Chapter

Chemical Pesticides and Food Safety

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Abstract

Pesticides are usually applied to protect crops against insects and other pests. These pesticides of synthetic origin are potentially toxic to humans and can have both acute and chronic health effects, depending on the quantity and ways in which a person is exposed. They play significant roles in food production as they protect or increase yields due to less attack by insect pests. This is particularly important in countries that face food security challenges. The general population—who are not in the area where pesticides are used—is exposed to significantly lower levels of chemical insecticide residues through food and water. Chemical pesticides are among the leading causes of death by self-poisoning, in particular in low- and middle-income countries. Adverse effects from these synthetic pesticides occur only above a certain safe level of exposure. When people come into contact with large quantities of it in food, it may cause acute poisoning or long-term health effects, including cancer and adverse effects on reproduction. Production, distribution, and use of pesticides require strict regulation and control. Regular monitoring of residues in food and the environment is also required. Best among all is the promotion and adoption of bio-insecticides as a better alternative to chemical insecticides.

Keywords: pesticides, food safety, public health, bioaccumulation, poisoning, chronic condition

1. Introduction

Actions for a noticeable increase in crop yields and food production over the last century have involved the use of pesticides and agrochemicals [1]. These chemical pesticides are used to provide protection to crops against weeds, fungi, insects, and other pests. Consequently, these chemical pesticides are potentially lethal to human and can exert both acute and chronic health effects, depending on the amount and the route of exposure.

World Health Organization reported that there are more than 1000 pesticides used around the world to ensure food is not damaged or destroyed by pests and each of these pesticides has different properties and toxicological effects. The cheaper and older and most likely the off-patent chemical pesticides, such as lindane and dichlorodiphenyltrichloroethane (DDT) tend to remain for years in soil and water. Due to this, some of these chemicals have been banned by countries that signed the Stockholm Convention of 2001—an international treaty that aims to eliminate or restrict the production and use of persistent organic pollutants.

The Stockholm Convention on the production and use of persistent organic pollutants mandates that each Party shall Prohibit, restrict and/or take the (i) legal and administrative measures necessary to eliminate the production and use of + chemicals as listed in the treaty; and (ii) it imports and export of the persistent chemicals as listed in the treaty and (b) it is the production and use of the chemicals as listed in the treaty. It also emphasized that each Party shall take measures to ensure that any chemical listed in the treaty is imported only for

i. the purpose of environmentally sound disposal

ii. a use or purpose which is permitted for that Party under Annex A or Annex B of the treaty

Notwithstanding, the high increasing human population and the need for farmers to guarantee good value for farming has further expressed the need for enhanced agricultural yield towards achieving increased food production. This need is provoked by the intensive damage to agro-products caused by pest attacks and diseases triggered by viruses, fungi, and bacteria. These pest attacks and diseases are also seriously affecting crop yield. It is based on this provocation that the increasing use of chemical pesticides has to be the case. However, [2] report identified that agrochemical residues did spread in the environment and food causing significant contamination of terrestrial ecosystems and poisoning human foods.

Alternatives to the intensive use of crop protection chemicals achieved through a science-based process that promotes efficient food production, enhances food safety, and guarantees environmental protection, are thus the necessary direction in reducing or eliminating the increasing use of chemical pesticides in agriculture, thus ensuring food safety.

2. The use of chemical pesticides in food production

Chemical pesticides in agriculture usually referred to as agricultural chemicals cover a wide range of compounds including insecticides, fungicides, herbicides, rodenticides, nematicides, and others [3]. After the banning of some of these chemicals for use in agriculture by most technologically advanced countries in the 1960s, organophosphates insecticides, carbamates, pyrethroids, herbicides, and fungicides were introduced between 1970 and 1980 [3]. These chemicals are said to have contributed immensely to agricultural pest control and agricultural output.

The benefits of these chemical pesticides cannot be overemphasized as the consequences of their effects lead to the advantages anticipated from their use. In re-emphasizing the benefits of these chemical pesticides in food production, it is important to note that without crop protection, including pesticides, more than half of the world's crops would be lost to insects, diseases, and weeds.

It is of importance to highlight that in the absence of pesticides, food production would be on the decrease, and increased cultivated farm areas would be necessary to produce the same amount of food, consequently impacting the wildlife habitat. The recurrent cultivation of the farm would be increase soil loss due to erosion, too. The other effects will include the decrease in agricultural production, rise in food prices, competitiveness for farmers in global markets would be less, and decrease in exports would drop, leading to many job losses.

Regardless of the benefits of pesticides, they can be harmful or hazardous to both humans and the environment. Innumerable chemicals are environmentally stable, toxic, and disposed to bioaccumulation. In some cases, pesticides can

persevere in the environment and remain there for years. Contamination of the environment or increased occupational use can expose the general population to pesticides residues, including physical and biological degradation products present in the air, water, and food.

3. Global application and management of chemical pesticides and its regulation

There is an ever-increasing global population and there has to be food to match the statistics. The United Nations Population Division estimates that there will be a tremendous increase on Earth emanating from developing countries by the year 2050 (9.7 billion people on Earth—around 30% more people than in 2017).

The Food and Agriculture Organization (FAO) estimated that, in countries of dwindling economy, Population growth keeps pace with the required increases in food production. This availability of food is seen to be increasing by 80%, and these increases are anticipated to emanate from rise in produces and the frequency crops are grown on the same land per year. This new production of food projected at 20% is likely to come from an extension of farming land [4]. Pesticide usage is almost inevitable in agriculture to maintain high yields and profits.

Pesticides can prevent large crop losses and will therefore continue to play a role in agriculture. However, the effects on humans and the environment of exposure to pesticides are a continuing concern.

Between the years 1970s and 1990s, most governments encouraged the usage of pesticides. This is evident in the amendment of several policies resulting in lessening in input subsidies as well as less monitoring by the government. This further led to more inflow occurring from the informal channels causing enhanced usage of pesticides and, leading to an increased import value by 261% from 2000 to 2010 [5].

In continents like Africa, nearly 59% of the population makes their living from farming, this is because the economy is highly dependent on agriculture [6]. Despite that, the African continent influences 2–4% of the international market for chemical pesticides which also accounts for the lowermost rate of their usage in the world [6]. Owing to the growing population, the food demand was projected in 2005 to enhance at a rapid rate in the next three decades [7]. This projection after the last decade remains valid considering the increased demand for pesticides, herbicides, and fungicides.

In Africa, the regulatory mechanism for pesticides is inadequate resulting in the import of pesticides that are banned. The farmers also lack awareness which causes poor pesticide practices and the usage of those pesticides which fall under the WHO risk classification system. Also, the registration of pesticides in West Africa is a multi-national process called Comité Sahélien des Pesticides (CSP) [8]. The African market is unregulated and does not comply with the code of conduct laid out by the Food and Agriculture Organization due to which most of the pesticides used are untested leading to the enhanced risks.

According to reports showing a limited capacity of CSP in Niger, 44% of pesticide dealers are unlicensed. Also, the registered chemicals account for only 8%, while 38% of pesticides have incomplete labels and 6% are unlabeled [9]. In the same report, 27% of the tested pesticides did not stipulate the active ingredients and 30% was tagged to be of poor quality. There are myriads of issues associated with pesticides usage in Africa.

In Southeast Asia, the use of pesticides in agriculture is increasing rapidly. An annual increase in the import of pesticides is reported as 61% for Cambodia, 55% for Laos, and 10% for Vietnam [10]. In the past 50 years, China has become the

major pesticide manufacturing country, and these pesticides are chiefly used for rice production [11]. The use of pesticides in China has increased from 0.76 million tonnes in 1991 to 1.8 million tonnes in 2011 [11]. In terms of use, Japan is also one of the largest pesticide users in the world and has the biggest pesticide market in Asia [12].

In a survey involving seven European countries including Germany, the Netherlands, Sweden, the UK, Denmark, Finland, and Latvia on the usage of pesticides in the urban or non-agricultural amenities, it was observed that the infiltrate on of arable lands in Europe has occurred swiftly due to improved application of insecticides. This ultimately has resulted in the loss of biodiversity and heterogeneity of the arable lands and other landscapes [13, 14].

The European Union has developed definite imperative regulation regarding pesticides usage. These include:

- Directive 2009/128/EC approved by European Parliament and Council in the year 2009: This directive is employed to manage methods and procedures to sustainably apply chemical pesticides;

- A regulation for sustainability and maintenance of Products of Plant Protection on the Market. This in the year 2009 was proposed in the European Parliament and Council and termed Regulation (EC) No. 1107/2009, and

- A regulation for monitoring the MRLs of chemical pesticides in food and its products, including plant-derived feeds and animals. This regulation was proposed by European Parliament and Council in the year 2005, and was termed Regulation (EC) No. 396/2005

4. Effect of chemical pesticides on safety of food: research studies implicating effect on human health

As population size increases in the world, the industrialization of agriculture and the escalation of animal production to meet the growing demand for food creates both opportunities and challenges for food safety. These challenges put more responsibilities on food producers and handlers to guarantee food safety. Food safety is the prevention of food contamination before its being released to the consumer. Access to sufficient amounts of safe food is key to sustaining life and promoting good health. Unsafe food containing harmful contaminants including chemical substances causes diseases ranging from diarrhea to cancers. Chemical contaminations can lead to acute poisoning or long-term diseases, such as cancer. An estimated 600 million (almost 1 in 10 people) in the world fall ill after eating contaminated food inclusive of chemical contaminants and 420,000 die every year, resulting in the loss of 33 million healthy life years [15].

Of most health concern are industrial chemicals and environmental pollutants which can accumulate in the environment without the exception of food and further accumulates in the human body when ingested. Some of these chemicals are very toxic and can cause reproductive and developmental problems, damage to the immune system, interfere with hormones. They are also made up of heavy metals such as lead, cadmium, and mercury which can cause neurological and kidney damage [15]. The harmful effects on human health linked with pesticide usage are considered by numerous factors, such as the chemical class in which those compounds belong, dosage, time, and exposure route. Insecticides accumulated in food can be lethal to humans at high and/or even lower doses [16]. Several health effects

can result from a prolonged exposure including the development of diseases such as cancer and neurodegenerative diseases, reproductive and developmental changes, and respiratory effects.

According to a study, an estimated 35% of all cases of cancer in the U.S. population originate from the diet, and the chemical pesticides present in foods are responsible [17]. Estrogenicity assays made by [18] show that pesticides of organochlorine origin usually act as endocrine disruption via more than one mode of mechanism, including agonist or antagonist effects of different receptors. Pre-emergent pesticides such as chloro-s-triazize which is popularly used in the world, have been generally considered as pesticides of low toxic potential for humans; nevertheless, there are many controversies on this issue. According to the Environmental Protection Agency (EPA), atrazine, for instance, was categorized as a chemical agent undoubtedly oncogenic to humans, even though the basis for this inference was only demonstrated in other animals [19]. This was also reported by the Development for Environmental Assessment Center of the United States, and Monographs of the International Agency for Research on Cancer (IARC). Since atrazine induces mammary tumors in female Sprague-Dawley rats, the EPA Office of Pesticide Program (OPP) through its Peer Review Committee resolved after its deliberations that atrazine be categorized in the Group of "Possibly Carcinogenic to Humans". Nevertheless, EPA has considered this chemical compound as most-likely non-carcinogenic to humans [2].

In certain studies, human exposure to high doses of atrazine can cause loss of body weight. Nevertheless, several epidemiological studies done with workers usually exposed to triazine indicate that these compounds show no potentials of been carcinogenic to the workers [20]. Furthermore, via analyses of different studies, it was observed that, though the chloro-s-triazine interferes in the endocrine responses of different species of mammals, their impending impact on humans seems to be primarily related to reproduction and development and not with human carcinogenesis [21]. An extensive list of epidemiological studies with the atrazine has described that the carcinogenic potential of this compound to humans is not conclusive [22], although there is a relationship between the high risk of prostate cancer and exposure to the insecticide [23].

The study by [24] evaluated the genotoxic and mutagenic effects of low concentrations of terbuthylazine, considered to be safe and, consequently accorded to possibly occur in occupational and residential exposures (ADI—Acceptable Daily Intake, REL—Residential Exposure Level, OEL—Occupational Exposure Level, and 1/100 and 1/16 LD50—Lethal Dose 50%—oral, rat), in human lymphocytes, with and without the use of metabolic activation (S9 fraction), using the FSH cytome assay and pan-centromeric DNA probes to evaluate the content of micronuclei and other chromatinic instabilities. The study showed that, treating terbuthylazine in the absence of metabolic activation indicated a dose-response escalation in the frequency of micronuclei of the lymphocytes exposed. The concentration of 0.0008 μg/mL (REL) tested was the basis of the significant data obtained. The hybridization of the micronuclei with the centromeric probe (C+) significantly occurred due to the concentrations ADI (0.00058 μg/mL), REL (0.0008 μg/mL) and OEL (0.008 μg/mL) of terbuthylazine. This was regardless of the presence or absence of S9, and nuclear buds containing centromeric signals, only in the presence of S9. Considering these outcomes, it was proposed that terbuthylazine presents a predominant aneugenic potential for the genetic material of human lymphocytes.

The chloro-s-triazine insecticide, which constrains the photosynthesis of weeds, by reaching photosystem II and impedes the effect of certain pests on crops has also being a serious food safety concern. It is a chemical used for

a variety of crops, such as maize, sugarcane, olive, and pineapple. Since the banishment of atrazine in European countries in 2006, chloro-s-triazines like terbuthylazine were recommended as its substitute since it is suspect of causing diseases in humans, such as non-Hodgkin lymphoma and lung cancer. A study showing the effects of persistent exposure (14 days) to low concentrations of terbuthylazine (0.58 ng/ml and 8 ng/ml) in human lymphocytes, using the comet assay and the comet-FISH assay (with the c-Myc and TP 53 genes) was carried out [24]. Treatment with the compound induced the migration of fragments of DNA in a significant manner, only for the highest concentration treated. The results indicated an impairment in the structural integrity of c-Myc and TP 53, as a result of the prolonged exposure of human lymphocytes to terbuthylazine. For the fact many copies of TP53 were affected by the compound, it indicates the ability of terbuthylazine to interfere in the control of the cell cycle negatively. Nevertheless, it was concluded that a more comprehensive evaluation of the risk of cancer associated with the exposure to terbuthylazine, be evaluated for the impact of these insecticides on other housekeeping genes and markers.

Concerning insecticides, a study by [25] assessed the genotoxic potentials using the FISH and comet assay, and the oxidative damages, by the TBARS lipid peroxidation, of different concentrations of glyphosate in human lymphocytes. These concentrations of glyphosate are similar to those observed in residential and occupational exposures and related to LC50. At concentration of 580 μg/mL, results from the comet assay indicated a stimulation with significant increase in the tail length, while at concentration of 92.8 μg/mL an increase in the tail intensity was noticed, both concerning the control test. However, the addition of the S9 fraction increased the tail length significantly, for all the concentrations tested. In furthering the experiment, an increase in the frequency of micronuclei, nuclear buds, and nucleoplasmic bridges were identified when the lymphocytes were exposed to the three highest concentrations without S9. It was the consequence of the addition of a metabolic activation system that only promoted a significant increase of the nuclear instabilities for the highest concentration tested. It was clearly shown that the values of TBARS significantly increased with the increase of the concentrations tested, regardless of the presence or absence of the S9 fraction. Because dose-dependent effects for all the assays used were not observed, the authors concluded that these concentrations of glyphosate are not relevant for human exposure, since they did not present a significant risk for human health.

According to a study by [26], paraquat, the second most widely used insecticide in the world, selectively accrued in human lungs by causing oxidative injury and fibrosis, causing several individuals to mortality. Chronic exposure to this insecticide is also linked with kidney failure, Parkinson's disease and hepatic lesions [27]. In the study by [26], they assessed the paraquat toxicity on BEAS-2B normal cells (human bronchial epithelial cells), which showed its dose-dependency resulting to death of lung cells exposed, damage of the mitochondria, oxidative stress, as well as production of pro-fibrogenic growth factors, cytokines, and transformation of myofibroblasts. In the study, the authors also demonstrated that polyphenolic phytoalexin naturally produced by several plants, resveratrol, to control bacteria and fungi, inhibited the production of reactive oxygen species, fibrotic reactions, and inflammations when induced by paraquat. This is as a result of the activation of the Nrf2 signaling (Nuclear Factor Erythroid-2), revealing a novel molecular mechanism for the intervention against oxidative damages as well as pulmonary fibrosis which resulted from the action of toxic chemical compound.

The study on the influence of a complex mixture of pesticides in workers exposed to them occupationally was carried out using the comet assay technique and standardly established cytogenetic methods (chromosome aberrations and

micronucleus assay). This study indicated that DNA migration significantly increased ($P < 0.001$). This suggests that over exposure to or ingestion of the pesticide may affect damages in the genome of somatic cells and, therefore, would pose a potential risk to human health [26].

5. Exposure to foods contaminated with chemical pesticides: overview of the public health concerns

Pesticide use has been closely associated with human poisonings and their related illnesses and has been long seen as a severe public health problem. The potential toxicity in pesticides has caused both acute and chronic health effects, depending on the quantity and ways in which the person is exposed (**Figure 1**).

The tenacious and pervasive nature of several pesticides used in agriculture and other carbon-based pollutants has posed chaos to mankind as a result of their high toxicity and potentials to bio-accumulate [28]. These chemical pesticides are identified to impede the usual effectiveness of reproductive and endocrine systems in living organisms [29]. Several pesticides such as dichlorodiphenyltrichloroethane (DDT), chlordane, aldrin, dieldrin, endrin, mirex, heptachlor, and hexachlorobenzene influence lethal effects on the health of human and the environment [28]. In the year 1990, a task force of the World Health Organization (WHO) estimated that about one million unintentional pesticide poisonings occur naturally, leading to approximately 20,000 deaths. There are also an estimated 385 million cases of unintentional acute pesticide poisoning UAPP occur manually worldwide including 11,000 fatalities. This estimation depends on the quality and validity of data as well as the estimation procedure [30].

In most regions of the world, the condition is even worse. Approximately 80% of the pesticides produced per annum in the world are used in developed countries [12], but less than half of all pesticide-induced deaths occur in these countries [31]. Increased proportion of pesticide poisonings and mortality occur in developing countries where there are insufficient occupational safety standards and regulations in its use on foods; insufficient enforcement; poor labelling of pesticides; illiteracy; and deficient knowledge of pesticide [31]. Moreover, usual pesticide residue levels in food are often higher in developing countries than in the developed countries. For example, a study in Egypt reported that most of assayed milk samples, when tested for fifteen

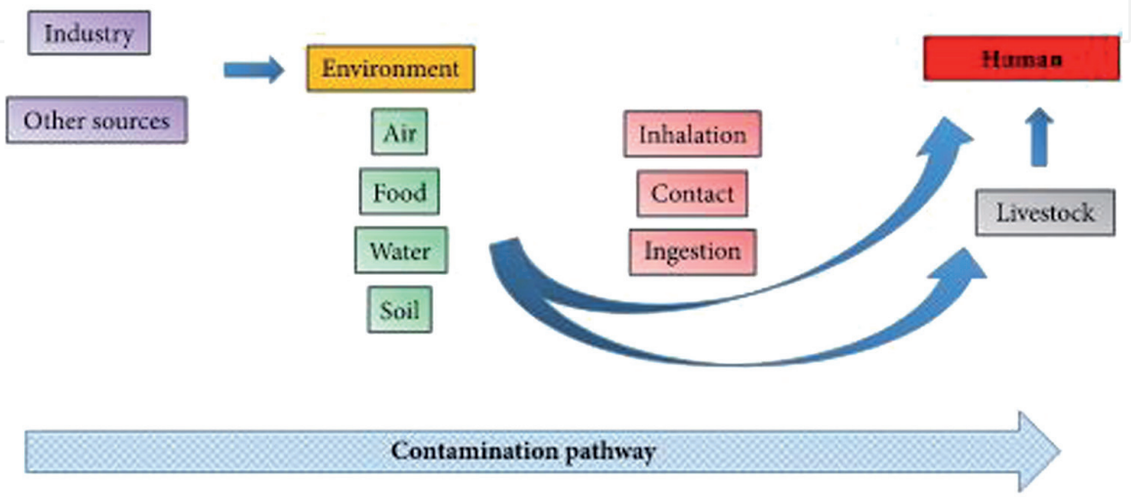

Figure 1.
Sources of chemical pesticide contamination in human foods [28].

different pesticides, contained residue levels between 60% and 80% [32]. By way of contrast, 50% of the milk samples analyzed in a US milk study had pesticide residues, all in trace quantities well below EPA and FDA regulatory limits [33].

Detectable levels of chemical pesticide residues are seen in about 35% of the foods purchased by consumers possess [34, 35]. Between 1 and 3% of these foods possess chemical pesticide residue levels that are beyond the permissible tolerance level [34]. Considering the analytical methods used in the developing countries, the residue levels may even be higher due to the reasons that they may detect just about one-third of the chemical pesticides in use. The rate of contamination is undoubtedly higher for fruits and vegetables because these foods receive the highest dosage of pesticides. One USDA study has shown that some pesticide residue remains in fruits and vegetables even after they have been washed, peeled, or cored [36]. Consequently, there are many justifiable reasons why 97% of the public is concerned about pesticide residues in its food [31].

All over the world, apart from exposure via contaminated food, pesticide exposure at the highest levels are found in farm workers, pesticide applicators, and people who live adjacent or very close to heavily treated agricultural land. Due to the fact that farmers and farm workers directly handle 70–80% of the pesticides they use, they are at the greatest risk of exposure [31, 37]. The epidemiological evidence suggests a significantly higher rate of cancer incidence among farmers and farmworkers in the US and Europe than among non-farm workers in some areas [34, 38]. In these high-risk populations, there is strong evidence for associations between lymphomas and soft-tissue sarcomas as well as between lung cancer and exposure to organochlorine insecticides [27].

Consequently, both the acute and chronic health effects of pesticides warrant attention and concern especially as it was used in farm food production and its storage. While the acute toxicity of most pesticides is well documented [39], there is no sound information on chronic human illnesses such as cancer. Though based on animal studies, the International Agency for Research on Cancer found "sufficient" evidence of carcinogenicity in eighteen pesticides and "limited" evidence in an additional sixteen pesticides [28]. However, some studies found no significant difference in non-Hodgkin's lymphoma mortality between farmers and non-farmers. In addition, [31] estimates that fewer than 1% of the human cancer cases in the US are attributable to pesticide exposure via food or otherwise. With the increasing number of cancer cases annually, [31, 40] assessment indicates that chemical pesticides causes less than 12,000 cases of cancer per year.

Studies with proven confirmation have also suggested that many severe and chronic conditions are linked with the use chemical pesticide [41]. For example, in an animal studies, dibromochloropropane (DBCP), the proscribed pesticide used for plant pathogen control, was found to cause testicular dysfunction [42] and was linked to infertility in human workers who had been exposed to the chemical [43]. Also, a large body of evidence obtained from animal studies suggests that pesticides can produce immune dysfunction [44]. In a study of women who had chronically ingested groundwater contaminated with low levels (mean of 16.6 ppb) of aldicarb, [44] reported evidence of significantly reduced immune response, although these women did not exhibit any overt health problems.

There is also growing evidence of sterility in humans and various other animals, particularly in males, due to various chemicals and pesticides they ingest through contaminated food and in the environment [45]. Sperm counts in Europe have reduced by about 50% and continue to decrease an additional 2% per year. In the study of [46], young male river otters in the lower Columbia River and male alligators in Florida's Lake Apopka have smaller reproductive organs than males in unpolluted regions of their respective habitats.

Even though it is habitually challenging to evaluate the influence of individual chemical pesticides, the serious health issues associated with organophosphorus related pesticides which have basically substituted the proscribed organochlorines are of specific interest [39]. The malady Organophosphate Induced Delayed Polyneuropathy (OPIDP) is well studied, reported, documented and is manifested by irreversible neurological defects. The deterioration of memory, moods, and the capacity for abstract thought has been observed in some cases [47], while other cases indicate that persistent neurotoxic effects may result even after the termination of an acute organophosphorus poisoning incident [39].

Chronic conditions such as OPIDP constitute an important public health issue because of their potential cost to society. For example, the effect of pesticides on children has become a growing concern [48]. Children can be exposed to pesticides daily through the foods they eat [31]. Considering the increased understanding of the distinctive biological differences between children and adults, it has shown noticeably that the current chemical pesticide acceptability level and the system of regulation, as it concerns children, is sternly lacking. Majority of the regulations are based on adult acceptability level and tolerances. Biologically, it is known that children's metabolic rates are higher than adults, and their capability to stimulate, detoxify, and excrete compounds that are xenobiotic in nature is dissimilar from that of adults. Also, considering of their slighter bodily size, children are exposed to increased levels of chemical pesticides per unit of body weight. Indication of this is seen in a study of [49] which reported that 50% of England and Wales pesticide poisonings involved children of or under the age of ten [49]. In general, the realization that children's sensitivities to toxins are much different than those of adults has provided the impetus for the movement towards setting specific pesticide regulations especially the level of residues in food with children in mind [36].

6. Conclusion

Chemical pesticides are often applied to control and manage weeds, and insect pests in the agricultural practices. Water, soil and air serve as dynamic medium for the movement of chemical pesticides from a point to another. Among several types of chemical pesticides, organochlorine and its related pesticides are the utmost risky ones as a result to their slow rate of decomposition, long half-life and greater stability. In the upper trophic levels of the food chain, these pesticides can move and accumulate. In any ecosystem, contamination by chemical pesticide is stern problem due to the harm it causes to all associated organisms. Hence, to control pesticide usage, novel methodologies and techniques are needed in curtailing the effect of widespread use of pesticides on the ecosystem including food production (farm to storage) and efforts should be made to provide awareness among the public to minimize the application of harmful pesticides. The better alternative remains in the use of microbial and plant-based bio-pesticides in control of field and storage pests as part of the integrated pest management (IPM). Also, the adoption of plant-incorporated protectants (PIPs) as seen in plants genetically modified to resist pests should be encouraged over chemical pesticides.

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