

Assessment of Pesticide Residues in Food Commodities from North-western Nigeria: Implications for Food Safety and Public Health

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Received on: October, 2024

Revised and Accepted on: November, 2024

Published on: December, 2024

ABSTRACT

Pesticides are an invaluable resource for the protection of crops and the assurance of food security. However, the improper application of these substances frequently results in the contamination of food commodities with hazardous residues. This article reviews the prevalence and concentrations of pesticide residues in food grains, vegetables, and fruits in North-western Nigeria. The excessive and improper use of pesticides in these regions has given rise to concerns regarding their potential impact on food safety and public health. The presence of residual pesticide contamination in edible crops has been linked to a number of significant health risks, including the development of acute and chronic health conditions such as cancer, birth defects and organ damage. This review employs a systematic approach to evaluate pesticide residue levels, compare them to internationally accepted maximum residue limits (MRLs), and identify deficiencies in existing agricultural and regulatory practices. It is the intention of this review to provide policymakers and stakeholders with the information they require to develop evidence-based strategies that will enhance food safety, protect public health and promote sustainable agriculture in Nigeria.

Keywords: Pesticide, Residue, Food Commodities, Food Safety, Public Health

1.0 INTRODUCTION

Pesticides are major chemical agents employed for the control of pests, particularly insects, fungi, nematodes, and weeds that may impact the production of crops, including fruits and vegetables (Sule *et al.*, 2020). Pesticides play a vital role in modern agriculture by safeguarding crops from pests, diseases, and weeds, thereby ensuring increased agricultural productivity and food security (Damalas and Eleftherohorinos, 2011). However, their widespread use has raised significant concerns regarding food safety and public health, especially in developing countries like Nigeria. Pesticides, when improperly applied, leave residues on food products that may persist beyond harvest, posing serious risks to consumers (Saheed *et al.*, 2020). These residues, comprising active ingredients and toxic by-products, can accumulate in food grains, vegetables, and fruits, leading to both acute and chronic health effects, including organ damage, neurological disorders, reproductive harm, and carcinogenesis (Saheed *et al.*, 2020; Munir *et al.*, 2024).

In northwestern Nigeria, agriculture serves as a critical component of the regional economy, with states like Sokoto, Kebbi, and Zamfara heavily reliant on farming for income and sustenance. Farmers in these areas often use pesticides to counteract pest infestations and improve crop yield. Despite their benefits, the improper use of these chemicals has led to significant challenges,

including contamination of food commodities with residues that exceed internationally recommended maximum residue limits (MRLs) (Okafogun *et al.*, 2017). This raises concerns about food safety, particularly as pesticide residues in food have been associated with long-term health implications such as endocrine disruption, developmental disorders, and immune system suppression (Akinloye *et al.*, (2011).

The situation in Nigeria is further complicated by inadequate enforcement of food safety regulations, insufficient monitoring systems, and limited awareness among farmers regarding the judicious use of pesticides (Alhassan *et al.*, 2021). Studies have revealed that pesticide residues in food commodities from Nigeria often surpass permissible levels, suggesting inappropriate application practices and poor adherence to recommended guidelines (Usman, 2024). This situation not only endangers public health but also poses a barrier to international trade due to non-compliance with food safety standards set by importing countries (Odehale *et al.*, 2021).

Food safety remains a major concern globally, with organizations such as the World Health Organization (WHO) emphasizing the need to minimize pesticide residues in food to protect consumers. In Nigeria, while some governmental agencies conduct pesticide surveillance, these efforts are often insufficient, resulting

in limited data on the extent of pesticide contamination in food products (WHO, 2023). This knowledge gap is particularly evident in Sokoto, Kebbi, and Zamfara states, where the agricultural sector is crucial for livelihoods, yet limited research has been conducted to assess pesticide residues in food commodities.

This review aims to address this critical knowledge gap by evaluating published articles that reported pesticide residue levels in food grains, vegetables, and fruits from northwestern Nigeria. The findings of this review are expected to provide empirical data that can guide policymakers, regulatory bodies, and agricultural stakeholders in implementing effective strategies to ensure food safety and protect public health. Moreover, this study will explore the implications of pesticide contamination on the health of local populations and propose recommendations for improving agricultural practices, pesticide management, and regulatory frameworks.

By focusing on pesticide residues in food commodities, this research highlights an urgent public health and environmental issue, underscoring the need for comprehensive and sustainable interventions to safeguard the health of Nigerian consumers and promote agricultural sustainability.

2.1 What are Pests?

A pest can be defined as any animal or plant which harms or causes damage to man, his animals, crops, or possession. Agricultural pests include insects, mites, plant pathogens, and weeds; while household pests include cockroach, fleas, mosquitoes, termites, bedbugs, and rodents etc. According to WHO and UNEP, (2012). Some pests occur perennially and could cause serious and persistent economic damage if not controlled, while some cause economic damages only on certain occasions, when there is disturbance in the ecosystem. Others migrate from one geographic zone to another under various environmental influences (Bhatt *et al.*, 2023).

2.2 Pesticide

Pesticides are used all around us, in farms, homes, schools, gardens, and public parks. A pesticide is defined as any substance or mixture of substances intended for preventing, destroying, or controlling any pest including vectors of human or animal diseases, unwanted species of plants or animals causing harm during, or otherwise interfering with, the production, processing, storage, or marketing of food, agricultural commodities, wood and wood products, or animal feedstuffs, or which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies (Guzman *et*

al., 2024). Pesticide includes chemicals used as growth regulators, defoliants, desiccants, fruit thinning agents, or agents for preventing the premature fall of fruits, and substances applied to crops either before or after harvest to prevent deterioration during storage or transport (Seralini *et al.*, 2024).



Figure 1. Pesticides (Source: <https://www.environewsigeria.com/tag/ikenna-donald-ofoegbu/>)

The term pesticide is also defined by FAO in collaboration with UNEP (1990) as chemicals designed to combat the attacks of various pests and vectors on agricultural crops, domestic animals and human beings. The definitions above imply that, pesticides are toxic chemical agents (mainly organic compounds) that are deliberately released into the environment to combat crop pests and disease vectors.

2.2.1 Types of Pesticides

Pesticides can be either biodegradable pesticides that break down into harmless compounds by bacteria and other living organisms or persistent/non-biodegradable pesticides, which can take months or years to break down.

1. Insecticides – Insects
2. Herbicide – Plants
3. Rodenticides – Rodents (rats & mice)
4. Bactericides – Bacteria
5. Fungicides – Fungicide
6. Larvicides – Larvae



Figure 2: Types of Pesticide use in Agriculture (Bateman, 2016).

2.3 Historical Background of Pesticides use in Agriculture And Public Health

The historical background of pesticides use in agriculture is dated back to the beginning of agriculture itself and it became more pronounced with time due to increased pest population paralleled with decreasing soil fertility (Muir, 2002). However, the use of modern pesticides in agriculture and public health is dated back to the 19th century. The first generation of pesticides involved the use of highly toxic compounds, arsenic (calcium arsenate and lead arsenate) and a fumigant hydrogen cyanide in 1860's for the control of such pests like fungi, insects and bacteria. Other compounds included Bordeaux mixture (copper, sulphate, lime and water) and sulphur. Their use was abandoned because of their toxicity and ineffectiveness. The second generation involved the use of synthetic organic compounds. The first important synthetic organic pesticide was dichlorodiphenyltrichloroethane (DDT) first synthesized by a German scientist Ziedler in 1873 (Othmer, 1996) and its insecticidal effect discovered by a Swiss chemist Paul Muller in 1939. In its early days DDT was hailed as a miracle because of its broad-spectrum activity, persistence, insolubility, inexpensive and ease to apply (Keneth, 1992).

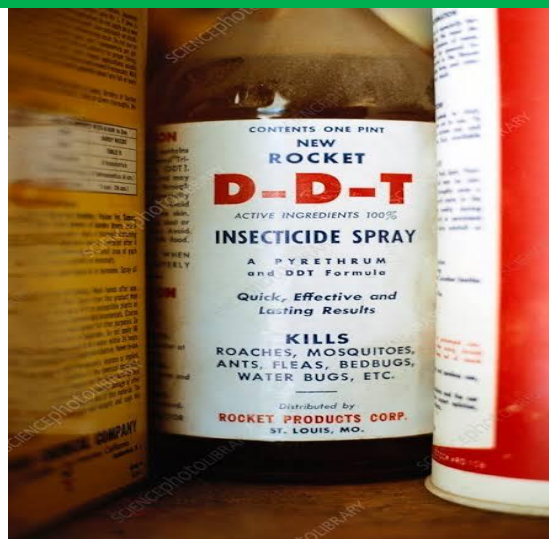


Figure 3: Battle of Dichlorodiphenyltrichloroethane (DDT) (Source: <https://www.sciencephoto.com/contributor/xxx/>).

P, p'-DDT in particular was so effective at killing pests and thus boosting crop yields and was so inexpensive to make its use quickly spread over the globe. DDT was also used for many non-agricultural applications as well. For example, it was used to delouse soldiers in the World War II and in the public health for the control of mosquitoes which are the vectors for malaria. Following the success of DDT, such other chemicals were synthesized to make this era what Rachel Carson, (1962) in her book "The Silent Spring" described as the era of "rain of chemicals".

The intensive use of pesticides in agriculture is also well known to be coupled with the "green revolution". Green revolution was a worldwide agricultural movement that began in Mexico in 1944 with a primary goal of boosting grain yields in the world that was already in trouble with food supply to meet the demand of the then rapidly growing human population. The green revolution involved three major aspects of agricultural practices, among which the use of pesticides was an integral part. Following its success in Mexico, green revolution spread over the world. Pest control has always been important in agriculture, but green revolution in particular needed more pesticide inputs than did traditional agricultural systems because, most of the high yielding varieties were not widely resistant to pests and diseases and partly due to monoculture system (Vocke, 1986).

Each year pests destroy about 30-48% of world's food production. For example, in 1987 it was reported that, one third of the potential world crop harvest was lost to pests. An Insect and rodents also account pests for a big loss in stored agricultural products. Internally feeding insects feed on grain endosperm and the germ the result

of which is the loss in grain weight, reduction in nutritive value of the grain and deterioration in the end use quality of the grain (Hellar, 2002). Externally feeding insects damage grain by physical mystification and excrement contamination with empty eggs, larval mounts and empty cocoons. A common means of pest control in stored agricultural products has always been the use of insecticides such as Malathion, chlorpyrifos-methyl or deltamethrin impregnated on the surfaces of the storage containers (McFarlane, 1989).

It is estimated that over 300 to 500 million clinical cases occur each year, with cases in tropical Africa accounting for more than 90% of these figures (WHO, 1995). Other vector-borne diseases that present a serious problem especially in the tropics include trypanosomiasis, onchocerciasis and filariasis. It is therefore quite apparent that, the discovery of pesticides was not a luxury of a technical civilization but rather was a necessity for the wellbeing of mankind (Nadeem, 2023).

2.4 Impacts of Pesticides Use in Agriculture And Public Health

The use of pesticides in agriculture has led to a significant improvement in crop yield per hectare of land. Studies have established a possible correlation relationship between the quantity of pesticides used per hectare and the amount of crop yields per hectare (Hellar, 2002). Pesticides such as DDT and others proved their usefulness in agriculture and public health. Economies were boosted, crop yields were tremendously increased, and so were the decreases in fatalities from insect-borne diseases. Insecticides have saved the lives of countless millions of people from insect-borne diseases (Youdeowei, 1983).

2.5 Side Effects of Pesticides Use to The Environment And Public Health

Despite the good results of using pesticides in agriculture and public health described above, their use is usually accompanied with deleterious environmental and public health effects. Pesticides hold a unique position among environmental contaminants due to their high biological activity and toxicity (acute and chronic). Although some pesticides are described to be selective in their modes of action, their selectivity is only limited to test animals. Thus, pesticides can be best described as biocides (capable of harming all forms of life other than the target pest (Buchel, 1983).

2.5.0 Method of Pesticide Application

Pesticide application methods are chosen based on the behaviour of target pests, the characteristics of the application site, and the properties of the pesticide used

(Matthews *et al.*, 2019). Common pesticide application techniques are band spraying, broadcast spraying, drenching, foliar, soil injection, space treatment, and spot treatment (Matthews *et al.*, 2019). Among these broadcast and band spraying are frequently employed to achieve uniform coverage across crop areas.

2.5.1 Band Spraying

Applying pesticide in parallel strips rather than uniformly over the entire field is called a band application. Band applications are used to apply pesticides, including but not limited to herbicides, in the rows or aisles. Potential herbicide drift, overspray and vaporization should be taken into consideration when using this technique, and the application should be done with guards or shields to minimize contact of the herbicide to the crop plant. The growth of some citrus trees has been set back by drift from herbicides applied beneath the tree, especially with stressed trees. Special care should be taken when using herbicides around young trees to avoid contact with the tree trunk, as injury could occur (Xiongkui *et al.*, 2017).

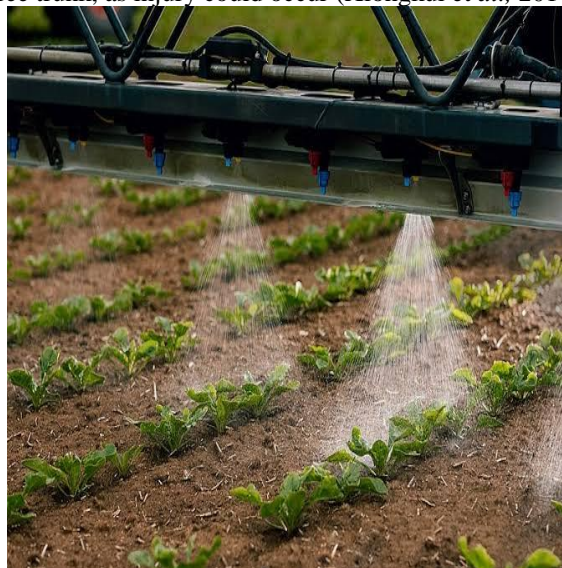


Figure 4: Band sprayer (Philis *et al.*, 2011).

2.5.2 Broadcast Spraying

Broadcast spraying involves applying pesticide uniformly to an entire area or field, it is termed a broadcast application. An application of ant bait to an entire field would be considered broadcast because it is covering the whole space. The method generally requires more pesticide than other types of applications because the entire area is covered, rather than targeted plants or areas.

There are several means by which non-spray pesticide can be applied, including drench, foliar, and soil injection methods. These approaches allow for more efficient use

of pesticides and more effective placement, especially against some borers, and eliminate drift.



Figure 5: Broadcast sprayer (Corteva *et al.*, 2020)

2.5.3 Hydraulic Sprayers

Hydraulic sprayers range from powered units with multi-nozzle boomed to hand-pumped backpack sprayers (Sumner *et al.*, 2011). In all cases, pressure from either a pump or compressed gas or air is used to atomize the spray mix at the nozzle. High-pressure pumps are needed to provide good spray coverage for large trees (Salcedo *et al.*, 2021).

2.5.4 Backpack Sprayers



Figure 6: Hydraulic Sprayers (Summer *et al.*, 2024)

The backpack sprayer is simple and consists of a tank, a

pump, a spray wand, and a nozzle (Blanco *et al.*, 2021). It is effective for treating small areas, spot spraying, and accessing hard-to-reach locations the main spray options are broadcast, band, space, and spot treatment (Thouvenin *et al.*, 2000).



Figure 7: Backpack Sprayer (Hernawa *et al.*, 2018)

2.5.5 Basal Trunk Sprayers

Basal trunk spraying is a straightforward and efficient pesticide application method that requires only a garden sprayer (Gangstad *et al.*, 2006). This method involves thoroughly wetting the lower 5 feet of a tree trunk with a water-soluble pesticide. Pesticides are absorbed through the bark and distributed by the vascular system of the tree. This application method does not harm the tree, as the chemicals do not pollute the soil when applied properly by farmers.



Figure 8: Basal Trunk Sprayer (ferril *et al.*, 2006)

2.5.6 sprayers

Aerial

Helicopters or fixed-wing aircraft are used for spraying pesticides on crops and plantations in large and inaccessible areas, such as highlands and special areas where pests and crop diseases occur repeatedly and frequently and when areas are not suitable for ground-based spraying (Xiongkui *et al.*, 2017).



Figure 9: Application of herbicide by aerial dispersion over plantations (Matthews, 2019).

When pesticides are applied to a target plant by the different application methods, they have the potential to enter the environment (Tudi *et al.*, 2021). On entering the environment, pesticides can undergo processes such as transfer (or movement) and degradation. Pesticides migrate from the target site to other environmental media or non-target plants by transfer processes, including adsorption, leaching, volatilization, spray drift, and runoff. Improper pesticide usage and management and pesticide behavior in the environment lead to environmental pollution, including soil pollution, water pollution, air pollution, and food contamination. Thus, residents and farmers are exposed to pesticides through exposure media, including soil, water, air, and contaminated food (Tudi *et al.*, 2021).

2.6.0 Toxicological Classification of Pesticides

These pesticides vary in their physical, chemical and identical properties from one class to other. Therefore, it is important to classify them based on their properties and study under their respective groups. Synthetic pesticides are manmade chemicals, and do not occur in nature. They are categorized into various classes depending on the

needs. Presently, Drum has identified three widely accepted method for classifying pesticide these are:

- (i) classification based on the mode of entry,
- (ii) classification based on pesticide function and the pest organism they kill
- (iii) classification based on the chemical composition of the pesticide

2.6.1 Pesticides on the Basis of Modes of Entry

Pesticides can be classified into two main categories based on their modes of entry: systemic pesticides and non-systemic pesticides.

2.6.1.1 Systemic Pesticides

Systemic pesticides are a category of pesticide that is absorbed by plants and transported throughout their tissues, including stems, leaves, roots and flowers. Unlike contact pesticides that persist on the outward of the plant, systemic pesticides are used by plant's vascular system and distributed internally (Cloyd *et al.*, 2011). Systemic insecticides are absorbed by plants and deliver a safeguard against insects that feed on the plant's tissues. Insects ingest the systemic pesticide when they consume sections of the treated plant and are injured or killed (Chagnon *et al.*, 2015). Systemic insecticides are mainly effective contrary to pests that have piercing-sucking mouthparts, as they can be controlled even if they are not directly exposed to the pesticide on the surface of plant (Cloyd *et al.*, 2011). Examples of systemic insecticides include imidacloprid, clothianidin, etc. Systemic pesticides have a high penetration capability in plant tissues, allowing them to flow either a unidirectional or multidirectional manner to kill target organisms (Suleiman *et al.*, 2019). The systemic nature of these pesticides provides various benefits. Even if the pesticide is only sprayed to a single area or place, it can protect the entire plant, including new growth. Because the pesticide is disseminated internally throughout the plant, systemic insecticides can also be effective against concealed or difficult-to-reach pests. However, systemic pesticides can also be absorbed by non-target plants, which might have unexpected repercussions for beneficial insects or species that feed on treated plants (Simon *et al.*, 2015).

2.6.1.2 Non-systemic Pesticides

Non-systemic pesticides are pesticides that do not migrate or translocate within the plant once they are applied. These pesticides remain on the plant's surface and are neither absorbed nor dispersed within its tissues. Contact between target organisms and pesticides determine non-systemic insecticides (Zhang *et al.*, 2023). Contact pesticides are administered directly to plant surfaces or to pests. They work by coming into contact

with the pests and either killing or repelling them. Contact insecticides have efficacy against pests present at the time of application but may not give long-term protection (Gerbig *et al.*, 2015). Non-systemic pesticides are chiefly suitable when instant control or knockdown of pests is essential, and there is no need for longstanding residual protection (Satpathy *et al.*, 2020). The effectiveness, however, may be limited to the sections of the plant that are directly treated, and they may need to be reapplied to new growth or when pests re-infest the treated region. When using non-systemic pesticides, it is critical to carefully follow the directions and safety precautions stated on the pesticide label (Łozowicka *et al.*, 2020).

2.6.2 Pesticide on the Basis of Chemical Composition

The most common and useful method of classifying pesticide is based on their chemical composition and nature of active ingredients. It is such kind of classification that gives the clue about the efficacy, physical and chemical properties of the respective pesticides (Shahinasi *et al.*, 2017). The information on chemical and physical characteristics of pesticides is very useful in determining the mode of application, precautions that need to be taken during application and the application rates. Based on chemical composition, pesticides are classified into four main groups (Yang *et al.*, 2023). Namely; organochlorines, organophosphorus, carbamates and pyrethrin and pyrethroids. The chemical-based classification of pesticides is rather complex. In general, modern pesticides are organic chemicals. They include pesticides of both synthetic and plant origin. However, some inorganic compound is also used as pesticides. Insecticides are important pesticides that can be further classified into several sub-classes (Ahmad *et al.*, 2023).

2.6.2.1 Organochlorines

Organochlorines pesticides are organic compounds with five or more chlorine atoms. Organochlorines were the first synthetic organic pesticides to be used in agriculture and in public health. Most of them were widely used as insecticides for the control of a wide range of insects, and they have a long-term residual effect in the environment since they are resistant to most chemical and microbial degradations. Organochlorine insecticides act as nervous system disruptors leading to convulsions and paralysis of the insect and its eventual death. Some of the commonly used representative examples of organochlorine pesticides are DDT, endosulfan, aldrin, dieldrin and Atrazine and their chemical structures are presented hereunder.

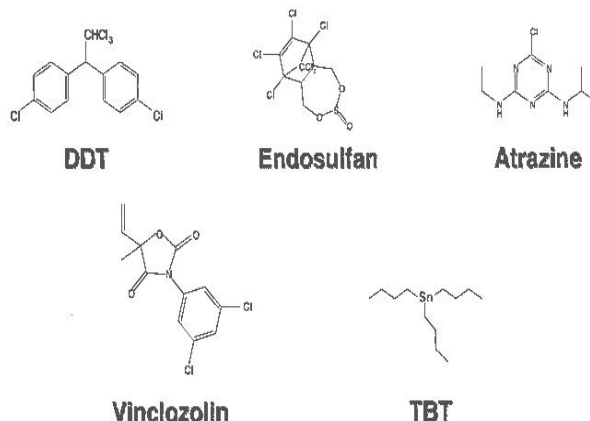


Figure 10: Examples of organochlorine pesticides associated with endocrine disruption: organochlorine pesticides DDT and endosulfan, atrazine, vinclozolin and tributyltin TBT (Hewitt *et al.*, 2001)

2.6.2.2 Organophosphate

Organophosphate pesticides are considered to be one of the broad spectrum pesticides which control wide range of pests due to their multiple functions. They are characterized with stomach poison, contact poison and fumigant poison leading to nerve poisons. These pesticides are also biodegradable, cause minimum environmental pollution and are slow pest resistance. Organophosphorus insecticides are more toxic to vertebrates and invertebrates as cholinesterase inhibitors leading to a permanent overlay of acetylcholine neurotransmitter across a synapse. As a result, nervous impulses fail to move across the synapse causing a rapid twitching of voluntary muscles, hence, leading to paralysis and death (Zaharia *et al.*, 2023). Some of the widely used organophosphorous insecticides include parathion, Malathion, diaznon and Parathion and Dieldrin.

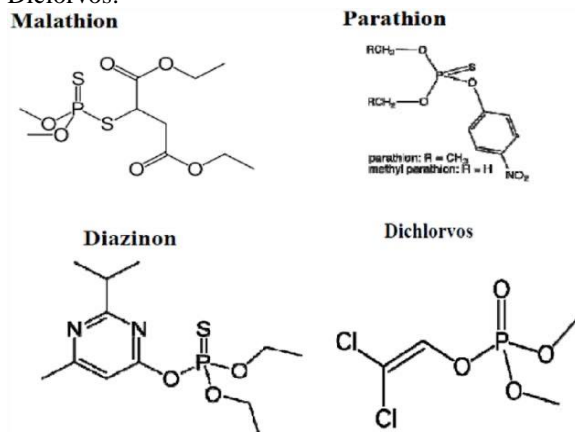


Figure 11: Chemical structures of main organophosphate pesticides (Adewale *et al.*, 2023)

2.6.2.3 Carbamates

Carbamates are similar to organophosphates. However, they differ in their origin. Organophosphates are derivatives of phosphoric acid, while carbamates derived from carbamic acid. The working principal of carbamate pesticides is similar to organophosphate pesticides by affecting the transmission of nerve signals resulting in the death of the pest by poisoning. Sometimes, they are also used as stomach and contact poisons as well as fumigant. They can be easily degraded under natural environment with minimum environmental pollution. Some of the widely used insecticides under this group include carbaryl, carbofuran, and aminocarb.

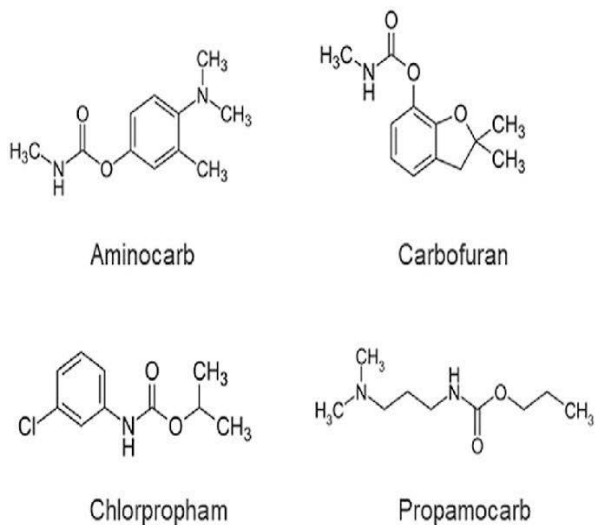


Figure 12: Chemical structures of carbamate pesticides (Bruyère *et al.*, 2020)

2.6.2.4 Pyrethroids

Pyrethroids are synthetic analogues of the naturally occurring pyrethrins; a product of flowers from pyrethrum plant (*Chrysanthemum cinerariaefolium*). The insecticidal components of pyrethrum flowers are the optically active esters derived from (+)-Trans-chrysanthemic acid and (+)-Trans-pyrethroic acid. Pyrethroids are acknowledged of their fast knocking down effect against insect pests, low mammalian toxicity and facile biodegradation. Although the naturally occurring pyrethrins are effective insecticides, their photochemical degradation is so rapid that their uses as agricultural insecticides become impractical. The synthetic analogues of the naturally occurring pyrethrins (pyrethroids) were developed by the modification of pyrethrin structure by introducing a biphenoxy moiety and substituting some hydrogen with halogens in order to

confer stability at the same time retaining the basic properties of pyrethrins. The most widely used synthetic pyrethroids include Esbiothrin, cypermethrin and Fenpropathrin.

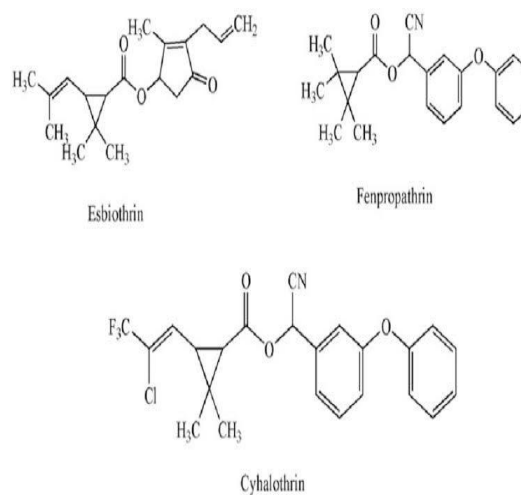


Figure 13: Structures of three kinds of pyrethroid pesticides (Tang *et al.*, 2013)

2.6.3 Pesticides on the Basis of Function

Pesticides are classified using this method based on the target organism, and pesticides are given specific names to represent their actions. Pesticides are also divided into groups based on their intended use; for example, growth regulators encourage or inhibit the growth of pests, defoliants lead to the dropping of plant leaves, desiccants lead to the drying and killing of insects, repellents repel pests, and attractants fascinate and trap pests (Łozowicka *et al.*, 2020). Some of the pesticides that are used in more than one category of pests may be included in more than one class of pesticide. Similarly, there are also several pesticides that control many insect classes and can be classified into multiple pesticide classes (Abubakar *et al.*, 2020). Aldicarb is extensively applied in Florida citrus production and may be categorized as an insecticide, acaricide, or nematocide as it controls insects, nematodes, and mites, respectively. Additionally, a common example is 2, 4-D, which is applied as an herbicide for the control of broadleaf weeds. Repellents and attractants are considered pesticides since they are applied for pest control (Yadav *et al.*, 2017). Furthermore, it's necessary to remember that these categories are not exclusive, and many pesticides may appropriate into more than one category depending on their properties and intended uses. Furthermore, laws and classifications may differ.

2.7 Pesticide residues in Food Grains, Vegetables, and Fruits

Pesticide or Pesticide residue refers to metabolic byproducts of the pesticides that may remain in food grains, vegetables and fruits after they are applied to crops. Many of these chemical residues, especially derivatives of chlorinated pesticides, can bioaccumulate potentially reaching harmful levels in both the body and the environment (Sachs *et al.*, 2010). Persistent chemicals can be magnified through the food chain and have been detected in products ranging from meat, poultry, and fish, to vegetable oils, nuts, and various fruits and vegetables (Crinnion *et al.*, 2009). Insects and pests can cause a loss in the quality and quantity of grains and their products. The application of pesticide is widely used for grains before harvest and after harvest to protect the grains from damage or loss. Cultivation and storage of grains often require an intensive use of pesticides, which may then be found in grains and in foods prepared from them (Vela *et al.*, 2016). Cereal grains are treated with degradable pesticides, such as organophosphates, carbamate, synthetic pyrethroids and insect growth regulators, to prevent insect infestations both during storages and prior to shipment (Collins *et al.*, 20017). The maximum residues level (MRL) is the highest level of a pesticide residue that is legally tolerated in or on food or feed when pesticides are applied correctly. Efforts by International bodies such as the European Union, Codex Alimentarius Commission, and North American Free Trade Agreement have attempted to harmonize pesticide legislation by providing maximum residue limits, but globally these limits remain variable.

2.8.0 Mechanisms of Action of Different Pesticides

Pesticides may exhibit numerous mechanisms of action based on the target pest. Here are a few typical mechanisms of action of pesticides.

2.8.1 Herbicides

Amino acid synthesis inhibitors act on an enzyme to inhibit the production of certain amino acids, which are important for the development and growth of plants. One type of herbicide stops the enzyme acetoacetate synthase (ALS), which makes branched-chain amino acids. ALS inhibitors include herbicides from the sulfonylurea family, and these compounds have a wide range of selectivity (Jablonkai, 2011). There is a process by which plants make the aromatic ring amino acids phenylalanine, tryptophan, and tyrosine. The herbicide glyphosate has been made commercially available to stop that process. The enzyme 5-enolpyruvyl-shikimate-3-phosphate synthase is blocked by the herbicide glyphosate and stops the growth of plants. Another enzyme that helps to make amino acids is glutamine

syntheses, which makes glutamine from ammonia and glutamate. This enzyme is also a target for herbicides because it helps to make amino acids (Jablonkai, 2011).

2.8.2 Insecticides

Numerous pesticides work by interfering with nervous system signals. Signal-interrupting chemicals are frequently potent toxins. Of this group, pyrethroids and organochlorines are the most important insecticides. Organochlorines, such as lindane and endosulfan, can indeed block gamma-amino butyric acid (GABA) channels and interfere with chloride ion (Cl⁻) flux in the nervous system. GABA is an inhibitory neurotransmitter in the central nervous system that plays a crucial role in regulating neuronal excitability. It binds to GABA receptors, which are chloride ion channels, causing an influx of chloride ions into the neuron. This influx of negatively charged chloride ions hyperpolarizes the neuron, making it less likely to generate an action potential and reducing neuronal activity (Roos *et al.*, 2015).

2.8.3 Fungicides

Fungicides act also through different modes of action that include inhibition of cell division, inhibition of ergosterol synthesis and by acting on sulfhydryl groups of enzymes of fungal cells. sulfhydryl (SH) is found in many enzymes that exhibit a significant role in fungicidal action. Dithiocarbamate fungicides attack the fungal cells enzymes and coenzymes that have SH group. Pesticides like captan and folpet work with enzymes that have SH groups. These fungicides change the structure and function of the cell membranes and stop the enzyme system (White *et al.*, 2010).

Tubulin is an essential protein of the intracellular skeleton, and benzimidazole inhibits the building of the intracellular skeleton by reacting with tubulin. Generally, pesticides prevent cell division by inhibiting the formation of microtubules. There are a lot of different types of fungicides that work this way; these include thiabendazole, carbendazim, and benomyl (Oruci, 2010).

Ergosterol-inhibitor fungicides can kill many different types of fungi, they stop the higher plants from making sterols and gibberellin. Sterols synthesis is a complex process, fungicides act on the synthesis path. There are several fungicides that are used as demethylase inhibitors such as pyridines, morpholines and piperazines (Bolognaise *et al.*, 2019). Furthermore, several fungicides that target many sites of the fungi that include inhibition antioxidant enzymes that lead to interrupt cell redox balance and several of them also prevent the nuclear factor-kB signalling cascade

consequently distress the numerous biochemical actions (Rath *et al.*, 2011).

2.9.0 Toxic Effects Of Pesticide Residues On Human Health

Many pesticides achieve their intended use of killing pests by disrupting the nervous system. Due to similarities in brain biochemistry among many different organisms, there is much assumption that these chemicals can have a negative impact on humans as well (Bjorling *et al.*, 2008). There are epidemiological studies that have shown positive correlations between exposures to pesticides through occupational hazard, which tends to be significantly higher than that ingested by the general population through food, and the occurrence of certain cancers (Damalas *et al.*, 2017). Although most of the general population may not expose to a large portion of pesticides, many of the pesticide residues that are attached tend to be lipophilic and can bio-accumulate in the body (Crinnion *et al.*, 2009). Toxic effects of pesticides depend upon their toxicological properties, the level of residues and degree of exposure of human beings to residues. The presence of pesticide residues in grains does not necessarily mean that it is hazardous. To be toxic, the residues have to be present in quantities large enough to be considered unsafe (Selvara *et al.*, 2014) The organophosphate, organochlorine and related pesticides act by binding to the enzyme acetyl cholinesterase, disrupting nerve function, resulting in paralysis and may cause death (Boon *et al.*, 2008). They may produce acute effects manifesting as meiosis, urination, diarrhea, diaphoresis, lacrimation, excitation of central nervous system and salivation. The chronic exposure in volvesneurotic and behavioral effects. Specific effects of pesticides can include damage to the central and peripheral nervous systems, cancer, allergies and hypersensitivities, reproductive disorders and disruption of the immune system (Mishra, 2014).

2.9.1 Acute Toxic Effects

Acute toxic effects occur within a few minutes to several hours after poisoning by pesticides (Gillet *et al.*, 2018). Poisoning impacts peripheral muscarinic and nicotinic receptors, as well as the central nervous system (Cetin *et al.*, 2010). Some manifestations of a cholinergic crisis include nausea, vomiting, diarrhea, abdominal cramp, urinary incontinence, meiosis, salivation, lacrimation, bronchorrhea, bradycardia, hypotension, fasciculation, muscle paralysis, dizziness, confusion, seizures, coma, and respiratory failure (Roos *et al.*, 2005).

These effects may occur immediately with exposure to pesticides. Moreover, if life-threatening complications

are not properly and immediately treated, death can also occur (Pretty *et al.*, 2018).

2.9.2 Chronic Disease

The likelihood of chronic health issues related to pesticide exposure is supported by a large number of data collected from laboratory (Corniani *et al.*, 2014). However, epidemiological data are not available for all health issues. It has been documented that various chronic diseases and disorders occur after people have been exposed to pesticides, including cancers, adverse reproductive outcomes, male sterility, peripheral neuropathies (Ratner *et al.*, 2016), neurobehavioral disorders, impaired immune function (Nankongnab *et al.*, 2020), and allergic sensitization reactions, particularly of the skin. Moreover, most of the pesticides examined affect male reproductive systems, causing sperm damage, DNA damage, and abnormal sperm morphology. As an example, cumulative inhalation of cholinesterase activity as a result of long-term, low-dose exposure to organophosphorus compounds leads to chronic diseases (Kalyabina *et al.*, 2021). Antonine *et al.*, tested the effects of low concentrations of Glyphosate; the decrease observed in levels of Clustering mRNA as suggested that glyphosate targets the integrity of Sertoli cells. The decrease in the numbers of germ cells from day 14 onward highlighted the chronic effect of glyphosate at 50 nm, 500 nm, or 5 μ m (Meltzer *et al.*; Mesnage *et al.*, 2019).

Three-million cases of severe acute poisoning may be matched by a greater number of unreported but mild cases of intoxication and acute conditions. Still, the numbers of cases of chronic effects are smaller than the number of acute effects. The high levels of acute and chronic morbidity urgently require medical and rehabilitation services. An unknown number of less serious health effects would add to the overall disease burden, while precise estimation of these effects requires future epidemiological studies. Children, pregnant women, aging populations, and workers directly exposed to pesticides are at higher risk of being affected by pesticides and their related diseases (Bolognesi *et al.*, 2019).

2.9.3 Carcinogenic Effects

Studies have revealed a correlation between pesticide use and sarcomas, multiple myelomas, cancer of the prostate, pancreas, lungs, ovaries, the breasts, testicles, liver, kidneys, and intestines as well as brain tumors. Zach and Ward, 1998; Alavanja *et al.*, 2004; ChemTrust, 2010).

2.9.4 Psychomotor Deficits and Physical Complaints

A clinical study showed that Gulf War veterans exposed to sarin and cyclosarin in Khamisiyah had impaired psychomotor fine motor skills, reduced visuospatial abilities, and deficits in motor function and coordination (Proctor *et al.*, 2006). After the Tokyo subway sarin attack, 23 subway workers exposed to sarin for 7 years had a chronic decline in psychomotor function. The highly exposed subway workers had significantly slower performance on finger tapping tests of both the dominant and non-dominant hands than the control group (Gullapalli *et al.*, 2018). In another clinical study, most of the victims of the Tokyo subway sarin attack were found to have long-lasting somatic complaints (such as gastrointestinal problems, constipation, heartburn, nausea, vomiting, colitis, migraines, headaches, backaches, and skin disorders) 5-6 years after the poisoning. The long-lasting somatic complaints and impaired psychomotor function of organophosphate-exposed victims may be related to neuronal damage in the cortex and thalamus (Nozaki *et al.*, 2019).

2.9.5 Oxidative Stress

In sub chronic or chronic organophosphate exposition induction of oxidative stress has been reported as the main mechanism of organophosphate toxicity (Ranjbar *et al.*, 2015). Oxidative stress is induced in both acute and chronic intoxication with organophosphate compounds in humans and experimental animals (Abdollahi *et al.*, 2010). Hyperglycemia is one of the mechanisms of oxidative stress in organophosphate intoxication (Rahimi *et al.*, 2008). Studies on chronic exposure to carbamate insecticides and case reports of long-term exposure give equivocal results. An extensive survey of the toxicology of the common insecticide, carbaryl, reports a variety of reversible neurobehavioral and neurotoxic effects in vertebrates, all associated with acute poisoning symptoms. The carbamate, carbofuran, has been observed to accentuate oxidative stress in rat brain by inducing lipid peroxidation and diminishing the antioxidant defense (Kamboj *et al.*, 2006).

2.9.4 Development of Cancer

The studies on cancer analyze the risks associated with the consumption of specific products which have some pesticide residues. These consumption products include fish, water, seafood, and milk or other dairy products. In general, these studies find a small but statistically significant association between cancer risks and some specific pesticide residues, such as dichlorodiphenyltrichloroethane and dichlorodiphenyltrichloroethane. Specifically polychlorinated biphenyls present a high risk for consumers. Organochlorine pesticide residue levels were

reported significantly higher in the cancer patients (Moon *et al.*, 2009).

2.9.5 Reproductive Disorders

Results indicated that increase of insecticides in blood level in vertebrates causes reproductive dysfunction and suggested that for human beings' food like fish, chick and goat containing beyond permissible limit of insecticides must be avoided (Singh *et al.*, 2008). Consumption of high pesticide residue fruits and vegetables was associated with lower total sperm count, ejaculate volume and percentage of morphologically normal sperm among men attending a fertility clinic. Pesticides exposure may lead to reduced fertility, early and late pregnancy loss, prolonged time-to-pregnancy, spontaneous abortion, and premature birth in female and genetic alterations in sperm, reduced sperm count, damage to germinal epithelium and altered hormone function in male (Bretveld *et al.*, 2018).

2.10.0 Preventive Measures To Reduce Pesticide Residues In Food Grains, Vegetables, And Fruits

Different types of pesticides are used in different countries for different types of crops to prevent pests, insects, and weeds. Because of the expansion of worldwide trade, more foods which are treated by pesticide are being imported into different countries. These worldwide trades increase the expansion of pesticide residues in different areas of the world and it's the issue of public health concern. There are a number of strategies which can be used to minimize pest and disease problems and reduce pesticide residues in food grains, vegetables and fruits (Gale *et al.*, 2017).

2.10.1 Organic Farming

One of the methods used to reduce the effect of pesticide residue in food is to eat organic foods that non-organic ones. According to standard meta-analyses the frequency of occurrence of detectable pesticide residues was four times higher in non-organic crops than organic crops (Baranski *et al.*, 2014). There is evidence that indicated organic food consumption can reduce exposure to pesticide residues in food (Smith-Spangler *et al.*, 2012). Organic crops, on average, have higher concentrations of antioxidants and a lower incidence of pesticide residues than the non-organic foods across regions and production seasons. It is advisable to consume foods rich in antioxidant to reduce effects of the chronic disease by suppressing oxidative activity. An increased dietary intake of antioxidant rich foods protects against chronic diseases, including cardio vascular diseases, certain cancers (e.g. prostate cancer) and neurodegenerative diseases (Wahlqvist *et al.*, 2013).

2.10.2 Washing Food Products

The second methods reported to reduce pesticide residue in food is washing. Washing may reduce pesticide residue in food commodities. Washing with water and various chemical solutions for domestic and commercial applications is necessary to decrease the pesticide residues. The efficiency of the washing treatments on pesticide removal depends on the washing solution, the chemical properties of the pesticide, the surface area, the nature of the food, the length of time the pesticide is in contact with the food, and the formulation and application method of the pesticide. Usually, the pesticide is lodged in the outer wax-like layers and then moves to the inside, making washing and removal of the pesticides less effective (Al-Taher *et al.*, 2013)

2.10.3 Processing Food Products

An important factor leading to a reduction of any residues left on crops at harvest are processing treatments such as washing, peeling, canning or cooking that the majority of foods receive prior to consumption (Holland *et al.*, 2019). Pesticide residue levels in fruit and vegetables may change due to processing, such as peeling, boiling, frying, fermentation, grinding (Gupta *et al.*, 2013).

2.10.4 Cooking also Reduces Pesticide Residues In Food

Boiling may remove 35 - 60% of organophosphate residues and 20 - 25% of organo chlorines (Holland, *et al.*, 2019). Husking and immersing of fruit and vegetables are reported to reduce pesticide residues especially organophosphates (Ziam *et al.*, 2009). Rational use of pesticides: Rational use of pesticides involves selection of correct pesticides, dosage rates, dilutions, timing, and frequency of application, treatment intervals, and method of application, precautions, and limitations. Rational use of pesticides can be useful to reduce pesticide residues in food products. In many cases, there may not be any need of a pesticide, particularly where cultural or biological methods are effective (Wahlqvist *et al.*, 2013).

2.10.5 Use of Natural Pesticides And Bio Pesticides

Bio-pesticides are biodegradable so no harmful residues are produced and are eco-friendly. Bio-pesticides encompasses a broad array of microbial pesticides, bio chemicals derived from micro-organisms and other natural sources that confer protection against pest damage. Some insect repellents can also be used for the prevention of pesticide residues accumulation in the food grains, vegetables and fruits. Natural pesticides such as extracts and compounds from neem tree are also very useful for the prevent (Gupta *et al.*, 2018).

2.11.0 Previous Studies on Pesticide Residues in Nigeria

Numerous studies have highlighted the presence of pesticide residues in foods from different regions, underscoring the global importance of pesticide contamination in the food supply. In Nigeria, agricultural practices in states such as Sokoto, Kebbi, and Zamfara have been associated with pesticide use and residue levels in food grains, vegetables, and fruits (Okafogun *et al.*, 2017; Alhassan *et al.*, 2021). While some studies have reported measurable levels of pesticide residues in these foods, comprehensive data on the extent of contamination and its impact on food safety and human health in these regions are still lacking. Recent research has also highlighted the need for systematic monitoring, regulatory enforcement, and sustainable pesticide management practices to mitigate the risks associated with pesticide residues in agricultural practice (Akinyole *et al.*, 2011; Saheed *et al.*, 2020; Odewale *et al.*, 2021).

Many authors have observed various reasons that lead to the misuse of pesticides in our environment, for example, Bon *et al.* (2015) listed reasons such as illiteracy of farmers, lack of knowledge about the risks of pesticides due to misuse, lack of clear instructions, use of pesticides on crops for which they are not intended, difficulty in properly preparing the solution to be used and poor adherence to dosage. Improper labeling of pesticide containers and inability of farmers to read the instructions on pesticide containers, which could increase the risk factors of exposure and poisoning as also observed by Ugwu *et al.*, (2015). Aminu *et al.*, (2020) in their study on pesticide use and health among cocoa farmers in Ondo and Kwara states, observed that they mix two or more chemicals to make the product stronger and more effective. They also found that the majority of farmers did not wear full protective clothing during application. However, Oshatumberu *et al.* (2023) reported the use of full PPE in Osun States, while about 67% of respondents in Lagos State reported the use of one or two PPE during pesticide handling and spraying (Adesuyi *et al.*, 2018). According to Akeem and Sofoluwe, (2012) in their study on pesticide use at farm level among maize farmers in Oyo State, they found that old age also contributes to the misuse of pesticides as many of them prefer old methods of pest control that are outdated, banned and no longer used. They also reported that old age reduces farmers' ability to take risks and adopt new techniques and ideas. Furthermore, they also noted the impact of education on pesticide use as educated farmers were able to read publications and access information on the internet on how to apply viable pesticide in correct proportion unlike the illiterate farmers. A corroborated report was observed by Adesuyi *et al.* (2018) in Lagos State.

However, Bulu *et al.* (2017) reported a contrary opinion that about 77.9% of farmers read the instructions on the pesticide containers before application, while 69.9% and 54.0% followed either the instructions given by the sellers or friends and relatives in Osun and Ogun states. They also reported that about 23.4% of the respondents' applied pesticides based on observations of how others applied it. They also observed that majority of the pesticide users in Ogun and Osun States take bath after spraying while low percentage of the users visit clinics, wear goggles and nose protection. Farmers were reported to be aware of the expiry date and that they can kill non-target organisms, and few of them drink or smoke cigarettes while spraying in the two states. The use of bare hands to scoop the pesticides was also reported. About 54% of the farmers in Fadan Daji Local Government of Kaduna identified the expiry dates on the labels of the pesticides, while about 46% of the respondents either checked the dates on the containers or asked the dealers for the expiry dates before using the pesticides as reported by Bassi *et al.* (2016) in Kaduna State. In the study by Adejumo *et al.*, (2014) on potential hazards of misuse of aluminium phosphide in Kaduna State, Nigeria, it was observed that majority of maize farmers misused these chemicals for storage of maize and even kept them in their houses where innocent children play, which may expose them to heart and kidney problems. They also noted that the majority of the farmers were male and illiterate, who could not identify the banned or fashionable pesticides to be used. This is because many of them had low level of education, i.e. (50%) had primary education. A similar observation was made by Adesina *et al.* (2015) who reported aluminium phosphide, organochlorines and alkane compounds as the major chemical residues in the food products sampled in major markets in Oyo State.

Borno State in north-eastern Nigeria contributes significantly to the national production of cereals and pulses and has received international support for these agricultural activities (Awofadeji, 2008). High levels of pesticide residues resulting from improper application and multiple spraying of sub-lethal doses have been reported to be responsible for poisoning and death of people in both rural and urban areas of Borno State and Nigeria in general.

Furthermore, Olufade *et al.* (2014) observed high percentage of insecticide residues (Aldrin) above the required limits in the food items (beans and dry yam chips) sampled in markets in Ile-Ife Southwest, Nigeria in the name of preservation. However, a contrary report was observed by Adeola and Oluwole (2022) in Ondo

State, where they reported full compliance of farmers with pesticide safety precautions such as proper handling, not mixing herbicides with fungicides, and using appropriate measurements in their cocoa farms. This was associated with the fact that majority of the farmers were well educated and able to understand the instructions on the labels and instructions for use of the chemicals. Olutona and Aderemi, (2019) reported indiscriminate use of pesticides by farmers, as cowpeas and beans sampled in selected markets in Ibadan contained high levels of pesticide residues in the name of preservation against pests.

A similar observation was reported by Oshatumberu *et al.* (2023) in their study of pesticide residues in grains in selected markets in the South-West, where high levels of pesticide residues in selected grains were observed in all the states studied. They also observed that majority of the pesticide users in Ondo and Ekiti states do not read the pesticide labels before application. The same observation of not reading the labels and not following the instructions was also observed in Lagos State by Adesuyi *et al.* (2018) in their study on pesticide-related knowledge, attitude and safety practices among small-scale vegetable farmers in Wetland Lagoon. Adeleke, (2009) in Ilorin also reported misuse of deadly chemicals on yam flour causing food poisoning affecting three households in Kano and the poisoned yam flour also affected five families in Ilorin Central Nigeria (Adedoyin *et al.*, 2008).

The following cases of bean food poisoning have been reported in Nigeria: NAFDAC report revealed that the offending beans originated from Taraba State (Northeast Nigeria). NAFDAC laboratory analysis reports of the moi-moi and beans from the victims' homes and beans from the open market in the state "contained outrageously high levels of organophosphates, carbamates, fenitrothion and chloropyrifos, which are highly toxic pesticides. They must have resulted from either higher-than-recommended doses or misapplication (Olufade *et al.*, 2014).

However, in 2008, several national dailies reported that 120 students of Government Girls Secondary School, Doma in Gombe metropolis (northeast Nigeria) were rushed to Gombe Specialist Hospital after consuming a meal of beans suspected to have been preserved with toxic chemicals - 10 of these students were reported to be in critical condition. Samples of the cooked beans consumed, samples of uncooked beans, palm oil, onions, Maggi, salt and other condiments used in cooking the beans were also tested at NAFDAC laboratories to ascertain the cause of the problem. The result of the

analysis showed that the samples of cooked and uncooked beans contained outrageously high levels of lindane, an organochlorine pesticide banned under the 1989 Rotterdam Convention (Awofadeji, 2008).

2.11.1 Risks of Pesticide Consumption

Food and Agriculture Organization (FAO) and World Health Organization (WHO) reported that, food contamination monitoring program found the presence of aldrin, dieldrin, DDT, lindane, heptachlor and heptachlor epoxide in human breast milk. The WHO and the United Nations Environment Programme estimate that 3 million workers in agricultural production in developing countries such as Nigeria are severely poisoned by pesticides each year, and about 18,000 of them die. As many as 25 million workers in developing countries were expected to suffer from minor pesticide poisoning annually (WHO, 2006; Bempah *et al.*, 2011). Bempah *et al.* (2011) indicated that the Hazard Quotient (HQ) values were higher, indicating that the health risks associated with the intake of endrin, aldrin, dieldrin, and heptachlor epoxide are higher, and therefore the human health risk was estimated to be higher than the Average Daily Intake (ADI) for the 10 kg weight group. The Estimated Average Daily Intake (EADI) for heptachlor epoxide and endrin exceeded the ADI for the 30 kg weight group, while the EADI for heptachlor epoxide exceeded the ADI for the 70 kg weight group. All pesticides with EADI higher than ADI had HQ greater than 1 (>1), indicating a high potential health risk from consumption (Bempah *et al.*, 2011). This finding is consistent with the studies conducted by Darko *et al.* (2008) who reported that lifetime consumption of perishable foods such as tomatoes and eggplant from Kumasi market (Ghana) could pose some health risk as the HQ was found to be greater than 1 (>1).

Another study investigated the levels of pesticide residues in three fresh fruits commonly consumed in Lagos State, Nigeria. The fruits (apple, watermelon and sweet orange) were collected from various fruit vending points in three local government areas; Eti-osa (Ajah), Lagos Mainland (Oyingbo) and Ifako-ijaiye (Ifako-Ijaiye).

The result of GC-MS analysis showed no significant difference ($P > 0.05$) in each fruit obtained per sampling locations. Fruits contained pesticides below the WHO/FAO limit, except for watermelon, which had mean pesticide residue concentration for atrazine (0.088-0.133 mg/kg), clothianidin (0.00-0.029 mg/kg), omethoate (0.094 - 0.205 mg/kg) and oxamyloxime (0.088 - 0.125 mg/kg) above the WHO/FAO MRLs of 0.02, 0.02, 0.01 and 0.03 mg/kg for atrazine, clothianidin,

omethoate and oxamyloxime, respectively (Saheed *et al.*, 2021).

2.12 Research Gaps and Future Directions

Although several studies have been conducted to assess the levels of pesticide residues in food grains, vegetables and fruits in different regions of Nigeria, including Sokoto, Kebbi and Zamfara states in the northwest, there remains a research gap in the comprehensive assessment of the long-term health effects of chronic exposure to pesticide residues among the local population in these regions. Previous studies have mainly focused on analyzing the presence of pesticide residues in food samples, but have not extensively investigated the potential health risks and implications for human consumers, especially in the context of sustainable agricultural practices and environmental conservation efforts. Therefore, there is a need for further research that not only quantifies pesticide residue levels but also explores the associated health risks, consumer awareness levels of food safety and public health in the North-West region of Nigeria. (European Food Safety Authority (EFSA), 2019).

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