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REVIEW ARTICLES

PESTICIDE RESIDUES IN VEGETABLE PRODUCTION SYSTEMS IN WEST AFRICA: A SYNTHESIS OF HEALTH AND ENVIRONMENTAL RISKS ASSOCIATED WITH AGRICULTURAL PHYTOSANITARY PRACTICES

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Abstract

In West Africa, vegetable production systems are essential for food security, nutrition, and income generation, especially in urban and peri-urban areas. However, strong pest pressure has resulted in heavy reliance on chemical pesticides, often applied outside formal regulatory frameworks. This review synthesizes evidence on pesticide residues in these systems and their associated health and environmental risks. Results show widespread use of unregistered products, non-compliance with recommended doses and pre-harvest intervals, and limited knowledge of good agricultural practices. These shortcomings lead to persistent pesticide residues in vegetables, soils, irrigation water, and air, frequently exceeding maximum residue limits. Health risks include acute poisoning, neurological disorders, cancers, and reproductive effects, particularly among farmers, children, and pregnant women. Environmentally, residues reduce soil biodiversity, contaminate water resources, and threaten pollinators. Strengthening regulation, monitorin g, and farmer training, alongside adoption of integrated pest manageme nt and biopesticides, is crucial for sustainable vegetable production in West Africa.

Introduction:-

Agriculture represents a fundamental pillar of West African economies, employing more than 60% of the active population and contributing significantly to GDP (ECOWAS, 2025). Among the agricultural sectors, vegetable production holds increasing strategic importance due to its contribution to food security, nutrition, income generation, and empowerment of vulnerable groups, particularly women and youth (Thomas, 2012). However, high pest pressure in these intensive systems drives farmers to heavily rely on chemical pesticides, often in contexts with limited technical and regulatory oversight (Halilou et al., 2022; Yami et al., 2025).This sometimes uncontrolled and inappropriate use of phytosanitary products leads to the accumulation of pesticide residues in vegetables, soils, irrigation water, and ambient air, threatening human health and the sustainability of agricultural ecosystems (Shekhar et al., 2024). Pesticide residues are defined as traces of active substances or their derivatives present in the

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environment or agricultural products following treatment (Riedo et al., 2023). In West African vegetable production zones, the situation is exacerbated by the circulation of unregistered pesticides, their sale in informal markets, non-compliance with pre-harvest intervals, and the use of obsolete compounds such as DDT or lindane (Haggblade et al., 2021; Hantchi et al., 2022).Recent studies have revealed residue concentrations exceeding MRLs in leafy vegetables, tomatoes, onions, and carrots cultivated in urban and peri-urban vegetable hubs in Senegal, Burkina Faso, Benin, Ghana, Niger, and Nigeria (Ags et al., 2020; Dione et al., 2023; Kumah et al., 2025). Regular consumption of these products exposes populations to chronic health risks, including cancers, endocrine disorders, developmental anomalies, and neurological or immunological impairments. Farmers themselves, often poorly informed and inadequately equipped with personal protective equipment, face high risks of acute, potentially lethal poisonings (Damalas & Koutroubas, 2016; Roula & Leghouchi, 2009). Children and pregnant women are particularly vulnerable (Eyasu et al., 2017; Ghozal, 2023).

Environmental impacts of phytosanitary practices in rainfed or irrigated systems include contamination of surface and groundwater, affecting aquatic fauna and ecosystem health (Fangue-Yapseu et al., 2023). Soil pollution disrupts microfaunal communities, alters fertility, and compromises essential ecological functions such as organic matter decomposition and biological regulation (FAO, 2018). Pollinating insects, including bees, are also threatened by systemic insecticides, jeopardizing crop pollination and long-term productivity (Sponsler et al., 2019).
Given this context, a critical analysis of available knowledge on pesticide residues in West African vegetable systems is necessary to assess the scope of the problem, identify high-risk agricultural practices, document health and environmental effects, and guide sustainable management strategies. This literature review synthesizes scientific data on residue sources, contamination levels, associated risks, and current or proposed regulatory and policy responses.

Research Methodology:-

This study is based on a systematic and analytical review of scientific literature addressing pesticide residues in West African vegetable systems, aiming to identify, compile, and analyze existing data on phytosanitary practices, contamination levels, and associated health and environmental risks.

Data Sources and Selection Criteria

Literature searches were conducted from January to August 2025 across international scientific databases including Scopus, Web of Science, PubMed, ScienceDirect, and Google Scholar. Institutional reports and technical documents from FAO, WHO, ECOWAS, and regional research programs were also considered.Inclusion criteria: Published between 2000 and 2025; Focused on pesticides used in vegetable production in at least one West African country; Provided quantitative or qualitative data on residues, usage practices, or health/environmental effects.Exclusions: non-scientific publications, studies outside the geographic focus, or those not specifically addressing residues.

Data collection and processing

Articles were analyzed using a thematic grid to extract: Identified chemical types and families of pesticides; Crops and application methods; Detected residue levels in vegetables, soils, water, and processed products; Exceedances of FAO/WHO MRLs; Reported health and ecotoxicological effects.Each study was assessed for methodological reliability (sample size, analytical techniques, reproducibility). Results were then synthesized narratively and descriptively.

Analytical approach

A regional comparative approach was used to identify similarities and differences between countries (Senegal, Benin, Burkina Faso, Ghana, Niger, Nigeria, etc.). Trends were grouped thematically: Phytosanitary practices; Residue presence in environmental compartments; Health impacts; Ecological impacts.Critical analysis identified primary determinants of contamination (socioeconomic, regulatory, and technical factors) and proposed avenues for sustainable pesticide management.

Study limitations

The review relies on published, often localized and fragmented studies, limiting generalization across the region. Data scarcity and diverse analytical methods complicate direct country comparisons. Nonetheless, convergence of observed results provides a reliable regional diagnosis.

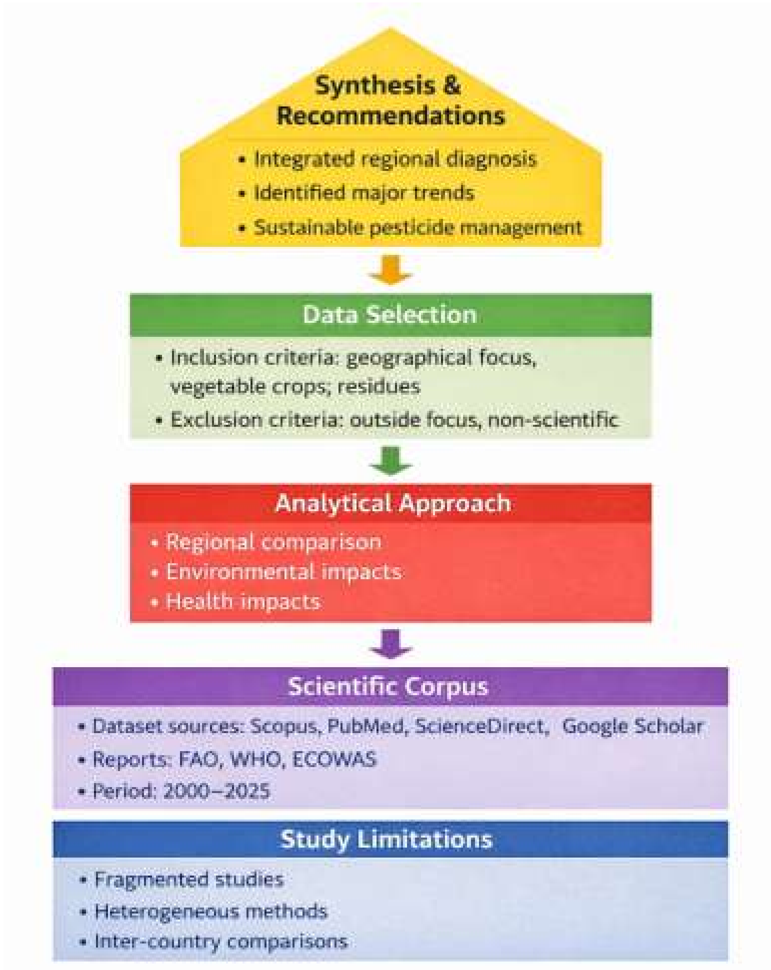

Figure 1: Conceptual prism diagram of the research methodology and analytical workflow

Phytosanitary practices in west african vegetable systems

Vegetable production systems in West Africa are characterized by intensive cultivation, driven by growing demand for fresh vegetables in urban and peri-urban areas (Dossa et al., 2011). This intensification, often implemented without adequate agronomic or ecological measures, has led to increased reliance on chemical pesticides to manage pests and diseases (Jepson et al., 2014). However, phytosanitary practices among farmers are heterogeneous and frequently involve inappropriate, excessive, or illegal use of agrochemicals, which constitutes the primary source of pesticide residues in vegetable agroecosystems (Diallo et al., 2020).

Typology of pesticides used

West African vegetable farmers primarily use insecticides and fungicides to protect crops such as tomatoes, lettuce, cabbage, carrots, eggplants, and peppers (Masumbuko et al., 2024). Commonly detected compounds include organophosphates (chlorpyrifos, profenofos), carbamates (carbaryl, mancozeb), synthetic pyrethroids (cypermethrin, deltamethrin), and copper- or dithiocarbamate-based fungicides (maneb, zineb) (Diop, 2013; Ntamuturanyi et al., 2025).Many pesticides used in these zones are not registered locally or are banned under international standards. Highly hazardous pesticides (HHPs) such as lindane, DDT, and paraquat remain in use due to their availability in informal, low-cost markets (FAO, 2025; Ngamo Tinkeu Léonard Simon et al., 2019).

Field application practices

Access to pesticides is often poorly regulated. Many farmers obtain products from unlicensed agricultural shops, itinerant vendors, or rural markets, where products may be repackaged, mislabeled, or expired (Haggblade et al., 2021). Instructions for use are often missing or written in languages not understood by farmers (English or French), whereas many are literate only in local languages (Aniah et al., 2021).Dosage and application frequency guidelines are rarely followed. Studies have reported weekly or biweekly applications without regard for re-entry intervals or pre-harvest periods (Nkuh et al., 2019). The practice of mixing multiple pesticides in a single sprayer, so-called "cocktails", is common, as farmers believe it enhances efficacy. However, such mixtures increase the risk of toxic synergies and complicate residue assessment (Donley, 2016; Göbölös et al., 2024).Most farmers lack adequate personal protective equipment (PPE), frequently handling pesticides with bare hands, without masks or goggles, increasing dermal and inhalation exposure. Contributing factors include high PPE cost, scarcity, and insufficient awareness of health risks (Okoffo et al., 2016).

Factors promoting residue persistence

Several agronomic and environmental factors contribute to residue persistence. Vegetable crops often have short cycles (two to three harvests per year), limiting safe treatment windows (Masumbuko et al., 2024). Absence of crop rotation or fallow periods sustains pest pressure, increasing chemical dependence (Zerbo et al., 2024). Climatic conditions, including high temperatures and irregular rainfall, influence pesticide volatility, degradation, and leaching (Anaduaka et al., 2023).Pesticides can accumulate in poorly drained clay soils or percolate into groundwater during heavy rainfall (Tachie-Menson et al., 2025). In irrigated areas, contaminated water can serve as a secondary source of residues. Manual spraying with unsuitable equipment (leaky pumps, blocked nozzles, uncalibrated sprayers) further increases overdosing (Viancelli et al., 2024). Limited adoption of integrated pest management (IPM) or ecological alternatives, such as botanical extracts or insect-proof nets, intensifies chemical reliance (Zhou et al., 2022).

Risk perception and sociocultural factors

Farmers' perceptions significantly influence pesticide use. In Senegal, Benin, and Côte d'Ivoire, surveys revealed partial or incorrect understanding of pesticide hazards. Many view pesticides as yield guarantees, downplaying health risks (De Bon et al., 2014; Mahamadou et al., 2009; Tudi et al., 2021; Vidogbéna et al., 2015).Market pressure drives rapid production of visually perfect vegetables, often prompting treatments until the day before harvest (Woltering et al., 2011). With limited certification or quality control systems, producers face few real constraints regarding residues (Assinou & Kpotchou, 2024).Low farmer organization, limited technical support, and inadequate training restrict adoption of rational phytosanitary strategies (Devèze, 2013). Women, highly involved in vegetable production, are disadvantaged by limited access to information, credit, and appropriate equipment (Sithole & Olorunfemi, 2024).

Agronomic consequences and emerging trends

Repeated intensive pesticide use has led to pest resistance in key species such as *Helicoverpa armigera*, *Tuta absoluta*, and whiteflies, particularly to pyrethroids and organophosphates (Martin et al., 2000, 2003). Resistance drives farmers to increase dosages or switch to more toxic compounds, exacerbating health and environmental risks (Diabate et al., 2003).Emerging alternatives include biopesticides (e.g., neem, *Bacillus thuringiensis*), insect-proof nets, and IPM training. However, adoption remains limited due to insufficient policy support.

Presence and levels of pesticide residues in vegetable systems

Analyzing pesticide residues in West African vegetable systems is essential to understand the scope of health and environmental risks. Although available data are fragmented and geographically limited, they reveal significant contamination of vegetables, soils, water, and sometimes air.

Residues in vegetables

Studies in urban and peri-urban vegetable hubs have reported concerning pesticide residue levels in fresh vegetables often consumed raw or lightly cooked (lettuce, cabbage, tomato, carrot, onion, parsley).In Senegal, Diop et al. (2015) found that 56% of sampled vegetables contained residues, with 32% exceeding FAO/WHO MRLs. Chlorpyrifos, dimethoate, and carbofuran were detected at concentrations above permissible limits. Similar findings in Nigeria (Okediran et al., 2019) revealed lambda-cyhalothrin, cypermethrin, and dichlorvos residues exceeding MRLs up to fivefold.

In Benin and Ghana, organophosphate residues persist across multiple crops due to frequent applications and non-compliance with pre-harvest intervals. Multiple treatments during short cycles often result in residue accumulation and "cocktail" effects (Kumah et al., 2025; Sæthre et al., 2013).

Residues in environmental compartments

Pesticide residues extend beyond crops to contaminate soils, water, and air (Tourinho et al., 2025): in soils, frequent applications lead to the accumulation of carbamates and pyrethroids, negatively affecting soil fertility and microfauna, including nematodes and microarthropods (Yasir et al., 2025; Mesele et al., 2025); water resources, including irrigation, drainage, and well water, contain organochlorine and pyrethroid residues that often exceed drinking water standards, with leaching and runoff further contributing to surface water contamination (Akoto et al., 2016; Osei-Owusu et al., 2022); finally, air quality is also affected, as unprotected spraying in dense peri-urban areas exposes nearby residents to airborne pesticide particles and vapors, with some volatile compounds exceeding safety thresholds (Aka et al., 2022; Sithole & Olorunfemi, 2024).

Residues in processed and marketed products

Contaminated vegetables are sold in urban markets or exported, raising food safety concerns (Negassa et al., 2023). Traceability is often lacking (Botwe et al., 2011). In Ghana, residues exceeding norms were documented in carrots and cabbage sold in Accra (Amoah et al., 2006). In Mali, 40% of tomatoes and lettuce contained at least one detectable residue (Cheng et al., 2017).Residues also persist in processed products (sauces, purees, juices), increasing exposure risk for children and the broader public (Abubakar et al., 2024). Non-compliance with standards hinders exports to European and regional markets (ECOWAS), affecting sector competitiveness.

Human health risks associated with pesticide residues

Pesticide residues in West African vegetable systems represent a major source of exposure to toxic chemicals for human populations (Jepson et al., 2014). Exposure occurs through multiple pathways and can result in a wide range of health effects, from acute intoxications to severe chronic diseases (Ahmad et al., 2024). This section analyzes exposure routes, health impacts, and available epidemiological data.

Human exposure pathways

Exposure primarily occurs through ingestion, inhalation, and dermal contact. Ingestion is the predominant route, particularly via consumption of contaminated vegetables (Tudi et al., 2022). Leafy vegetables, lettuce, cabbage, and amaranth, are especially vulnerable to pests and are often heavily treated without adherence to pre-harvest intervals, resulting in residues exceeding MRLs at the point of sale (Sawyer et al., 2024).Irrigation water contaminated by pesticide runoff and consumption of fish from polluted water bodies constitute additional indirect ingestion pathways (Demelash Abera & Alefe Adimas, 2024). Inhalation affects mainly farmers handling concentrated products, preparing sprays, or applying pesticides without proper ventilation or respiratory protection (Damalas & Koutroubas, 2016).Dermal contact is frequent among farmers applying products without gloves, boots, or long clothing, or re-entering treated fields prematurely (MacFarlane et al., 2013). Lipophilic compounds, such as organochlorines, are readily absorbed through the skin (Guo et al., 2025). Children living near vegetable plots are exposed via contaminated soil, dust, or raw vegetables (Hauptman & Woolf, 2017). Pregnant women, often involved in harvesting or washing vegetables, risk fetal exposure to endocrine-disrupting chemicals (Ma et al., 2025).

Health effects

Health impacts range from acute poisoning to chronic diseases. Acute exposures are common among farmers who apply pesticides without training or PPE. Reported symptoms include headaches, vomiting, abdominal pain, dizziness, itching, respiratory difficulties, and in severe cases, convulsions or loss of consciousness (Shekhar et al., 2024; Akter et al., 2018).Chronic low-dose exposures, often through repeated consumption of contaminated foods or long-term cohabitation in polluted environments, are particularly concerning. Epidemiological studies link chronic exposure to cancers (lymphomas, leukemias, brain tumors), endocrine disruption (infertility, miscarriage, congenital malformations), developmental disorders in children (growth retardation, precocious puberty), and metabolic disorders (type 2 diabetes, obesity) (Anne & Raphael, 2000; Bassil et al., 2007; Gatto et al., 2021; Pluth et al., 2019). Neurological effects include reduced cognitive function, memory impairment, tremors, irritability, and long-term risks of neurodegenerative diseases such as Parkinson's disease. Immune function may also be compromised, increasing susceptibility to infections (Botnaru et al., 2025). Children are particularly vulnerable due to immature detoxification systems and ongoing organ development (Rauh et al., 2010). The WHO considers childhood pesticide exposure a major public health concern, especially in regions with weak regulatory oversight (FAO, 2025).

Epidemiological evidence in west africa

Reliable epidemiological data remain limited. Most studies are cross-sectional, small-scale, and lack biological confirmation (blood, urine, or hair analysis). Nevertheless, some findings are alarming. In Ghana, over 70% of farmers exhibited clinical signs of chronic pesticide exposure linked to poor PPE use and inadequate handling (Miyittah et al., 2024). In Burkina Faso, vegetables such as tomatoes and eggplants contained residues exceeding MRLs by 5-10 times (Dione et al., 2023). In Senegal, Diop et al. (2015) found multiple residues, including banned substances like lindane, in vegetables consumed raw or minimally processed.Beyond farmers and consumers, agro-industry workers, including handlers, traders, and transporters, may experience passive exposure. Few studies have assessed cumulative exposure across the food chain (Motshabi et al., 2025). Limited access to analytical laboratories, insufficient funding, and lack of integrated surveillance partially explain the scarcity of data (Olopade et al., 2012). In many West African countries, long-term effects are insufficiently recognized in public health policies, limiting prevention and management efforts (Ansu-Mensah et al., 2024).

Environmental impacts of pesticide residues

The intensification of vegetable production in West Africa relies heavily on chemical pesticides to manage pests, fungal diseases, and weeds. A significant proportion of applied substances does not reach target organisms, dispersing into soil, water, and air, where they persist, accumulate, and affect non-target species, compromising ecosystem health. This section examines ecological impacts on soils, aquatic systems, and pollinators (Bolfrey-Arku et al., 2024).

Soil impacts

Soils are the primary reservoir for pesticides following application, especially in intensively cultivated systems with limited rotation (Nuruzzaman et al., 2025). Residues can persist for weeks or months depending on chemical properties, soil characteristics, and management practices (Faraj et al., 2024). Persistent organochlorines, still illegally used in some areas, pose particular risks due to their lipophilicity and stability (Olisah et al., 2020).

Microfauna such as collembolans, mites, nematodes, and microarthropods are negatively affected, disrupting decomposition and soil structuring processes (Thompson et al., 2017).Microbial biomass and enzymatic activity decline in intensively treated soils, compromising fertility and increasing dependence on chemical inputs (Reddy et al., 2024; Țopa et al., 2025; Wang et al., 2021). Herbicides like atrazine and glyphosate can disrupt microbial communities, favoring pathogens over beneficial organisms and exacerbating crop disease risk (Meena et al., 2020; Weaver et al., 2007). Figure 2 illustrates the pesticide cycle, highlighting the various pathways pesticides follow after application in soil (Acharya et al., 2025).

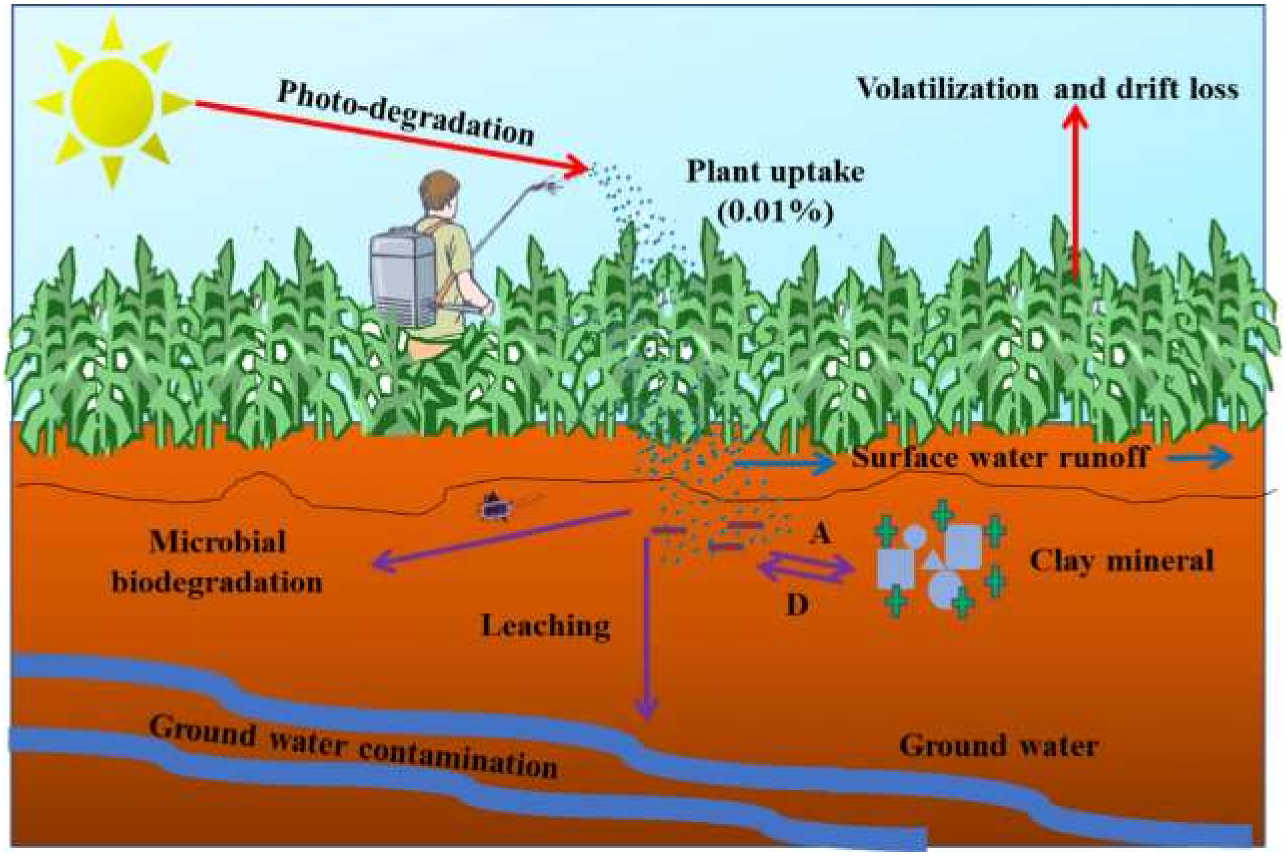

Figure 2 : Pesticide cycle, showing various pathways pesticides undergo after application in soil (Acharya et al., 2025)

Aquatic ecosystem impacts

Water systems serve as a major pathway for pesticide dissemination. Intensive irrigation facilitates leaching and runoff into surface and groundwater (Rad et al., 2022) (figure 3). Residues of carbamates, organophosphates, and pyrethroids have been detected in irrigation water and aquifers in Mali, Senegal, and Togo, negatively affecting aquatic organisms (Le Bars et al., 2022; Alamgir et al., 2012).Impacts include neurological disorders, behavioral changes, embryonic malformations, and increased mortality in fish, crustaceans, insect larvae, and mollusks (Asamba & Wepukhulu, 2023). Bioaccumulation threatens mollusks consumed locally (Ochoa-Esteso et al., 2024). Amphibians, already declining globally, are highly sensitive to aquatic contamination, especially during reproduction and larval development (Mann et al., 2009). The presence of multiple residues raises concerns about “cocktail effects,” which remain poorly understood in West Africa (Ripanda et al., 2021).

Figure 3: Illustration of an aquatic environment polluted by the cocktail effects of pesticide residues

Impacts on beneficial insects and pollinators

Pollinators are essential for vegetable crop yields. Uncontrolled use of systemic insecticides (neonicotinoids, pyrethroids) threatens bees (*Apis mellifera*) and other wild pollinators (bumblebees, solitary bees, certain Diptera) (Alagidede & Alagidede, 2015; Kopit & Pitts-Singer, 2018). Effects include direct mortality, ingestion of contaminated nectar or pollen, altered behavior, immune suppression, and reduced longevity (Azpiazu et al., 2023).

Auxiliary insects such as parasitoids and predators of pest insects (ladybirds, lacewings, hoverflies) are also affected, potentially causing secondary pest outbreaks and reinforcing chemical dependency (Ray & Banerjee, 2025; Quandahor et al., 2024).

Overall ecological consequences

Accumulated residues degrade agroecosystem resilience, disrupt biological interactions, and compromise natural pest and disease regulation (Akhter et al., 2024). In fragmented peri-urban vegetable systems, this loss of ecological resilience increases both pest vulnerability and economic risk (Baffoe & Antwi-Agyei, 2025). Over the medium to long term, environmental impacts threaten agricultural sustainability, food security, biodiversity conservation, and natural resource protection (Ali et al., 2021; Baldock, 2020).

Conclusion:-

West African vegetable systems are essential for food security and income diversification but are increasingly threatened by intensive and often inappropriate pesticide use. This review documents widespread pesticide residues in vegetables, soils, water, and air, driven by weak regulation, access to unauthorized products, and limited farmer training. These residues pose serious health risks, ranging from acute poisoning to cancers, endocrine disruption, and neurological disorders, particularly for farmers, children, pregnant women, and urban consumers. Environmental impacts include water contamination, soil biodiversity loss, toxicity to aquatic organisms, and pollinator decline.

To address these challenges, priority actions should focus on three key areas. First, governments should strengthen pesticide regulation and enforcement by harmonizing national legislations with regional frameworks (e.g., ECOWAS/CILSS), banning highly hazardous pesticides (HHPs), and implementing routine residue monitoring systems in vegetables and environmental matrices. Second, large-scale farmer training programs must be deployed to promote safe pesticide use and accelerate the adoption of Integrated Pest Management (IPM), including biological control, agroecological practices, and the use of biopesticides adapted to local conditions. Third, targeted public health and environmental surveillance systems should be established to monitor pesticide exposure in vulnerable populations and assess ecological risks, thereby informing evidence-based interventions and awareness campaigns. Implementing these prioritized, evidence-based interventions will significantly improve the safety, sustainability, and resilience of vegetable production systems in West Africa.

Conflict of interest: no conflicts of interest.

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