American Journal of Biomedical Science & Research

www.biomedgrid.com

ISSN: 2642-1747

Review Article

Review of Human Exposure Hazards and Health Risk Assessment of Microbial Pesticides

John Kanayochukwu Nduka[1,2*], Ogechi Irene Eboh Ajoku[1,3], Martin Osita Anagboso[4], and Daniel Omeodisemi Omokpariola[1,5]

[1]Environmental Chemistry and Toxicology Research Unit, Pure and Industrial Chemistry Department, Nnamdi Azikiwe University, P.M.B 5025, Awka, Anambra State, Nigeria

[2]Department of Industrial Chemistry, Madonna University Elele, Nigeria

[3]Department of Pure Chemistry, Kingsley Ozumba Mbadiwe University, Imo State, Nigeria

[4]Department of Microbiology, Madonna University Elele, Nigeria

[5]Department of Production and Technical, Office Chérifien des Phosphates (OCP) Africa Fertilizer Nigeria Limited, Abuja, Nigeria

***Corresponding author:** John Kanayochukwu Nduka, Environmental Chemistry and Toxicology Research Unit, Pure and Industrial Chemistry Department, Nnamdi Azikiwe University, P.M.B 5025, Awka, Anambra State, Nigeria.

To Cite This article: *John Kanayochukwu Nduka*, Ogechi Irene Eboh Ajoku, Martin Osita Anagboso, and Daniel Omeodisemi Omokpariola, Review of Human Exposure Hazards and Health Risk Assessment of Microbial Pesticides. Am J Biomed Sci & Res. 2026 29(5) AJBSR.MS.ID.003837,*

DOI: 10.34297/AJBSR.2026.29.003837

Received: December 15, 2025; **Published:** January 09, 2026

Abstract

This review thoroughly examines microbial pesticides and pesticide risks, emphasizing their roles, benefits, and associated hazards. Microbial pesticides, derived from naturally occurring microorganisms that may provide sustainable alternative to chemical pesticides directed to specified pests with minimal environmental impact. The review describes different types of microscopic pesticides, like (bacteria, fungi, and viruses), discussing their mechanisms of action, potency, and advantages over chemical pesticides. In contrast, chemical pesticides, while effective for pest control, results in a great deal of risks to human health and the environment when improperly managed. The review highlights the importance of proper risk assessment practices to reduce these hazards, focusing on pesticide negativity on public health - like acute and chronic poisoning symptoms and the environment, including impacts on non-target species and resistance development. By analyzing recent studies and data, the review offers insights into current practices and proposes improvements in risk management and regulatory frameworks to strengthen the safety and sustainability of pesticide use.

Keywords: Microbial pesticides, Risk assessment, Human health hazards, Environmental impact, Nigerian scenario

Introduction

Pesticides

Pesticides play a crucial role in modern agriculture, enhancing crop yield and quality by controlling pests that threaten food production and human health. A pest is any organism that competes with humans for food, nutrients, space, or other essential resources or poses a threat to human health [1,2]. Pests can transmit diseases and cause significant damage to agricultural and domestic settings. They encompass a wide range of organisms, including insects, fungi, bacteria, rodents, birds, nematodes, algae, and weeds, all of which can be problematic due to their activities that are either directly or indirectly detrimental to human interests. Pesticides, defined as chemical agents capable of destroying pests [3], are pivotal in managing these harmful organisms. They are utilized to reduce the population of pests to acceptable levels and can be either natural or synthetic. Pesticides are applied in various formulations and delivery systems to target specific pests, which has led to a broad categorization of these chemicals based on their target pests, such as insecticides for insects, fungicides (fungi), herbicides (weeds), and so on [4]. Moreover, pesticides include growth regulators, defoliants, desiccants, repellents, attractants, and chemo-sterilants, each serving distinct functions to control pest growth and reproduction [5]. The effectiveness of a pesticide hinges on its ability to be selective in toxicity - killing the target pest while being harmless to crops, humans, non-target animals, and beneficial organisms. Ideally, pesticides should be effective, safe, easy to apply, and cost-effective. However, achieving this ideal balance is challenging, as most pesticides come with inherent advantages and disadvantages. Various factors such as persistence, environmental impact, and the potential development of resistance among pest populations play critical roles in the overall assessment of a pesticide's suitability for use [6].

Classification of Pesticides

Pesticides are a diverse group of substances, and understanding their classifications is essential for comprehending their use, efficacy, and associated risks. Pesticides can be classified in several ways, including chemical structure, target organism, route of entry into the targeted pest, and hazard potential [5].

Chemical Classification: Chemical classification groups' pesticides based on common chemical structures, as the chemical classes of pesticides include organochlorines, organophosphates, carbamates, pyrethroids, and organosulfur compounds.

Organochlorines: or chlorinated hydrocarbons, are synthetic pesticides known for their persistence and lipophilic nature, leading to bio-concentration and bio-magnification [7]. These characteristics make them hazardous to the environment and human health. Although largely replaced by less persistent compounds in developed countries, organochlorines are still used in many developing countries due to their cost-effectiveness and broad-spectrum activity [8].

Common organochlorines include Dichloro Diphenyl Trichloroethane (DDT), lindane, and cyclodienes such as chlordane and aldrin as shown in (Figure 1).

Organophosphates: are derivatives of phosphoric acid and have become crucial in pest control due to their high potency and selectivity [9]. Unlike organochlorines, they are less persistent but highly toxic to vertebrates, including humans, due to their action as acetylcholinesterase inhibitors [10]. Examples include Malathion, diazinon, and chlorpyrifos as shown in (Figure 2).

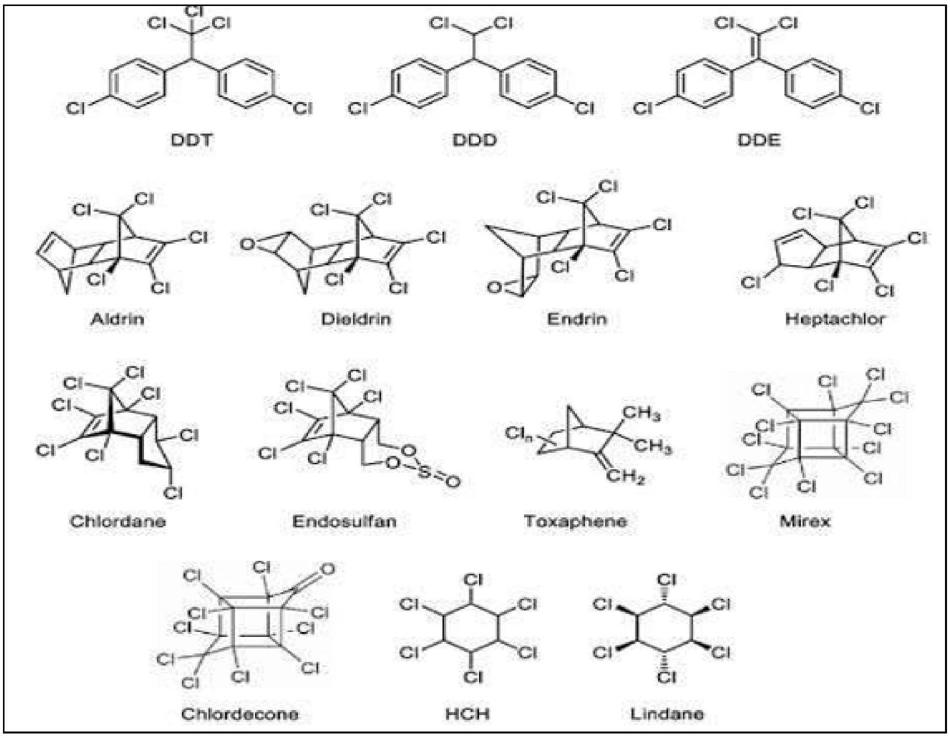

Figure 1: Structure of some organochlorine pesticides.

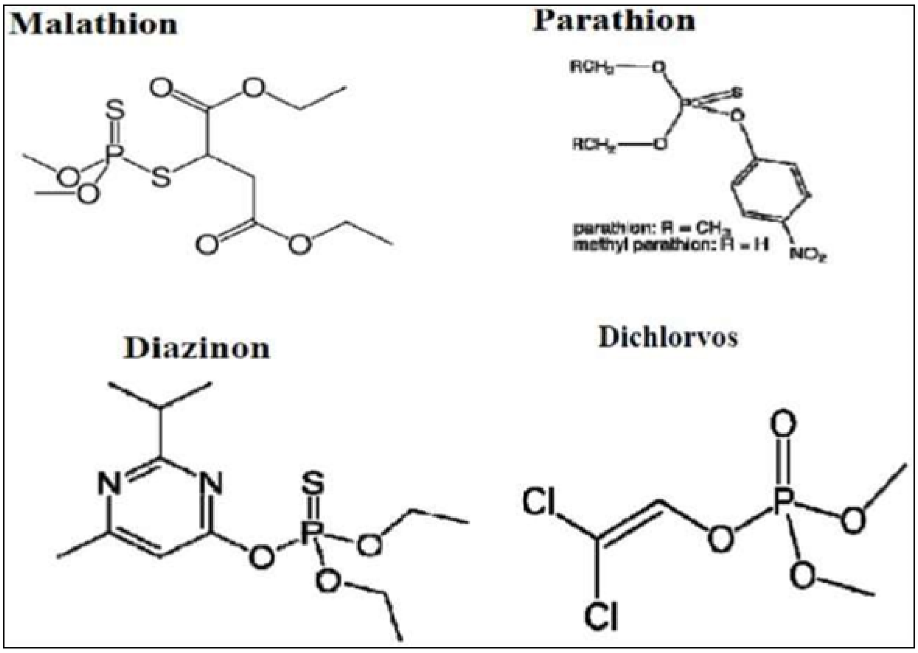

Figure 2: Structure of some organophosphate pesticides.

Carbamates: are N-substituted carbamic acid esters, known for inhibiting cholinesterase enzyme activity [10]. They offer the advantage of lower mammalian toxicity compared to organophosphates and are widely used as insecticides, fungicides, herbicides, and nematicides. Notable carbamates include carbofuran, carbaryl, methomyl, propoxur, and aldicarb.

Pyrethroids: are synthetic analogues of natural pyrethrins, known for their effectiveness against a broad range of insect pests at low concentrations. They exhibit low mammalian toxicity due to rapid metabolic degradation. Common pyrethroids include cypermethrin and deltamethrin [11].

Organosulphur Compounds: containing sulphur as a central atom, are primarily used as acaricides and fungicides. They vary in the mechanism of action and include groups such as dithiocarbamates and trichloromethylsulphenyl compounds. These compounds have historically been effective but are limited in use due to their high toxicity [12].

Classification Based on the Target Organism

This classification is based on the intended target of use [13]:

Fungicides: are pesticide agents used to control (powdery mildew, a form of fungal diseases) on tree plants and potato blight. They are from different chemical categories and are minimal in toxicity to humans in comparison to insecticides. Fungicides may likely be applied in farmlands as sprays on plants or as seed dressings while in storage houses. Regularly applied chemicals within this category include dithiocarbamates and fungicidal carbamates.

Herbicides: are compounds employed in controlling weeds, which are normally unwanted plants that interfere with human purposes [14]. Looking at agriculture and forestry, release of herbicides hinders crop plants from competition, while horticultural use is primarily for aesthetics. Weeds struggle for space, nutrients, light, and moisture with the plant of choice, reducing crop yield in quality and quantity. Most weeds are parasitic, obtaining nutrients and other requirements for survival from plant hosts. Herbicides are (the commonest applied agricultural pesticides utilized in advanced countries of the world), but in less developed countries, insecticides are more often utilized because of the prevalence of manual weed control methods like hoe weeding and hand pulling. Herbicides has a generally reduced toxic impact on humans than insecticides, and herbicide-resistant weeds are less common compared to insecticide resistance. Herbicides can negatively affect the growth of plant by interdicting cell division, elongation and enlargement, tissue and organ differentiation, seed germination, and seedling growth.

Insecticides: are a group of compounds employed in exterminating insect pests in agriculture, horticulture, or forestry management, or those that redistribute diseases like mosquito vectors of malaria, yellow fever, and encephalitis. Some insecticides act and behave as Insect Growth Regulators (IGRs) and Insect Development Inhibitors (IDIs), primarily affecting immature forms. IGRs mimic juvenile growth hormone, stopping insects from growth and developing into mature forms, and leading to death. IDIs retards the synthesis of chitin, necessary for forming the hard outside skin (cuticle) of insects, preventing the adult form from developing. This group of chemicals is widely used to combat fleas in pets (cats and dogs). Examples include fenoxycarb and diflubenzuron.

Rodenticides: these are chemicals originally formulated to control of mice and other rodents. This category of pesticides includes various chemicals utilized as baits, tracking powders, or fumigants. Baits are attracted to rodents which feed on them, tracking powders are spread along paths suspected to be rodents track and usually picked up by the fur as the animal passes by. Fumigants are mainly formulated to kill rodents in their burrows.

Acaricides: are types that kill mites, which are pests in agriculture and ticks which are well known vectors of diseases such as Lyme disease and typhus.

Molluscicides: are specific and used to eliminate snails and slugs in agriculture, gardens, and aquatic snails that are vectors of water borne diseases such as schistosomiasis.

Nematicides: are utilized to kill nematodes, which damages the roots of agricultural plants.

Degree of Hazard Based Classification

The group as ranked by World Health Organization (WHO), utilizes the lethal dose (LD50) is the quantum of health risks the populace are exposed to by pesticides compound [6]. LD50 is a value depicting the dose that will exterminate half the test population (typically rats) and normally measured in milligrams of pesticide per kilogram of body weight (mg/kg body weight). Pesticides are grouped into four hazard classes based on their toxicity as below (Table 1).

Reference from: WHO [6].

Table 1: Pesticides classification According to Degree of Hazard.

		LD_{50} (rat) in mg/kg Body Weight	
Class	**Description**	**Oral**	**Dermal**
Ia	Extremely Hazardous	< 5	< 50
Ib	Highly hazardous	5 – 50	50 – 200
II	Moderately hazardous	50 – 2000	200 – 2000
III	Slightly hazardous	> 2000	> 2000
U	Unlikely to present acute hazard	5000 or higher	

Classification Based on Nature

Toxicants (pesticides) may be grouped based on origin into natural pesticides, synthetic (manmade) pesticides, and biological pesticides [5,15,16]:

Typical Organic Pesticides: are pesticides which are extracted from trees, it include substances such as nicotine which exudes from tobacco (Nicotiana tabacum) usually utilized as insecticide, often in the form of nicotine sulphate. Pyrethrum, an intricate chemicals from chrysanthemums (*Chrysanthemum cineraria folium and C. coccinium*) used as an insecticide. Rotenone is extracted from tropical shrubs (*Derris elliptica and Lonchocarpus utilis*), used as an insecticide, rodenticide, or piscicide. Red Squill is gotten from the sea onion (*Scilla maritima*) and used as a rodenticide. Strychnine is extracted from the shrub Strychnos nux-vomica and used as a rodenticide.

Synthetic Pesticides: These are man-made pesticides and include various classes like Organomercurials (Methylmercury and phenylmercuric acetate). Phenols (Trichlorophenols, tetrachlorophenol, and pentachlorophenol) are regularly utilized as fungicides for wood preservation. Carbamates regarded to be moderate environmental persistence and highly toxic to arthropods, including insecticides like aminocarb, carbaryl, and carbofuran. Triazines, which finds use as herbicides and soil sterilants, with illustrations like atrazine, simazine, and hexazinone. Synthetic Pyrethroids (analogues of natural pyrethrum) are used as insecticides and acaricides with examples including cypermethrin, deltamethrin, permethrin, and tetramethrin.

Microbial (Biological) Pesticides: are a subcategory of pesticides, that utilize microorganisms in the form of bacteria, fungi, viruses, and protozoa to control the population of pest, since they are formulations of microbes which are pathogenic to specific pests and have a narrow spectrum of toxicity, including *Bacillus Thuringiensis* (Bt) applied to inhibit moths, flies, and beetles, Nuclear Polyhedrosis Virus (NPV) developed for specific insect pests, insect growth regulators utilized in pest control formulations, Genetically Modified Organisms (GMOs) are crops engineered to be resistant to certain pesticides or pests, including glyphosate-resistant soybean and canola, and Bt maize.

Formulation of Pesticide

Pesticides are not typically made use of used in their unadulterated or industrial grade forms due to the potential hazards they pose and the need for dilution [17,18]. Instead, they are formulated into various products to enhance their usability, safety, and effectiveness. Formulation involves processing active ingredients into forms that are easier to apply and handle, addressing factors like storage, application methods, and local conditions.

Dry Formulations

Dusts: These consist mainly of micro particles, normally in a size below 30µm in diameter. They can be used undiluted or mixed with inert diluents to form dilute dust. Undiluted dusts, like sulfur dust, are applied directly, whereas diluted dusts contain 0.5% to 10% active ingredients mixed with diluents such as kaolin or talc. Dust is advantageous in water-scarce regions since water is not a serious necessity in its application. But, they are less effective under adverse weather conditions, like high wind or rain, which can cause drift and deterioration. They are often used for specialized applications, such as seed treatments or grain storage.

Granules: Granules are larger particles designed for use with highly toxic pesticides, which are not suitable for spraying. The pesticide is impregnated with a carrier material, and the granules are intended to disintegrate upon contact with moisture, releasing the active ingredient. Granules reduce the risk of splash and skin contamination and allow for precise application. They are particularly useful for spot treatments and gradual delivery of active substances. Application can be done by hand or using equipment with metering devices.

Dry Baits: are group of eatable or unreactive materials mixed with pesticides and formed into pellets to attract pests. They are used against various types of pests such as locusts and rodents. However, dry bait can be consumed by non-target animals and may disintegrate in wet conditions. This limits their effectiveness and raises concerns about environmental contamination.

Dry Fumigants: This formulation involves compressing pesticides into a pill or balls that give out fumigant gases when exposed to moisture. Dry fumigants are utilized in prolonging the usefulness and safeguard of the stored grains from pests. They require an exposure period and are distributed throughout the grain mass. Examples include aluminum phosphide and methyl bromide.

Spray Formulations: These type are formulations prepared and applied on the target location only when in form of solutions (for water-soluble pesticides) or suspensions (for water-insoluble ones) [19-21]. These formulations include dispersible powders, emulsifiable concentrates, liquid concentrates, ultra-low volume, pressure packs, fogs, and smokes, each suited to specific application needs. The choice of formulation depends on various factors, including the type of pesticide, application method, and environmental conditions:

Dispersible Powders: These powders are finely divided and dissolve in water to form a homogeneous suspension. They may contain up to 50% active ingredients. Wetting agents are added so as to stabilize the suspension, especially for water-insoluble pesticides. Dispersible substances recognized as powders which are wettable or dissolvable powders. They can be kneaded into compactible, but dispersible grains to prevent puffing during application.

Emulsifiable Concentrates (EC): These formulations contains pesticide made into a solution with a solvent by adding emulsifier to create a stable oil-in-water emulsion. Typically containing about 25% of active ingredients, ECs are designed for uniform dispersion in water. While oil-inwater emulsions are common, water-in-oil emulsions are less frequent due to their viscosity and specialized application equipment requirements.

Liquid Concentrates: These are pure pesticides that breakdown in none heavy mineral oils, for utilization as aerosols in fogging devices. Their strength can be reduced with water and may be encapsulated in gelatine microcapsules for co**ntrolled release and reduced exposure to non-target organisms.**

Ultra-Low Volume (ULV) Formulations: are made to produce very fine droplets, ULV formulations use suitable solvents to achieve effective coverage over large areas. They are particularly useful for broad applications and are dispensed through specialized nozzles.

Review Methodology

Our curiosity emanated from the work of Unachcukwu and Agomuo [22] the work was a cross sectional review of medical admissions in University of Port-Harcourt Teaching Hospital, Nigeria. The work x-rayed the alarming high levels of non-communicable diseases like kidney diseases, liver impairment, cancers, cardiovascular issues, blood effect, it linked the outcome to environmental pollutant (heavy metals, pesticides, organochlorine compounds, polychlorinated biphenyl, Polyaromatic Hydrocarborns (PAHs), glyphosate etc) exposure. A good example, cadmium has no bodily beneficial function, but it acts an endocrine disruptor, inhibiting reproduction, destroys spermatogenesis, plays prominent effect in androgen and estrogen receptors, cognitive reduction, causes testicular toxicity and infertility and prostrate issues in men [23-25]. The more worrisome scenario is that several literatures abound that shows increased detectable levels of these pollutants in foods, water, air and several environmental matrices largely consumed by the populace. In addition to textbook consultation, we employed online literature search by visiting PubMed, Scopus, Google Scholar and other online search engines that can be beneficial and serve our purpose [26,27].

Microbial Pesticides

Microbial pesticides represent a significant advancement in pest control, which makes room for providing a more environmentally benign and targeted approach in comparison to synthetic chemical pesticides [10, 15]. Microbial pesticides evolve from microorganisms such as bacteria, fungi, viruses, protozoa, and nematodes. But for chemical pesticides, it has a broad-spectrum impact and equally cause detrimental risks to non-target organisms, microbial pesticides offer a more precise and sustainable method of pest control. They address many of the drawbacks associated with synthetic pesticides, including environmental persistence, health impacts, and pest resistance [28,29].

Classes of Microbial Pesticides

They include:

Pathogenic Fungi: are among the most extensively used microbial pesticides. They operate by infecting insects through their cuticle and subsequently causing death through nutrient depletion and toxin production [30]. The mechanism of action is fungi penetrate the insect's cuticle, access the hemolymph, and utilize the nutrients therein. They produce toxins and enzymes that break down the insect's tissues, ultimately leading to the insect's death. This mode of action does not require ingestion of fungal spores, which differentiates them from other types of microbial pesticides. Some common examples include *Beauveria bassiana* used against various pests including aphids, whiteflies, and weevils in addition to thrips and beetle infestations; *Metarhizium anisopliae* is known for its effectiveness against mosquitoes like *Aedes aegypti* and *Aedes albopictus*, significantly reducing their lifespan and reproduction [29] I. is used to control soil-borne pathogens that cause root rot and other diseases in crops like chickpeas and groundnuts. These fungi are typically applied as conidia or mycelium, which then sporulates after application. They can be used alone or in combination with chemical pesticides to manage resistance [19].

Viral Pesticides: utilize viruses to target specific insect pests. Baculoviruses are a prominent example, infecting insects and leading to their death through a complex lifecycle. The mechanism of action is that viruses like baculoviruses infect the insect's midgut cells after ingestion. The alkaline conditions in the insect's gut dissolve the virus's protein coat, releasing viral particles that replicate and eventually kill the host [2016]. These are highly specific to certain insect species, such as the *Nucleopolyhedrovirus* (NPV) used against caterpillars, which are effective but expensive and may degrade under UV light, limiting their field efficacy [20]. Baculoviruses are often encapsulated by UV protectants to extend their field life, despite their efficacy, their slow action and specificity limit their use in diverse pest management scenarios [31].

Protozoan Pathogens: infect a range of insect hosts and are known for their chronic effects rather than immediate mortality, often leading to reduced fecundity and prolonged debilitating effects. These pathogens play a role in natural pest population control but are less frequently developed into commercial products due to limited effectiveness [32]. Protozoa are less common in commercial pesticide formulations, primarily due to their slow action and the challenges in their mass production.

Bacteria Biopesticides: are one of the most widely studied and commercially used forms of microbial pesticides. They are particularly effective against insects. Bacteria like *Bacillus thuringiensis* (Bt) produce toxins that, when ingested by insects, disrupt their digestive system, leading to death. Bt produces delta-endotoxins that are specific to certain insect groups [29] and effective against lepidopteran larvae, such as those of moths and butterflies. Variants of Bt, like *Bt kurstaki* and *Bt israelensis*, target different pests including mosquitoes and cabbage worms. *Bacillus subtilis* and *Pseudomonas fluorescens* are used for their antagonistic properties against various plant pathogens. These pesticide products are used extensively in agriculture to manage pests like cabbage worms and potato beetles. However, their effectiveness can be limited by rapid degradation in sunlight, heat and their short activity period.

Good Effects of Microbial Pesticides

Microbial pesticides gives a host of useful application, including environmental safety, target specificity, compatibility with other control methods, and sustainability. Their ability to provide calculated pest management while diminishing unwanted impacts on non-target organisms and the environment makes them an essential tool in modern pest management [13,15]. Due to extended innovation, research and advanced findings, the potential benefits of microbial pesticides are expected to grow, offering even more opportunities for sustainable and effective pest management solutions, which include:

Environmental Safety: Microbial pesticides are celebrated for their minimal environmental impact. Unlike chemical pesticides, with the ability to resist degradation in soil and affect nontarget species, microbial pesticides decompose rapidly and do not leave or deposit harmful residues. The rapid decomposition minimizes the risk of long-term contamination of soil and water resources, making microbial pesticides an environmentally benign option. Microbial pesticides, derived from natural organisms that decompose into non-toxic by-products, as property, ensure that they do not add to the build-up of persistent toxicants in the environment because they break down quickly, microbial pesticides reduce the risk of water and soil pollution compared to synthetic chemicals, which can leach into groundwater and persist in ecosystems.

Target Specificity: An important but enduring benefits of non-synthetic pesticides is their high specificity. They are generally effective only against particular pests or groups of pests, leaving other organisms largely unaffected. This selectivity helps preserve beneficial insects, pollinators, and other non-target species in the ecosystem. Microbial pesticides specifically target pest species, reducing harm to useful bugs like pollinators (bees) and natural predators (ladybugs) that help control pest community. This is due to their specific action; microbial pesticides may not likely cause resistant development in the microbes as against broad-spectrum chemical pesticides.

Compatibility with other Control Methods: Microbial pesticides effectively fits into and can be in-cooperated into wider and embracing pest management strategies, in addition to the application of chemical pesticides, without significant interactions.

The compatibility makes room for flexible and sustainable model to pest control. Microbial pesticides can be used in conjunction with a variety of pest control methods, such as chemical pesticides, native ideas, and bio-agents regulation, to enhance overall pest management. When combined with certain chemical pesticides, microbial pesticides may enhance overall effectiveness by targeting different aspects of the pest's life cycle or through complementary modes of action.

Harvest Flexibility: Microbial pesticides finds useful utilization close to the harvest time. This flexibility brings about minimization of the time between application and harvest, allowing farmers to manage pests effectively without compromising food safety. The safety profile of microbial pesticides enables their use in environments where conventional pesticides might not be suitable due to residue concerns. Farmers can apply microbial pesticides right up to the harvest period, facilitating better control of late-season pests.

Sustainable Pest Control: Microbial pesticides often provide sustainable pest management solutions by promoting natural pest control processes and reducing reliance on chemical inputs. Their ability to persist in the environment and their potential to reproduce can lead to ongoing pest control effects. Some microbial pesticides can establish populations in the environment or on plants, providing extended control over multiple pest generations. By targeting specific pests and promoting beneficial microorganisms, microbial pesticides help maintain ecological balance and support natural pest control mechanisms.

Enhancement of Plant Growth: Certain microbial pesticides not only control pests but also contribute to plant health and growth. They can enhance soil quality and stimulate plant growth through interactions with beneficial soil microorganisms. Some microbial pesticides promote the growth of beneficial soil bacteria and fungi, which can improve nutrient availability and soil structure. By enhancing soil health and plant resilience, microbial pesticides can contribute to increased crop yields and better overall plant performance.

Low Environmental Exposure: Microbial pesticides often require application in smaller quantities compared to chemical pesticides, and their rapid degradation means that they are less likely to persist in the environment and cause long-term exposure risks. This is due to their effectiveness in small amounts, microbial pesticides often require less frequent application, reducing the overall quantity of pesticide introduced into the environment and minimizing entry into food chain. The biodegradable nature of microbial pesticides decreases the risk of runoff into waterways, minimizing potential water contamination.

Potential for Natural Pest Control: Microbial pesticides leverage natural processes to control pests, providing a more ecological approach to pest management. Their use can support the development of natural pest control agents and help build resilient pest management systems. The use of microbial pesticides can support beneficial microorganisms that contribute to natural pest control and plant health. By relying on natural processes and organisms, microbial pesticides reduce the need for synthetic chemicals and contribute to more sustainable agricultural practices.

Demerits of Microbial Pesticides

While microbial pesticides offer significant benefits, they also present challenges that must be addressed for successful implementation. Their limited spectrum of activity, providing targeted, environmentally friendly pest control solutions, specialized application requirements, and higher costs are some of the key demerits [2,33]. However, with ongoing research and development, many of these issues can be mitigated, leading to more effective and widespread use of microbial pesticides in integrated pest management strategies, which are:

a. Limited Spectrum of Activity: Microbial pesticides are often specific to certain pests or groups of pests, which limits their effectiveness in managing a broad range of pest problems. This specificity can be both an advantage and a limitation. Each microbial pesticide typically targets only a particular pest or group of pests. This means that if a field or crop is infested with multiple pest species, a single microbial pesticide may not be sufficient for comprehensive pest control. Narrow spectrum of activity, the market for some microbial pesticides may be limited leading to higher costs and reduced availability for users.

b. Environmental Sensitivity: Microbial pesticides can be sensitive to environmental conditions, which may affect their efficacy and stability. Some factors such as temperature, humidity, and UV exposure can impact their performance. Many microbial pesticides are sensitive to high temperatures and dry conditions, which can reduce their effectiveness. Exposure to Ultraviolet (UV) radiation from sunlight can degrade some microbial pesticides, leading to reduced effectiveness.

c. Specialized Application Requirements: Microbial pesticides often require specific application methods and conditions to be effective. This can complicate their use compared to more straightforward chemical pesticides. Some microbial pesticides require specialized application equipment to ensure distribution and effective contact with pests, and can involve additional costs and training for users. Proper storage conditions, such as refrigeration or protection from extreme temperatures, may be necessary to maintain the viability of microbial pesticides. Hence can add to the logistical challenges and costs.

d. Slow Action and Limited Efficacy: The action of microbial pesticides can be slower compared to chemical pesticides, and their effectiveness may vary under different conditions. The time required for microbial pesticides to kill pests can be longer than that of chemical pesticides. This delayed action may not be suitable for rapidly changing pest situations. The effectiveness of microbial pesticides can vary based on factors such as pest species, environmental conditions, and application methods. This variability can make it challenging to achieve consistent pest control.

e. Higher Costs and Limited Availability: Microbial pesticides can be more expensive to develop and produce than chemical pesticides, leading to higher costs for users. Their availability can also be limited in some regions. The research, development, and production of microbial pesticides can be costly, which may be reflected in the price for end-users. The availability of microbial pesticides may be restricted in certain areas, particularly in regions where the infrastructure for production, distribution and application is underdeveloped.

f. Short Shelf Life: Many microbial pesticides have a relatively short shelf life compared to chemical pesticides, which can affect their storage and usability. The viability of microbial pesticides can decline over time, especially if not stored under optimal conditions. This can lead to reduced effectiveness and waste if products are not used within their effective period.

g. Potential for Resistance Development: Although less common than with chemical pesticides, resistance to microbial pesticides can still develop in target pest populations. The potential for resistance requires careful management practices, including rotating different types of microbial and chemical pesticides and integrating other pest control strategies to delay or prevent resistance development.

h. Limited Understanding and Adoption: The understanding and adoption of microbial pesticides may be limited due to a lack of familiarity or experience among farmers and pest management professionals. Farmers and pest managers may need additional education and training to effectively use and integrate microbial pesticides into their pest management programs. There may be resistance to adopting new pest control methods due to traditional practices or skepticism about the efficacy of microbial pesticides.

Pesticides Risks and Assessment

Hazards assessment of pesticides is a critical process that involves evaluating the level of harmful impacts of pesticides on public health and the environment. This process compares toxicity information with the amount of pesticide an organism may be exposed to within the surrounding. The USA EPA [34] developed risk assessments model used to assess the possible risks accompanying pesticide application and if possible changes can be of usage and whether any changes for environmental protection and public health [35,36].

Human Health Risk Assessments

Exposure assessment risk status to humans' estimates the nature and the likelihood of hazardous health effects in people exposed to pesticides through various means, such as food, water, air, occupational exposure, or contact with pesticide residues [37,38]. The process involves four key steps:

Hazard Identification (Toxicity): Looking at this initial step, the capability inherent in pesticides to cause distress to the populace is examined, which involves studying the potential health effects and identifying the circumstances under which these effects occur. Researchers look at data from laboratory studies, clinical observations, and epidemiological studies to determine the pesticide's toxic properties. This step answers the question: Can pesticide cause adverse health effects, and under what conditions?

Dose-Response Assessment: looks at what connects the amount of pesticide exposure and the harshness of the toxic actions. This step determines the levels at which harmful actions are taken note of in testing animals and translates these findings to potential human exposures. The principle of dose-response is encapsulated in the famous saying by Paracelsus, the inventor of advancement in today's modern toxicology: "The quantity determines the toxic effect". Meaning that even substances typically considered safe can be harmful at high enough doses, and conversely, toxic substances may be safe at very low or diluted doses.

Exposure Assessment: evaluates the extent, duration, and frequency of human contact with a pesticide. It examines various pathways through which people might be exposed to pesticides, including Dietary exposure; the residue of pesticides which may be present on or inside the foods we eat, as most crops are treated with pesticides. Pesticides applied on farmland to can be drained down into the groundwater or as run-off into surface water, thereby polluting drinking water supplies. Occupational exposure: People who work with or around pesticides, such as applicators, farmers, and agricultural workers, can be exposed during their jobs.

Risk Characterization: this is the last stage final step, adding up data from the other three stages (hazard identification, dose-response assessment and exposure assessment), to describe an overall risk posed by a pesticide (WHO, 2010) [8]. This step synthesizes all data to conclude the description and the degree of pesticide risk exposure, considering both toxicity and exposure levels.

Risk Equation: This involves a risk equation, a known risks to human health when subjects are exposed to pesticide, this is a function of both the toxicity of the pesticide and the likelihood of exposure. The basic risk equation can be expressed as:

$$Risk = Toxicity \times Exposure$$

The above equation implies that both toxicity and exposure must be present for there to be a risk. For instance, a highly toxic pesticide poses no risk if there is no exposure, while extensive vulnerability of harmless substances that poses no risk. Typically, nonetheless, pesticide use involves some degree of both toxicity and exposure, creating potential risks that must be assessed and managed.

Toxicological Reference Values: To take into account the negative effects of pesticide exposure, toxicological reference values such as the minimal Daily Acceptable Intake (ADI) and the Acute Reference Dose (ARfD) are used. ADI is the maximum value of a given pesticide which is consumed daily over a person's lifetime without significant health risks, it is given in milligrams of pesticide per kilogram of body weight, while the ARfD is an estimate of the maximum amount of pesticide that can be consumed within 24 hours without significant health risks. Comparable the ADI, the ARfD is based on all available data and is given in milligrams of pesticide for a known kilogram of body weight.

Exposure of Pesticides to Humans

Widely applied Pesticides are utilized across various sectors, leading to human exposure through multiple pathways [6]. The extent of effect of health problem is dependent on the type, route, and source of pesticide exposure.

Types of Human Exposure

Population contact with the pesticides may be subdivided into three main types: acute exposure occurs when a subject is in contact with a substantial amount of pesticides at once, resulting in immediate toxic effects, typically within 24 hours leading to severe health consequences, including death; sub-acute exposure involves continuous exposure at moderate levels of pesticides over a period ranging from a week to a year, as the toxic effects manifest after a delayed period, which can complicate diagnosis and treatment; and chronic exposure that results from prolonged exposure to small doses of pesticides over an extended period, often more than a year. The symptoms of toxicity appear much later and can be insidious, making long-term health monitoring essential.

Routes of Entry

Pesticides can enter the human body through four primary routes: oral (by mouth), dermal (through the skin) and inhalation (by respiration), which depends on the source of contact with pesticides in addition to unique risks and mechanisms for pesticide absorption and toxicity [6,39].

a. Inhalation is a significant route of exposure to many pesticides in the form of vapors, gases, mists, or particulates. Upon inhalation, pesticides may be exhaled or deposited in the respiratory tract. If deposited, they can damage respiratory tissues or diffuse into the bloodstream through the lung-blood interface. The lungs' extensive blood supply, designed for oxygen absorption, can also facilitate the uptake of toxic chemicals, potentially leading to serious injury or death due to impaired oxygen absorption. Once in the blood, these chemicals are distributed to organs sensitive to pesticide, causing health effects.

b. The skin, being the largest organ of the body, plays a critical role in protecting against environmental hazards. However, some pesticides can penetrate the skin and enter the bloodstream, leading to systemic damage to internal organs. Severe effects may include tissue destruction or other debilitating conditions. Eyes are particularly vulnerable to chemical exposure, and even brief contact can cause significant damage. Pesticides can be absorbed through the eyes and transported throughout the body, causing harmful effects.

c. Pesticides ingested through the mouth may not harm the gastrointestinal tract unless they are irritating or corrosive. Insoluble pesticides are typically excreted, while soluble ones are absorbed through the gastrointestinal lining and transported via blood to internal organs, where they can cause damage. Ingestion can also occur through contaminated food and drinking water, highlighting the importance of unpolluted water and safe food supplies.

d. Injection: Although less common, pesticides can enter the body through injection if the skin is punctured by contaminated objects. This route allows pesticides to be directly introduced into the bloodstream, leading to systemic distribution and potential damage to target organs. Once absorbed, pesticides undergo one of three processes: metabolism, storage, or excretion. Metabolism involves the chemical transformation of pesticides in the body. Some chemicals may be stored in specific organs, reducing metabolism and increasing persistence in the body [39]. Excretion mechanisms, including exhalation, perspiration, urination, defecation, or detoxification, eliminate chemicals over time. Elimination rates vary, with some chemicals persisting for a lifetime and causing long-term effects.

Human Exposure Sources

Exposure of pesticides to the human populace may not be deliberate or on purpose, with various sources contributing to these exposures [37,38]. Contacting pesticides spontaneously is the commonest means of exposure and includes workplace, non-workplace, and by chance or accidental sources (Fig 3):

Occupational Exposure: Workers in the pesticide industry, such as those within the production line, compounding, and branding, face significant exposure risks. Farmers and agricultural workers whose duties entails pesticides application to crops are exposed subjects with high risk factor, especially if they use leaking or inappropriate equipment or do not wear safety kits. Public and community health personnel that engage in spraying pesticides within living in or manufacturing concerns are equally exposed. Occupational susceptibility can take place through dermal route and inhalation and likely in critical level, sub-acute, or chronic, based on the level and extent of exposure and intensity.

Non-Occupational Exposure: The general public are open to contact with pesticides by consuming treated or toxicant prone agricultural products. Reports have indicated that vegetables and fruits in Nigeria contain organochlorine and organophosphate pesticides, sometimes exceeding maximum residual limits [40]. Processed foods can also contain pesticide residues from contaminated raw materials or water used during processing. Consumable supplies of water can possibly be contaminant laden by runoff emanating from nearby agro fields, especially after excessive pesticide application or adverse weather conditions. Improper use of pesticide containers for storing food or water can lead to oral exposure, often chronic due to the consumption of small doses over time. Inhalation of contaminated air during home pesticide use or public health programs also poses a risk, with respiratory or dermal exposure routes.

Accidental Exposure: occurs unintentionally, both occupationally and non-occupationally, often involving high pesticide doses. This can happen only if pesticides are kept in a container without labelling or within children's contact, leading to accidental ingestion. Seeds treated with pesticides might be mistakenly consumed, and spills from improperly packaged pesticides can result in significant exposure. None use of safety coverall at the point of pesticide usage and faulty equipment can also lead to accidental exposure. All three routes of entry (oral, dermal, and respiratory) may be involved, with acute or sub-acute exposure.

When Exposure Is Intentional: Actually less common, intentional contact with pesticides occurs primarily in cases of suicide or homicide (Figure 3). This type of exposure is typically oral, although inhalation can also be a route. Intentional exposure usually results in acute poisoning or death. In some cases, dermal exposure may occur when chemicals are poured on victims to cause chemical burns (Figure 3).

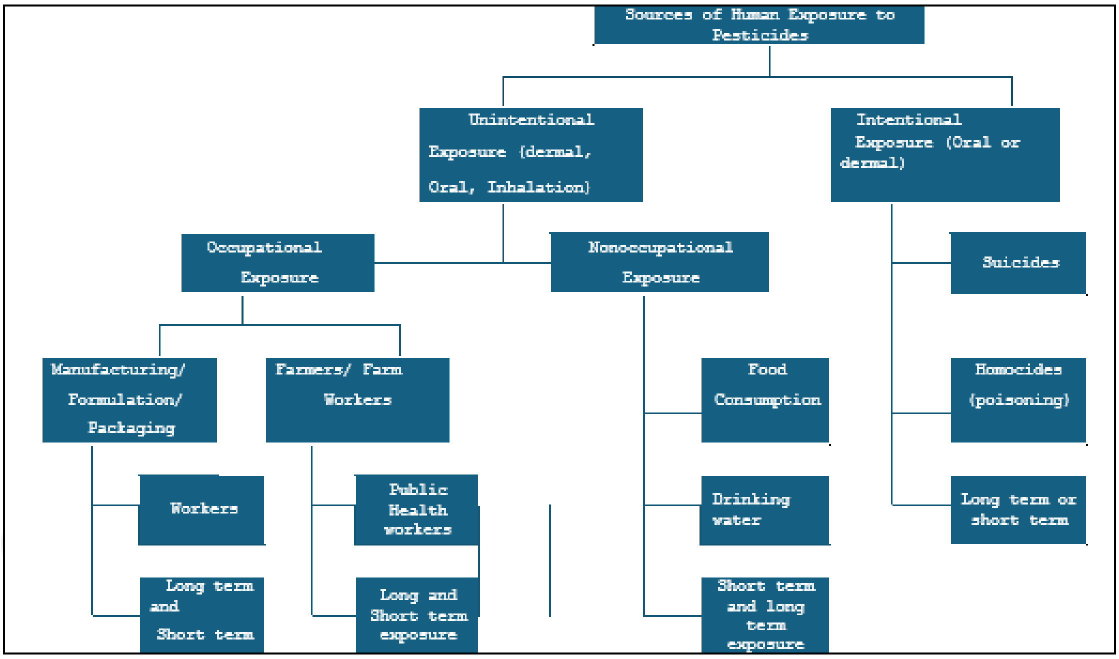

Figure 3: Summary of Sources of Human Exposure to Pesticides.

Assessment of Human Exposure to Pesticides

Human exposure to pesticides can be potential or actual, while assessing these exposures involves different methodologies to determine pesticide levels in the environment and human tissues [41]. Potential exposure is estimated through environmental monitoring, which measures pesticide residues in air, food, water, and soil. These values are compared to WHO guidelines. Several factors influence the extent of pesticide residues entering the human body, which are:

a. Chemical Nature: Stable pesticides resist degradation, leading to higher residue levels in human tissues.

b. Climatic Conditions: High temperatures and humidity can degrade some pesticides, reducing exposure risk.

c. Education and Awareness: Knowledge of safer pesticides and Good Agricultural Practices (GAP) reduces residue levels in food.

d. Processing: Washing and cooking can reduce surface residues and break down thermally unstable pesticides, lowering residue levels in consumed food.

Tables 2 and 3 give the ecological and health risk assessment template in assessing microbial pesticides from identification to vulnerability and effect evaluation to risk analysis and control measures to documentation and communication in addition to monitoring and evaluation. Regular analysis of environmental and health sources is pivotal in to adducing that Maximum Residue Limits (MRLs) instituted by the control organs are not superseded. MRLs represent the highest acceptable pesticide residue levels on food commodities, ensuring consumer safety. Definite vulnerability is quantified via bio-surveillance of human organelles, subcellular structure and body fluids like fat, serum, urine, blood, breast milk, skin, or hair. This involves analyzing samples for pesticide residues and calculating daily intakes. These intakes are compared to tolerable daily intakes (ADIs) established by FAO/WHO [41], representing the safe daily intake level of a pesticide over a lifetime (Table 2,3).

Table 1: Pesticides classification According to Degree of Hazard.

		LD_{50} (rat) in mg/kg Body Weight	
Class	**Description**	**Oral**	**Dermal**
Ia	Extremely Hazardous	< 5	< 50
Ib	Highly hazardous	5 – 50	50 – 200
II	Moderately hazardous	50 – 2000	200 – 2000
III	Slightly hazardous	> 2000	> 2000
U	Unlikely to present acute hazard	5000 or higher	

Table 2: Environmental risk assessment template for microbial pesticides.

S/N	Risk Indices	Factor	Assessment and Questionnaires
1	Identification of Pesticide Characteristics	Microbial Agent	Determine the specific microorganism used (bacteria, fungi, viruses).
		Mode of Action	Understand how microbial pesticide affects target pests and potential non-target organisms.
		Formulation and Application	Document the concentration, application methods, and persistence in the environment.
2	Exposure Assessment	Environmental Distribution	Assess how microbial pesticide disperses in different environments (soil, water, air). Consider factors such as volatility, solubility, and degradation rate.
		Application Rates and Frequency	Evaluate the amount and frequency of application and its potential impact on the environment.
		Transport Pathways	Identify how the pesticide may move through the environment, including runoff, leaching, or drift.
3	Effect Assessment	Target Organisms	Evaluating proficiency of contagious pesticide against the target pests.
		Non-target Organisms	Assess potential Impacts on non-specific organisms, and beneficial insects, plants, animals, and microorganisms. Include laboratory and field studies to gauge impacts.
		Ecosystem Impact	Analyze how microbial pesticide might affect ecosystem role, in the form of biogeochemical cycle, soil health and biodiversity.
4	Risk Characterization	Risk Calculation	Combine exposure and finding data to estimate the potential threat to non-specific organisms and ecosystems. Use risk quotients to compare exposure levels with toxicological thresholds.
		Uncertainty Analysis	Identify and assess uncertainties in the risk assessment process, such as variability in environmental conditions or gaps in data.
5	Mitigation and Management Measures	Risk Reduction Strategies	Develop strategies to minimize potential risks, such as modifying application methods, using lower doses, or implementing buffer zones.
		Monitoring Programs	Establish monitoring programs to track the environmental impact of microbial pesticide and verify the effectiveness of mitigation measures.
		Regulatory Compliance	Ensure that microbial pesticide complies with relevant environmental regulations and guidelines.
6	Documentation and Communication	Report Findings	Document the results of the risk assessment, including methodologies, data analysis, and risk characterization.
		Stakeholder Engagement	Communicate findings to stakeholders, including regulators, farmers, and the public, to ensure informed decision-making and promote transparency.
7	Monitoring and Evaluation	Post Application Monitoring	Continuously monitor the environmental impact of microbial pesticide after application to detect any unforeseen effects.
		Adaptive Management	Adjust management practices based on monitoring results and new scientific data to address any emerging risks.

Table 3: Health Risk Assessment Template for Microbial Pesticides.

S/N	Risk Indices	Factors	Assessment and Questionnaires
1	Identification of Microbial Pesticide Characteristics Mode of Action Formulation and Application	Microbial Agent	Identify the microorganism (e.g., bacteria, fungi, viruses) used as a pesticide.
		Understand how microbial pesticide affects pests and potential health risks to humans and animals.	
		Document the pesticide's formulation, concentration, and methods of application, including any potential exposure routes.	
2	Exposure Assessment Exposure Levels Duration and Frequency	Routes of Exposure	Assess potential routes of exposure to humans, including inhalation, ingestion, and dermal contact such as direct application, drift, or residues on crops.
		Estimate the concentration of the microbial pesticide in different environments (air, water, soil) and how this may affect human exposure.	
		Evaluate the frequency and duration of exposure through direct application or consumption of treated crops.	
3	Effect Assessment Human Health Effects Population Sensitivity	Toxicity Data	Review available toxicity data for the microbial pesticide, including acute, sub chronic, and chronic studies such as infectious potential, allergenicity, or pathogenicity.
		Identify potential health effects based on the microbial agent's properties such as allergic reactions, infections, or other diseases	
		Assess potential risks to vulnerable populations, including children, elderly individuals, pregnant women, and those with pre-existing health conditions.	
4	Risk Characterization Uncertainty Analysis	Risk Estimation	Combine exposure and effect data to estimate the potential health risks associated with microbial pesticide. Calculate risk estimates using exposure levels and toxicity data to determine risk quotients or safety margins.
		Identify uncertainties in the risk assessment process, such as gaps in data or variability in individual susceptibility. Address these uncertainties to refine risk estimates.	
5	Mitigation and Management Measures Regulatory Measures Emergency Response Plans	Risk Reduction Strategies	Develop strategies to minimize health risks, such as using appropriate protective equipment, implementing safety guidelines, and controlling application methods.
		Ensure the microbial pesticide complies with health and safety regulations and guidelines. Review and adhere to recommended safety practices and application limits.	
		Establish plans for responding to accidental exposures or adverse health effects, including medical treatment protocols and reporting procedures.	
6	Documentation and Communication Stakeholder Communication	Report Findings	Document the results of the health risk assessment, including methodologies, data analysis, risk characterization, and management recommendations.
		Share findings with relevant stakeholders, including regulatory agencies, workers, and the public, to ensure informed decisions and promote transparency.	

7	Monitoring and Evaluation	Health Monitoring	Implement monitoring programs to track potential health effects in populations exposed to microbial pesticide. Collect data on adverse health outcomes and adjust risk management practices as needed.
	Continuous Review	Regularly review and update the health risk assessment based on new research, emerging health data, and changes in pesticide use practices.	

Ways to Reduce Human Exposure to Pesticides

Reducing human exposure to pesticides requires attention to various sources and precautionary measures, including:

a. Packaging, Storage, and Transportation: Proper packaging, labelling, and storage of pesticides are essential to prevent leakage, spillage, and accidental exposure as recommended through the Global Harmonized System of Classification and Labelling of Chemicals (GHS) by the UN Economic Commission for Europe [42]. Labels should provide comprehensive information, including product names, active ingredients, usage instructions, toxicity, and safety precautions. As a safety precaution, pesticides are normally kept away from the reach of children and consumables and transported with care to avoid contamination

b. Education for Users: Consumers should be trained on safe pesticide use, including appropriate application methods, employing safety clothes and kits, and proper disposal of containers and unused stock [43,44]. Good Agricultural Practices (GAP) should be observed to minimize residues in crops and food.

c. Use of other Pest Management System: Other pest management system, such as biological control, natural predators, pheromones, and pest-resistant crops, can reduce pesticide use and human exposure.

Benefits of Pesticides to Humans

Pesticides offer significant benefits to human health and the economy [45] when used responsibly, as they increase agricultural yield and food redistribution by safe keep from pests, increasing food production; pesticides control disease causative agents, inhibiting disorder and death from vectorborne diseases; pesticides control ecto-parasites in pets and farm animals, improving animal product quality and quantity; Pesticides control weeds, reducing manual or mechanical labour and increasing crop harvest; pesticides destroy seaweeds that clog waterways, facilitating ship movement; pesticides preserve materials such as wood and cotton; pesticides maintain the health and appearance of lawns, gardens, and beauty trees.

Hazards of Pesticide Use

Despite extensive usefulness in agriculture and pest control, pesticides are inherently hazardous and results in quantified risk to public health and surrounding [46]. Therefore the negative effects masks the benefits when pesticides are wrongly applied or made use of by none professionals. The possible toxic effect associated with pesticide use include adversity to public health and environment.

Effects on Human Health

Pesticides, are compounded to inhibit and possibly kill organisms (animals and plants), they are by nature detrimental to humans and other animals, and hence consumption of agricultural produce subjected to pesticides treatment, mainly fruits and vegetables which may be properly washed, can lead to health hazards. The work of Akinloye et al. [47], revealed substantial paraquat residues presence in daily consumed vegetables in Abeokuta, Nigeria. Organophosphate toxicity was reported in a child in Uyo, Nigeria, this was evidence of accidental childhood poisoning [48]. The detrimental and negative effects of pesticides differs according to their chemical class and mechanism of action.

a. Organophosphates and Carbamates: are compounds that decelerate the function of the enzyme Acetylcholinesterase (AChE), bringing about continuous accumulation of acetylcholine (ACh) at neuromuscular junctions, resulting in muscle twitching and eventual paralysis [47]. It is these type of pesticides that cause acute and embedded neurotoxic effects in mammals due to the resemblance that exist between mammalian and insect circulatory systems.

b. Organochlorines: These disrupts the stability of Na^+ and K^+ inside neurons, inhibiting usual nerve impulse transmission. Chronic predisposition is expected to cause adverse neurological effects and behavioral changes [6].

Pesticides, such as xenobiotics, can affect well and outstanding organs of the body like liver, interacting with enzymes like the cytochrome P-450 class. Organochlorines can cause combined function oxidases in liver microsomes, while dithiocarbamates can inhibit them, altering the metabolism of various compounds. Pesticides can also interface with dietetical nitrites to form potentially carcinogenic nitrosamines. Multiple pesticides may interact synergistically or antagonistically in the body, affecting toxicity levels. Some pesticides are known endocrine disruptors, interfering with human growth and reproduction [49].

Human Exposure to Pesticides Due to Acute or Chronic Poisoning

a. Acute Poisoning: This occurs under a day of vulnerability to high concentration of pesticides, through consumption of contaminated food or accidental exposure. Symptoms can include dizziness, headaches, vomiting, respiratory tract irritation, and organ damage. The severity rests on pesticides type, extent of vulnerability, and route of entry. The factors increasing acute poisoning risk include improper packaging, damaged labels, and failure to observe safety waiting periods. WHO/FAO [8], estimated that over a 1,000.000 cases of severe pesticide toxicity occur yearly with a fatality rate of 0.4-1.9%.

b. Chronic Poisoning: Emanates from prolonged vulnerability to reduced value of pesticides through food, water, and air. Chronic exposure can lead to carcinogenic, mutagenic, and teratogenic effects, infertility, immunological disorders, and organ damage. Ojo [50], noted that organic metal-based pesticides could cause developmental issues in unborn children. Chronic exposure can also suppress immune responses, as seen with low doses of certain pesticides [51,52].

Effects on the Environment

Pesticide applications aim to manage pests by reducing their populations to acceptable levels. However, this often results in non-target species exposure. Broadcast applications, such as crop dusting, can expose many non-target organisms to pesticides through direct contact or environmental drift [42]. Pesticides are toxic to aquatic life, with high levels of tenacity behaviour by organochlorines seen in aquatic fish and other water species. Pesticide use can disrupt the natural balance of ecosystems, potentially increasing pest populations by eliminating their natural predators.

Pesticides Resistance Development

Resistance occurs when a given population of pest thrives despite exposure to a certain concentration was originally lethal. Resistance develops through genetic changes that detoxify pesticides. Inappropriate use can eradicate susceptible species, allowing resistant strains to thrive. This leads to increased pesticide use, further harming the environment and human health. Crossresistance can occur, where pests resistant to one pesticide develop resistance to others [53], exacerbating the problem of multiple resistance.

Management of Pesticides

Pesticides, though beneficial for agriculture and public health, pose significant dangers when used inadequately, impacting the combination of the surrounding and public health [6,53]. Population vulnerability to pesticides can be evident in acute or chronic symptoms, influenced by parameters like chemical nature, exposure duration, amount, and natural or medical state of the individual. Other factors affecting toxicity include feeding habit of the affected individual, the occurrence or absence of contagious, natural physical and psycho stress, other poisons, and already known body organelles damage. The signs of deleterious pesticide toxicity consists of dizziness, sweating, cramps, and coma, whereas the symptoms of chronic pesticide poisoning include nausea, headache, chest pain, restlessness, liver damage, kidney damage, infertility, impotence, congenital malformations, allergies, cancers, changes in blood count, skin alterations, neurotoxic disorders and worsening of existing health conditions.

Pesticide Poisoning and Management

For acute pesticide poisoning, immediate actions should be taken, which is to remove the affected individual from the reach of the pollutants; take away the affected wears and clean the surface of the body with water, then try to enforce throw out within the possible time not above sixty minutes, if the pesticide is already ingested, administer antidotes specific to the pesticide, like atropine or pralidoxime for organophosphate and carbamate poisoning [54]. Atropine binds to acetylcholine (ACh) markers, stopping overdose ACh binding. Pralidoxime assists recreate the phosphorylated or carbamylated enzyme by breaking the bond connecting the poison and the enzyme, making the enzyme available to clear unuse ACh.

To prevent pesticide poisoning, there must be proper instruction and guidance of pesticide utilizers on safe and appropriate end-use, including wearing protective clothing, proper dumping of waste and unused packaging materials, and adherence to label manual instructions and acceptable farming practices. Also, the employment of alternative pest control methods can reduce pesticide use edibles and surroundings, like biological pest control and natural predators [40]. These methods are part of Integrated Pest Management (IPM). Integrated Pest Management (IPM) is a more acceptable method of controlling pest, utilizing complementary tactics to minimize physical space and risk effect. The components of IPM include non-man made eaters, microbes, and bioagents in management of pests with minimal non-target damage; pest-resistant crop varieties; habitat management which enables the surrounding hostile to pests; a well structure pest population observation as to apply guidance when it is needed and judicious utilization of pesticides as it relates to IPM strategy. Acceptable IPM schedule can significantly minimize reliance on pesticides. For instance, cotton cultivation in the southern United States of America, traditionally relied heavily on insecticides against pests like the boll weevil. IPM seeks specific control methods to avoid non-target damage, though biological control is not always suitable for all pests.

Pesticide use and Status in Nigeria

Despite that poor nations of world are using a quarter of the world's pesticides usage, they account for about 99% of related life loss [52]. It is a result of heavy and unacceptable pesticide, weak and none existent framework guide, health, and education systems. Looking at Nigeria, weakened pesticide education may be leads to massive misuse [55]. Estimates indicate that close to 125,000 - 130,000 metric tons of pesticides were used yearly in Nigeria since 1998. Pesticides used for cocoa amounted to 31% of the total agrochemical market in 2011, fungicides amounted to over 65%, and insecticides for 35% [18]. Glyphosate (Roundup) and atrazine is the most frequently used pesticides globally [18] and the most toxic chemicals are often utilized in Nigeria due to their lower cost compared to newer, more benign pesticides [56-58]. WHO classifies pesticides into extremely hazardous (Class Ia), highly hazardous (Class Ib), moderately hazardous (Class II), slightly hazardous (Class III), and may likely not cause hazardous effect under short-term use (Class U) (WHO, 2020). Smallholder farmers in developing countries constantly utilize Class Ia, Ib, and II pesticides because of its affordable cost [57]. Newer formulations are expensive because of foreign patents and heavy charges imposed on local firms, driving up market prices [59]. Low information and awareness about pesticide dangers are prevalent among Nigerians. Improper disposal of empty containers is a major issue. Medical personnel often lack training to recognize and treat pesticide poisoning, with symptoms easily misattributed to other causes [17]. Laboratory equipment for analysis used for diagnosis are scarce or costly. Over 98% of sprayed insecticides and 95% of herbicides reach non-target species, air, water, and soil. Pesticide residues can move from the soil surface, contaminating runoff water or groundwater [56,60].

Metabolic Effect of Pesticides

Exposure to certain chemicals can trigger metabolic consequences. Several literatures connect undue exposure to toxic chemicals to many non-communicable diseases as reported by Unachukwu and Agomuo [22], contact with lead triggers cholesterol changes, which directly affects Cardiovascular (CVD) ailment and ups atherosclerosis in subjects exposed to lead, who then exhibit Blood Pressure (BP) rise and hypertension [61,62]. Pollution Keratoconjuctivitis (PKC) is caused by high lead with signs of tear film among children [63]. The review by Orisakwe [64], amplifies how cadmium is a potential trigger of diabetes prevalence in Nigeria. Metabolic conditions aggregates to high blood pressure, high sugar levels in the blood, abdominal fat accumulation, cholesterol and triglyceride build up, all these together magnify the hazards of cardiovascular effect, stroke, and type 2 diabetes mellitus [65]. Together they are regarded as metabolic syndrome (Mets), a steady rise of such effect has been reported in United States (37.6% - 41.8) (2011–2012 to 2017–2018) among adults as shown by the data from National Health and Nutrition Examination Survey (NHANES) [66]. In Nigeria, although such diseases are grossly prevalent, there may be no centralized data information. Risk factors for metabolic conditions can be categorized into non modifiable and modifiable factors. Age, sex, and degree or levels of environmental chemical exposure are factors are modifiable. Taken all these into consideration, the impact of environmental chemical exposure, especially common compounds like glyphosate, has attracted global attention. Glyphosate is globally known herbicides already flagged in the USA [67], it impedes aromatic amino acid synthesis route in plants, it can be utilized in killing grasses and weeds, but active to some form of gut bacteria. Originally believed to be human friendly, the International Agency for Research on Cancer (IARC), has classified it as a possible human carcinogen [68] and possibly exert effect human fertility. Several literatures evidenced that glyphosate exhibit neurological effect, damages mitochondria, even mild exposure leads to fibrosis of the liver, elevates apoptosis, oxidative stress induction, and changes gut microbiome and distorts adipocytes intake from glucose [69-72]. Glyphosate was originally designed to kill weeds, used directly on grains and impulse crops to quicken desiccation, in addition to inhalation and dermal contact, dietary residual exposure via food crops like wheat, maize, beans, oats etc becomes a sure exposure pathway for farmers and the general populace [73]. Another example of globally recognized and used pesticide is pyrethroid.

(PYR) synthesized from plant part- flowers of Chrysanthemum cinerariaefolium to obtain naturally occurring compound pyrethrum or pyrethrin, the wide and global utilization covers about 30% pesticides trade, this because of phasing out of organophosphate, a more persistent and toxic substance. Pyrethroids is represented by deltamethrin, cypermethrin and permethrin and the main usage is an active ingredient in Protection of Plant Products (PPP) and biocides in home use products, where it finds application in timber products, textiles, animal medicine for treating scabies and lice. Human exposure occurs via occupational act via skin and inhalation during application, but the most versatile exposure route is ingestion of residual pyrethroids via consumption of agricultural produce and contaminated water [74-77]. Ubiquitous toxic environmental chemicals like pesticides from gestational exposure, foods, body and hygienic care products slows fetal growth, though some exhibit opposite effect, environmental chemicals such as heavy metals and organochlorine are complicit in infant birth weight reduction, lead (Pb) and organochlorine compound concentration in trimester blood of trans-nonachlor is inversely related with birth weight [78-80]. In sub-Saharan Africa, where poverty and stressful lifestyle exerts overriding effect on life event, poor nutrition, loneliness, unwanted pregnancy, can intricately affect fetal growth through immunological physiological and behavioural pattern [81].

Conclusion

These review highlights the critical role of micro-organism pesticides that is promising and geographically benign and an alternative to conventional synthetic pesticides. Micro-biological pesticides, utilizing organisms like bacteria, fungi, and viruses, offer targeted pest control with reduced ecological footprints, presenting a viable solution for sustainable agriculture. Their specificity to pests minimizes the risk to non-target species and ecosystems, demonstrating their potential in integrated pest management (IPM) strategies. Conversely, the use of chemical pesticides continues to be prevalent due to their effectiveness in managing pest populations. However, their application is fraught with significant risks, including potential health hazards and environmental damage. Chemical pesticides can lead to acute and chronic poisoning in humans, manifesting in symptoms ranging from dizziness and vomiting to long-term effects such as cancer and neurological disorders. Environmental concerns include contamination of soil and water, nontarget species exposure, and the development of pesticide resistance. The review emphasizes the necessity for continuous hazard assessment and control practices to reduce these hazards. Effective hazard analysis involves evaluating the potential effects of pesticide application on human hazard and the environment, incorporating both acute and chronic exposure scenarios. Enhanced regulatory frameworks and education on safe pesticide use are crucial for minimizing risks. Additionally, promoting the adoption of alternative pest control methods, such as microbial pesticides and IPM, can reduce reliance on chemical pesticides, thus mitigating their adverse effects. While microbial pesticides offer a sustainable alternative with numerous benefits, the continued reliance on chemical pesticides necessitates comprehensive risk assessment and management strategies. Future research and policy development should focus on improving pesticide safety, fostering the use of environmentally friendly alternatives, and ensuring effective regulatory oversight to safeguard public health and environmental integrity.

Authors' Contributions

JKN conceived the study, designed the research area, and reviewed the work and made the final corrections before submission. OIE-A and MOA: Assisted in data collection, managed data preprocessing, and wrote the initial draft and literature review. DOO: Supported the study by correcting the initial draft, reviewing the literature, and aiding manuscript editing. All authors reviewed and approved the final manuscript.

Declarations

Consent to Publish

All the authors agreed to publish the manuscript with Discover Environment.

Ethics Declaration

Not applicable.

Clinical Trial Number

Not applicable.

Data Availability

Not Applicable.

Competing Interest

The authors declare no competing interests.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgment

None.

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