network of nerves and neurons, all of which are responsible for a majority of body functions—from the art of sense to whole body movement. However, exposure to certain chemicals, such as pesticides, can cause neurotoxic effects or intensify preexisting chemical damage to the nervous system. Pesticide exposure can impact a plethora of neurological diseases, including amyotrophic lateral sclerosis (ALS) and Parkinson's disease, along with cognitive function and dementia-like diseases like Alzheimer's.

Alzheimer's disease

Ruiz-González et al. (2024) conducted a cross-sectional study to evaluate the association between pesticide exposure and the prevalence and risk of AD in Andalusia, Spain. Approximately 40,044 cases were drawn from computerized hospital records between 2000 and 2021. The findings of their study indicated that people living in districts with higher pesticide use showed significantly higher prevalence and increased risk of developing AD than those with lower pesticide use.

Low-level chronic exposure to diazinon (DZN) has been implicated in detrimental neurobehavioral impairments, disturbances in IA memory performance, and alterations in amyloid beta precursors, which can be related to an increased risk of Alzheimer's disease (Afshari et al., 2024). Finhler et al. (2023) evaluated the potential association between pesticide exposure and cognitive impairment in farmers. Strong scientific evidence supports the association between cognitive impairment and pesticide exposure.

Low-level exposure to deltamethrin (DM) increased locomotion activity (open field) and caused spatial working memory impairment (spontaneous alternation task) in rats. In fact, reduced TH immunoreactivity in the SNpc, VTA, and dorsal striatum caused spontaneous alternation task (Marina et al., 2020). Several epidemiologic and laboratory animal studies have demonstrated a strong association between pesticide exposure and cognitive dysfunction, dementia, and Alzheimer's disease (Aloizou et al., 2020).

Epilepsy and seizures

A case-referent study was conducted on 19,704 individuals over a 17-year study period (2000–2016), and the data were obtained from the Center for Prevention of Occupational Risks, Almería (South-Eastern Spain). This study investigated the influence of occupational risk factors on the occurrence of epilepsy among farmers and pesticide applicators (sprayers). The findings showed a significant increased risk of having epilepsy in farmers and sprayers working in intensive agriculture who do not wear face masks (Alarcón et al., 2023).

Similarly, data generated from hospital records of the Spanish health care system between 1998 and 2010 revealed that the prevalence of epilepsy was significantly higher in areas with greater pesticide use than in areas with lesser pesticide use. Moreover, the results further indicated that environmental exposure to pesticides might increase the risk of developing epilepsy (Requena et al., 2018). In a cross-sectional pilot study, high concentrations of beta and gamma hexachlorocyclohexane (HCH) were detected in children (2–12 years) with idiopathic seizure compared with the control group (Arora et al., 2013).

Parkinson's disease (PD)

Parkinson's disease (PD), considered the most common neurodegenerative disease, occurs when nerve cells in the substantia nigra region of the brain are substantially damaged or destroyed and can no longer produce dopamine, a nerve-signaling molecule that helps control muscle movement.

Parkinson's disease is now seen as the world's fastest-growing brain disorder, and exposure to environmental toxicants, such as chemical pesticides, is the most common cause (Dorsey and Bloem, 2024). Exposure to agricultural pesticides may alter genes associated with lysosomal function, thereby increasing the susceptibility for developing PD (Ngo et al., 2024). Exposure to pesticides causes imbalances in the gut bacteria, gut barrier, and blood–brain barrier, thereby influencing PD development and progression, evidently harming more than just dopamine neurons (Ghosh et al., 2024). Early environmental exposure to pesticides alters the development of the nervous system and increases the risk of Parkinson's disease in rodents (Jiménez-Salvador et al., 2023).

Reproductive dysfunctions

Numerous laboratory and epidemiologic studies have shown that low-level exposure to pesticides and other related chemicals interferes with reproductive capabilities. Different studies have implicated that endocrine disruption and oxidative stress can alter fertility.

Vasseur et al. (2024) reported for the first time a significantly high concentration of glyphosate in human seminal plasma, which was four times higher than that observed in blood plasma. The study also established a strong positive correlation between plasma seminal GLY and 8-OHdG concentrations, with the latter reflecting the impact of DNA. Hence, GLY has a negative impact on human reproductive health. Similarly, Chang et al. (2023) reported for the first time a significantly high percentage of mLOY in male farmers exposed to glyphosate for a long time.

Exposure to pesticides such as cyfluthrin, zeta-cypermethrin, malathion, carbaryl, and propamocarb hydrochloride during pre-conception and the first trimester was associated with stillbirth in women living within 500 m of any pesticide application (Ni et al., 2022). Chronic exposure to an environmentally atrazine concentration alters testicular steroid-associated gene expression in male mice through the F1 and F2 across generations (Kolaitis et al., 2023).

Challenges

Inadequate Information, Knowledge, and Awareness

Inadequate information, knowledge, and awareness on pesticide applications among farmers, agricultural extension workers, and food wholesalers/retailers appeared to be a major setback in pesticide management in Nigeria. Similarly, many farmers are unaware of the damaging health effects associated with the use of pesticides, and several dangerous habits and practices have been innocently imbibed over the years (Ojo, 2016). These habits include, but are not limited to, the domestic use of pesticide empty containers for water and food storage, the use of domestic utensils for measuring and dispensing pesticides, and improper storage of pesticides in many residential houses (Asogwa and Dongo, 2009; Adesuyi et al., 2018).

Poor legislation and lack of enforcement

Despite the existing laws and regulations concerning the regulation, manufacturing, formulation, importation, exportation, advisement, sales, distribution, use, and registration of pesticides in Nigeria, the majority of the pesticides used by small-scale farmers in Nigeria are hazardous. Several studies have observed that poor legislation on pesticide application and distribution is a major cause of pesticide poisoning in Nigeria (Ojo, 2016; Omoyajowo et al., 2022). Pesticide mismanagement and handling are also common among unlicensed retailers and untrained farmers in developing countries, such as Nigeria.

Several factors are considered responsible for the ineffectiveness of pesticide regulation in Nigeria. These include outdated laws, overlapping regulatory functions, resource limitations, inadequate laboratory testing facilities, and the influence of multinationals. Nigeria's laws on pesticide regulation do not hinder the importation of banned chemical products into the country. Most of the pesticides products approved by NAFDAC contain harmful active ingredients that are banned by the European Union and the USA due to their adverse impacts on human health, the environment, and animals. In Nigeria, there are no provisions to hold manufacturers accountable for the health effects of these notorious chemicals, and no law requires the use of PPE when applying them.

None of the collaborative efforts among agencies

No collaboration exists even among the government regulatory agencies in the country; thus, some of their functions overlap and others are neglected. Effective collaborations between academia and regulatory bodies and between civil society organizations. This lack of cooperation makes it difficult to develop and use robust pesticide regulations in the country. Academia-based research generates significant information about pesticide contamination in the food chain and its consequential impact on public health. However, such information remains untapped.

Monitoring of pesticide residues in locally consumed agricultural products

Regulatory agencies usually scrutinized cash crops or food products meant for export, among which pesticide residues are evaluated. However, foods meant to be consumed locally are left unchecked. Moreover, some food products that were rejected because of high concentrations of residual pesticides are usually returned to the country to be sold and consumed by innocent and teeming Nigerian population (Abubakar, 2008; Ojo, 2016).

Poor attention to pesticide poisoning by medical practitioners

To be candid, medical personnel in developing countries seem to be inadequately trained to recognize and deal with chemical poisoning, especially pesticides, the symptoms of which can be easily attributed to other causes ([Konradsen et al. 2003, PAN 2012]. However, improper diagnosis and misinterpretation of pesticide poisoning were common even among astute medical personnel in the USA (National Disease Research Council, 2016). The lack of a comprehensive database on the use, handling, storage, and adverse effects of pesticides in Nigeria is grossly inadequate.

Limited testing facilities and resources

To be candid, the government agencies are faced with financial and human resources challenges and lack of adequate laboratory testing facilities that can detect the presence of banned or restricted chemicals in pesticide products. The interference of large multinational companies is another problem in its own. Some international companies that manufacture highly hazardous pesticides appeared to be given seats for the proposed Nigerian Pesticides Council, enshrined with the responsibility to make decisions and provide strategic direction for the pesticide council. How can the suspect be a part of the panel of judges?

Preventive measures

Given the evidence of high pesticide residues in food commodities and the incidence of pesticide poisoning in Nigeria, concerted efforts are needed to reduce this menace. Moreover, if adopted, the following approaches will definitely contribute immensely in cabbing pesticide contamination in foods.

Proper use of the pesticide

Proper use of pesticides could be a major step in reducing pesticide residues in food products. This involves the selection of registered and correct pesticides, as well as the manufacturer's instructions and precautionary guides. Dosage rates, dilutions, timing and frequency of application, treatment intervals, and method of application, precautions, and limitations should be labeled and written in the local language. Moreover, farmers and pesticide applicators should be well informed about the necessary steps to be taken when they are exposed to pesticides via ingestion, inhalation, and dermal contact. The use of protective clothing during pesticide application should also be encouraged. Relevant governmental and non-governmental agencies should be empowered to provide directives on the advertisement of all registered pesticides (Ojo, 2016; Grewal et al., 2017; Adesuyi et al., 2018).

Organic farming

This implies the use of naturally occurring compounds, such as compost manure, green manure, and bone meal, and the avoidance of synthetic pesticides, fertilizers, and genetically modified organisms in agriculture. This method improves soil quality, environment, and food safety. Several reports have indicated that pesticide residues are four times higher in non-organic agricultural products than in organic ones (Baranski et al., 2014). Organic foods are rich in antioxidants and adequate di, 2013). Eatary intakes of antioxidant rich foods have been shown to ameliorate chronic diseases such as cardiovascular diseases, neurodegenerative disorders, and cancers (Wahlqvist, 2013).

Biopesticides

Compounds derived from natural sources, such as plants, animals, bacteria, fungi, and earth minerals, have the potential to protect crops against pests and pathogens. Biopesticides are eco-friendly, more specific, effective, and decompose quickly without leaving residues than synthetic pesticides (Essiedu *et al., 20220;* Kumar et al., 2021). Studies have observed decreased nutrient contents and increased incidence of diseases in crops treated with synthetic pesticides (Tripathi et al., 2020). Therefore, the application of biopesticides/biofertilisers can improve and restore soil fertility and ensure sustainable agricultural production using green technology. Recently, the search and use of biopesticides have received considerable attention worldwide due to their efficiency in sustainable agricultural practices. In fact, the global application of biopesticides is increasing by almost 10% every year. Notwithstanding, research input on different sources of biopesticides is required to achieve eco-friendliness and food safety. The government, NGOs, academia, farmers' associations, and civil societies should provide sufficient funds/grants for enormous research in the field. This will definitely go a long way in reducing pesticide residues in our foods.

Food Processing Techniques

Several food processing methods reduce pesticide residues in foods. Washing, blanching, peeling, and thermal treatments have been found to be effective for reducing pesticide residues (Mir et al., 2022). These techniques can invariably reduce the potential health risks associated with pesticide residues in food products. Newer methods, such as cold plasma, pulsed electric field, irradiation, and ultrasonication, have been applied to degrade pesticide residues in food products (Munir et al., 2024). Cold plasma effectively breaks down pesticide residues in food via the production of reactive gas species, such as radicals, excited neutrals, ions, and free electrons.

Conclusion

Pesticide residues in cereals are a significant food safety and public health concern in Nigeria. Several studies across the country have observed significant contamination of the residues in food grains, which has resulted in many incidences of pesticide poisonings among families, boarding school students, and different communities. Although the government has set regulations to control pesticide use and residue levels, gaps exist in enforcement, monitoring, and farmer education. Addressing these challenges requires a multifaceted approach, including better regulation, improved monitoring systems, and more sustainable farming practices, such as integrated pest management (IPM), to reduce the reliance on harmful chemicals. Increased public awareness and stronger consumer demand for safe, certified food products may also play a key role in mitigating the risks posed by pesticide residues in cereals.

Recommendations

This includes training programs for farmers, improving regulatory frameworks, and increasing public awareness of the dangers of pesticide misuse.

Additionally, some NGOs and advocacy groups have been working on educating farmers about IPM techniques to reduce reliance on chemical pesticides.

There is also a growing demand for more transparency and food safety certification systems, which could help improve confidence in the safety of cereals and other food products.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the findings of this study.

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