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Pesticide regulations and their malpractice implications on food and environment safety

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Abstract: Although pesticides have a positive effect on plant health in terms of insect pests and diseases control, increased productivity and improved crop storage, their malpractice impacts on food safety negatively. Pesticide residues and corresponding metabolites are left as runoff to the environment affecting non-targeted organisms like fish, bees, butterflies, birds and other beneficial organisms in soil and water bodies. Moreover, the application of pesticides in non-agriculture activities goes unnoticed, such as spraying for *anopheles* mosquito to control malaria. Human health effects caused by pesticide residues in food include headache, vomiting, itching and skin irritation, restlessness, dizziness, breathing difficulties, neurotoxicity and chronic poisoning-related diseases such as cancer and death incidences. Maximum residue limits are the maximum pesticide residues limit in food considered safe to human as set by the Codex Alimentarius Commission and the joint Food and Agriculture Organization/World Health Organization meeting on pesticide residues. The residues of dichlorodiphenyltrichloroethane and chlorpyrifos are reported in various foods globally. Additionally, food safety is largely obstructed by illegal use of pesticides and the presence of counterfeit pesticides in the market. This review provides detail on pesticide control and regulations, residues in food,

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PUBLIC INTEREST STATEMENT

Pesticides are useful in promoting food production by preventing insects and pests damage at various stages of food production. They are widely used in plant and animal production to prevent, destroy, repel and control pest during production, transport, storage and distribution of food. Also, pesticides are useful in controlling vectors such as *anopheles* mosquitoes responsible for malaria in the tropics. Despite their benefit, they may cause adverse health effects including restlessness, neurotoxicity, breathing difficulties, unconsciousness, cancer and death. At the same time, pesticide residues affect non-targeted organisms including aquatic life, bees, butterfly, birds, livestock and beneficial soil microorganisms. Communities should use pesticides responsibly by ensuring proper dosage and abide to disposal guideline as stipulated by regulatory authorities.



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their health impacts and link approaches like good agricultural practices for ensuring sustainability on safe food production.

Subjects: Agriculture & Environmental Sciences; Plant & Animal Ecology; Marine & Aquatic Science; Food Additives & Ingredients; FoodChemistry; Food Laws & Regulations

Keywords: food safety; pesticide residues; pesticide regulations; MRLs; GAP

1. Introduction

Pesticide refers to any substance purposely released into the environment for preventing, destroying, repelling, attracting or controlling any pest, including unwanted species of plant or animals (FAO, & WHO, 1997; Yamada, 2017). Pesticides are applied during the production stage, storage, transport, distribution and processing of food and feeds. They are also administered to animals for the control of ectoparasites (FAO, & WHO, 1997; Yamada, 2017). On the other hand, pesticides include substances used as plant growth regulators, defoliator, desiccant, fruit thinning agents, sprouting inhibitors and substances applied to crops either before or after harvest to protect them from deterioration during transport and storage (FAO, & WHO, 1997). Insecticides, herbicides, fungicides, nematocides and avicides are some of the examples (Botitsi, Tsipi, & Economou, 2017). Pesticides application has increased agriculture productivity, crops yield, crop protection, affordable food and increased farmers' income (Antonini & Argilés-Bosch, 2017).

Increased food demand to feed the growing population, which is estimated to be 8.5 billion people by 2030, has intensified the use of pesticides (Clark & Tilman, 2017; Crist, Mora, & Engelman, 2017). Globally, the average insecticides, herbicides and fungicide and acaricides usage from 1990 to 2010 was 342,000, 566,000 and 353,000 t, respectively (Liu, Pan, & Li, 2015). Also, Bernhardt, Rosi and Gessner (2017) reported 6 million metric tons as total global pesticides usage. Europe is the largest pesticides consumer followed by China and the United State of America (USA) (Benbrook, 2016; Hossain, Rahman, & Khan, 2017). Pesticides application in developing countries is about 25% with exceptionally high application on vegetables (de Bon et al., 2014; Schreinemachers & Tipraqsa, 2012).

However, uncontrolled pesticides application and abuse leave residues in the environment may persist leading to pollution and adverse human health effects (Udeigwe et al., 2015). Pesticide residues are also found in cereals, vegetables, fruits and honey and their corresponding products such as juices and wine depend on farmers' and processors' practices (Heard et al., 2017; Rivera-Becerril et al., 2017). Coupled to that, poor disposal affects non-target organisms like fish and other aquatic life, natural pollinators (bees and butterflies), livestock, birds and beneficial soil microorganisms (Buah-Kwofie, Humphries, & Pillay, 2018; van Lexmond, Bonmatin, Goulson, & Noome, 2015). For instance, organochlorines popularly used to control plant pest and diseases for years have been found very stable and persistent in the environment (Buah-Kwofie et al., 2018). Organochlorine pesticides (OCPs) such as aldrin, dieldrin, endosulfan, dichlorodiphenyltrichloroethane (DDT), hexachlorobenzene (HCB) and hexachlorocyclohexane (HCH) can persevere in the environment for years after application (Debnath & Khan, 2017; Kaushik, Chel, & Gadekar, 2017). Also, most of the pesticides are fat soluble as they can be found in milk, blood and fatty tissues accumulating in the food chain (Buah-Kwofie et al., 2018; Du et al., 2017). Human health effects associated with pesticide residues exposure include headache, skin irritation, itching, dizziness, restlessness, neurotoxicity, breathing difficulties, unconsciousness, chronic poisoning-related diseases such as cancer and death incidences (Evangelou et al., 2016; Guyton et al., 2015).

Therefore, this review puts together facts and scientific findings on pesticide application management, pesticides regulations, pesticide residues in food and their health impacts to lives. Also, link practices like good agricultural practices (GAP) and various food safety initiatives to promote safe food production practices.

2. Types of pesticides

Pesticides are classified based on active ingredients, chemical structure, mode of action and toxicity (Botitsi et al., 2017). There are organic and inorganic pesticides. Organic pesticides are carbon based, either natural pesticides from natural occurring materials or synthetic pesticides, synthetically produced from organic chemicals (Biondi, Desneux, Siscaro, & Zappalà, 2012; Cantrell, Dayan, & Duke, 2012). Inorganic pesticides are derived from mineral or chemical compounds that occur as deposit in nature, mainly compounds of antimony, copper, boron, fluorine, mercury, selenium, thallium, zinc and elemental phosphorus and sulfur (Patinha et al., 2018; Sarwar, 2016).

Additionally, pesticides are classified based on the acute oral and dermal toxicity to the rat as the standard toxicology procedure, presented as LD₅₀ in Table 1. According to the World Health Organization (2010), LD₅₀ is the statistical estimate of the number of milligrams (mg) of toxicant per kilogram (kg) of body weight required to kill 50% of the large population of test animals. Although most of the pesticides classification is based on the acute oral LD₅₀ value, dermal toxicity is always considered since pesticides handling takes a high proportion of dermal exposure (Maul, Blackstock, & Brain, 2018; Strickland et al., 2018). Moreover, according to Giusti et al. (2018), pesticides concentration in the air exposes community through inhalation. For instance, the use of the median lethal dose (LC₅₀) which defines the average concentration of chemicals as gas, vapor, mist, fume or dust is capable of killing 50% of the test animals exposed by inhalation under specific experimental conditions, expressed as milligram (mg) per liter (l) over a given period of exposure (Deadman, 2017). Pesticide formulation may contain more than one ingredient such as wetting agent of significant toxicity, then the classification should correspond to the toxicity of mixed ingredients (World Health Organization, 2010). Based on the active and inert ingredients and target pests, pesticides have different mode of action: interfering with amino acid and protein synthesis, nervous system, cell division, energy production, respiration, growth or development regulation, photosynthesis, deoxyribonucleic acid (DNA) damage and methylation, membrane integrity or multisite and sometime with unknown specificity (Table 2).

3. Counterfeit pesticides

Counterfeit pesticides are substances that may contain no/or very little active ingredients and substances that may pose threat to the environment, crops, animals, humans and inconsistent with the label misleading the public (Miszczyk et al., 2018). Counterfeit pesticide results into a range of food safety hazards; phytotoxicity due to their impurities and unregistered chemicals, decreased efficacy or no efficacy at all, increased unknown-uncontrolled residues in food and toxic substances getting into the food chain (Karasali, Kasiotis, Machera, & Ambrus, 2014). Presence of counterfeit pesticides in the market is a growing global jeopardy which largely affects consumers, national security, the economy and the environment (Drury, 2014). They are sold at a relatively low price as legal branded and generic pesticides resulting in unfair competition (Hoi, Mol, Oosterveer, van Den Brink, & Huang, 2016). Sales

Table 1. Classification of pesticides based on acute toxicity

Class		LD ₅₀ for rat (mg/kg body weight)	
		Oral	Dermal
Ia	Extremely hazardous	<5	<50
Ib	Highly hazardous	5–50	50–200
II	Moderately hazardous	50–2,000	200–2,000
III	Slightly hazardous	Over 2,000	Over 2,000
U	Unlikely to produce acute hazard	Over 5,000 or higher	

Source: World Health Organization (2010).

Table 2. Pesticides chemical type and mode of action

Chemical types	Mode of action and effect on pest	References
Organochlorine	Sodium channel modulator and nervous system disruptor, leading to convulsion and paralysis	Aliferis and Jabaji (2011)
Organophosphate	Acetylcholinesterase inhibitors, causing nervous impulse failure across the synapses leading to a rapid twitching of voluntary muscles hence paralysis and death	Aliferis and Jabaji (2011) and Heard et al. (2017)
Carbamates	Acetylcholinesterase inhibitors, affects nervous system and muscles	Aliferis and Jabaji (2011)
Pyrethroids	Sodium channel modulators; binds to voltage-gated sodium channels to depolarize nerves. Potent neurotoxins and endocrine disruptor leading to paralysis	Dekeyser (2005) and Heard et al. (2017)
Neonicotinoids	Nicotinic acetylcholine receptor competitive modulator binds nicotinic acetylcholine receptors leading to paralyses	Aliferis and Jabaji (2011)
Phenylpyrazoles (Fiproles)	Gaba-gated chloride channel blockers, affecting nerves and muscles	Buckingham, Ihara, Sattelle, and Matsuda (2017) and Wei, Mu, Wu, Wang and Gao (2017)
Organotin compounds	Endocrine disruption effects. Also, inhibition of oxidative phosphorylation	Glória et al. (2018) and Yan et al. (2018)
Pyrazole	Affect mitochondrial respiration	Aliferis and Jabaji (2011)
Triazine derivatives	Affects cell division cycle resulting into cell death	Baréa et al. (2018) and Nasr, Bondock, Youns, Fayad and Zaghary (2017)
Arsenic compounds	Predominantly DNA damage and epigenetic effect on DNA methylation	Heard et al. (2017)
Bipyridylum derivatives	Affect photosynthesis and photosystem	Aliferis and Jabaji (2011)
Copper compounds	Multisite activity, mostly DNA damage	Bednarska, Choczyński, Laskowski and Walczak (2017)
Nitrophenol derivatives	Respiration, affecting oxidative phosphorylation	Aliferis and Jabaji (2011)
Buprofezin	Chitin biosynthesis inhibitors	Sparks and Nauen (2015)
Imazamox	Targets nucleic acid, amino acid and protein synthesis	Velki and Ečimović (2015) and Zulet et al. (2013)
Propiconazole	Demethylation of C-14 in ergosterol biosynthesis, leading to accumulation of C-14 methyl sterols	Heard et al. (2017)
Avermectins	Glutamate-gated chloride channel allosteric modulator, affecting nerves and muscles causing paralysis	Aliferis and Jabaji (2011) and Sparks and Nauen (2015)
Triflumezopyrim	Nicotinic acetylcholine receptor competitive modulator, acting on nerves and muscles as a target	Cordova et al. (2016)
Diamides (cyantraniliprole)	Ryanodine receptor modulator; acting on nerves and muscles as a target	Sparks and Nauen (2015) and Troczka et al. (2015)

estimate of counterfeit pesticides is at 5–7% and 20–30% in developed and developing countries, respectively (Karasali et al., 2014; Płonka, Walorczyk, & Miszczyk, 2016).

The first illegal unlabeled and unregistered pesticide in Europe was uncovered in Spain (Miszczyk et al., 2018). Other attempts for introducing illegal pesticides in the market were uncovered in Italy, Germany, the Netherlands and Poland (Miszczyk et al., 2018). Responding to the situation, the European Food Safety Authority (EFSA), Emerging Risks Exchange Network through 2010–2014 stated that the use of the banned, unauthorized and counterfeit pesticides is one of the potential emerging risks (Costa et al., 2017). Some countries report neither low incidences nor counterfeit pesticides due to weak or inadequate control systems instituted (Hoi et al., 2016; Mununa, Mkenda, & Sikay, 2014). Also, farmers lack motivation in food safety issues as most of them are aware of counterfeit and illegal pesticides and use them to produce food for the public market and, at the same time, avoid them for food production intended for their families (Qian et al., 2018; Xianxia & Yunxi, 2018; Zhang, Li, Yu, & Yao, 2018; Zhao, Wang, Gu, & Yue, 2018). In other words, some farmers might be effective in protecting their families' health but not thoughtful about food safety and the environment. It is high time for policy makers especially in the developing countries to review and enforce pesticide regulations and product traceability policy to guarantee farmers' commitment to safe food production (Qian et al., 2018).

4. Pesticides control and regulations

Food industries and stakeholder need to ensure that food comply with legal requirements at all stages of the food chain. Accordingly, national authority and regulatory bodies have to control and enforce maximum residue limits (MRLs) by regularly checking pesticide residues in food. Although the Codex Alimentarius Commission (Codex) and Joint Meeting of the Food and Agriculture Organization of the United Nations (FAO) Panel of Experts on Pesticide Residues in Food and Environment and the World Health Organization (WHO) Core Assessment Group on Pesticide Residues (JMPR) have attempted to set, review and harmonize pesticide MRLs, globally these limits remain variable (Hamilton, Yoshida, Wolterink, & Solecki, 2017; Yamada, 2017; Yeung, Kerr, Coomber, Lantz, & McConnell, 2017). Developed countries have more stringent regulations than developing countries, with the later lacking expertise, commitment, resources and readiness to enforce legislation on pesticide residues (Handford, Elliott, & Campbell, 2015).

4.1. Pesticides control and regulations in developed countries

In the USA, pesticides safety is shared by the Environmental Protection Agency (EPA), which enforces pesticides registration, regulations and establishes MRLs in food and feeds; the US Department of Agriculture enforces MRLs in poultry and meat commodities; the Food and Drug Administration (FDA) enforces MRLs for plant commodities, fish, dairy products and processed food; the Occupational Safety and Health Administration ensures the safety of workers, working with pesticides such as farm workers; and the Fish and Wildlife Service and the National Oceanic and Atmospheric Administration oversee the administration of the endangered species (Ambrus & Hamilton, 2017). In Canada, the Pesticides Management Regulatory Agency has the mandate to protect people from pesticide risks and provide them with safe pesticide management tools (Islam, Bint-E-Naser, & Khan, 2017).

The European Commission (EC) is responsible for the approval of pesticide active substances in the European Union (EU), whereas member states authorize their use and competent authorities in the member state are allowed to verify compliance with MRLs in food (Ferrer, Lozano, Uclés, Valverde, & Fernández-Alba, 2017). The EC *regulation 396/2005* provides a harmonized system of setting MRLs for all food treated with pesticides (Brancato et al., 2018; Islam et al., 2017). Even the methods of sampling for pesticide residues determination are outlined in the EU document SANCO12571/2013 (Abdelraheem, Hassan, Arief, & Mohammad, 2015; Paoloni, Alunni, Pelliccia, & Pecorelli, 2016). The EFSA also works with regulatory bodies worldwide refining methodologies and provides risk assessors with new tools to determine possible combined effects derived from multiple pesticides exposure through food (EFSA Scientific Committee, 2015; von Goetz et al.,

2017). Moreover, foods imported to the EU member state are sampled to ensure that they do not contain illegal ingredients or pesticides above the set MRLs (Brancato et al., 2018). Likewise, in Russia, federal law No. 107 FL regulates pesticides application (Islam et al., 2017).

In Australia, pesticides regulation is the shared responsibility of the Commonwealth and the state and territories through the national registration scheme of the Australian Pesticides and Veterinary Medicines Authority and Food Standards Australia New Zealand which establish pesticide MRLs in food (van der Velde-Koerts et al., 2018). However, the use of pesticides is controlled and regulated by states and territories individually (Islam et al., 2017).

4.2. Pesticides control and regulations in developing countries

In Asian countries, for instance, the Institute for Control of Agrochemicals regulates pesticides in China (Han et al., 2018; Handford et al., 2015). China mostly adopted Codex MRLs as organized by the National Pesticide Residues Committee under the Ministry of Agriculture (MOA) (Yang, Luo, Duan, Li, & Liu, 2018). The MOA and the Ministry of Health, China develop pesticides residue limits as well as associated testing methods and procedures (Buijs, van der Meulen, & Jiao, 2018; Jia & Jukes, 2013). In India, pesticides are regulated under the Central Insecticides Board and Registration Committee, while the Food Safety and Standard Authority of India sets the MRLs of registered pesticides (Bedi, Gill, Aulakh, & Kaur, 2015; Nambirajan, Muralidharan, Manonmani, Kirubhanandhini, & Ganesan, 2018). However, some countries in Southeast Asia do not have pesticides legislation and regulations (Shahid et al., 2016).

African countries have adopted pesticide MRLs from the Codex limits or that of the importing country (Islam et al., 2017). Some countries do not have pesticides registry system leading to high frequency of using highly toxic illegal pesticides (Handford et al., 2015). Most countries have developed their pesticide laws and regulatory authorities although present several challenges, such as lack of fund and resources to enforce regulations. In Tanzania, pesticide registration, use, effectiveness and protection of public health and safety are regulated under the *Tropical Pesticides Research Institute Act*, while residues in food are monitored by the Tanzania Food and Drug Authority under the *Food, Drugs and Cosmetics Act No. 1 of 2003*, other legal framework includes *Pesticide Control Regulations, 1984* for pesticides import, *Plant Protection Act No. 13*, *National Environmental Management Act No. 20*, *Industrial and Consumer Chemicals (Management and Control) Act No. 3* and *Occupational Health and Safety Act No. 5*. In Kenya, the Pest Control Products Board regulates the import-export, manufacture and distribution of pesticides and provide the list of registered, restricted and banned pesticides. In Nigeria, the National Agency for Food and Drug Administration and Control is responsible for regulation of pesticide management; pesticide safety in Ghana is shared by the *Environmental Protection Act (EPA), No. 490 of 1994*, which is responsible for the whole pesticide cycle, Food and Drugs Authority (FDA), Ghana Standards Authority and the Ministry of Agriculture; the Agricultural Pesticides Committee is the legal authority for agricultural pesticides management and regulation in Egypt; in South Africa, pesticides are managed under *Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act*, governed by the Department of Agriculture, Forestry and Fisheries (Arora, Verma, Prakash, & Mishra, 2016; Islam et al., 2017; Onwona-Kwakye, Mengistie, Ofosu-Anim, Nuer, & Van Den Brink, 2018).

4.3. Pesticide MRLs

MRL is the maximum permissible concentration of a pesticide residues (expressed as mg/kg), recommended by the Codex Alimentarius Commission to be legally permitted and toxicological accepted on or in food commodities and animal feeds (FAO, 2013). It represents the highest residue that is expected if the crop is treated with pesticides according to the instructions on the label as well as approved usage in accordance with GAP (Yeung, Kerr, Coomber, Lantz, & McConnell, 2018). Determination of MRLs follows the general requirements of protected field trials, processing studies, rotational crop studies and supporting data from storage stability and analytical methods (Ambrus & Hamilton, 2017). It is the tolerable expression for compliance with the residue of concern for dietary risk assessment. Codex MRLs are primarily to enforce and control compliance with nationally

authorized pesticides use on commodities moving in international trade (Yeung et al., 2018). The burden of proof is on the monitoring authority to establish, with a high degree of assurance, whether the residue examined in the lot exceeds the MRLs, in order to take regulatory actions.

5. Pesticide residues and health impacts

Pesticide residue is any specified substance in food, agriculture commodities or animal feed resulted from the use of a pesticide (Kaushik et al., 2017). It includes any derivatives of a pesticide such as their metabolites, conversion products, reaction products and impurities considered to be of any toxicological significance (FAO, 2013). Some of the pesticides cannot be degraded easily and thus remain in the environment for years and can be bioaccumulated up to 70,000-folds of the initial active ingredient, for example the half-life of neonicotinoids in soil can exceed 1,000 days (Bonmatin et al., 2015). Frequent pesticides application has resulted into killing of beneficial organisms, increased pest resistance and loss of biodiversity, facilitating pest resurgence (Sparks & Nauen, 2015). Heptachlor, endrin, dieldrin, aldrin, chlordane, DDT and HCB are some of the persistent organic environment pollutants (Bonmatin et al., 2015; Kaushik et al., 2017).

Over use, poor storage, accidental spillages, inappropriate disposal, not using protective gears, mixing several pesticides in a single spray (cocktail application) are among pesticide malpractice leading to pesticides exposure (Lekei, Ngowi, & London, 2014; Ngowi, Mrema, & Kishinhi, 2016). The risks are exacerbated by ignorance and lack of information on pesticides handling, as some pesticide products are unlabeled and sometimes in the foreign languages (Bhandari, Atreya, Yang, Fan, & Geissen, 2018; Miszczyk et al., 2018). Also, farmers unknowingly purchase or obtain illegal versions of registered products, generic or counterfeit with neither clear directions nor safety warnings (Ngowi et al., 2016). For example, a global data review conducted by Stehle and Schulz (2015) revealed 52.4% of global water resources contaminated with insecticide residues above the legal levels, leaving the questionable integrity of water and aquatic food as far as food safety is concerned. Additionally, pesticides are tested on the active ingredients while they may contain highly toxic and carcinogenic substances declared as inert in the formulation, for instance, the adjuncts of glyphosate-based herbicides (Fritschi et al., 2015; Mesnage, Defarge, Spiroux de Vendômois, & Séralini, 2014). Most often, the ingredients declared inert has a greater tendency to contaminate the environment including ground water (Deadman, 2017).

The risks of pesticides exposure can be acute or chronic (Bonmatin et al., 2015; Du et al., 2017; Lekei, Ngowi, & London, 2016). Their effects vary depending on toxicity of active ingredients, concentration, time of exposure and individual's health status (Debnath & Khan, 2017). Their effects may include vomiting, headache, skin irritation, neurotoxicity, itching, dizziness, restlessness, mental confusion, unconsciousness, allergic reaction, breathing difficulties and long-term adverse effects such as kidney problem, birth defects, impaired reproductive system, tumor development, cancer and death incidences (Debnath & Khan, 2017). Infants, children and pregnant women may be more sensitive to pesticides exposure than other groups (Singh, Sharma, Parween, & Patanjali, 2018; Winter, 2017). For instance, Lekei, Ngowi and London (2017) reported 53 cases of children acute pesticides poisoning from 3 districts in Tanzania in the course of 2005–2006. Also, 2,952 children cases of pesticides poisoning and 66 children death incidences were reported from the Zhenjiang Provincial Center for Diseases Control and Prevention, China, in a 2006–2015 retrospective study (Yimaer et al., 2017).

6. Impacts of pesticide residues on food safety

Worldwide, people are unwillingly exposed to pesticide residues through food. Dietary exposure is the function of pesticide residues level in food and rate of consumption of that food (Zarn & O'Brien, 2018). Pesticide maximum residues in food are approved as legal MRLs by the Codex Alimentarius Commission (Codex) of the JMPR (Hamilton et al., 2017; Winter, 2017). The JMPR aims to protect consumer's health and ensures fair practices in international food trade (FAO, 2013).

If residues exceed MRLs, comparison of the exposure with Acceptable Daily Intake (ADI) and/or Acute Reference Dose (ARfD) is taken into account to assess the risk for the consumer whether

there is a possible chronic or acute health risks (FAO, & WHO, 2015, 2017). The ADI is the amount of pesticides to which human can be exposed daily for a lifetime without appreciable risks to the health on the bases of all known facts at the time of evaluation by the JMPR (FAO, & WHO, 1997). An ARfD is defined as pesticide exposure level at which no harmful effects are likely to occur in the most sensitive individuals in a population during a single day, exposure within 24 h (Hamilton et al., 2017). The ARfD is established for general population based on children and infants as well as women of childbearing age from 13 to 49 years (Hamilton et al., 2017). In that regards, the mean daily residue intake should not exceed the ADI over a period of time, while short time intake should not exceed the ARfD. Nevertheless, the JMPR meeting held on 8 and 9 September 2015 suggested pesticide exposure assessment methods for longer than 1 day, but shorter than lifetime exposures due to the fact that modern pesticides have little tendency to accumulate (FAO, & WHO, 2015). According to FAO and WHO (2018), “Whatever the future holds, food safety measures will need to be taken and when they are taken they will need to follow internationally agreed harmonized standards born out of consensus and founded on sound science, that is Codex”.

A study by Skretteberg et al. (2015), in the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden) revealed 111 different pesticide residues in 721 fruits and vegetable samples at wholesale, retail and storage room imported from Southeast Asian countries, and 14% were above the MRLs. Szyrka et al. (2015) conducted a study on pesticide residues in fruits and vegetable in Poland and found that 36.6%, 1.8% and 2.7% of 1,026 samples had residues, exceeded MRLs and unrecommended substances, respectively. Most of the articles referring to the EU pesticide residues in food report very low as compared to MRLs and neither exceeds ADI nor ARfD which is a good indication of strict regulations and active-functioning regulatory authorities (Zoller, Rhyn, Rupp, Zarn, & Geiser, 2018). For instance, the raising alarm on chlorpyrifos residues in fruits, vegetables, spice and herbs suggests a chance that may present public health risks although the values are below ADI, ARfD and MRLs (Sieke, Michalski, & Kuhl, 2018; van Asselt, Banach, & van der Fels-Klerx, 2018). Similarly, the USA has established a traceability mechanism for individual producers to conform to pesticide regulations and safe food (Zhang, Zeiss, & Geng, 2015).

Moreover, 8.7% of wheat, rye oat and barley sampled in Kazakhstan contained pesticides residue exceeding MRLs with OCPs, organophosphates and pyrethrin most frequently detected (Lozowicka et al., 2014). Significant amount of pesticide residues is commonly reported in China's fresh produces, although OCPs are detected at low concentration to MRLs (Fang et al., 2015; Zhang, Jin, Qiao, & Zheng, 2017). Consequently, Chinese consumers prefer food product that provides traceability information and quality certification of pesticides used in food production (Jin, Zhang, & Xu, 2017; Yu, Gao, & Zeng, 2014). Persistent organic pollutants mainly OCPs in the food chain in India are reported by several findings in almost all crops, although pesticide MRLs are set considerably higher compared to EU and USA (Jasbir Singh Bedi, Singh, Gupta, Gill, & Aulakh, 2018; Yadav et al., 2015).

In Argentina, a dietary risk assessment of pesticide residues reported 27, 22, 10 and 6 active ingredients to exceed 100% ADI in 6–23 months old children, 2–5 years old children, pregnant women and 10–49 years old women, respectively (Maggioni et al., 2017). Some of the ADI exceeding compounds were carbofuran, diazinon, dichlorvos, dimethoate, oxydemeton-methyl and methyl bromide mainly from milk, apple, potato and tomato consumption in the studied age groups (Maggioni et al., 2017).

OCP residues in Africa are among food safety hazards reported in vegetables, fruits, cereals, legumes, fish, meat, liver and milk in almost all countries (Thompson et al., 2017). A recent study in South Africa reported high levels of OCPs; heptachlor, heptachlor epoxide, dieldrin, endrin and aldrin residues in fish from iSimangaliso Wetland Park, indicating possible health risks associated with fish consumption (Buah-Kwofie et al., 2018). Moreover, fish sampled from Klip River in Soweto contained OCP residues; DDT, chlordane and HCH revealed food safety risks from contaminated fish (Pheiffer et al., 2018). Also, Nuapia, Chimuka and Cukrowska (2016) reported OCP exposure from cabbage, beans, fish and beef sampled in Johannesburg and Kinshasa, whereas values of DDT

and HCB were above MRLs set by FAO/WHO Codex in all samples. Likewise, Mekonen, Ambelu and Spanoghe (2014) reported chlorpyrifos ethyl, cypermethrin, deltamethrin, permethrin, endosulfan and DDT in red pepper, coffee bean and teff samples from Jimma town in Ethiopia, with one-third of the samples indicating residues above Codex MRLs. The residues are being accumulated from agriculture activities and *Malaria* control applications. No wonder, OCPs were detected and reported in human serum and breast milk in most of the African Countries (Thompson et al., 2017).

7. GAPs

GAPs are set of rules, principles and technical recommendations that ensure safe farming practices with reasonable pesticide use, providing an important step in food supply chain, traceability, food safety and sustainable production (Cuggino, Pérez Agostini, Kopp, & Novo, 2018). It is the voluntary audit designed to verify that produces are grown, packed, handled and stored as safe as possible (Olsen & Allen, 2017). It incorporates other practices which include integrated pest management (IPM), integrated crop management, standard operating procedures (SOPs), sanitation standard operating procedure programs (SSOPs), good manufacturing practices, good storage practices and hazard analysis critical control point (HACCP) (Cuggino et al., 2018). There are different adopted GAP audit protocols which may be applied to a wide range of farming systems at different scales; GlobalGAP, Harmonized GAP and Group GAP, all being driven by buyers and private sector food safety certification of agricultural produces around the world (Johannessen & Cudjoe, 2014; Shaw, Strohbehn, & Naeve, 2015). Also, GAP requires a documented farm food safety plan, traceability and recall plan, pesticide residues testing and a continuing observance of practices (Olsen & Allen, 2017). GlobalGAP is the key reference for GAPs that describe essential elements and best practices for agriculture production and demonstrate commitments to produce safe and quality food by reducing the risks associated with pesticides in a sustainable way (Pandit, Nain, Singh, Kumar, & Chahal, 2017). Moreover, it impacts and cares about occupational health, safety and workers' welfare. Although global compliance with GAP is optional, production for the European market requires compliance with GlobalGAP standards and certification (Cuggino et al., 2018).

As food production in the agriculture sector relies highly on smallholder farmers which necessitate technology transfer in agriculture a crucial approach to ensure their livelihood and guarantee safe food production (Ibrahim et al., 2018). The approach for food safety education that provides knowledge on GAP, guides development and documentation of food safety practices and aids growers' readiness for third party audit can provide the long-term and sustainable food safety knowledge, attitude and behavior toward GAP (Shaw et al., 2015). Moreover, integration of practices like HACCP to establish logical control points, IPM for alternatives to manage pests, SOPs, SSOPs with GAP to manage, regulate, control and dig down the root cause of pesticide residues in food are recommended (Alldrick, 2017; Schreinemachers et al., 2012; Uyttendaele, Jacxsens, & Van Boxstael, 2014). When farmers are informed and embark on GAP, they will obtain healthy, safe and quality food; assure the general population nutrition and income in a safer sustainable way.

8. Conclusions

Although pesticide residues below MRLs in food are considered non-hazardous to human, more research on chronic exposure are suggested because most of the pesticides are fat soluble and accumulate in body tissue over time. Regular investments in research are required to innovate non-persistence active chemicals for pest control. Consumers and all players in food production chains should be constantly informed on safe use of pesticides. This should include making convenient access to updated information on pesticides, use of generic and counterfeit pesticides and health risks associated to pesticide residues. Societies especially those working in pesticide factories and agriculture industries should be cautioned on other routes of pesticide exposure which includes skin, eye contact and inhalation and be monitored accordingly. It goes without saying, international, regional and national authorities have the responsibilities to guarantee safe food, free from pesticide residues and put in place traceability systems for both raw and processed food. Moreover, consumer bears responsibility to table safe food by ensuring safe source and abide to safe food preparation guidelines.

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Competing interest

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