Evaluation of pesticide residues on *Beta vulgaris* subsp. vulgaris, *Solanum tuberosum* and *Brassica oleracea* var. capitata in Bloemfontein

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Dissertation submitted in fulfilment of the requirement for the degree

MASTER OF HEALTH SCIENCES: ENVIRONMENTAL HEALTH

in the
Department of Life Sciences

at the
Central University of Technology, Free State

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Bloemfontein 2020

DECLARATION OF INDEPENDENT WORK

I, the undersigned, do hereby declare that this research project submitted to the Central University of Technology, Free State, for the degree MASTER OF HEALTH SCIENCES: ENVIRONMENTAL HEALTH my original and independent research work that is true and authentic. This research work has not been submitted before to any institution by myself or any other person in fulfilment of the requirements for the attainment of any degree or qualification.

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ABSTRACT

The presence of pesticide residues in vegetables and related fresh products agricultural products is a health concern to consumers. Thus, this study aimed to evaluate the level of pesticide residues in the staple vegetables; cabbage (*Brassica oleracea* L.), Swiss chard (*Beta vulgaris* spp.) and potato (*Solanum tuberosum* L.) from fresh produce markets in Bloemfontein area. A total of 15 vegetable (three per five sites) samples were analyzed for the presence of 16 selected, commonly detected pesticides using the quick easy cheap effective rugged and safe (QuEChERS) extraction method and further quantified using gas chromatography coupled to high-resolution time-of flight mass spectrometry (GC-HR-TOF-MS). Results from GC-HR-TOF-MS were used to estimate human health risk exposure and uncover the limitation of the Fertilizers, Farm Feeds, Seeds and Remedies Act No.36 of 1947 (Fertilizers Act) safety on the use of pesticides on vegetables to human.

The results revealed that all of the residues detected were below the maximum limits set by the Codex Alimentarius Commission (CAC). Vegetable samples analyzed had detected pesticide residues in 73.4% of the samples, while 26.60% had no compounds. The highest concentration of chlordane at 1.62 x 10^{-2} ng·g^{-1} and heptachlor at 1.22 x 10^{-2} ng·g^{-1} was detected from cabbage; followed by Swiss chard with endosulfan ether at the concentration of 1.33 x 10^{-2}; and lastly potato with methoxychlor at the concentration of 1.05 x 10^{-2} ng·g^{-1}. The highest estimated daily intakes (EDIs) for an average person was 10 % for aldrin of the acceptable daily intake (ADI). The most critical commodity was cabbage, contributing 1.27% to acute consumer health risk (aHI) for chlordane. Regardless of low levels of pesticide residues in vegetables.

Results in this study could indicate Good Agricultural Practices (GAPs) by farmers. However, there are still presence of long time banned pesticides residues such as hexachlorobenzene, lindane, heptachlor, heptachlor epoxide, chlordane, chlorbicyclen, dieldrin, endrin, methoxychlor, endosulfan ether, *p,p'*-DDE, *o,p'*-DDD, *o,p'*-DDT and aldrin. Thus, there are limitation and discrepancies in the Fertilizers Act, particularly on effective pesticide residues management in the country. Moreover, this shows the gap on the RSA pesticide monitoring program, procedure of pesticides registration and personnel training. To date, RSA only enforce monitoring adherence on exportation than the importation due to lack of expertise and expensive procedures mentioned. Furthermore, the regulations of the Fertilizers Act do not encourage co-ordination among departments that focuses on pesticides controls. These challenges impact the effectiveness of pesticides management and safety of agricultural products.

ACKNOWLEDGEMENTS

I want to express sincere gratitude to specific individuals and institutes for support and assistance in the completion of this study, notably:

- To the ALMIGHTY GOD for all His providence and wonderful Grace throughout this journey;
- Dr J.N Malebo, and Mr Z.P Khetsha for their incredible supervisory support, patience and provision of disciplinary expertise on the subject;
- Dr S. Ncube, who assisted in data analysis, despite his heavy workload and Ms Shela Lesetja (Librarian), who eagerly and swiftly provided with articles needed for this research;
- All members of the Unit for Applied Food Science and Biotechnology, especially Dr G.G Lenetha for the contribution in my work, and creating an outstanding atmosphere, thus making my studies enjoyable.
- The Central University of Technology, Free State and the National Research Foundation, for awarding me a postgraduate bursary.
- I dedicate this thesis to my loving husband, the pillar of my strength, Tshepang Thapelo Motshabi, my lovely boys Tshepo and Tshepang. Thank you for your endless support unending patience, assistance, love, support, guidance and encouragement during this trying time. To my mother, Ms Adeline Mokhemisa whom I am blessed to have around and who have taught me to live up to the motto of “have faith in God in all you do”. Special thanks to my brothers (Pule and Morena) for their love and support. I love you all dearly!

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LIST OF ABBREVIATION AND ACRONYMS

ADI:	Acceptable Daily Intake
AHA:	American Heart Association
aHI:	Acute consumer health risk
AOAC:	Association of Official Analytical Chemists
ATSDR:	Agency for Toxic Substances and Disease Registry
ARC:	Agricultural Research Council
ARfD:	Acute Reference Dose
CAS:	Chemical Abstracts Service
CCAP:	Committee on Pesticides in Central Africa
CCPR:	Codex Committee on Pesticide Residues
CEDAC:	Community Economic Development Assistance Cooperation
CH_3COOH:	Acetic Acid
CH_3CN:	Acetonitrile
$C_2H_8O_2$:	Ethyl Acetate
$C_2H_3NaO_2$:	Sodium Acetate
CoPR:	Control of Pesticides Registration
DAFF:	Department of Agriculture, Fisheries and Forestry
DAIC:	Directorate Agriculture Inputs Control
DDT:	Dichlorodiphenyltrichloroethane

d-SPE:	Dispersive-solid-phase extract
EDI:	Estimated Daily Intake
EFSA:	European Food Safety Authority
EPA:	Environmental Protection Agency
EI:	Electron Ionization
ESTI:	Estimate of Short-Term Dietary Intake
FAO:	Food and Agricultural Organization
FBDG:	Food-based Dietary Guidelines
FCDA:	Foodstuffs, Cosmetics and Disinfectants Act
FDA:	Food and Drug Administration
FFDCA:	Federal, Food, Drug and Cosmetics Act
FIFRA:	Federal, Insecticide, Fungicide and Rodenticide Act
FSIS:	Food, Safety and Inspection Services
FQPA:	Food Quality Protection Act
GAP:	Good Agricultural Practices
GC-MS:	Gas Chromatography-Mass Spectrometry
GC-HR-TOF-MS:	Gas Chromatograph High Resolution Time-of-Flight Mass Spectrometry
GCB:	Graphite Carbon Black
GDP:	Gross Domestic Product
GLP:	Good Laboratory Practice

HCH:	Hexachlorocyclohexane
HPLC:	High Performance Liquid Chromatography
IARC:	International Agency for Research on Cancer
IFSS:	International Food Safety Standards
ILO:	International Labour Organization
IOP:	Inter-Organization Programme
IOMC:	International Organization programme for the sound Management of Chemicals
ISO:	International Organization for Standardization
IUPAC:	International Union for Pure and Applied Chemistry
JMPR:	Joint Meeting on Pesticide Residues
LRS:	Legal Resources Service
$MgSO_4$:	Magnesium Sulphate
MRLs:	Maximum Residue Limits
NHANES:	National Health and Nutrition Examination Survey
NEMA:	National Environmental Management Act
NOAEL:	No-Observed-Adverse-Effect Level
OECD:	Organization for Economic Co-operation and Development
OHSA:	Occupational Health and Safety Act
PANAP:	Pesticide Action Network Asia Pacific
PCA:	Principal Component Analysis

PDP:	Pesticide Data Program
POPs:	Persistent Organic Pollutants
PSA:	Primary Secondary Amine
PTFE:	Polytetrafluoroethylene
QuEChERS:	Quick Easy Cheap Effective Rugged and Safe
RCF:	Relative Centrifuge force
RSA:	Republic of South Africa
SABS:	South African Bureau of Standards
SAEDA:	Subversion and Espionage Directed Against the US Army
SPSS:	Statistical Program for Social Sciences
STMR:	Supervised Trials Median Residue
UK:	United Kingdom
UN:	United Nation
USA:	United State of America
USEPA:	United State Environmental Protection Agency
UNEP:	United Nations Environmental Programme
WHO:	World Health Organization
WHOPES:	World Health Organization Pesticide Evaluation Scheme
WSSP:	World Summit of Sustainable Development

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND MOTIVATION FOR THE STUDY

Pesticides play a leading role in food production and are an essential contributor to the protection of crops against disease and pests (Akan *et al.,* 2013; Macharia, 2015). In the Republic of South Africa, as one of the primary users of pesticides in sub-Saharan Africa; the dual need to sustain both agricultural productivity and human health has become obligatory (Dabrowski *et al*., 2014). The use of pesticide impacts populations, farmer, consumer, exporter and end-user of food and water (Quinn *et al*., 2011).

Extensive use of pesticides has caused significant environmental destruction, and due to its ability to enter the tissues of vegetables, it affects human health (Pujeri *et al*., 2015). The deleterious effects of pesticides on human health have increased due to their ability to enter the food chain, toxicity and persistence in the environment (Gill and Garg, 2014). There is growing public concern about the extent of pesticide residue contamination of local fresh produce after harvest because pesticides are known to have potentially harmful effects on other non-targeted organisms than pests and disease (Keikotlhaile and Spanoghe, 2011). Pesticides cause adverse risks to human health and the environment, especially when farmers ignore the period between harvest time and spray intervals (Damalas and Eleftherohorinos, 2011; Amir *et al.*, 2015).

Some pesticides are persistent and remain in the body where they are further metabolised (Keikotlhaile and Spanoghe, 2011; Li, 2018). These pesticide metabolites are linked to a wide variety of health effects, ranging from acute to chronic toxicity; such as cancer, endocrine disruption and neurological effects (Fothergill and Abdelghani, 2013; Dabrowski *et al*., 2014). Pesticide poisoning is a global public health problem with an estimated three million acute poisonings occurring worldwide each year (Tago *et al*., 2014; UNEPA, 2016). Due to the side effects linked to pesticides, it has become crucial to control the use of pesticides within regulatory limits (Munawar and Humeed, 2013).

Developed countries pass appropriate legislation concerning pesticide use to ensure optimal safeguards; however, the situation is different in developing countries. The required advisory notes on the safe use of the products are in (almost) unreadable, the fine print on containers, and most are simply ignored! Most disturbing is the reality that even the basic regulations governing the importation of banned or restricted pesticides into some countries are mostly unenforced (Nnamonu and Onekutu, 2015). A study conducted in Nigeria showed that 93% of farmers used pesticides primarily to reduce losses due to pests and diseases in vegetable production (Abubakar *et al*., 2015), and this resulted in farmers facing risks of pesticide exposure due to the use of toxic pesticides that are banned or restricted (Damalas and Eleftherohorinos, 2011). Additionally, most farmers lack adequate knowledge of pesticide use and tend to ignore safety measures by not wearing protective clothing, proper pesticides storage, and proper disposal of pesticides (Quinn *et al*., 2011; Amir *et al.*, 2015). These findings highlight the need for continuous monitoring of pesticide residues on vegetables supplied by farmers as observed in developed countries.

More recent studies also indicate that farmers should improve pesticide safety practices and awareness to reduce potential health risks from chemical pesticide application and the ensuing hazards, especially by adhering to recommended pre-harvest interval applications (Abbassy, 2017; Jallow *et al*., 2017). Most developed countries have established regulatory frameworks in order to protect consumers;

amongst others, inspection bodies that monitor pesticide residue levels in food (Mutengwe *et al*., 2016a). Hence, pesticide residue analysis is a critical process in determining the safety of using certain pesticides. Pesticide monitoring programmes are essential to ensure that vegetables do not exceed the Maximum Residues Limit (MRL) regulated by the government (Keikotlhaile and Spanoghe, 2011). Furthermore, making informed decisions about reducing food-poisoning related problems, risk analysis is crucial because pesticides may induce adverse health effects, hence, produce should be tested for possible health effects before being authorised for use (Keikotlhaile, 2011; Eskola *et al.,* 2019). Such an assessment provides a scientific foundation of risk analysis on hazard identification, hazard characterisation, exposure assessment and risk characterisation (Keikotlhaile, 2011).

Pesticides are evaluated for compliance as part of safety assurance (WHO 2010a; WHO 2010b). The observed values are compared with the Acceptable Daily Intake (ADI) for chronic assessment for safety evaluation. Food safety is evaluated by observing levels of pesticides on vegetables and comparing these to health safety limits or toxicological endpoint values such as ADI, Acute Reference Dose (ARfD) and consumption patterns of different vegetables (Wanwilmolruk *et al*., 2015). Hence, the use of pesticides is regarded as a management issue at the farm level and government level. Consequently, one of the objectives of this study is to review the current Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 (Fertilizers Act) as amended (RSA 1947 as amended 1996), the regulatory framework of pesticide residues in the RSA including laws and regulations, management responsibility and safety of pesticides in ensuring human health safety on the use of pesticides in vegetables.

The agricultural sector is still faced with a number of significant constraints, like inappropriate pesticide use, lack of safety precautions, absence of effective control measures on MRLs, and absence of government's regulatory role on pesticide control. The use of pesticides for effective management is generating public health and environmental concern. No studies have been carried out to evaluate the presence of pesticide residues in vegetables at market level in Bloemfontein, Free State. This includes the studies to assess the health risk that might be posed by pesticides to humans and the environment. Some studies conducted thus far in the RSA reveal levels of pesticides in water, sediments, food, fruits and vegetables (Barnhoorn *et al.,* 2015; Keikotlhaile and Spanoghe, 2011; Dalvie *et al*., 2014) from past use of pesticides chemicals.

On the other hand, some of these studies were undertaken in other countries, and they never probed the relevant Acts. Moreover, the monitoring and assessment of pesticides levels in vegetables may provide the basis for risk assessment as a result of human exposure to these chemicals. This study intends to propose comprehensive monitoring of pesticide residues in vegetables and the assessment of the pesticide health risk to humans in Bloemfontein. Consequently, the results might be used when designing future control programmes for this area and in taking preventive actions to minimise human health risk if any is found.

1.2 PROBLEM STATEMENT

The Free State Province produces about two-fifths of South Africa's corn and wheat, and it also provides grazing for sheep. Bloemfontein is the sixth-largest city in the RSA and is situated in the Modder River catchment, which has insufficient water resources to meet the growing water requirements (Woyessa *et al*., 2006). The use of pesticides in agricultural areas can increase toxicity and pollution in the environment and compromise the availability of limited water resources. Pesticides are chemical pollutants extensively used for agricultural purposes due to their low cost and high effectiveness. They may accumulate in living creatures after decomposition.

Active surveillance is required to reduce pesticide exposures and poisonings, especially from illegal pesticides found in vegetables. Studies in Johannesburg and other places in the RSA have assessed the potential health risks associated with pesticides residues (Balme *et al.,* 2010; Mutengwe *et al*., 2016a; Nuapia *et al*., 2016); however, no such study has been conducted in Bloemfontein. Residues that are left on staple vegetables after pesticides have been applied during production are a health concern, especially in vegetables meant for human consumption. Many of the pesticide residues accumulate and build up to harmful levels in the body as well as in the environment. Some are persistent and can remain in the body for a long time, with a half-life of up to 10 years (Jayaraj *et al*.*,* 2016).

Pesticides can be harmful to human health, depending on the quantity consumed, and cause both acute and chronic health risks. It is therefore of paramount importance to continuously evaluate pesticide residue levels on vegetables. By the time fresh produce reaches the markets or retail outlets, residue levels on crops should be well below legal limits. Environment and human health risks are caused by the improper use of pesticides and the absence of stringent policy regulations of the pesticide.

1.3 AIM AND OBJECTIVES OF THE STUDY

The main aim of the study was to evaluate pesticide residues on staple vegetables (*Beta vulgaris* spp*., Brassica oleracea* L. *and Solanum tuberosum* L.) in

Bloemfontein, Free State in order to estimate the human health risk exposure. The estimation of human health risk will be correlated with the limitations on the Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 regarding the safety of the use of pesticides on vegetables grown for human consumption. To attain this aim, the following specific objectives had to be achieved:

- To review the Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 on the management and control of pesticide use.
- To evaluate selected pesticides residues on staple vegetables in Bloemfontein (Free State) fresh produce markets to compare with permitted Maximum Residue Limits.
- To estimate acute and chronic human health risk caused by selected pesticides found in staple vegetables.

1.4 HYPOTHESIS

Pesticides residues above acceptable levels exist in fresh produce markets in the Bloemfontein area. Consumption of cabbage with the presence of chlordane pesticides residues will lead to short and long-term human health risk.

1.5 THESIS OUTLINE

The dissertation is presented in five chapters. Chapter one gives background and motivation to the study. Chapter two is the literature review, and it includes the discrepancies and limitations in the Fertilizers Act and the effects of pesticides on human and environment. Chapter three provides the material and methods used to analyse the pesticides residues found in staple vegetables (*Beta vulgaris* spp., *Brassica oleracea* L. and *Solanum tuberosum* L.) and models used to estimate the health risks that may be caused by pesticide residues. Chapter four focused on the results and interpretation of pesticides residues found in staple vegetables in Bloemfontein fresh produce markets and also the estimation of acute and chronic health risks that may be caused by pesticide residues. Chapter five gives a general conclusion and recommendation for the Fertilizers Act review based on the levels of pesticides causing the acute and chronic risk exposures observed in the current study.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Pesticide poisoning is a global public health problem, and an estimated three million acute poisonings occur worldwide each year (Tago *et al.,* 2014; Gyenwali *et al*., 2017). It has been reported that pesticides related poisonings frequently occur in many countries due to lack of proper control of pesticides, insufficient resources and lack of training programmes for pesticide monitoring (Gerage *et al*., 2017). Health risk caused by residues include endocrine disruption, carcinogenicity, teratogenicity, mutagenicity and neurotoxicity (Dabrowski *et al.,* 2014).

Another major problem associated with pesticide exposure includes the use of banned pesticides, bioaccumulation and biological magnification. Early synthetic pesticides, such as dichlorodiphenyltrichloroethane, commonly known as DDT, were intensively used to control agricultural pests, cattle ticks and human parasites, but are banned today (Gerber *et al.,* 2016; Kim *et al.,* 2017; Rodrigues *et al.,* 2018). Furthermore, many synthetic pesticides are difficult to break down and may result in the occurrence of potential adverse effects on humans and wild animals (Harada *et al.,* 2016). Once they enter the body of an organism, they are permanently stored in the body tissue (Gerber *et al.,* 2016).

Pesticides are integrated into the tissue of an organism when a predator consumes it. As the predator consumes more exposed individuals, the concentration of pesticides in their own body will increase (Okoffo *et al.,* 2017). Organisms that are higher in the food chain will have increased concentrations of pesticides because they consume many lower-level organisms and thus take in the pesticides stored in those organisms (Deribe *et al.,* 2013).

According to Abubakar *et al.* (2015), most (93%) vegetable farmers apply pesticides (85%) without the use of protective clothing. Furthermore, the majority of the farmers tend not to use pesticides according to the procedures prescribed by the supplier (Sharifzadeth *et al.,* 2018). In one study, the majority of farmers (74%) used inorganic fertilizers, and 65% were reported not to be able to read agrochemical application instructions (Apeh, 2018). Due to such inappropriate practices, farmers increase the health risk of pesticide use.

According to Mwabulambo *et al*. (2018), personal protective equipment (PPE) such as a nose mask, rubber gloves, and overall, long coat, facemask and boots should be when handling pesticides and during the application. Of the total pesticide farmers participating in this study, 40% applied pesticides with no PPE, while the majority of farmers (60%) used PPE during pesticide application. Another study established that farmers who adapted extra personal protective measures were educated about protective equipment and pesticide exposure risks, and managed to reduce the risk of acute pesticide poisoning by 55% (Jensen *et al.,* 2011). Therefore, the failure of farmers to use PPE during pesticide application presents potential risks to pesticide exposure, and evidence shows that exposure can be reduced when handling or applying pesticides with caution.

Training farmers in the safe use of pesticides has been shown to increase safety behaviours. Without required training and management, farmers often do not take measures to prevent misuse or careless use of pesticides (Mengistie *et al.,* 2016; Moradhaseli *et al.,* 2017). Where this occurs, pesticide poisoning becomes a problem among farmers and workers, particularly in rural areas and in many developing (Abubakar *et al.,* 2015; Donga and Eklo, 2018) and developed countries (Harada *et* *al.,* 2016). A survey of acute poisonings in the RSA was conducted by Veale (2013) based on data of the Tygerberg Poison Information Centre. Veale's study showed that accidental exposure was more common than intentional poisoning (65.20% and 34.80%, respectively), and a predominance of accidental exposures (98.8%) and a male predominance (59.70%) was found among children. Pesticides were the source of 34.80% of poisoning exposures across all age groups. The study by Lekei *et al.* (2014) revealed that health care practitioners in northern Tanzania lacked adequate skills to diagnose and manage acute pesticide poisonings. Therefore, a need exists to include training in dealing with hazards, classification of pesticides and other poisonous consumables, diagnosis, and health effects in the training programmes.

2.2 PESTICIDES

Pesticides are defined as any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest or for use as a plant regulator, defoliant, or desiccant (da Silva and Chan, 2014; Joint FAO/WHO meeting, 2017). Pesticides play a leading role in food agriculture, and it is an essential contributor to the protection of the crop against disease and pests (Akan *et al.,* 2013; Macharia, 2015). Despite the beneficial results of using pesticides in the agricultural sector, their use also results in contamination of the environment and the accumulation of pesticide residues in food products (Fothergill and Abdelghani, 2013).

Pesticides are toxic to humans and the environment; most pesticides cause adverse health effects if ingested or if they are improperly handled and come in contact with the skin for a certain period. However, they need not be harmful if they are correctly used, and the safety guidelines are strictly observed and rigidly followed. However, even when these guidelines are adhered to, pesticide particles still may be inhaled with the air while they are being sprayed; another risk is the contamination of the environment, water and food plants, soil and untargeted organisms.

Pesticides can enter the human body through the skin, lungs and mouth (Genuis *et al*., 2016). They enter the body through the pores that release sweat from the body, or when suitable personal protective clothing is not worn when a worker mixes or sprays pesticides or becomes exposed (Okoffo *et al.,* 2017). Skin contact can occur when a piece of equipment, protective clothing, or a surface that carries a pesticide residue is touched. The pesticides also may enter the body through the lungs when a person is exposed, for example, when a worker breathes in pesticides due to working without wearing suitable personal protective equipment (Abubakar *et al*., 2015). The pesticides also may enter the body if a person takes contaminated food and drinks, or handles pesticides and then eats without washing the hands (Betterhealth, 2019). Therefore, the risk of illness increases as the concentration of the pesticide and the duration of exposure increase.

The possibility of becoming ill due to exposure to pesticides depends on several factors, including the type of pesticide, the amount of pesticide to which a person is exposed, the concentration or strength of the pesticide, the duration of the exposure, route of entry into the body, and other carriers or chemicals in the pesticide products (Sarwar, 2015). Hence, following the regulations and strict procedure of pesticide handling are essential (Damalas and Eleftherohorinos, 2011). The necessary precautions at all stages of pesticide handling are essential for reducing farmers' exposure to pesticides, including training and reading labels.

2.2.1 Application of pesticides to plants

The widespread use of pesticides by farmers provides many possible sources of pesticides in the environment. During application to crops, pesticide may land in the soil, in water and in the air we breathe depends on how it is applied, the weather conditions, like wind and rain, and the amount of care taken; pesticides do not always stay in the location where they are applied and then cause contamination (Mwanja *et al.,* 2017; Okoffo *et al.,* 2017). The irresponsible handling, storage and transport of pesticides also can lead to contamination of the environment (Gill and Garg, 2014). Increased exposure results in incorrect application techniques and poorly maintained or inappropriate spraying equipment (Damalas and Eleftherohorinos, 2011).

After pesticides have been applied to the crops because they spread across entire agricultural fields. Pesticides may interact with the plant surfaces and are exposed to environmental factors such as wind and sun (Gill and Garg, 2014). Additionally, the quantity of pesticides absorbed by a given plant generally depends upon the water solubility of the pesticide, the quantity of pesticide within the soil and the organic matter content of the soil (Akan *et al*., 2013). While still on the surface of the crop, the pesticide can undergo wash-off, volatilisation, and photolysis, and chemical and microbial degradation, potentially affecting other species (Keikotlhaile, 2011; Akan *et al*., 2013). Each pesticide or pesticide class comes with a specific set of environmental concerns. Such undesirable effects have led to many pesticides being banned, while regulations have limited and reduced the use of others.

2.2.2 Banned or restricted pesticides

Banned pesticides are pesticides that have been denied approval for first-time use, or withdrawn by industry either from the domestic market or from further consideration in the domestic approval process, where there is clear evidence that such action has been taken in order to protect human health or the environment (da Silva and Chan, 2014). Every country has its regulations and laws in this respect, in order to keep hazardous and toxic chemicals away from human consumption and the environment.

Agricultural residue pesticides such as DDT, malathion, cypermethrin, aldrin, endrin, chlordane, heptachlor, dieldrin, and endrin are currently banned due to bio-concentration and bio-magnification in the food chain and negative consequences to human health (Naidoo and Buckley, 2003; Gyawali, 2018). These substances were banned due to their toxicity, human exposure to chemical residues present in food, as well as the chemicals' persistence in the environment and toxification of biota (Deribe *et al.,* 2013).

Endosulfan is a substance that imitates or enhances the effect of the female hormone estrogen, which may cause reproductive and developmental damage to both animals and humans (Saxena, 2016; Patočka *et al.,* 2016). Endosulfan was banned in 2012, because of high its toxicity to humans and nearly all other organisms, and its persistence in the environment (DTI, 2016). Endosulfan on crops usually breaks down within a few weeks; however, it may stay in the soil for several years before it all breaks down (Patočka *et al.,* 2016).

The use of aldicarb, dinoseb and endosulfan (NDA, 2018) were prohibited by the Environmental Health Authority in the Republic of South Africa. These substances were contained in an insecticide which was found to be harmful to the human brain, and consequently, the insecticide was banned from indoor use in 2000 but continues to be sprayed on crops on farms across the Republic of South Africa. Furthermore, in the tropical regions of sub-Saharan Africa, compounds such as DDT, hexachlorocyclohexane and lindane, that are environmentally unmanageable, today are banned from use on farms in developed countries of the world, but tragically remain in widespread use in developing countries (Yadav and Devi, 2017).

Chlorpyrifos is an organophosphate, which was used to control and eliminate fleas, insects, termites, pests and mosquitoes. The use of the chemical was proven to harm children and foetuses (Grandjean and Landrigan, 2014; Wong *et al.,* 2015). The revised analysis of food crops and drinking water dietary exposure risks conducted by EPA showed a human health risk in the assessment of chlorpyrifos residues (Smegal, 2000). These include dichlorvos; organophosphates are associated with documented cases of poisoning resulting in acute or chronic adverse health effects (Mwanja *et al*., 2017).

The banning of pesticide chlorpyrifos was reported in the RSA by the Agriculture Department, the Legal Resources Centre (LRC) (IOL News, 2010). However, the safety of chlorpyrifos was reregistered by the United States Environmental Protection Agency (EPA) in 2006 after a thorough scientific review of its safety that was supported by more than 4 000 regulatory studies (UFPA, 2017).

Some pesticides as banned chemicals in the RSA that are harmful to the environment and result in long-lasting adverse effects include binaparcyl, dinoseb, chlordecone, monocrotophos, leptophos, dimethylammonium salt, dicamba, triclopyr and lindane still in use (AZchemistry, 2017). Dichlorvos has been among pesticides most commonly used pesticides since the banning of organochlorine pesticides, despite their World Health Organization classification (WHO) as “hazardous” (Wang *et al*., 2019).

Every country has its very own characteristic uses, application methods and regulations regarding pesticides; however, governments in developing countries do not adequately address the unsafe use of pesticides (Mwatawala and Yeyeye, 2016; Jallow *et al.,* 2017). Hence, in developing countries, a particular need exists for governments and industry, as well as every individual citizen or member of the public, and especially all consumers to fulfil their obligations of protection from insecticides, pesticides and other such substances that may threaten their well-being and health. Pesticide retailers play a crucial role in influencing farmers' choice of safe pesticides, in educating the farmers on pesticide use safety measures, informing them about restricted pesticides, and ensuring that they read pesticide labels carefully, and adhere to instructions (Wang *et al.,* 2015).

2.2.3 Pesticide residues on plants

Residue here refers to any specified substances in or on food, agricultural and other types of commodities or animal feed, as well as in environmental media including soil, air and water resulting from the use of a pesticide (Pandya *et al.,* 2014). The term "pesticide residue" includes residues from unknown or unavoidable sources (for example, environmental contamination), as well as known, authorised uses of pesticides (da Silva and Chan, 2014). Due to a large number of chemical and pesticide combinations, compounds have been classified for use in insecticides, algicides, miticides, herbicides, nematicides, fungicides, biocides, molluscicides and rodenticides (Garcia *et al.,* 2012). Pesticides also are grouped according to their chemical properties, and these include the organophosphates, organochlorines (chlorinated hydrocarbons), carbamates and thiocarbamates, and pyrethroids (Adewunmi and Fapohunda 2018).

Organochlorine

Organochlorine pesticides (OCPs) have been used worldwide since the 1940s to control pests and diseases in plants (Rodrigues *et al*., 2011; Samsidar *et al.,* 2018). Organochlorinated insecticides include DDT, chlordane, aldrin, dieldrin, heptachlor, endrin, toxaphene and Hexachlorocyclohexane (Tsai, 2010). DDT is used in the prevention of disease vectors such as malaria and other vector-borne diseases (Van den Berg *et al.,* 2017). These compounds are known for their high toxicity, slow degradation and bioaccumulation, and they were banned in developed countries. However, their use has been continued in some developing countries (Jayaraj *et al.,* 2016).

Organophosphates

Organophosphate (OPPs) insecticides are commonly used in agriculture (Vale, 2015). They are used in vegetable crops, fruit trees, grains, cotton, and sugarcane, among many others. Essential organophosphorus pesticides include disulfoton, azinphosmethyl, parathion, methyl parathion, chlorfenvinphos, dichlorvos, diazinon, dimethoate, trichlofon and malathion (Samsidar *et al.,* 2018). The use of OPPs is associated with a risk of breast cancer and increased risk of non-Hodgkin lymphoma. The OP use also is linked to several hormone-related cancers, including breast, thyroid and ovary cancer, suggesting the potential for hormonally mediated effects (Lerro *et al.,* 2015). Organophosphate pesticides (OPPs) have been shown to have effects on the immune system of rodents and fish reproduction (Díaz-Resendiz *et al*., 2015).

Carbamates

Carbamates are used as insecticides, herbicides, fungicides and nematicides. They are primarily used in agriculture to protect crops against agricultural and household pests (Fothergill and Abdelghani, 2013). The carbamate group mode of action is similar to that of the organophosphates, but carbamates are less persistent than organochlorines and organophosphates (Garcia *et al.,* 2012). Carbamates are reversible inhibitors, rapidly detoxified and eliminated from animal tissues (Naidoo and Buckley, 2003). Sometimes they are also used as stomach and contact poisons, as well as fumigants (Yadav and Devi 2017). Some of the widely used insecticides in this group are propoxur metabolite, 2-Isopropoxyphenol (2-IPP) and carbofuranphenol (Samsidar *et al*., 2018).

Pyrethroids

Pyrethrum is the natural extract that occurs in the flowers of *Chrysanthemum cinerariaefolium* and *Chrysanthemum cineum* (Schleier and Peterson, 2011). Pyrethroids are synthetic analogues of pyrethrins, insecticidal substances used to control pests in a variety of crops (Fothergill and Abdelghani, 2013; Sarwar, 2015). The main commercially available pyrethroids include allethrin, bifenthrin, cyfluthrin, lambda-cyhalothrin, cypermethrin, deltamethrin, permethrin, *d*-phenothrin, resmethrin and tetramethrin (Sainllenfait *et al.,* 2015). Pyrethroid use, in contrast to other insecticides, exhibits lower mammalian and avian toxicity and better selectivity to target species than OPs, and less persistence than organochlorine insecticides (Palmquist *et al.,* 2012). Both groups, the pyrethrins and the pyrethroids, are very important insecticides because of their rapid paralysis of flying insects, relatively low mammalian toxicity, and rapid rate of degradation in the environment (Schleier and Peterson, 2011).

2.3 VEGETABLES

Vegetables are herbaceous plants of which the roots, fruits, seeds, tubers and leaves are used as food (Akter *et al.,* 2011). They are considered essential for well-balanced diets since they supply vitamins, minerals, dietary fibre and phytochemicals (Dias, 2012a). A high intake of vegetables has been encouraged to prevent consequences due to vitamin deficiency and to reduce the incidence of major diseases such as cancer, cardiovascular diseases and obesity (Dias, 2012b; Slavin and Lloyd, 2012; Pem and Jeewon, 2015).

The present study focuses on the fresh vegetables mostly used by consumers, namely cabbage, Swiss chard and potatoes. Cabbage belongs to a *Brassica* class of vegetables, also known as cruciferous vegetables because their flowers are cross-shaped (Herr and Bücher, 2010). It is an excellent source of minerals and vitamins, and cabbage juice has been known to promote rapid healing of peptic ulcers (Mogala, 2017). Cabbage can be consumed raw, cooked or processed, and can grow in temperatures as low as 3°C (ARC, 2013a).

The potato is a most important vegetable crop in the RSA and the world’s recognized staple food, consumed by many people (Marketing, 2011). Potatoes are fat and cholesterol-free and high in fibre, vitamin C and essential minerals like potassium, phosphorus and calcium (Mogala, 2017). They are a crucial component in the worldwide fight against hunger and malnutrition and the creation of food security (Marketing, 2011; Prosekov and Ivanova, 2018).

Swiss chard is a biennial vegetable with luscious leaves, which is exceptionally nutritious (Ninfali and Angelino, 2013). It is a good source of magnesium, iron, folate and potassium as well as vitamin A and ascorbic acid, but is also low in calories and fat (Ninfali and Angelino, 2013). Swiss chard is a popular substitute for true spinach because it has a similar flavour and nutritional quality as spinach (ARC, 2013b).

It is estimated that the global production of food is required to increase by at least 70% by the year 2050 in order to feed the growing human population (Farha *et al.,* 2018). Vegetables are not only known as essentials for human consumption, but vegetable production also contributes to economic growth through job creation as a result of its links with the economy (Njaya, 2014; Schreinemachers *et al*., 2018; Warid, 2019). Consequently, it plays a significant role in reducing poverty (Huong *et al.,* 2013; Mwabu, 2016), and governments worldwide recommend the daily consumption of vegetables (Oyebode *et al.,* 2014).

2.3.1 Vegetables in the Republic of South Africa

The Republic of South Africa is a food-secure country in terms of aggregate food availability and is listed as one of 36 high-burden countries by the World Health Organization (Faber *et al*., 2011). Approximately 14.5% of South Africa's commercial farming takes place in the Free State province. This sector is critical to the well-being of the province, both as the provider of food and as a significant employer (FPM, 2008). However, there still is a significant challenge of malnutrition globally (WHO, 2018).

According to the reported estimates provided by the government, the total production of cabbage in 2011 increased by 1.3% in 2013, and production volume slightly increased by 2.3% when compared to the previous year’s output. During 2016, the cabbage production output increased by 3.2% in comparison to the previous year’s production output (Mogala, 2017). Potatoes account for over 50% of South Africa’s vegetable production (Ngobese *et al*., 2017). The Free State province produces about 100 000 tonnes of vegetables each year (FDC, 2019) and is responsible for 15% of South Africa's gross agricultural income.

Studies conducted in developing countries have shown a high prevalence of malnutrition (Vorster, 2013; Modjadji and Madiba, 2019). In 2014, over 10 million South Africans, 19.70% of the country’s population, reported having inadequate access to food due to unavailability, unaffordability, and poor quality of available food (Mbhenyane and Labuschagne, 2017). It is, therefore, essential to consider the consumption of vegetables to avoid malnutrition, which leads to diseases.

2.3.2 Vegetable consumption

South Africans, on average, are recommended to eat at least 400g vegetables and fruit per day, which equals five servings, which is considered the minimum by WHO for a healthy diet (PMA, 2014; Anand, 2015). Studies around the world have demonstrated the importance of regular consumption of a vegetable-rich diet (Kushi *et al*., 2012; Borokini *et al*., 2017). Vegetables are essential for good health and have been associated with improvement of gastrointestinal health, good vision, reduced risk of heart disease, stroke and chronic diseases which may be fatal (Dias, 2012a; Hartley *et al*., 2013; Wu *et al*., 2013; Hu *et al*., 2014; Li et al., 2014; Aune *et al*., 2017).

Insufficient consumption of vegetables is estimated to cause around 14% of gastrointestinal cancer deaths, about 11% of ischemic heart disease deaths and about 9% of stroke deaths globally (WHO, 2018). Globally, low vegetable consumption in 2015 accounted for 44.6 million disability-adjusted life years (DALYs - healthy years lost to heart-disease-related disability or death) (AHA, 2017). In a recent study, it was found that South African rural communities show a higher prevalence of low vegetable consumption than urban communities (Okop, 2018).

Furthermore, high consumption of fruit and vegetables was shown to be significantly associated with a lower risk of all-cause mortality (Wang *et al*., 2014). This indicates that vegetable consumption can also be associated with mortality; this was demonstrated in an investigation among a cohort of Swedish men and women (71,706 participants). The results of the study indicated that in comparison with participants who consumed five servings of fruit and vegetables(FV) per day, lower consumption was associated with progressively shorter survival and higher mortality rates. Those who never consumed FV lived three years shorter and had a 53% higher mortality rate (Bellavia *et al.,* 2013). It is, therefore, essential to guide people on the importance of a healthier diet in combating malnutrition-related public health problems through vegetable consumption.

The implementation of Food-Based Dietary Guidelines (FBDG) has been investigated in South African in response to the burden of disease (Nguyen *et al*., 2017). Implementing FBDG in the national school curriculum is regarded as an important factor in optimizing schools' physical environment (Nguyen *et al*., 2017). The purpose of FBDGs is to change the eating behaviour of the general population towards diets that meet their energy and nutrient requirements and help protect them against non-communicable diseases (Alasfoor *et al*., 2013). As a need for specific FBDGs exists, motivated by prevailing health risk factors and dietary intakes in the RSA, the implementation of such guidelines, and the development of educational material, an implementation plan, and monitoring and evaluation programmes should be a priority. The use of guidelines to educate people on how to follow a healthier diet could be a powerful tool in combating malnutrition-related public health problems throughout a person’s life course (Vorster *et al.*, 2013).

Policies worldwide should promote the availability and affordability of vegetables. Growers need better returns to ensure the resilience of quality horticulture value chains to supermarkets. Public and private policy needs to enhance the skills and empowerment of workers and support social provision to increase the appeal of working in horticulture (Barrientos and Visser, 2013). Additionally, African countries need to take into account the effects of pesticides on their ability to deal with food security, malnutrition, and lowering mortality rates.

2.3.3 Pesticide use in the production of vegetables

Food safety has become a primary public concern worldwide due to pesticide residues in food resulting from the direct application of pesticides to crops (Grace, 2015). Pesticides are toxic substances and are persistent, thus, and food becomes the primary source of exposure of the general population to pesticides. Vegetables are one of the supplementary sources of carbohydrates, lipids, vitamins, minerals, antioxidants and other essential nutrients. A high intake of vegetables is encouraged to prevent negative consequences due to vitamin deficiency and to reduce the incidence of major diseases such as cancer (Pem and Jeewon, 2015), cardiovascular diseases, and obesity. However, fresh vegetables also might be a potential source of harmful and toxic substances.

It is estimated that about 25% of crops in developing countries are exposed to pesticides use, with high application reported for vegetables (de Bon *et al*., 2014). A general requirement exists for documentation of pesticide use on vegetables by farmers to ensure that food complies with legal requirements at all stages of the food chain (Facts Network, 2017). Developed countries have more stringent regulations than developing countries to enforce regulations on pesticide residues (Handford *et al.,* 2015). The chemicals used in pesticides are regulated by the United States Environmental Protection Agency (EPA), United States Department of Agriculture (USDA), and the Food and Drug Administration. Such agencies monitor the types and amount of pesticides used on vegetable crops (Zikankuba *et al.,* 2019). Based on scientific evidence, these agencies have deemed the use of pesticides to be safe and the residues that remain on food, if any, do not cause adverse health effects.

2.3.4 Reducing excess pesticides on vegetables

There are relatively few pesticide excess reduction tactics that have been proposed safe and have a reasonable chance of success under a variety of different circumstances (Gill and Garg, 2014). These include the monitoring of pesticide residues in food after pesticide application, taking into consideration proper pesticides application, and restriction of certain pesticides. The most difficult challenge is monitoring pesticide reduction in food production, especially with the world population being expected to grow to nine billion people by 2050. Farmers may want to reduce pesticide use, due to concerns for their health; however, they do not have access to information on alternatives. Hence, the optimized use of pesticides is essential to reduce human impact on the consumption of the contaminated food while reducing their effect on humans.

Human should reduce their exposure to pesticides because of its links to severe illnesses. Pesticide exposure has been found to be related to health risks such as cancer, nervous system diseases and reproductive problems (PANUK, 2019). Similarly, a study in Bangladesh has linked exposure to pesticides to an increase in the prevalence of neurological disorders, Parkinson's disease, leukaemia, cancer, asthma and many more (Kim *et al.,* 2017). Hence, exposure to pesticide residues should be avoided.

Pesticide residues in food can be controlled by using alternative pesticides that are less harmful to human health and the environment. Farmers may also have to consider spraying less often during the growing season because the detected residue concentrations might double with increased treatment for some products, while other pesticides will disappear faster and hence do not result in increased residues on crops (Delcour *et al.,* 2015). In addition, routine monitoring of pesticide residues is necessary for the prevention, control and reduction of health risks (Okoffo *et al.,* 2017).

Markets that sell fresh produce to the public are required to adhere to pesticide tolerance limits defined as the amount that may legally remain on food post-production. In the RSA, the Department of Health agencies perform relatively low levels of testing on vegetables and information remains limited on the extent to which vegetables sold at fresh produce markets may expose South African consumers to elevated levels of pesticide residues relative to domestically grown produce (Makhafola, 2010). Furthermore, the National Environmental Management Agency (NEMA) provides for control of pesticide use through the licensing system and ensures that only acceptable pesticides are allowed in the country and found on the South African market (DAFF, 2010). Furthermore, a monitoring programme in Zambia ensures that pesticide residues in vegetables do not exceed maximum residue levels allowed by the government, that is, there is no misuse of pesticides that could result in unexpected residues in food (Mwanjwa *et al*., 2017).

The risk of pesticides for human health can also be minimized with commercial processing operations applied to food, such as washing, peeling (Yang *et al.,* 2017), frying and freezing (Keikotlhaile and Spanoghe, 2011; Syed *et al.,* 2014; Wanwimolruk *et al.,* 2015). Moreover, treatment of vegetables with acidic and alkaline solutions can effectively minimise the pesticide residues (Ahmed *et al.,* 2011). Reports show that surface pesticide residues can be more effectively removed by a sodium bicarbonate (baking soda - $NaHCO_3$) solution when compared to either tap water or bleach (Yang *et al*., 2017).

Strict implementation of pesticide-related laws and amendments to reduce cases of pesticide residues in food is a necessity. Additionally, the negative impacts of pesticides can be reduced by proper education of farmers regarding pesticide usage and handling, and by training (Syed *et al.,* 2014). Hence, to align farmers' practices with sustainability goals, a screening framework is required that aids farmers and other relevant stakeholders in identifying the most sustainable pesticides under specific conditions. Such a framework must apply to a wide range of pesticide-crop combinations and settings (Steingrímsdóttir *et al.,* 2018).

2.4 PESTICIDES HEALTH RISK ASSESSMENT

Risk assessment of pesticides is described as a process intended to calculate or estimate the risk to a given target organism, system or population, including identification of attendant uncertainties, following exposure to a particular agent considering the inherent characteristics of the agent of concern as well as the characteristics of the specific target system (Wood, 1996; Covello and Merkhoher, 2013). Therefore, in the context of pesticide use, risk assessment is a process for describing and quantifying the risk associated with pesticides.

Risk assessment for pesticide residues in food is conducted globally by the Joint Meeting on Pesticide Residues (JMPR), which comprises the WHO core assessment group and the FAO panel of experts on pesticide residues in food and the environment. The WHO Core Assessment Group is responsible for reviewing pesticide toxicological data and estimating acceptable daily intakes (ADI), acute reference doses (ARfDs) and characterizes other toxicological criteria (FAO, 2019c). The risk assessment process includes hazard identification, hazard and risk characterization, and the WHO, in collaboration with FAO, is responsible for assessing the risks of pesticides to humans (EPA, 2019). They recommend adequate protection against the risk of pesticides, both through direct exposure and through residues in food (Kim *et al.,* 2017).

Hazard identification is the first step in risk assessment, and recent international regulations require that hazard identification be performed before a pesticide can be approved for usage in agriculture or other areas (Keikotlhaile and Spanoghe, 2011). In order to assess the risks of pesticide use for human health, and for the authorization of pesticide commercialization in Europe, data of potential adverse effects of the active substances on human health are required. Such data usually are obtained from several tests focused on metabolism patterns, acute toxicity, sub-chronic or sub-acute toxicity, chronic toxicity, carcinogenicity, genotoxicity, teratogenicity, generation study, and also irritancy trials using rats as a model mammal, or in some cases dogs and rabbits (Damalas and Eleftherohorinos, 2011).

Hazard characterization is the qualitative and, wherever possible, quantitative description of the inherent property of a pesticide having the potential to cause adverse effects. This, wherever possible, should include a dose-response assessment and its attendant uncertainties (Benford, 2013). The acceptable daily intake is calculated by dividing the no-observed-adverse-effect level (NOAEL) for animal studies with an uncertainty factor of 100 to convert to a safe level for humans. A factor 100 (10 x 10) is used to account for species differences and individual variability in sensitivity to the chemicals (Watkins and Klaasen, 2010).

The Acceptable Daily Intake (ADI) procedure has been used to calculate permissible chronic exposure levels for humans based on non-carcinogenic effects. The ADI is the amount of a chemical to which a person can be exposed each day for a long time without suffering harmful effects. It is determined by applying safety factors to the highest dose in human or animal studies which has been demonstrated not to cause toxicity (Ibanez *et al.,* 2010). The no-observed-adverse-effect level is the highest dose of the pesticide that does not cause detectable toxic effects on the test organisms.

Exposure assessment is the process of measuring or estimating the intensity, frequency and duration of human exposures to an environmental agent. Exposure to contaminants can occur via inhalation, ingestion of water or food, or the skin. Contaminant sources, release mechanisms, transport and transformation characteristics all are critical aspects of exposure assessment, as are the nature, location and activity patterns of the exposed population (Gerba, 2015). Exposure assessment is required to decide on the acceptability of Maximum Residue Limits (MRLs) globally.

To assess the level of risk globally, the JMPR establishes limits for safe intake to ensure that the amount of pesticide residues people are exposed to through eating food over their lifetime will not result in adverse health effects (WHO, 2018). In exposure assessment, the potential intake or consumption of pesticide residues is divided by the body weight and compared to ADI or ARfD (Zarn and O'Brien, 2018). However, short-term intake above the ADI is not necessarily considered a health hazard.

Exposure to residues in food becomes harmful only in extreme instances. When amounts of residues are ingested daily over a lifetime, it may have chronic long-term risks to consumers due to accumulation (Keikotlhaile and Spanoghe, 2011). In order to measure the risk of pesticides exposure, the concept of ADI is used. The acceptable daily intake is the estimated amount of a substance in food, usually expressed in milligrams of the pesticides per kilogram ($mg \cdot kg^{-1}$) on body weight.

The ADI is set based on all known facts at the time of evaluation, considering sensitive groups within the population (EFSA, 2013). For this purpose, the Codex Alimentarius was established by the FAO of the United Nations and WHO to develop International Food Standards (Berry, 2016). The Codex Committee on Pesticide Residues (CCPR) establishes the maximum limits for pesticide residues and environmental contaminants in food and monitors the methods of sampling and analysis (Bateman, 2010; Richter *et al.,* 2018).

The acute reference dose is the amount of the pesticide that can be consumed in a single intake. An estimation of the ARfD is required to evaluate the safety of all pesticides. The acute reference dose is an estimate of the amount of a residue in food expressed as a percentage of body weight. It can be consumed over a short period, usually one meal or one day, without any known effect on health (ECHA, 2016).

Maximum residue limit (MRL) is the maximum concentrations of pesticide residues which are legally permitted in food crops if pesticides are applied to the crop according to good agricultural practices (Fothergill and Abdelghani, 2013; Munawar and Humeed, 2013). The MRL is the maximum concentration of a pesticide residue recommended by the Codex Alimentarius Commission to be legally permitted in or on food commodities and animal feeds (Wanwimolruk *et al.,* 2015).

Therefore, exposure to a particular pesticide below the health safety limit is considered safe, but the concentration may be above the established Maximum Residue Limits (Fothergill and Abdelghani, 2013). Maximum Residue Limits are set at levels which would result in the consumption of any residue at a level substantially lower than the ADI or the ARfD for the pesticide, and any residue level which exceeds the MRL would not receive approval.

2.4.1 Human risk assessment

Pesticides are stored in the colon from where they slowly, over time, poison the body. Human exposure to pesticides can occur through ingestion of contaminated foods, drinking water, and animal products because of bioaccumulation, inhalation, or skin contact (Bakırcı *et al.,* 2014). Pesticides exposure can lead to severe effects on human health, ranging from acute impacts, such as nausea, headaches, and skin and eye irritation, to lasting impacts, such as cancer, neurological and development defects, diabetes, reproductive disorders, congenital disabilities, and cardiovascular disease (Mostafalou and Abdollahi, 2013).

Chronic exposure risk

Chronic exposure risk is the ability of a pesticide to cause adverse health effects over an extended period, usually after repeated or continuous exposure, which may last for the entire life of the exposed organism. This type of pesticide risk is of concern not only to the general public but also to those working directly with pesticides, given the potential exposure to pesticides found on or in commodities, water and the air. It is measured in experimental conditions usually after three months of either continuous or occasional exposure (Damalas and Eleftherohorinos, 2011).

Acute exposure risk

Acute exposure risk of a pesticide refers to the pesticides' ability to cause injury to a human or animal from a single exposure of short duration. Acute risk studies are conducted to determine the short-term adverse effects of a drug when administered in a single dose, or multiple doses for 24 hours by examining the dermal toxicity, inhalation toxicity, and oral toxicity of test animals (Colerangle, 2017).

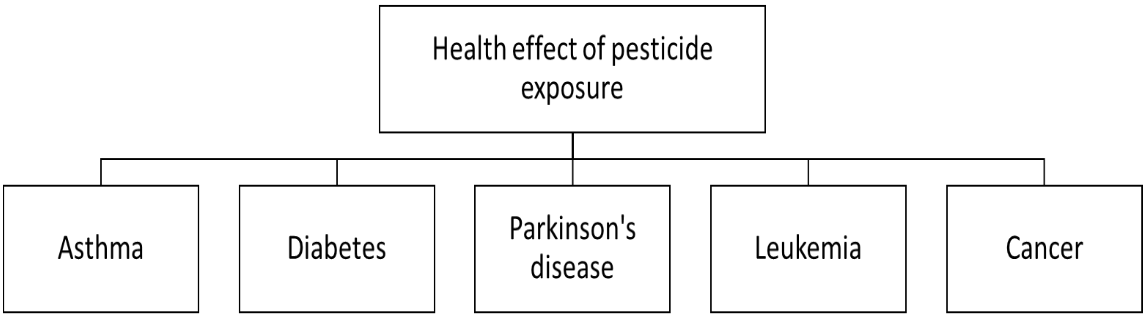


Figure 2.1: Human health impact of pesticide exposure (Kim *et al.,* 2017).

Circumstantial evidence exists of the relation between exposure to pesticides and elevated rates of chronic diseases observed in farmers and consumer (Njoku *et al.,* 2017). Pesticides are related to various diseases, including cancer risk, for example, organophosphate (OP) use is associated with several hormone-related cancers, including breast, thyroid and ovary, as well as leukaemia, Parkinson's disease, diabetes and asthma, as early-life exposure to OP pesticides is associated with respiratory symptoms consistent with asthma in childhood (Lerro *et al.,* 2015;

Macharia, 2015; Gunier *et al.,* 2017). Figure 2.1 displays the general types of health impacts caused by pesticide exposure (Kim *et al.,* 2017).

Asthma

Asthma is a common chronic inflammatory disease of the airways, characterised by variable and recurring respiratory symptoms (wheezing, breathlessness, chest tightness and dry cough), airflow obstruction, and increased bronchial responsiveness (Lötvall *et al.,* 2011). In some studies, it was found that exposure to pesticides is associated with respiratory symptoms consistent with a possible diagnosis of asthma (Amaral, 2014). Exposure to organophosphate (OP) pesticides was associated with respiratory symptoms consistent with possible asthma in childhood (Raanan *et al.,* 2014). Outcome measurements included respiratory symptoms, immunological status and lower airway inflammation.

Diabetes

The global health problem of diabetes creates a major public health burden (Taylor *et al.,* 2013; Li *et al.,* 2014). The global burden of diabetes was estimated to be 171 million in 2000, and it is projected to increase (Rowley *et al.,* 2017) to at least 366 million by the year 2030 (Bazzano *et al.,* 2005). The presence of OC pesticides in several environmental compounds like food and soil may pose a risk factor for human health. Most studies have investigated the relationship between exposure to specific agricultural pesticides and diabetes incidence among some populations. It can be demonstrated that simultaneous exposure to various persistent organic pollutants (POPs) in the general population may contribute to common precursors of type 2 diabetes (Cooper *et al.,* 2012; Sharaf *et al.,* 2013).

Parkinson's disease

Parkinson's disease (PD) is a progressive movement disorder characterized by progressive bradykinesia, rigidity, rest tremor and postural disturbances (Baltazar *et al.,* 2014). According to Betarbet *et al.* (2000), PD is associated with pesticides and other environmental toxins. A study conducted in the USA by Tanner *et al*. (2011) found that pesticides caused mitochondrial dysfunction, and another group of pesticides, including rotenone and paraquat, inhibited mitochondrial complex I and caused oxidative stress.

Leukaemia

Parental occupational pesticide exposure before birth may be a risk factor for childhood leukaemia. An association was found between residential and childhood pesticide exposure and childhood leukaemia; additionally, maternal occupational pesticide exposure during pregnancy and paternal occupational pesticide exposure around the time of conception had been suggested to increase the risk of leukaemia in the offspring (Bailey *et al*., 2014; Malagoli *et al.,* 2016). Furthermore, Gunier *et al.* (2017), after assessing parental occupational pesticide exposure from the year before pregnancy to the child's third year of life, found an increased risk of acute lymphoblastic leukaemia (ALL) due to paternal occupational exposure to any pesticides. Therefore, an increased leukaemia risk among children residing close to crops production indicates the need to consider preventive actions, including educational measures, to decrease the use of pesticides and pesticide exposure of consumers (Chen *et al*., 2015; Garcia *et al*., 2012).

Cancer

To determine whether specific compounds are responsible for specific human cancer risks is a significant challenge to the field of epidemiology (Alavanja and Bonner, 2012). Nowadays, chronic low-dose exposure to pesticides is considered as one of the important risk factors for cancer expansion (Damalas and Eleftherohorinos, 2011). A study conducted in Canada demonstrated the total lifetime cancer risk, and the results of prostate cancer, lip cancer and multiple myeloma were observed for private and commercial applicators in Iowa (Koutros *et al.,* 2010).

Assessing the cancer risk of pesticide exposure was very challenging due to the scientific evidence that strongly suggests that pesticides cause cancer in both those who use the pesticides directly and those who are exposed indirectly via the application by others. However, the problem is no longer regarded to be extremely urgent due to existing regulatory controls (Alavanja *et al*., 2013; Reeves *et al*., 2019).

2.4.2 Environmental risk

Pesticides can move through the air during application and end up in other parts of the environment, such as in soil or water when sprayed on crops (Kim *et al.,* 2017). When pesticides are applied to water for weed control, as a result of leaching from boat paint or runoff from the soil, it may lead to the build-up of pesticides in water which ensues in and contribute to increased pesticide levels in the air through evaporation (Khatri and Tyagi, 2015). The substantial use of pesticides may result in environmental problems like disturbance of the natural balance, widespread pest resistance and environmental pollution.

Pesticides may be degraded by sunlight, water or other chemicals and or microorganisms (Tiryaki and Temur, 2010), but they also can be very resistant to degradation and thus remain unchanged in the environment for long periods. Persistent pesticides move over long distances and build up in the environment, leading to a more significant potential for adverse effects to occur (Al-Ahmadi, 2019). Once they enter the body of an organism or entity, they are permanently stored in its body tissue, and subsequently are integrated into the tissue of the organism and transferred if the organism is consumed by a predator (Abubakar *et al.,* 2015; Gerber *et al.,* 2016).

Organisms that are often consumed, like fish, may carry heavy concentrations of pesticides because of accumulation due to the exposure of fish to pesticides (Deribe *et al.,* 2013), which is the same issue with the vegetables which are consumed. Excessive use of pesticides thus will result in environmental problems like disturbance of the natural balance, widespread pest resistance and environmental pollution. Figure 2.2 provides a diagrammatic representation of the circulation of pesticides in nature (Fenik *et al*., 2011).

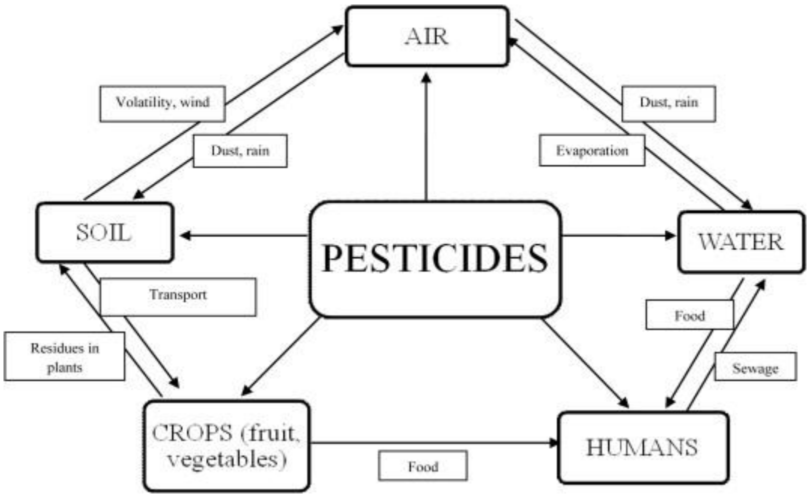


Figure 2.2: The circulation of pesticides in nature (including crops) (Fenik *et al.,* 2011).

Many of the substances that play essential roles in modern society are persistent, organic and halogenated and cause problem associated with bioaccumulation (Rodrigues *et al.,* 2018), and many synthetic pesticides are difficult to break down. The persistent pesticides can move over long distances and can build up in the environment leading to a significant potential for adverse effects to occur (Pandya *et al.,* 2014). Persistence is affected by photodegradation, chemical degradation and microbial degradation. All three processes may participate in the breakdown of a single pesticide (Tiryaki and Temur, 2010).

The United Nations Environment Program's (UNEP) governing council set up an international negotiating committee that led to an international agreement to phase out production, use and release of persistent organic pollutants (POPs). The Stockholm Convention aims to protect human health and the environment from POPs by eliminating and reducing the worldwide production, use and emission of persistent organic pollutants (FAO/WHO, 2015).

Persistent organic pollutants have been used in a wide range of agricultural and industrial commodities, resulting in vigorous deterioration of the environment and human health. The occurrence of POPs confirm their presence in various environmental compartments and the human body. In order to deal with this global concern, countries such as India implemented the National Implementation Plan (NIP) of the Stockholm Convention and investigated the distribution patterns of POPs in multi-compartment environments, and human samples did meta-analyses of time trends in exposure levels to environment and humans, and a cross-country comparison of POP contamination with China. The comparative meta-analysis showed similar high DDT and HCH exposure levels for humans and the environment in India and China. It was concluded that the Indian environment and human population are highly contaminated by DDTs and hexachlorocyclohexanes (Sharma *et al.,* 2014).

Uncontrolled application of pesticides can contaminate soil, and the bioactivity of pesticides together with resistance to chemical degradation may kill other non-target organisms. The resistance of pests in the environment is commonly managed through pesticide rotation, which involves alternating among pesticide classes with different modes of action to mitigate existing pest resistance (Keikotlhaile and Spanoghe, 2011). The correct way to minimalize pesticides in the soil would include the suitable utilization of the factors influencing the persistence. Thus, attempts have been made to measure directly volatile losses of pesticides in the environment which is the concept limited to the zone of application. Furthermore, breaking down organic substances, degradation and interactions among microorganisms in the soil seem to have potential to develop microbially derived pesticides, which are effective, reliable and have a low environmental risk. Adsorption affects the bio-accumulation of pesticides which are dependent on organic matter in the soil. Sorbed chemicals have been shown to be less accessible to microorganisms (Arias-Estévez *et al.,* 2008; Sparks and Nauen, 2015).

The South African Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 is responsible for reducing the risk posed by pesticide residues on the environment and management practices in vegetable production and safety approach as stated by the Fertilizers Act. This act provides directions for proper use, safety restrictions on pesticides users and continuous monitoring programmes to be implemented.

2.5 A REVIEW OF THE SOUTH AFRICAN FERTILIZERS, FARM FEEDS, SEEDS AND REMEDIES ACT NO. 36 OF 1947

The Republic of South Africa is one of the largest consumers of pesticides, domestically manufactured or imported, which are used in agriculture (Sola *et al.,* 2014; FRC, 2018). More than 3000 pesticide products have been approved for use in the Republic of South Africa (DAFF, 2010). However, farmers' misuse of pesticides in agriculture results in adverse environmental and health effects, and this practice has been observed in South Africa and globally (Handford *et al.,* 2015). In general, pesticide manufacturing is well controlled by internationally based companies, but the use of pesticides is susceptible to inappropriate usage by the end-users (Damalas and Eleftherohorinos, 2011). An observation was made that developing countries mostly fail to comply with pesticide safety regulations, and this often results in economic losses, and adverse environmental and public health effects (Grewal *et al.,* 2017). This was proven by the variety of pesticides available and the reported inappropriate applications of pesticides on crops, the latter being a cause for concern as it compromises food safety (Mahmood *et al.,* 2016; Carvalho *et al.,* 2017).

Global estimates indicate that approximately 1.8 billion people that engage in agricultural production use pesticides to protect commercial products (Carvalho *et al.,* 2017). Furthermore, the WHO estimates that between one and five million acute poisoning cases occur each year due to pesticide use (McDaniel, 2019). Thus, the implementation of pesticide regulations becomes essential for reducing risks to human health and the environment. In the RSA context, the Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947; is the Act responsible for the governance of pesticides use (DAFF, 2010). However, it is not clear whether the policies on pesticide registration and use are effectively implemented in a sustainable way countrywide. Nevertheless, it is presumed that legislation, registration and enforcement are the instruments through which authorities can exercise significant control over how pesticides should be managed (Matthews *et al.,* 2011). Hence, in this section on the literature, the gap is investigated between the Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 and its implementation concerning pesticides used in the Republic of South Africa.

The unsafe wide distribution and use of pesticides in many African countries such as in Ghana, Tanzania, Uganda, Kenya and the RSA have been widely documented (Tago *et al.,* 2014; Smart *et al.,* 2018). In the West-African sub-region, farmers reportedly use large quantities of pesticides, sometimes not appropriately, in terms of dose and efficacy (de Bon *et al.,* 2014). The use of banned pesticides is not uncommon in these instances, for example, endosulfan is still in use even though it was banned in 2007 due to its ability to pollute the environment and its toxicity to human health (Nicolopoulou-Stamati *et al.,* 2016; Carvalho *et al.,* 2017). Additionally, chemical compounds such as DDT, HCH and lindane that are environmentally recalcitrant, are also banned from use in farms in developed countries, but tragically remain in widespread use in developing countries (Vega *et al.,* 2016), including the Republic of South Africa.

The enforcement of pesticide regulations is inadequate in most developing countries (Matthews *et al.,* 2011). Studies demonstrated that immediate profit motives dominate the organization of the pesticides supply chain without consideration for human health or the environment (Mengistie *et al.,* 2016). Other studies also reported poor pesticide practices by African farmers (Apeh, 2018). The practices include the use of unsuitable products, poor handling of the substances, wrong dosages, incorrect timing and targeting of applications, non-calibrated equipment and application equipment that is poorly maintained (de Bon *et al.,* 2014). These practices place farmers and those directly involved in pesticides use at a high risk of exposure to pesticides through contact with pesticide residues on treated crops. Other factors that result in unsafe exposure include improper storage and disposal practices, and the lack of protective equipment or failure to use it properly (Abubakar *et al.,* 2015). Hence, pesticide policies should be enforced and strictly regulated; the distribution and use should be licensed and must comply with existing global standards.

Developed nations have more stringent regulations than developing countries, that lack the resources and expertise to adequately implement and enforce legislation (Phung *et al.,* 2012). The inappropriate use and distribution of pesticides probably are due to a lack of information about the products handled in developing countries (Lekei *et al.,* 2014). In many countries, where a range of products has been banned or withdrawn for health or environmental reasons, the fate of remaining stocks is given scarce consideration. This is a major problem. Stockpiled pesticides are up to 30 years old, are poorly stored and are leaking into the environment and contaminating soil and water (FAO, 2019a). Such stock causes significant concern in developing countries. An example of the problem of obsolete pesticide stock is the accumulation of the pesticides used for locust control, especially for combating the *schistocerca gregaria* (desert locust), which often remain in isolated locations for many years after having been banned, and that can no longer be used (Schrimpf and Morgan, 2017).

Existing data indicate that more than 20% of obsolete pesticide stockpiles consist of organic compounds that are resistant to environmental degradation and persistent organic pollutants (FAO, 2019a). The poorly stored pesticides can leak into the environment, contaminating soil and water directly (Damalas and Eleftherohorinos, 2011). Even though dieldrin was banned from use in donor-supported locust control programmes in the late 1970s, no provision was made by the Occupational Safety and Health Administration globally for the eradication or removal of existing stocks (FAO, 2019a). In some cases, the banned pesticides are brought into the countries across the borders, without being checked by the government (CEDAC, SAEDA & PANAP, 2013).

Problems encountered in other countries, including the RSA, include laboratories that are poorly equipped (Tago *et al.,* 2014), lack of pesticide monitoring, and failure to gather information on common conditions of use and the impact of pesticides on health and the environment (Quinn *et al.,* 2011). These are issues not addressed in the Act; however, including these important matters will help minimise pesticide risks for humans and the environment, and then the Act and its regulations will be the backbone of a management system for pesticide residues in the Republic of South Africa. It is, therefore, against this background that the South African government should review the existing Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 legislation to ensure adequate control of pesticides-related risks that could cause public health risks.

2.5.1 Pesticide regulation

Pesticides are among the most strictly regulated substances in the world; regulation is in place to control their use due to their high toxicity and extensive use in agricultural practices (Schreinemachers and Tipraqsa, 2012). Different countries have different pesticide regulations, including limits for pesticide residues on food, product registration requirements and pesticide use restrictions. Due to these differences, pesticides in international trade are subject to pesticide regulations from multiple countries (NPIC, 2019). Pesticides management legislation in most European countries is strictly regulated; to ensure these laws are implemented, numerous bodies and institutions are involved to ensure compliance (Handford *et al.,* 2015).

In European countries, the European Chemicals Agency (ECHA) and the European Food Safety Authority (EFSA), in addition to the European Commission (EC) and Parliament are the key agencies responsible for governing pesticide regulations (PANUK, 2019). The EU regulates the sale and use of active pesticide substances. Plant protection products cannot be placed on the market or used without prior authorization (EFSA, 2019a). Matters related to legal limits for pesticide residues in food and feed are covered by Regulation EU 62/2018 (EFSA, 2019b). The EU restricts or bans dangerous substance (EUROPA, 2019). For instance, in 2013, the EU Commission restricted the use of three neonicotinoid pesticides to protect bees (PANEurope, 2018). In 2016 the Commission asked EU Member States to limit the use of glyphosate in particular circumstances and banned a dangerous co-formulant EU-wide (Andriukaitis, 2019).

The Organization for Economic Co-operation and Development (OECD) cooperates with governments to develop and align methods to evaluate test results and other information and draw conclusions about hazards and risks. It harmonises exposure, hazard and risk assessment methods to interpret the test results and to assess a pesticide's risk; furthermore, the OECD assists countries to ensure accordance on guidelines for the testing of chemicals and good laboratory practice, in order to ensure high quality and reliable data for countries and industry (OECD, 2019a). The FAO and WHO develop pesticide specifications and set standards for pesticide quality to protect consumers and the environment from the use of substandard products. Additionally, these organizations encourage the implementation of the International Code of Conduct on Pesticide Management (CAC, 2019).

The Environment Protection Agency in the USA regulates pesticide registration, manufacture and distribution under the authority of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) (NPIC, 2019). All pesticides distributed in the USA must first be registered with the USA EPA unless they qualify for an exemption. Other bodies also play a role in issues regarding pesticides, namely the Federal Food, Drug and Cosmetic Act (FFDCA) that authorizes the EPA to establish tolerable levels for pesticide residues in foods (Fenner-Crisp, 2010). The FDA monitors the pesticide residues and allows no tolerance in both imported foods and domestic foods for which the Food Safety and Inspection Service (FSIS) of the United States of America Department of Agriculture (USDA) is responsible (FDA, 2016).

Developing countries often lack the resources and expertise to implement or enforce legislation; some studies compared the stringency of MRL standards of various countries, and it was confirmed that Japan had the strictest MRL standards (Drogué and DeMaria, 2012). It has been established that developed countries like the UK, USA and Poland have more stringent regulations than developing countries. The MRLs in the EU, the USA, Canada, China, Japan, India, Australia, and the RSA generally were found to be the lowest in the EU (Handford *et al.,* 2015). Pesticide-related poisoning, mortality and morbidity of humans due to exposure to pesticides frequently are observed in many developing countries, due to lack of reasonable pesticide use control and regulation (Gerage *et al.,* 2017). Also, a quarter of the regions in African and Southeast Asian countries reported the absence of such legislation (Matthews *et al.,* 2011). However, in African countries where legislation does exist, the implementation of most of the policies and regulations is rather weak (Loha *et al.,* 2018).

In the RSA the Department of Agriculture, Forestry and Fisheries (DAFF), through the Directorate of Agricultural Inputs Control (DAIC), regulates the distribution and use of agricultural remedies through the Fertilizers Act (Makhafola, 2010; Mudzunga, 2015). The National Department of Agriculture (NDA) gives guidance for usage of pesticides (DAFF, 2015). However, the activities of the DAFF, which is the body that administers the Fertilizers Act, have not been publicly evaluated since the inception of this Act (DAFF, 2015). The DAFF does not evaluate registered pesticides regularly, as legislation standards are in order to assess the pesticide before the decision to accept or decline the registration, and to consider new data. However, existing national pesticide legislation has become outdated, and it should be revised taking cognisance of the Constitution, and to establish the alignment with current standards. The re-evaluation of the safety of each pesticide should be done every 15 years, as is done by the Environmental Protection Authorities in the USA (EPA, 2019). Reviewing and revising pesticide legislation should also advance an overall objective to develop unified legislation covering all aspects of pesticides (FAO/WHO, 2015).

In the RSA, pesticides are regulated through the Fertilizers Act and the Medicines and Related Substances Control Act No. 101 of 1965 (RSA, 2003). In order to control the importation of pesticides and minimise the adverse effects on human health, the government of the RSA developed the Pesticide Policy in 2006 (South African

Government 2006; DAFF, 2019). The DAFF administers the legislation in partnership with other government Departments; Section 24 of the Constitution of the RSA, Act No. 108 of 1996, Hazardous Substances Act No. 15 of 1973 and Foodstuffs, Cosmetics and Disinfectants Act (FCDA) Act No. 54 of 1972, The Occupational Health and Safety Act (OHSA) No. 85 of 1993 and Agricultural Pest Act No. 36 of 1983 (Mudzunga, 2015). In 1994, the new constitution created the right to the environment as a fundamental right, and this led to the National Environment Management Act (107 of 1998). In addition to the National policy, the RSA also has adopted the FAO formulated code of conduct for pesticides and entered an agreement with Rotterdam, Stockholm, Basel, to abide by the FAO code of conduct on pesticides use and distribution (UNEP, 2015).

Under the Foodstuffs, Cosmetics and Disinfectant Act (FCDA), the Department of Health (DoH), DAFF and the Department of Trade and Industry (DTI) is responsible for food legislation (DoH, 2012; Sikuka, 2016). The FCDA ensures that the approval or compliance of foodstuffs is taken into account to provide the information on safety for regulatory purposes (Gana, 2014). The National Department of Health (NDoH) is the main food control body that approves the MRLs for pesticides present in foodstuffs for both exports and imports. For exports, the MRLs in foodstuffs regulations are established by the DAFF, the South African Bureau of Standards (SABS), and Perishable Products Export Control Board (PPECB), Industry working groups, agricultural chemical companies and technical experts, all guided by fourteen Acts (PPECB, 2019).

The PPECB, an independent service provider of quality certification and cold chain management services, handles MRL analysis for exports. Another government agency advising about MRLs is the Agricultural Research Council (ARC) for technical expertise (DAFF, 2014). Compliance with prescribed levels is critical in the import and export of agricultural products. In the RSA, DoH agencies perform relatively low levels of testing on vegetables; information thus remains limited on the extent to which these vegetables may expose the RSA consumers to elevated levels of pesticide residues relative to domestically grown produce (Makhafola, 2010), although the role of the DoH is to protect human health by measuring if the present pesticides may pose a risk to consumers. The DoH does not play this role effectively, even though there is a regulation in place that guides the actions to be taken to protect consumers, like in other developed countries. The challenge, however, lies with the implementation and monitoring.

In systems where pesticides are governed by two different administrative bodies, for example, the Ministry of Agriculture for agricultural pesticides and the Ministry of Health for public health pesticides, it is unclear to the user or even governments themselves which system is responsible for regulation (FAO/WHO, 2015). Therefore, the regulation of pesticide should be centrally regulated, and through one pesticide law that applies to all pesticides, instead of having many bodies trying to deal with one issue. Furthermore, the RSA is a member of the Codex Alimentarius Commission (CAC), which serves as a guideline for establishing the RSA health guideline and standards (Berry, 2016). The code was published for most developing countries and countries with economies in transition, which did not have pesticide legislation in place (FAO/WHO, 2015). The RSA complies with the proposed mandate as stipulated by the Codex.

In the context of developing countries, pesticide regulation challenges issues such as lack of resources; insufficient knowledge of the pesticides; limited environmental standards, and the unclear role of responsibility for implementing regulations on the part of the relevant authorities (Mengistie *et al.,* 2016; Loha *et al.,* 2018) hampers implementation of pesticide guidelines. A study by the WHO reported that there are no national guidelines for health monitoring of pesticide applicators in pesticide control operations of developing countries, such as in African and the Western-Pacific Regions (van den Berg *et al.,* 2011). South Africa lacks a complete supervision framework on pesticide residues with clear responsibilities. Furthermore, countries such as in the EU, the USA, Japan and China have a complete supervision framework on pesticide residues with clear responsibilities (Liu and Guo, 2019). The Republic of South Africa needs the Fertilizers Act to stipulate a definite share of responsibilities in the management of pesticides.

Regulations alone may not be sufficient to reduce the risk posed by pesticides to protect humans and the environment, stricter legislation like the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) in the USA is required. The FIFRA requires all pesticides sold or distributed in the USA to be registered (USEPA, 2018). The pesticides are registered under Federal Registration Actions to issue Experimental Use Permits (EUPs), Special Local Needs (SLNs) registrations, and to apply for Emergency Exemptions under specific conditions. The RSA is mainly affected by the more stringent food safety standards of developed nations, including developing countries (Handford *et al.,* 2015).

Food safety systems in developing countries are not effective to protect consumers' health or help countries competing for export markets. Many countries rely purely on a small scale and street vendors to feed their populations. Yet, these traders are not usually included in mainstream food safety systems (Oloo *et al*., 2018). The regulations regarding pesticides should be centrally regulated instead of having the DoH and DAFF to deal with one issue.

2.5.2 Pesticide registration

The registration process involves evaluation of the chemical content of pesticides, and usage instructions and labelling to ensure the pesticide will not have unreasonable adverse effects on humans or the environment (EPA, 2018). The registration enables authorities to regulate the quality, to use patterns, claims, labelling, packaging and the advertising of pesticides (FAO/WHO, 2010). The data required for the registration process usually are provided by the applicant. During the pesticide registration process, the responsible national government or regional authority approves the sale and use of a pesticide (WHOPES, 2010). The use of pesticides usually is authorized only after a risk assessment has been done to ensure that any residue remaining after the correct use of the pesticide will not lead to any consumer concern (Adewunmi and Fapohunda, 2018). Hence, the country's pesticide registration authorities must ensure that pesticides authorised by them are safe.

In the European Union (EU), pesticides are assessed by following a phased approach whereby a manufacturer submits an application for approval of a pesticide. The agreed guidance from the Commission or European Food Safety Authority (EFSA), containing the required details, is used, and information and studies are included to complement the data requirements in the relevant regulations (EFSA, 2019b). The EFSA's guidance is updated regularly, and an initial draft or renewal assessment report is produced; at this stage, public and expert consultations are included. The EFSA then drafts a report on the pesticide and publishes its conclusion. The European Commission decides whether or not to include the substance in the EU’s list of approved pesticides (EFSA, 2019b).

The OECD pesticide registration and re-registration project helps governments work together to assess chemical pesticide risks to humans and the environment. By cooperating, governments can evaluate a chemical pesticide's risks more quickly and thoroughly (OECD, 2019b). Governments routinely accept dossiers prepared by stakeholders in the OECD format and exchange monographs. Monographs form a basis for independent risk assessments and regulatory decisions for new and existing pesticides. The data are submitted to governments, which use them to assess the pesticide's risks and benefits and to decide whether or not to approve the registration (OECD, 2019b).

The World Health Organization’s Pesticide Evaluation Scheme (WHOPES) oversees the phased evaluation of pesticide products and produces international recommendations to support national regulatory authorities and disease control programmes in product registration and use globally (DEA, 2010; WHO, 2010a). The outcome of the registration process, whether provisional or full registration, with or without restrictions, conditions or refusal of registration, is equally vital for registration to be cancelled or permitted (WHO/FAO, 2010). Therefore, the legislation should have provisions for issuing permits for experimental as well as emergency use of pesticides by the responsible authority.

In the USA, the federal government requires all pesticides sold or distributed, including those imported, to be registered by an Environmental Protection Agency (USEPA, 2018). The EPA is responsible for reviewing information and data to determine whether a pesticide product may be registered for use (USEPA, 2018). All pesticides must be distributed bearing their EPA-approved pesticide label, and other material submitted should comply with the requirements of the Federal, Insecticide, Fungicide and Rodenticide Act (NPIC, 2016). Anyone applying pesticides must comply with federal and state laws in the USA, which, additionally, have the primary authority for compliance monitoring and enforcing prosecution for illegal use (USEPA, 2018).

Under similar conditions in the RSA, the pathway for the registration of a pesticide is divided into three categories, namely verification, scientific screening, and evaluation. The Fertilisers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 (RSA, 1996) sets forth detailed provisions regarding registration, manufacturing, labelling, and packaging requirements for agricultural remedies. Published guidelines also are provided with guide applicants in the registration process (DAFF, 2015). The Fertilizers Act requires applicants to submit data generated from scientific studies on the evaluation of safety, efficacy and quality of products (NDA, 2015).

However, the Directorate Agricultural Inputs Control (DAIC) performs a full evaluation and does not consider approval by another regulatory authority as criteria for registration (NDA, 2015). The DAIC first screens the application to assess whether it is complete. A decision by the registration authority either to register the pesticide, based on the merits of the submitted data or to deny registration is made (DAFF, 2018). If registered, the pesticides product may then be legally sold and used in South Africa (Mudzunga, 2015). The information required from the applicant for the registration of a pesticide consists of toxicological and epidemiological studies, data on pesticide residues in foods and the environment, reports of adverse effects, and other information of interest for assessing the desirability of continued registration or registration. The registrant will be convicted of a violation of the law if the required information is not reported correctly (DAFF, 2018).

Developing countries, including the RSA, lack expertise and capacity in risk assessment of pesticides (Utembe and Gulumian, 2015). A global survey by Matthews *et al.* (2011) indicates that unlike developed countries many developing countries lacked procedures for registration of public health pesticides, for example, 40% lacked guidelines that inform the registration process. Also, toxicity studies are very costly with the result that toxicity data used to register pesticides in Africa often have their source in countries in the northern hemisphere (Utembe and Gulumian, 2015).

The study by Utembe and Gulumian (2015) suggests that the countries in Africa, which include the RSA, should generate their own required data, although such studies may be costly. Registrants should rather do comprehensive tests that they can afford, as they know that there might be a lack of expertise in the country. The European Food Safety Authority (EFSA) requires pesticide assessment to be conducted by peer reviews in the member state before the decision is made to accept or decline the registration, which is not the case in South Africa.

2.5.3 Pesticide evaluation

The International Programme on Chemical Safety (IPCS), a joint venture of the United Nations Environment Programme (UNEP), International Labour Organization (ILO) and the WHO, carries out evaluations of and disseminate the findings on the effects of pesticides on human health and the quality of the environment (WHO/FAO, 2010). The roles of IPCS are to establish the scientific basis for the safe use of chemicals, to implement programmes related to chemical safety, and to strengthen national capabilities and capacities for chemical safety (Panuwet *et al*., 2012).

The Inter-Organization Programme (IOP) for the sound management of chemicals (IOMC) was established by UNEP, ILO, the FAO of the United Nations, WHO, the UN Industrial Development Organization, the United Nations' Institute for Training and Research, and the Organization for Economic Co-operation and Development (WHO, 2010b). The Inter-Organization Programme for the Sound Management of Chemicals (IOMC) is the pre-eminent mechanism for initiating, facilitating and coordinating international action to achieve the World Summit of Sustainable Development (WSSD) 2020 goal for sound management of chemicals (Directorate-General for Environment: European Commission, 2013). The purpose of the IOMC is to promote coordination of the policies and activities pursued by the participating organizations, jointly or separately, to achieve the sound management of chemicals that affect human health and the environment (WHO, 2010b).

The OECD pesticide assessment and testing project works to harmonize the methods used by OECD countries to evaluate pesticide risks to health and the environment (OECD, 2019a). This includes developing test guidelines for the tests used to fulfil the pesticide registration data requirements and to align exposure, hazard and risk assessment methods to interpret the test results and to assess the risk a pesticide may hold. Harmonization or alignment means that the methods used by the OECD governments are mostly similar; though governments may retain some differences to account for social conditions and preferences (OECD, 2019a).

The EFSA is responsible for the review of active pesticide substances and also in charge of the risk assessment of MRLs of pesticides permitted in food products marketed in the European Union (EFSA, 2017). Approved effective pesticides are re-evaluated before the expiry date under the Amending Implementing Regulation (EU)

No 686/2012, AIR-renewal programme (EFSA, 2019e) by the EC (SANCO/10181/2013), and after re-evaluation, member states authorize their use (Handford *et al.,* 2015). The Control of Pesticides Regulations 1986 (CoPR) aims to protect human beings, creatures and plants, safeguard the environment, ensure safe, effective and humane methods of controlling pests and make pesticide information available to the public (HSE, 2019).

In the EU, a member state is appointed as a rapporteur to carry out an initial risk assessment and to prepare a draft assessment report which EFSA, together with the member states, peer reviews the procedure for new active substances introduced by Regulation EU 2018/605. Approved active substances are re-evaluated before their expiry date under the renewal programme (EFSA, 2019b). In the USA, EPA evaluates every new pesticide and its use for safety before registration and prior selling. Through these evaluations, EPA ensures the overall safety of proposed pesticides as required by the Food Quality Protection Act. After pesticide registration, the EPA re-evaluates its safety every 15 years, taking into consideration any new data (EPA, 2017b). The registration reviews allow the agency to assess any new data, issue requirements for new data and ensure that the information available for each pesticide meets the requirements. Furthermore, the EPA can take immediate action to restrict the use of a pesticide if pertinent new information becomes available, regardless of registration review status (USEPA, 2018).

The government agencies that take responsibility for evaluating pesticide risks in the RSA include DAFF, the Department of Environmental Affairs and Tourism (DEAT), and the Department of Health (NDoH, 2010). In more than 3000 pesticides products approved for use in the RSA, many have not been re-evaluated for years

(DAFF, 2010). Their safety, therefore, has not been reassessed to align them with more stringent standards of risk assessment. The Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 does not clarify what should happen in this instance.

2.5.4 Pesticides standards and monitoring programme

A monitoring programme is essential to ensure conformity with Good Agricultural Practices (GAPs) and the trade requirements set by the importing country when it comes to residual pesticide monitoring on food (Mutengwe *et al.,* 2016a). Implementing Good Agricultural Practices (GAPs) during on-farm production and post-production processes resulting in safe agricultural products is of immense importance for ensuring a safe food supply (FAO, 2016). Most countries have established pesticides monitoring programmes to protect consumer health, including improved management of agricultural resources. However, developing countries lack monitoring programmes and some are either non-existent or not adequately implemented to cover all local, exported, and imported produce (Mutengwe *et al.,* 2016a). Such food surveillance programmes generally focus on the proper use of pesticides in terms of authorization, registration and disposal.

Globally, the WHO has ongoing programmes to identify, assess and review the toxicity of pesticides, related data in order to establish ADI and ARfD and releases tables annually on recommended MRLs (FAO/WHO, 2019). Besides pesticides monitoring, the WHO has the authority to ban pesticides, especially those pesticides that remain in the environment for a long time (WHO, 2018). To protect food consumers against the adverse effects of pesticides, the WHO reviews the evidence and develops internationally accepted maximum residue limits. Different countries develop their MRL guidelines, often based on the WHO recommendations (FAO/WHO, 2019).

The EFSA prepares an annual scientific report on pesticide residues in food (EFSA, 2019d). The report also comprises the outcome of the consumer risk assessment of pesticide residues (Golge *et al.,* 2018). The European Food Safety Authority (EFSA) presented the results of a pilot cumulative risk assessment to multiple chemical residues for the first time in 2013. Finally, the report provides some recommendations aimed at the improvement of future monitoring programmes and the enforcement of the European pesticide residue legislation (EFSA, 2013). In an annual report many food samples from the EU Member States, collected in the EU, were analysed, and the results showed that they were free of pesticide residues or contained traces that were within legal limits (EFSA, 2016).

In the USA, the Food and Drug Administration (FDA) employs a three-fold strategy to enforce EPA's pesticide tolerances in human and animal foods. In its regulatory pesticide residue monitoring programme, the FDA enforces tolerances in both imported foods and domestic foods shipped in interstate commerce, except for meat, poultry, and certain egg products for which the Food Safety and Inspection Service (FSIS) of the USA Department of Agriculture (USDA) is responsible (FDA, 2019). The FDA also monitors pesticide chemical residue levels in commodities representative of the USA diet by carrying out market basket surveys (FDA, 2016).

The role of the Department of Health (DoH) in South Africa is to outline monitoring standards for the prevention of environmental conditions that may constitute a health hazard for public health; this function is implemented by environmental health practitioners. Although, the DoH is the one who should play an essential role in this regard, the exclusion of the role it is expected to play in implementing the Act creates gaps (Wright *et al.,* 2014). South Africa lacks a complete supervision framework on pesticide residues, with responsibilities set forth clearly.

South Africa does not have an established pesticide monitoring programme; neither does it publish annual reports to profile pesticide residue levels on individual food commodities (Mutengwe *et al.,* 2016 a; b). In terms of minimising pesticide residues, fresh produce that is imported or exported must by law undergo routine inspections, but this is not always the case for locally-traded fresh produce. Locally traded products are not regularly monitored for MRLs in the same way as export commodities (Mutengwe *et al.,* 2016c). Mutengwe *et al.* (2016a) found unregistered pesticides and samples that generally exceeded the allowed levels in fresh produce sold locally, compared to fresh produce destined for the export market. Monitoring it is not done by the local authority; analysis for MRLs is seldom done because of the complexity of the analysis (Gama, 2015; DoH, 2019). Import tests for MRLs are conducted only when international alerts were reported for specific consignments (DoH, 2019).

2.5.5 Testing of pesticides and resources

Quality assurance is an essential consideration in the operation of a laboratory in general. Accreditation, according to ISO/IEC17025 through a national body, responds better to the specific need of an official quality control laboratory than the quality assurance scheme under Good Laboratory Practice (FAO/WHO, 2011). Laboratories are of utmost importance for monitoring pesticides through scientific research, production guidance, consumer guidance and risk communication (Chen *et* *al.,* 2015). Pesticides manufacturers must comply with national pesticide standards, as well as the FAO and WHO specifications for pesticides (FAO/WHO, 2015).

The EU Reference Laboratories ensure high quality, testing and support activities in risk management and risk assessment in the area of laboratory analysis (EUROPA, 2019). According to South African National Civic Organization (SANCO)/12571/2013, it is vital that official laboratories that are engaged in the development and use of analysis of pesticides possess up-to-date test equipment (IAS, 2015). Additionally, having a competent and adequately trained staff is another critical factor in staying compliant (Goudarzi, 2018). Developed countries with local pesticide analytical laboratory facilities are in a better position to implement quality control programmes compared to developing countries.

The EFSA monitors and analyses the risk of residues of pesticides in food for exposure annually, according to the Regulation EU No, 400/2014 for the European monitoring programme (EFSA, 2017). The pesticides peer-review expert consults on scientific issues under Regulation EC No. 882/2004 (Weimer *et al*., 2015). This a regulation of the European Parliament and the council of 29 April 2004 on official controls performed to ensure the verification of compliance with pesticides rules (EUR-LEX, 2019). The EFSA also provides scientific advice on risks and other issues relating to food safety, decision-making including scientific uncertainty (Hart *et al.,* 2019).

The joint FAO/WHO Meeting on Pesticide Residues (JMPR) follows the general principles and methods for chemical risk assessment, which are published in the reports (FAO, 2019b). The JMPR evaluates pesticides within the periodic review programme of the Codex Committee on Pesticide Residues (CCPR). The Meeting also establishes ADIs and ARfDs and estimates MRLs recommended for use by the CCPR. It also estimates supervised trials median residue (STMR) and highest residue levels as a basis for estimation of the dietary exposure to residues of the pesticides reviewed (JMPR, 2018).

The Organisation for Economic Co-operation and Development (OECD) issues principles for Good Laboratory Practices (GLPs) concerning the safety testing of any chemical substance (WHO, 2010b). The OECD principle of GLP ensures the generation of high quality and reliable test data related to the safety of industrial chemical substances and preparations. The principle has been created in the context of harmonising testing procedures for the Mutual Acceptance of Data (MAD). The MAD helps to avoid conflicting or duplicating national requirements (OECD, 2019d).

The EPA operates two pesticide laboratories, analytical chemistry and a microbiology laboratory that provide a variety of technical services to the agency, other federal and state agencies, tribal groups and other organisations (EPA 2019). The USA has a national pesticide residue monitoring programme division that administers the Pesticide Data Program (PDP) activities, including the sampling, testing and reporting of pesticide residues on agricultural commodities (USDA, 2019). The laboratory assists the EPA to develop analytical methods, provide reference standards, training personnel and assist with audits (EPA, 2017b).

The RSA has ISO 1725 accredited laboratories for pesticide residues analysis in plant product, which are able to meet EU MRL requirements and thereby ensuring trade within the South African framework (Quinn *et al.,* 2011). Similarly, because of the lack of accredited pesticide residue laboratories, exporters dealing with the European market send samples to European laboratories instead of local, unaccredited laboratories (Cox, 2000). The DoH does not have the capacity to test a large number of samples for residues due to a high turnover of analysis, and a lack of skilled technicians (WHO/FAO, 2010). Furthermore, there is a lack of expertise and capacity in risk assessment of pesticides in Africa (Utembe and Gulumian, 2015). Toxicity studies are very costly with the results that toxicity data used to register pesticides in South Africa. Therefore, the Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 should encourage the development of more accredited laboratories for regulating pesticide to the extent to control their misuse.

2.5.6 Public participation in decision making

Public participation promotes sustainable decisions by recognizing and communicating the needs and interests of all participants, including decision-makers (Glucker *et al*., 2013; Dearsouthafrica, 2019). Participation can be viewed as a continuum of interaction between government and the public, which ranges from informing and listening at one end, to implementing jointly agreed solutions at the other; and in between there is dialogue, debate and analysis. All stages of the process (preparation, drafting, adoption, implementation, and evaluation) should be subject to public participation to ensure efficient laws (De Fouley, 2016). The EU and other countries aim to minimize the effect of those challenges and to pave the way for more effective participatory law-making processes. When developing the appropriate standards for participation in one country, it is essential to consider not only the opportunities but also the challenges that surround it so that appropriate mechanisms are adopted to address and avoid those (De Fouley, 2016).

Citizens in all OECD countries are demanding greater transparency and accountability from their governments. New forms of public participation are emerging as citizens seek opportunities to actively participate in shaping the policies that affect their lives. In response, governments are exploring new ways to inform and include citizens and civil society organizations in policymaking. However, consultation and public participation highlight the lack of systematic evaluation of government efforts to engage citizens and civil society in policymaking (OECD, 2019c).

In the USA, EPA's public participation takes place in accordance with a guide that provides tools for public participation and public outreach in environmental decision-making (USEPA, 2018). The EPA places a high value on transparency in decision-making (Tago *et al.,* 2014). The public is invited to comment throughout the decision-making process, to request studies and data, take findings to independent expert panels and to consult the National Academy of Sciences on broad scientific policy questions (USEPA, 2018). The agency receives comments from the public on draft assessments and proposed decisions. Public concerns about specific pesticides and food safety do not go unnoticed by the Environmental Protection Authority. The EPA can and has used its authority to have products removed from the market immediately when risks are imminent (EPA, 2019).

A global survey showed that among other obstacles, some of the staff responsible for decision-making and the implementation of vector control, lack the training to do so, especially in Africa (WHO/FAO, 2017). This is a serious concern, but apart from that, it is advisable that public concerns about the use of pesticides be taken into consideration during decision-making (Quinn *et al.,* 2011). The public also should be able to access information about the use of pesticides, openness and transparency must be the norm, and public concern should be considered in the international decision-making process regarding the use and import of pesticides (DAFF, 2010;

Handford *et al.,* 2015). Information exchange and coordination are vital to ensure consistency and efficiency in pesticide management. Findings of a study, however, indicated that evidence-based decision-making might be lacking among some staff responsible for decision-making and implementation of pesticide control (van den Berg *et al.,* 2011).

2.5.7 Responsibility and use

Pesticides use may be restricted by the responsible authorities in different ways, such as not registering a product or putting a condition in place before registration. The role of ensuring the safety of humans and the environment when and where pesticides are used remains with the relevant department of agriculture and health (Mudzunga, 2015). This will allow a nationwide control network for the quality and safety of agricultural products and diminish or eliminate the risk associated with pesticide residues. Hence, countries in which pesticides are used should have a valid pesticide registration and monitoring procedure that ensures that pesticide use does not result in an unreasonable risk to humans and the environment.

The EU Directive 2009/128/EC achieves the sustainable use of pesticides by reducing the risks and impacts of pesticide use on humans and the environment, promoting the use of Integrated Pest Management (IPM) and alternative approaches or techniques, such as chemical alternatives to pesticides. The EU countries also have drawn up a National Action Plan to implement a range of actions set out in the directives such as the training of users, advisors and contributors of pesticides, inspection of pesticide application equipment, the prohibition of aerial spray, limitation of pesticide use in sensitive areas and information and awareness-raising about pesticide risks (EUROPA, 2019). The EU has an authorisation procedure involving

EFSA, EC and the Member States. Pesticide applications from industry pass along a chain formed by these parties with each one carrying out a specific task. The EFSA's role is to carry out risk assessments of pesticides and provide the EC and member states with scientific support in the decision-making process (EFSA, 2017).

When dealing with pesticides, operators must comply with the standard law regulating the duty of care for storage, transport, application and disposal of pesticides. In the USA, EPA regulates pesticide storage and disposal for four categories of pesticide users: household consumers, farmers, retailers and commercial applicators. For each of these groups, it provides detailed instructions (EPA, 2019). Most states have developed programmes on how farmers may collect and dispose of pesticides in a safe manner (EPA, 2019).

In Vietnam, regulations on pesticide handling, storage and disposal are the same for every user. The focus is on storage and preservation requirements for industrial manufacturers and distribution companies rather than individual retailers and household applicators (Phung *et al*., 2012). Similarly, pesticide disposal is regulated by a national chemicals law on hazardous waste management, as in the United States of America. However, no specific regulatory programme for the safe storage and disposal of agricultural pesticides has been developed by provincial agencies.

According to Sola *et al*. (2014), it is also important to consider setting up and revising the national standards of pesticide residues, for example by establishing food surveillance programmes which focus on the proper use of pesticides in terms of authorisation, registration and disposal. The health risks associated with certain pesticides are for end-user exposure. The advantages of introducing these chemicals into the environment need to be weighed against the possible adverse side effects.

Therefore, serious consideration should be given to expanding the correct use of less harmful alternatives. Additionally, the exposure of farmers increases in the case of not paying attention to the instructions on how to use the pesticides and mainly when they ignore basic safety guidelines on the use of personal protective equipment (Abubakar *et al.,* 2015). Therefore, it is the responsibility of the end-user to ensure safe use and disposal of pesticides.

According to Jallow *et al.* (2017), access to information and knowledge of the risks associated with pesticides and how to avoid exposure may help in the ability to understand the hazard warnings on pesticide labels, how to avoid exposure, and how to follow recommended safety and application guidelines. The FAO provides information on pesticide use and distribution. The Crop Protection and Animal Health Association of the RSA provides most of the information on pesticide use (Chemicals in agriculture, 2019). Some developing countries, including the RSA, rely on information provided by international manufactures (EU, Germany and the USA) on the use of pesticides (Mengistie *et al.,* 2016). For example, port health authorities rely on reports from organisations like the USA FDA, UK Food Authority, and Australian Food Authority, and this approach is reactive to any threatening health alert imposed by any of the pesticide groups (Zach *et al*., 2012).

Education provides pesticide users with better access to information and more knowledge of the risks associated with pesticides, and how to avoid exposure, while less educated farmers may be hampered in their ability to understand the hazard warnings on pesticide labels, how to avoid exposure, and how to follow recommended safety and application guidelines (Jallow *et al.,* 2017). A study conducted in Pakistan by Mubushar *et al.* (2019) found that farmers employed unhealthy and poor practices by not following the recommendations regarding the safe usage of pesticides. The study also revealed that the majority of farmers obtained information from private agents and only about one third (34.40%) of the respondents got information on the safe use of pesticides from the Department of Agricultural Extension, and 48.2% did not follow the instructions. Farmers should not rely on their own experience when choosing and using pesticides. Most studies show the effects of education on the safe use of pesticides (Hau *et al.,* 2014; Mwatawala and Yeyeye, 2016). Gaber and Abdel-Latif (2012) pointed out the need for health education programmes to provide farmers with detailed instructions about precautions that should be taken during the mixing and spraying of pesticides and introduced them to the principle of recycling.

Sharifzadeh *et al*. (2018), based on their study in Iran, concluded that learned farmers favoured awareness and information criteria, whereas experienced farmers favoured criteria of performance and effectiveness in decision-making for pesticide selection and used in the pest control process. Additionally, Tago *et al.* (2014) found that there was growth in agricultural production and the inappropriate use of pesticides in developing countries, due to the lack of risk information on the majority of pesticides, and the discrepancy in information accessibility of safer pesticides among countries (WHO, 2016). This is because pesticides remain a means of poisoning, accounting for an estimated one-third of all poisonings globally (Saxena, 2016). As a result, farmers with good pesticide knowledge will apply good practices in pesticide use.

Although pesticide labels provide information about required application rates for registered combinations of pests, crops and volumes of carriers to be used, farmers tend not to follow these guidelines. The major limitation is the failure to get information about crop environment status so that it can be used in making pesticide application decisions. Some risks, for example, are detectable only once they have become well established enough for significant losses to be unavoidable (Shogren, 2013). According to Naidoo *et al.* (2010), the use of pesticides in developing countries persists in the presence of illiteracy and limited safety training and practices. In the RSA, there is little information on pesticide exposure and safety practices among farmers using pesticides. Although there is technical information on the pesticides, sufficient knowledge on the correct application of pesticides is required to be made known to farmers by various experts through agricultural extension services.

2.5.8 Limitations

In this section gaps in the Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 will be reviewed, with specific attention to the following areas: (i) regulation; (ii) registration, (iii) monitoring and assessment; (iv) testing of pesticides; (iv) public participation in decision-making; (vi) responsibility and safe use of pesticides, knowledge and training on the safe use of pesticides. The Republic of South Africa has not been enforcing legislation on the management of pesticides effectively. This is a clear indication of a country’s failure to improve the management of pesticides use. The study has also exposed other significant gaps in pesticide management in the areas listed above.

It was observed that pesticides registration in the RSA uses a framework different from that in the EU, where pesticide registration is the crucial element in regulating pesticide use (Phung *et al.,* 2012). The legislative basis for pesticide regulation in the RSA is also not reviewed to reflect the International Code of Conduct on the Distribution and Use of Pesticides since the Fertilizers Act was adopted 80 years ago (DAFF, 2010). Furthermore, the only provision under which the DAIC can claim to regulate end-users is through the application of the legislation that makes it an offence to use a pesticide in contravention of the label (DAFF, 2010). Republic of South African use of pesticide is not centrally regulated, and many bodies deal with this issue. Additionally, developing countries, including the RSA, often lack the resources and expertise to implement or enforce legislation (Loha *et al.,* 2018).

Regulations make no provision for continuing reports on the adverse effects of pesticides on humans and the environment during the registration process. The country lacks expertise and capacity in risk assessment of pesticides and procedures for the registration of pesticides. Besides, toxicity studies are very costly in order to get data to be used to register pesticides. There are no peer reviewers to assess pesticides before the decision is made to accept or decline the registration. The DAIC performs a full evaluation and does not consider approval by another regulatory authority as a criterion for registration.

Also, the Fertilizers Act is obsolete and needs evaluation, and more than 3000 registered pesticides have not been evaluated for years (DAFF, 2010), as happens in other countries. By reviewing the Fertilizers Act, the regulations of the Act can be updated and aligned with those required internationally. Moreover, it is unlikely that the EPA, which requires a registration review for all pesticides at least every 15 years, will allow the agency to assess new data and to ensure that the information available on each pesticide meet the EPA requirements (EPA, 2018). The RSA does not even publish annual reports to profile pesticide residue levels on individual food commodities (Mutengwe *et al.,* 2016 a; b). The safety of these pesticides, therefore, has not been revised to align them with more stringent standards of risk assessment. The Fertilizers Act does not clarify what should happen in such an instance.

Furthermore, the RSA has not instituted a pesticide monitoring programme; neither does it publish annual reports to profile pesticide residue levels on individual food commodities (Mutengwe *et al.,* 2016 a; b). The analysis for MRLs is seldom done because of the complexity of the analysis (Gama, 2015; DoH, 2019). Import tests for MRLs are conducted only when international alerts are reported for specific consignments (DoH, 2019). The DAFF and DoH government entities are responsible for pesticide residues in South Africa. Fresh produce for export is monitored by the Perishable Products Export Control Board (PPECB, 2016). The analysis and approval of MRLs for agricultural products are the responsibility of the Department of Health. The RSA lacks a complete supervision framework on pesticide residues with clear responsibilities.

The DoH does not have the capacity to test a large number of samples for residues due to a high turnover of analysis and a lack of skilled technicians (WHO/FAO, 2010). In terms of minimizing pesticide residues, agricultural produce that is imported or exported also must undergo routine inspections, but this is not always the case for locally-traded fresh produce. The global survey showed that the staff responsible for decision-making and the implementation of pesticides control lack training to do so, especially in Africa (WHO/FAO, 2017). Van den Berg *et al.* (2011) maintain that most staff members responsible for decision-making and implementation of pesticide control lack evidence-based decision-making skills). Furthermore, public concerns are not taken into consideration during the decision-making and approval of pesticides process, which could be helpful because they are also users of pesticides. These gaps in the RSA pesticide regulations bring about limitations in pesticide management and control that hinder the improvement of safe use of pesticides in order to prevent harm to humans and the environment.

2.6 CONCLUSION

The framework used for pesticide regulations in the RSA differs from that used in the USA and EU, in which pesticide registration is the critical component in regulating pesticide distribution and use, as has been discussed in the preceding sections. Various areas of pesticide regulations in the Republic of South Africa urgently need to be updated and adapted to reduce the risk of harmful effects on humans and the environment, as has been identified in the course of the study. The legislative basis for pesticide regulations in the RSA, namely the Fertilizers Act, must be reviewed and revised to reflect the International Code of Conduct on the Distribution and Use of Pesticides since the Fertilizers Act was adopted has never been revised.

The challenge is emphasized by outdated laws on pesticide use in agriculture, pesticide control, and pesticide management. Although the pesticide management policy is relatively new, it should be taken into consideration, too, as regulations alone may not be sufficient to reduce the risks posed by pesticides. To protect consumers and workers, more training in the safe use of pesticides, exposure to pesticides and pesticide residues, and continuous pesticide residue monitoring of agricultural products are needed.

CHAPTER 3

MATERIALS AND METHODS

3.1 STUDY AREA AND SAMPLING TECHNIQUE

Site description

This study selected four major vegetable markets in the Mangaung region of Bloemfontein, Free State. The samples were collected from Westdene (site A), Langenhovenpark (site B), Masselspoort (site C), Showgate (site D) and (site E) Metro Food Market on 13 April 2019. The weather condition on this day was fair, with temperatures between 10° and 27°C from 12:00-14:00 when the samples were collected. In Table 3.1, a list of the fresh produce markets involved, as well as their locations and the GPS coordinates of the sampling sites in Bloemfontein is given.

Table 3.1: Markets in Bloemfontein where samples were collected randomly

Site	Markets	Location	GPS Coordinates
Site A	Johnny's Fruits and Vegetables market	43 2nd Avenue, Westdene	29°6'22" S 26°12'34" E
Site B	Food Lover's Market	Cnr. Nelson Mandela Drive & Miller Road, Langenhoven Park	29°4'51" S 26°9'31" E
Site C	RSA Mangaung Fresh Produce	Cnr. Rudolf Greyling Street & Masselspoort, Estoire	29°6'34" S 26°15'47" E
Site D	Food Lover's Market	Showgate Centre, Curie Road	29°8'16" S 26°12'5" E
Site E	Metro Food Market	21 Lessing Avenue, Estoire	29°6'37" S 26°15'56" E

Sampling technique

The selected vegetables purchased from fresh produce markets were *Brassica oleracea* var. *capitata* (cabbage), *Beta vulgaris* spp.*, vulgaris* (Swiss chard) and *Solanum tuberosum* L. (potatoes). A total of 15 samples (five heads of cabbage, five bunches of Swiss chard and five potatoes) were purchased from the fresh produce supermarkets (Maliwichi *et al*., 2014). Cabbage, Swiss chard and potato samples were placed in sterile polythene bags, in an ice chest box, to avoid contamination and deterioration. Samples were marked with a label for identification. In the laboratory, the samples were stored in a fridge at between 0˚ and -4˚C until further processing.

Sample preparation and extraction

Chemicals with their Chemical Abstracts Service Number (CAS No.) used (ethyl acetate [141-78-6], acetonitrile [75-05-08], formic acid [64-18-6] and acetone [67-64-1]) were purchased from Sigma-Aldrich (St. Louis, MO, USA). Pesticide reference standards, with certified purity of at least 98% were obtained from Supelco (Bellefonte, PA, USA) and Sigma-Aldrich. The AOAC; Quick Easy Cheap Effective Rugged and Safe (QuEChERS) Packets of pre-weighed extraction salts, each containing 6 g anhydrous $MgSO_4$, 1.50 g anhydrous sodium acetate were obtained from Restek United Kingdom Ltd. Pre-packed mini centrifuge tubes (15 mL) each containing 150 mg of $MgSO_4$, 50 mg primary, secondary amine (PSA), and 50 mg graphitized carbon black (GCB) also from Restek UK Ltd.

The standard pesticide mix stock solutions included (hexachlorobenzene [118-74-1], chlorbicyclen [2550-75-6], aldrin [309-00-2], endosulfan ether [3369-52-6], chlordane [57-74-9], lindane [58-89-9], heptachlor [76-44-8], heptachlor epoxide [76-44-8], methoxychlor [72-43-5], endrin [72-20-8], dieldrin [60-57-1], endrin aldehyde [7421-93-4], *p,p'*-DDE [72-55-9], *o,p'*-DDD [53-19-0], *o,p'*-DDT [50-29-3] and dicofol [115-32-2]).

A total of 15 samples (of each sample per site) were prepared by using a knife to cut off all unwanted plant parts, including stalks (Tapia *et al.,* 2015). This was followed by washing off soil and dirt with water 50-55˚C from the tap (Wanwimolruk *et* *al.,* 2015). A potato peeler was used to peel potatoes. Then followed the cutting of samples into small portions (1.27 to 2.54 cm sized chunks) and homogenized using a blender. The homogenized samples were portioned into triplicates of ±200 g, placed into polyethene plastic bags and stored in a freezer at -20˚C. The samples were analysed within 24 hours (USFDA, 2012).

The extraction and clean-up method used was conducted according to the manufacturer's instructions for QuEChERS kits, the Association of Official Analytical Chemists (AOAC) 2007.01, with acetate buffering described by Lehotay *et al*. (2010). The homogenized 15 g cabbage, Swiss chard and potato samples were placed in a 50 mL centrifuge test tube. Then 15 mL of 1% acetic acid (CH_3COOH) in acetonitrile (CH_3CN) was added. This was followed by adding 6 g of magnesium sulphate ($MgSO_4$) and 1.5 g of sodium acetate ($C_2H_3NaO_2$). A vortex was created by stirring the mixture and centrifuging it at 1500 relative centrifugal force (rcf) for 1 min. Then the upper layer extract, the supernatant was removed for clean-up and the dispersive-solid-phase extract (d-SPE) ion clean-up was performed to remove organic acids, excess water and other components with a combination of primary secondary amine (PSA) sorbent and magnesium sulphate.

The 8 mL supernatant clean-up was transferred into a 15 mL centrifugal tube. Then 400 mg PSA and 1200 mg magnesium sulphate were added to all vegetable samples and 400 mg graphite carbon black (GCB) for Swiss chard. The extract was shaken for 30 seconds and then centrifuged for 1 min at 1 500 rcf to separate the solid material. Approximately 3 mL of the supernatant was then filtered through a 0.45 mm PTFE filter (13 mm diameter), and 800 mL portions were transferred to auto-sampler vials. The extracts were evaporated to dryness using liquid nitrogen and reconstituted in 800 mL acetonitrile/water (20/80, v/v) for the analysis. The pesticides were weighed, mixed and dissolved in acetonitrile to produce a 100 $mg \cdot L^{-1}$ mixed stock solution. The stock solution was stored at -4˚C and only removed to prepare calibration and spiking standards.

3.2 PESTICIDE RESIDUES ANALYSIS

The analysis was performed using a Pegasus GC-HR-TOF-MS from LECO Ultra, equipped with gas chromatography (GC) with an autosampler (Agilent Technologies, Palo Alto, CA), interfaced to a LECO Pegasus® GC–HRT high-resolution time-of-flight mass spectrometer with an electron ionization (EI) ion source (LECO, St. Joseph, MI).

For the mixture of compound standards, the GC was equipped with a GC×GC accessory (LECO, St. Joseph, MI) and a two-column set installed in the modulator and secondary oven. A 10 m x 0.18 mm i.d. x 0.2 µm df Rtx - 5 column (Restek Corp., Bellefonte, PA) connected to a 1 m x 0.1 mm i.d. x 0.1 µm df Rxi - 17 column (Restek Corp., Bellefonte, PA) was used with the following conditions: helium carrier gas at 0.8, 1.0, and 1.2 $mL \cdot min^{-1}$; splitless inlet at 250°C and split ratio of 100:1; GC oven temperature programme of 45°C for 2 min and then at 18°C·for min^{-1} to 315°C for 5 min; modulator temperature programme of +40°C relative to the GC oven; secondary oven temperature programme of +25°C relative to the GC oven; and a transfer line temperature of 300°C. The initial temperature programme was 50°C, held for 1 min. The temperature was then increased to 160°C at 10°C·min^{-1} and held for 1 min.; then ramped up to 280°C at 5°C·min^{-1} and held for 5 min. The GC was run for a total time of 42 min (see Figure 3.1).

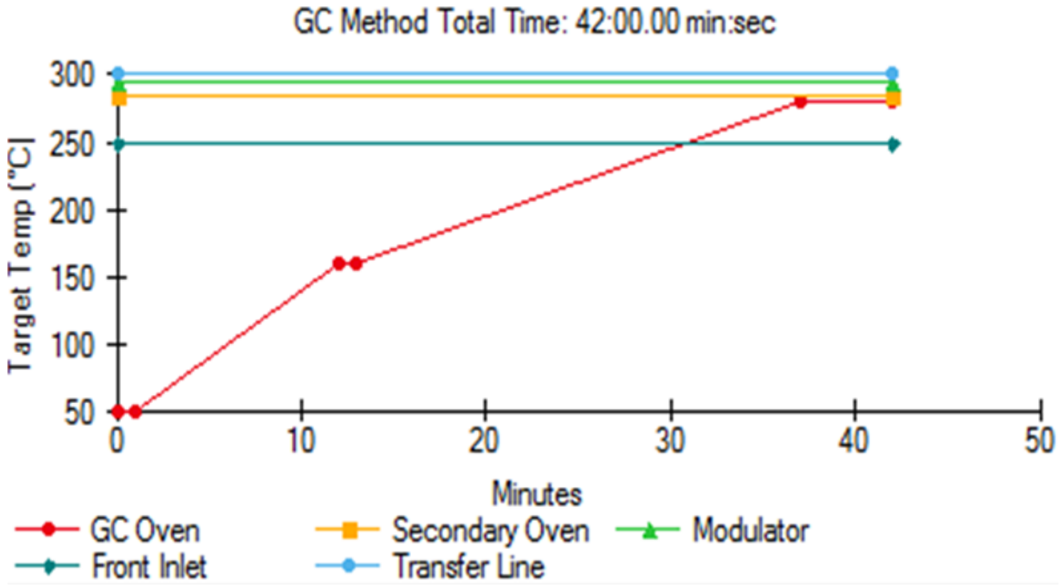


Figure 3.1: Temperature programme of GC method

3.3 PESTICIDES QUANTIFICATION

The identification of the compounds was accomplished by comparing the retention times and peak area spectra of the analytes in samples to those of reference standards run under the same conditions as the samples. The analytes were further verified using the NIST 11 mass spectral library (US National Institute of Standards and Technology). The pesticide compound was identified as if it had the same retention time as that of the standard (within a deviation of ±0.05 min) and their spectra matched.

The raw instrument data first were reduced to a peak list by LECO ChromaTOF-HRT® software (Beta Version 1.59), using the vendor suggested parameters. Internal mass calibration was done with PFTBA using the manufacturer's default calibration matrix applied to each injection. The data processing parameters in ChromaTOF-HRT® for the analysis of the compound mixture was set as S/N ≥ 50, peak quality ≥ 0.9, and peak confidence ≥ 6.0. The data processing parameters for analysis of the spiked-in data are S/N ≥ 20, peak quality ≥ 0.7, and peak confidence ≥ 6.0 (see appendix).

An external standard method was used to determine the quantities of residues in the sample extracts. A standard mixture containing known amounts of pesticides was run, and the response for each compound was determined. The area of the corresponding peak in the sample was compared with that of the known standard. The calculation of pesticide residue concentration was quantified following Omeroglu *et al*.'s (2018) description, where the amount of the pesticide in each sample was calculated based on the slope of the standard curve. The pesticide residue concentration was deduced from the following equation:

$$C = Ap + b/a$$

C = concentration of pesticide residue (ng·mL-1)

Ap = peak area of a compound

b = the b value from the calibration curve

a = the a value from the calibration curve

3.4 RISK ASSESSMENT

Health risk estimations were calculated based on an integration of pesticide analysis data and exposure assumptions. The human health risk was calculated through the comparison of residues found to the established acceptable daily intake (ADI) and acute reference dose (ARfD) values. The consumption rate for vegetables in the RSA is 235g per person·day^{-1} (Vorster *et al.,* 2013). For the precise evaluation, the ARfD and the ADI were expressed as a percentage of daily intake for a person with a body weight of 60 kg (Mathieu *et al.,* 2017). The estimated short-term intake (mg·kg^{-1}·day^{-1}) for each type of exposure was obtained by multiplying the highest residual pesticide concentration determined ($mg \cdot kg^{-1}$) in the food of interest by the food consumption rate ($kg \cdot day^{-1}$), and dividing the product by the bodyweight (kg):

$$ESTI = Rh \, x \, fc / \, bw \tag{1}$$

ESTI = the estimated short-term intake ($mg \cdot kg^{-1} \cdot day^{-1}$)
Rh = highest residual pesticide concentration determined ($mg \cdot kg^{-1}$)
fc = food consumption rate ($kg \cdot day^{-1}$)
bw = body weight (kg)

The acute (short-term) consumer health risk (aHI) was calculated based on the estimated short-term intake (ESTI) and the acute reference dose. The ARfD is an estimate of the amount of a residue in food expressed as a percentage of body weight. It can be consumed over a short period, usually one meal or one day, without any known effect on health (ECHA, 2016).

$$aHI = ESTI/ARfD \times 100\% \tag{2}$$

Pesticide residue concentrations on vegetables were determined as the arithmetic mean of all results obtained. The EDI was calculated by multiplying the pesticide concentration of each pesticide ($mg \cdot kg^{-1}$) with the food consumption rate ($kg \cdot day^{-1}$) and dividing this by the bodyweight *(bw)* (Adewunmi and Fapohunda, 2018).

$$EDI = mean \, residue \, level \times fc/bw \tag{3}$$

The chronic consumer health risk (hazard quotient, HQ) was calculated based on the estimated daily intake (EDI) and the acceptable daily intake (ADI) (Watkins and Klaasen, 2010; Ibanez *et al.,* 2010). The hazard quotient (HQ) was calculated using the formula below, as was stated by Lozowicka *et al*. (2013):

$$HQ = EDI/ADI \times 100\% \tag{4}$$

The hazard quotient (HQ) indicates an unacceptable risk when it is higher than 100%, and the higher aHI divided by HQ value represents a higher risk.

3.5 QUALITY CONTROL

A quality control spiking and stock solution of 40 mg·mL^{-1} were prepared by diluting the standard pesticide mix in acetonitrile containing 0.1% acetic acid. Calibration curve standard solutions of (0.05, 0.10, 0.20, 0.50, 1, 2 and 5 ng·mL^{-1}) were prepared from a 2, 10, and 40 µg·mL^{-1} solution in acetonitrile containing 0.1% acetic acid by serial dilution. The calibration curves obtained from the vegetable sample matrix and prepared standards (matrix-matched calibration) showed good linearity between the concentration of 0.05 and 5 ng·mL^{-1}, with a correlation coefficient (R^2) larger than 0.99 (see Figure 3.2 to Figure 3.6).

3.6 STATISTICAL DATA ANALYSIS

All parameters were statistically analysed and compared using a Microsoft Excel spreadsheet and XLSTAT (2015). Due to financial constraints, data collected from different vegetable sites were pulled together to represent only 15 samples of the vegetables collected from different sites. Thus, the replicates were disregarded, and all variables were compared using only descriptive statistics.

For an overview observation of all the variables, unsupervised multivariate data analysis was performed by using principal component analysis (PCA) and cluster analysis (CA). Scatter score plots from PCA were constructed to identify and evaluate groupings, trends and outliers of the vegetable accession; while the dendrogram for CA was performed to identify the similarities between the vegetable sites accessions.

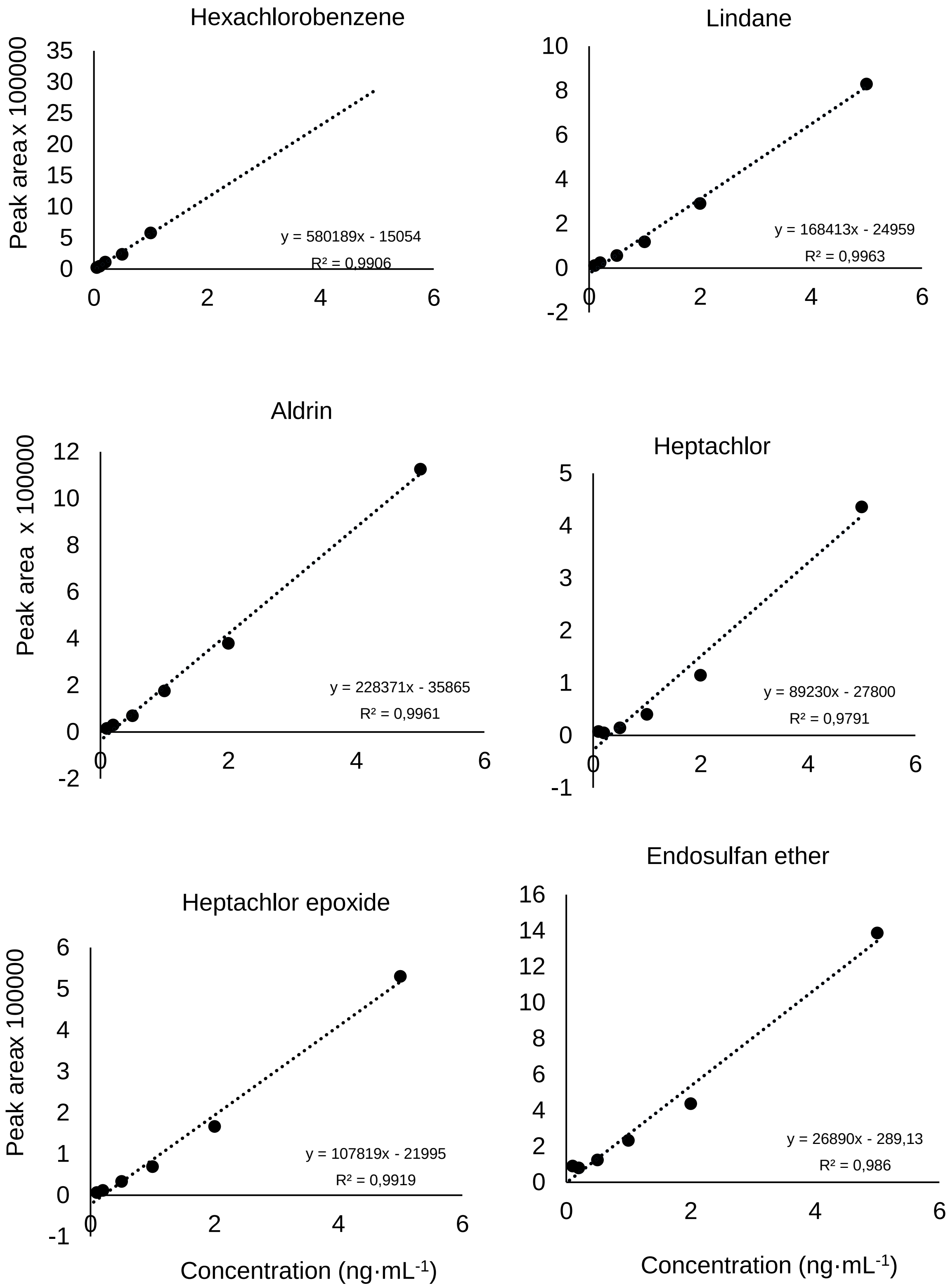


Figure 3.2: Calibration curves for (hexachlorobenzene, lindane, aldrin, heptachlor, heptachlor epoxide and endosulfan ether) compounds obtained from prepared standards in vegetable matrix (analysed concentrations range from 0.05 to 5 ng·mL^{-1})

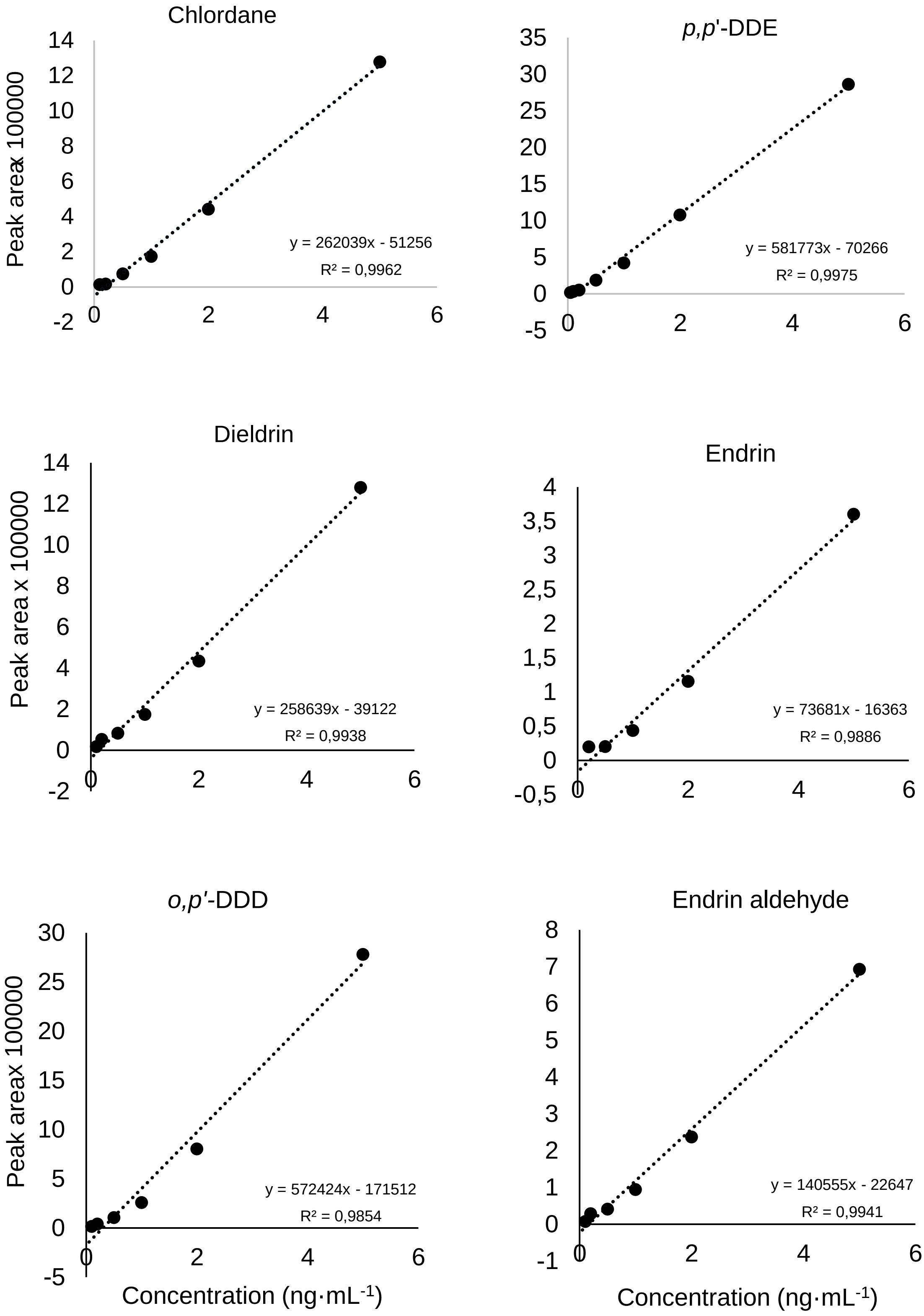


Figure 3.3: Calibration curves for (chlordane, *p,p*,'-DDE, dieldrin, endrin, *o,p'*-DDD and endrin aldehyde) compounds obtained from prepared standards in vegetables matrix (analysed concentrations range from 0.05 to 5 ng·mL^{-1})

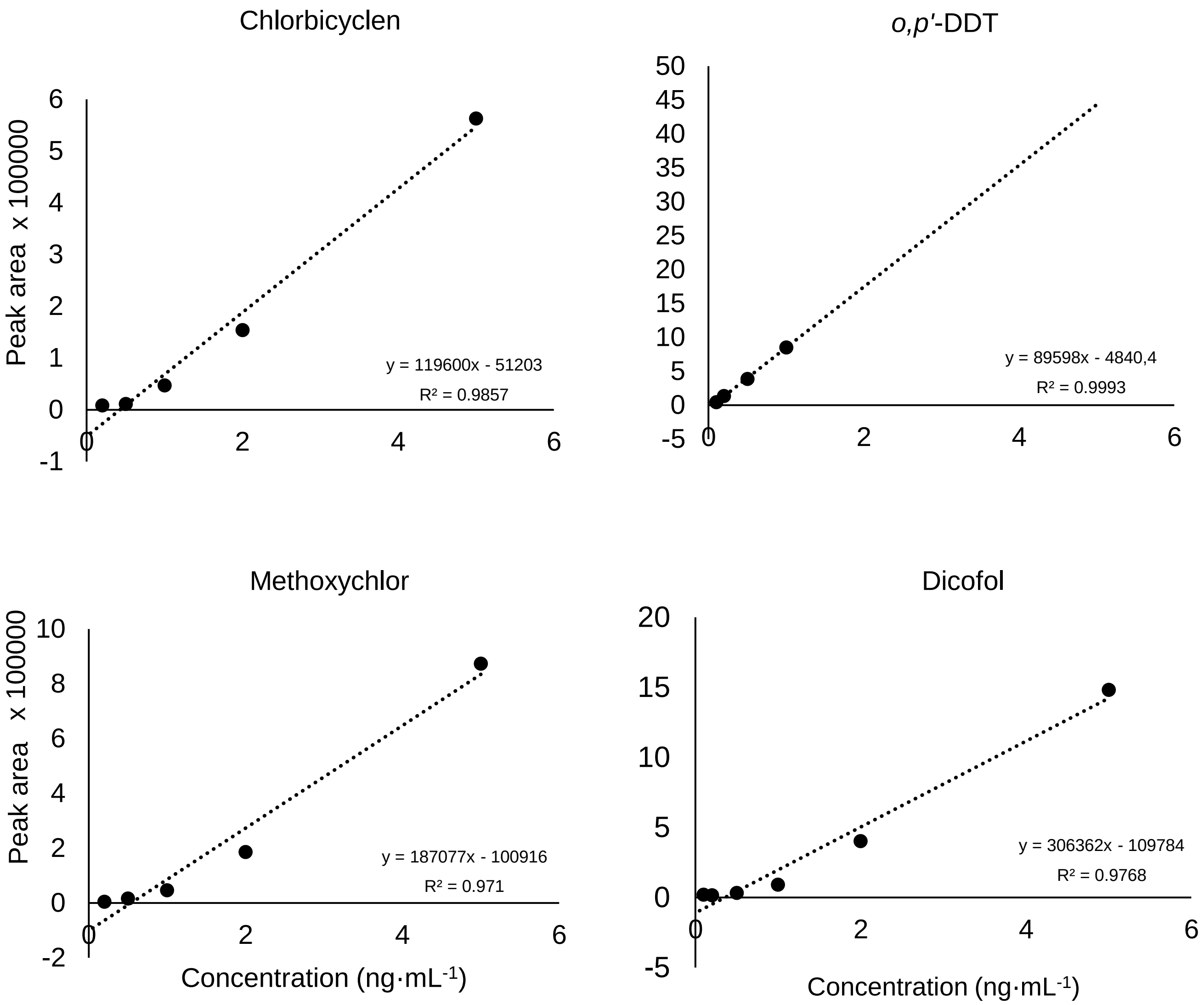


Figure 3.4: Calibration curves for (chlorbicyclen, *o,p'*-DDT, methoxychlor and dicofol) compounds obtained from prepared standards in the vegetable matrix (analysed concentrations range from 0.05 to 5 ng·mL^{-1})

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 PESTICIDE RESIDUES IN VEGETABLES

The present study evaluated the presence of the selected pesticide residues in staple vegetable samples, namely *Brassica oleracea* var. *capitata* (cabbage), *Beta vulgaris* spp.*, vulgaris* (Swiss chard) and *Solanum tuberosum* L. (potatoes), collected from different fresh produce markets in Bloemfontein. As shown in Tables 4.1 to 4.3 below, the vegetables sampled were analysed for the following pesticide residues: hexachlorobenzene, lindane, heptachlor, aldrin, heptachlor epoxide, endosulfan ether, chlordane, *o,p'*-DDE, dieldrin, endrin, endrin aldehyde, dicofol, *p,p'*-DDD, chlorbicyclen, *o,p'*-DDT and methoxychlor. However, endrin aldehyde and dicofol were not detected in any of the samples analysed. The highest concentration of pesticide residues found in the cabbage, Swiss chard and potato samples was chlordane, endosulfan ether and methoxychlor at the concentration of 1.62 x 10^{-2}, 1.33 x 10^{-2} and 1.04 x 10^{-2} ng·g^{-1}, respectively.

4.1.1 Cabbage

Among the pesticide residues detected in the cabbage samples analysed, the concentration of chlordane was the highest at 1.62 x 10^{-2} ng·g^{-1}; a range of 1.53 x 10^{-2} and the median of 0.99 x 10^{-3} ng·g^{-1} (see Table 4.1 below). The next highest concentration was heptachlor between the concentration of 1.95 x 10^{-3} and 1.22 x 10^{-2} ng·g^{-1} at a range of 1.02 x 10^{-2}, and a median of 6.98 x 10^{-3} ng·g^{-1}. Other pesticide residues included methoxychlor, lindane, endosulfan ether, *o,p'*-DDT, heptachlor epoxide and chlorbicyclen at the concentrations between 1.18 x 10^{-3} and 0.77 x 10^{-2} ng·g^{-1}. While, hexachlorobenzene, aldrin, *p,p'*-DDE, dieldrin, endrin and *o,p'*-DDD were found at the concentrations between 0.42 x 10^{-3} up to 0.96 x 10^{-3} ng·g^{-1}. The total mean concentration of pesticide residues in cabbage was 2.03 x 10^{-2} ng·g^{-1}.

Table 4.1: The level of pesticide residues in ng·g^{-1}, detected in cabbage samples from all sites.

	Pesticide concentrations in cabbage (x 10^{-3} ng·g^{-1})													
Sites	**HCB**	**Lin.**	**Hept.**	**Ald.**	**HepEp.**	**EndoEth.**	**Chlord.**	**ppDDE**	**DieL.**	**Endr.**	**opDDD.**	**ChlorBic.**	**opDDT**	**Methoxy**
Site A	0.40	1.04	12.16	1.17	1.31	0.99	0.99	0.96	ND	0.80	0.84	1.18	0.84	6.21
Site B	0.16	ND	ND	1.05	1.13	0.89	ND	0.77	0.69	0.69	0.82	1.10	0.82	ND
Site C	0.42	0.21	2.32	1.06	1.30	1.72	0.89	0.86	0.82	0.82	0.91	1.03	0.91	ND
Site D	0.21	0.54	1.95	0.87	1.27	0.81	ND	0.80	ND	ND	0.88	ND	0.88	7.70
Site E	0.35	0.35	11.64	0.88	1.22	1.73	16.22	0.70	0.71	0.71	0.86	0.99	0.86	7.59
Range	0.21	0.83	10.21	0.30	0.18	0.92	15.33	0.26	0.14	0.14	0.09	0.19	0.09	1.38
Median	0.35	0.35	6.98	1.05	1.27	0.99	0.99	0.80	0.71	0.75	0.86	1.07	0.86	7.59

A comparative level of pesticides in cabbage purchased in Site A (Johnny's Fruits); Site B= Food Lover's Market; Site C= RSA Mangaung Fresh Produce; Site D= Food Lover's Market and Site E= Metro; ND= Not detected; Abbreviation: HCB= Hexachlorobenze. Lin.= Lindane. Hept.= Heptachlor. Ald.= Aldrin. HepEp.= Heptachlor epoxide. EndoEth= Endosulfan ether. Chlord.= Chlordane. ppDDE= *p.p'*-DDE. DieL.= Dieldrin. Endr.= Endrin. opDDD= *o.p'*-DDD. ChlorBic.= Chlorbicyclen. opDDT= *o.p'*-DDT. Methoxy= Methoxychlor

Chlordane concentration on cabbage was the highest because it is a common pesticide which has been used for several decades on crops to control termites (Crawford and Quinn, 2017). Chlordane is preliminarily identified as persistent in the environment, and it also bio-accumulates (Shields *et al.,* 2015). This may be the reason why it is still found in crops, although at low levels. Chlordane was banned in 1983 by the Environmental Protection Agency (EPA) due to its negative effect on the human immune system and also was classified as a possible human carcinogen (Beiras, 2018).

The findings of this study are comparable to the findings of the study conducted by the WHO (1984) on vegetable samples analysed in a USA market-basket survey, during which chlordane residues were found in less than 1% of samples at levels of 1–5 $\mu g \cdot kg^{-1}$. In another study conducted in Egypt, potato and cucumber samples analysed for heptachlor and its epoxide, contained residues at levels of 0.2-8 $\mu g \cdot kg^{-1}$ (Badr *et al*., 2019). Some recent studies, analysed pesticide residues on cabbage; however, no chlordane was detected (Mwanja *et al*., 2017; Machekano *et al.*, 2019).

A study conducted by Kolani *et al.* (2016) on cabbage samples collected from markets in Togo, revealed the sum of hexachlorocyclohexane (ΣHCH) found in cabbage at the concentrations of 93.40 $ng \cdot g^{-1}$, above 1 $ng \cdot g^{-1}$. Another study, conducted in the RSA by Nuapia *et al*. (2016) detected heptachlor epoxide up to 78.93 $\mu g \cdot kg^{-1}$ on cabbage samples among other residues. These pesticide compounds exceeded the prescribed limit set by different international agencies. The residues originated from past and present agricultural activities and might reach the top of the food chain by bioaccumulation if not controlled. This may pose serious public health problems, as the concentrations are comparable to those found in the study reported here.

Table 4.2: Codex Alimentarius MRLs (Detected pesticide residues levels) of permitted in vegetables.

Pesticide residues	**Vegetables MRLs** (kg·mg^{-1})	**Cabbage**	**Swiss chard**	**Potato**
		(x 10^{-3}ng·g^{-1})		
Hexachlorobenzene	0.01	0.35	0.26	0.28
Lindane	0.01	0.35	ND	0.79
Heptachlor	0.05	6.98	1.92	1.86
Aldrin	0.05	1.05	0.95	0.06
Heptachlor epoxide	0.05	1.27	10.00	1.19
Endosulfan ether	0.05	0.99	0.88	7.33
Chlordane	0.02	0.99	2.89	0.83
p.p'-DDE	0.01	0.80	0.82	0.80
Dieldrin	0.05	0.71	0.91	0.79
Endrin	0.05	0.75	0.88	0.79
o.p'-DDD	0.20	0.86	0.91	0.92
Chlorbicyclen	0.01	1.07	ND	1.12
o.p'-DDT	0.20	0.86	0.91	0.90
Methoxychlor	0.05	7.59	8.90	9.14

MRLs = Maximum Residue Limits; ND= Not detected

Heptachlor was used in the past for killing insects on food crops, and because of its persistence in the environment, humans may be exposed to contaminated cabbage. In the areas where heptachlor was used for termite control on crops, heptachlor still may hold a risk of exposure through contaminated soil, water and crops. Chlordane and heptachlor are considered together because of their similarity and because technical-grade products contain approximately 20% of the other compound (IARC, 1991). Therefore, the presence of heptachlor in biological media may be indicative of exposure to heptachlor or chlordane, because chlordane is a metabolite of chlordane (ATSDR, 2007).

The concentrations of pesticide residues reported here were compared with the Maximum Residue Limits (MRLs) set by FAO and WHO (FAO/WHO, 2013). Codex Alimentarius MRLs of permitted cabbage, Swiss chard and potato are given in Table 4.2 (previous page). Chlordane and heptachlor were detected below the MRLs of 0.02 and 0.05 mg·kg^{-1}. The MRL is the maximum concentration of a pesticide residue recommended by the Codex Alimentarius Commission to be legally permitted in or on food commodities and animal feeds, expressed in (mg·kg^{-1}) (Wanwimolruk *et al.,* 2015). Exposure to a particular pesticide below the health safety limit is considered safe (Fothergill and Abdelghani, 2013).

4.1.2 Swiss chard

As illustrated in Table 4.3, the endosulfan ether concentration on Swiss chard was found to be highest with the mean concentration between 8.54 x 10^{-3} and 13.26 x 10^{-3} ng·g^{-1}, at the range of 4.73 x 10^{-3} and median of 0.10 ng·g^{-1}. Followed by methoxychlor, chlordane and heptachlor at the concentrations of 9.74 x 10^{-3}, 5.07 x 10^{-3} and 1.92 x 10^{-3} ng·g^{-1}, respectively. Pesticide residues such as *p,p'*- DDE, *o,p'*-DDD, heptachlor epoxide, dieldrin, endrin aldrin, *o,p'*-DDT and hexachlorobenzene were also detected at the concentration up to 0.94 x 10^{-3} ng·g^{-1} (Table 4.2). The total concentration of pesticide residues in Swiss chard was 30.46 x 10^{-3} ng·g^{-1}.

The results regarding pesticide residues in different Swiss chard samples reported by Amir *et al.* (2015), showed residue concentrations of endosulfan of between 0.43 x 10^{-2} and 13.27 x 10^{-3} mg·kg^{-1} below the limit. Esturk *et al*. (2014) did not analyse endosulfan residues, but monitored pesticide residues in Swiss chard and reported that it contained-

Table 4.3: The level of pesticide residues in ng·g^{-1}, detected in Swiss chard samples from all sites

	Pesticide concentrations in Swiss chard (x 10^{-3} ng·g^{-1})											
Sites	**HCB**	**Hept.**	**Ald.**	**HepEp.**	**EndoEth.**	**Chlord.**	**ppDDE**	**DieL.**	**Endr.**	**opDDD.**	**opDDT**	**Methoxy**
Site A	0.23	2.87	0.93	1.09	ND	ND	0.00.75	ND	ND	0.87	0.87	ND
Site B	0.29	1.99	1.01	1.13	8.54	5.07	0.91	1.08	1.08	0.90	0.90	8.90
Site C	ND	1.86	0.95	1.08	9.92	0.72	0.90	ND	0.85	0.91	0.91	ND
Site D	ND	1.92	0.95	1.10	3.27	ND	0.82	ND	0.91	0.93	0.93	8.38
Site E	ND	1.81	0.80	1.12	10.09	ND	0.78	0.75	0.75	0.94	0.94	9.74
Range	0.06	1.06	0.08	0.05	4.73	4.34	0.09	0.33	0.33	0.07	0.07	1.36
Median	0.26	1.92	0.95	1.10	10.00	2.89	0.82	0.91	0.88	0.91	0.91	8.90

A comparative level of pesticides in cabbage purchased in Site A (Johnny's Fruits); Site B= Food Lover's Market; Site C= RSA Mangaung Fresh Produce; Site D= Food Lover's Market and Site E= Metro; ND= Not detected; Abbreviation: HCB= Hexachlorobenze. Lin.= Lindane. Hept.= Heptachlor. Ald.= Aldrin. HepEp.= Heptachlor epoxide. EndoEth= Endosulfan ether. Chlord.= Chlordane. ppDDE= *p.p'*-DDE. DieL.= Dieldrin. Endr.= Endrin. opDDD= *o.p'*-DDD. ChlorBic.= Chlorbicyclen. opDDT= *o.p'*-DDT. Methoxy= Methoxychlor

- carbendazim, cymoxanil, fenarimol and dichlorvos in the concentration range of <0.01 x 10^{-2} to 2.89 x 10^{-2} mg·kg^{-1}. Mutengwe *et al*. (2016b) in their study done in South Africa, detected endosulfan ether below the limit at the concentration of (0.05 mg·kg^{-1}), which is comparable with what was found in the study reported here.

Endosulfans are recognized for their endocrine disrupting properties (Patočka *et al.,* 2016). Among others, it may lead to increased congenital disabilities and sexual abnormalities and may also increase the risk of cancers of the reproductive organs (Saxena*,* 2016). Although endosulfan was banned in the RSA in 2012 because of its high toxicity to humans and its persistence in the environment (DAFF, 2017), it continues to be used. It was detected on cabbage and Swiss chard in our study, because some farmers still use banned pesticides, which is evidence of farmers' incompliance about which concerns were raised in numerous studies, for example by Damalas and Eleftherohorinos (2011).

Methoxychlor is not usually found in food; however, it may be found in low levels in foods obtained from areas where methoxychlor was used earlier (ATSDR, 2015). There possibly are high levels of methoxychlor on farms, or in the environment and water near farms (Boyd, 2014). Methoxychlor was registered for use against parasites in cattle, animal feed, pets and home gardens. In the 1970s, methoxychlor was seen as a safer alternative than the pesticide DDT and was used extensively as a replacement. However, methoxychlor was banned in Europe in 2002 and the USA in 2003 due to a variety of adverse health effects (Boyd, 2014). The use of methoxychlor; however, remains undefined with little information available about its registration in South Africa (Neves *et al*., 2018). Methoxychlor can accumulate in some living organisms; however, very few reports exist on the health effects of methoxychlor in humans. In animals, exposure to high levels of methoxychlor caused effects on the nervous system. These effects included tremors, convulsions, and seizures (ATSDR, 2015).

The manufacturing and use of methoxychlor have long been banned, yet significant levels of these pesticides or their metabolites persist in the environment. As a persistent organic pollutant, chlordane is readily detectable in the environment (ATSDR, 2000). Chlordane exposure can cause permanent alterations of the nervous system function, including problems with memory, learning, thinking, sleeping, personality changes, depression, and numbness in the extremities, headache, and sensory and perceptual changes. It has been suggested that chronic exposure can cause blood disorders (ATSDR, 2014). The analysis by Abdulhamid *et al.* (2015) showed the presence of cypermethrin in the concentration range of 0.51 to 9.95 µg mL^{-1} in two samples of Swiss chard. The presence of heptachlor, however, was not confirmed in these samples.

4.1.3 Potato

Table 4.4 (see below) presents the concentrations of detected pesticides residues in potato samples. The highest concentration of pesticide residues in potatoes is presented in Table 4.4. Methoxychlor was detected at the mean concentration of 10.45 x 10^{-3} ng·g^{-1} at the range of 0.26 x 10^{-2} and median of 9.14 x 10^{-3} ng·g^{-1}, followed by endosulfan ether at the concentration of 7.87 x 10^{-3} at the range of 3.03 x 10^{-3} and the median of 7.33 x 10^{-3} ng·g^{-1} (Table 4.4).

Other pesticide residues detected in potato samples were heptachlor, chlordane, *p,p'*-DDE hexachlorobenzene, heptachlor epoxide, chlorbicyclen, lindane, dieldrin, *o,p'*-DDT and endrin were detected in the potato samples between the mean concentration of 0.68 x 10^{-3} and 2.33 x 10^{-3} ng·g^{-1}. The total concentration of pesticide residues in potatoes was 27.33 x 10^{-3} ng·g^{-1}.

Table 4.4: The level of pesticide residues in ng·g^{-1}, detected in potato samples from all sites

Pesticide concentrations in potato (x 10 $^{-3}$ ng·g^{-1})														
Sites	**HCB**	**Lin.**	**Hept.**	**Ald.**	**HepEp.**	**EndoEth.**	**Chlord.**	**ppDDE**	**DieL.**	**Endr.**	**opDDD.**	**ChlorBic**	**opDDT**	**Methoxy**
Site A	ND	ND	1.85	ND	1.15	6.04	0.77	0.77	0.79	0.79	0.93	1.06	0.93	10.45
Site B	1.9	ND	2.01	0.60	1.26	7.50	0.77	0.80	0.75	0.75	0.90	1.12	0.90	ND
Site C	0.29	ND	1.82	ND	1.13	7.87	0.84	0.80	ND	ND	ND	ND	0.88	ND
Site D	0.27	0.54	1.86	0.57	1.19	7.33	0.83	0.83	0.99	0.99	0.67	1.13	0.67	ND
Site E	0.68	1.04	2.23	0.71	1.77	4.84	1.35	1.43	ND	ND	0.93	ND	0.93	7.84
Range	0.48	0.50	0.41	0.14	0.64	3.03	0.58	0.66	0.24	0.24	0.26	0.06	0.26	2.61
Median	0.28	0.79	1.86	0.60	1.19	7.33	0.83	0.80	0.79	0.79	0.92	1.12	0.90	9.14

A comparative level of pesticides in cabbage purchased in Site A (Johnny's Fruits); Site B= Food Lover's Market; Site C= RSA Mangaung Fresh Produce; Site D= Food Lover's Market and Site E= Metro; ND= Not detected; Abbreviation: HCB= Hexachlorobenze. Lin.= Lindane. Hept.= Heptachlor. Ald.= Aldrin. HepEp.= Heptachlor epoxide. EndoEth= Endosulfan ether. Chlord.= Chlordane. ppDDE= *p.p'*-DDE. DieL.= Dieldrin. Endr.= Endrin. opDDD= *o.p'*-DDD. ChlorBic.= Chlorbicyclen. opDDT= *o.p'*-DDT. Methoxy= Methoxychlor.

The outcomes regarding pesticide residues in potato samples by Chowdhury *et al*. (2013) revealed endosulfan residues concentration (below the MRLs 0.05 mg·kg^{-1}) between 0.39 x 10^{-2} and 0.02 mg·kg^{-1}. Other studies analysed pesticide residues in potatoes (Ahmed *et al*., 2014; Skovgaard *et al.,* 2017); however, no endosulfan residues and methoxychlor concentrations were found in potato samples.

4.2 VARIATION OF PESTICIDES RESIDUES IN VEGETABLES BETWEEN DIFFERENT SAMPLING SITES

In the study reported here, variations were found in the occurrence of hexachlorobenzene in the cabbage and potato samples from all sampling sites (from Site A to Site E) (see Figure 4.1). Hexachlorobenzene was detected in Site E Potato at 76.04%, followed by Site C Cabbage at 61.13% and Site D Cabbage at 47.33%. Variations also were observed in the detection of lindane residues in cabbage and potato samples from all sampling sites. The lindane detected on Site A Cabbage measured 171.44%, and Site E Potato was 91.37% (Figure 4.1).

In terms of heptachlor, there were variations in the incidence of lindane residues in cabbage samples (Figure 4.2). Heptachlor had the highest detection of 113.04% in Site A Cabbage. Site E Cabbage was detected at 108.18%, while Site C Cabbage was detected at 21.56%. However, there were variations in the concentration of aldrin residues in cabbage samples. Aldrin was detected at 45.13% in Site A Cabbage, 40.42% Site B Cabbage and 40.95% in Site C Cabbage (Figure 4.2).

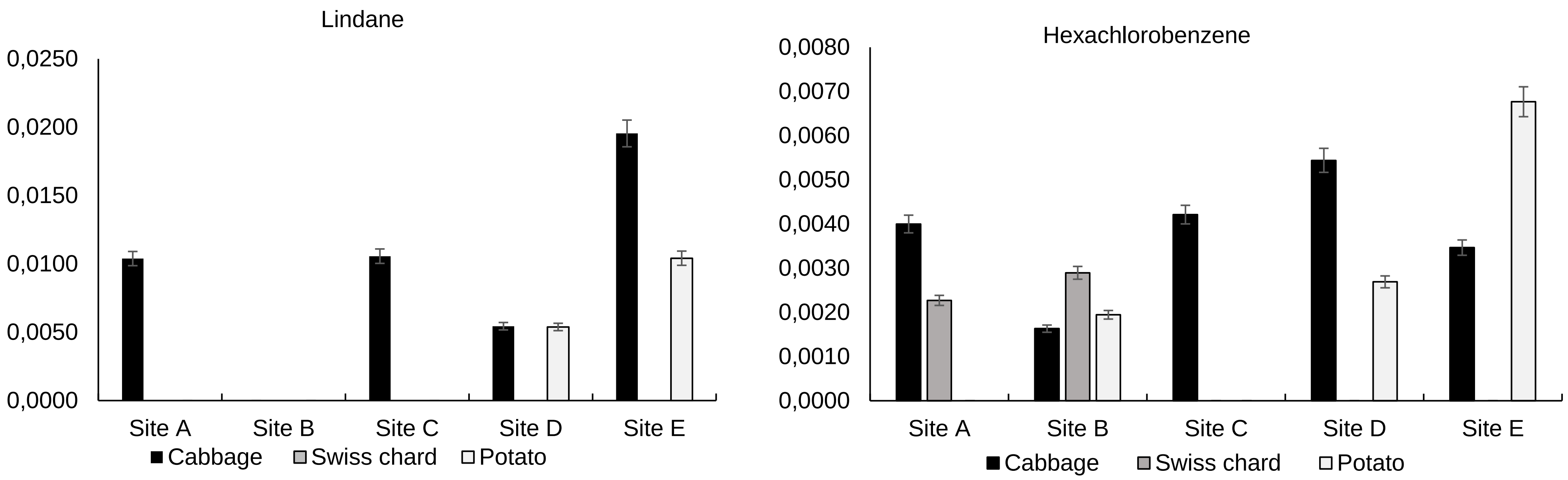


Figure 4.1: Variation between lindane and hexachlorobenzene residues on vegetable sites accession.

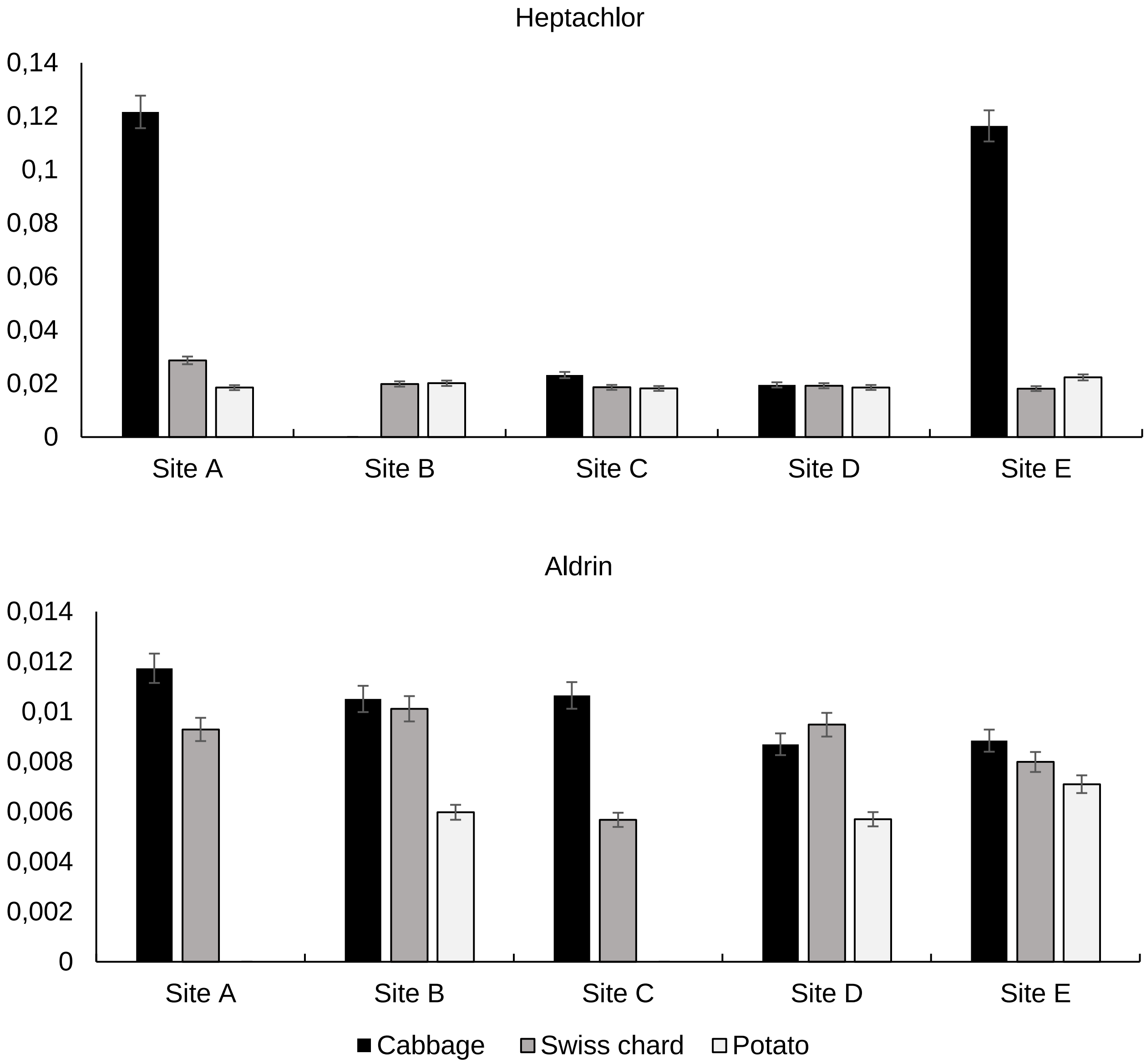


Figure 4.2: Variation between heptachlor and aldrin residues on vegetable sites accession.

Variations were not observed in heptachlor epoxide in potato and cabbage samples and the sampling sites (Figure 4.3). Heptachlor epoxide was detected at 49.75% in Site E Potato, 36.85% in Site A Cabbage and 35.76% in Site D Cabbage. Furthermore, endosulfan ether had no variations among Swiss chard samples and sampling sites. It was detected at 55.05% in Site E Swiss chard, followed by 54.13% in Site C Swiss chard and 46.6% in Site B Swiss chard (Figure 4.3).

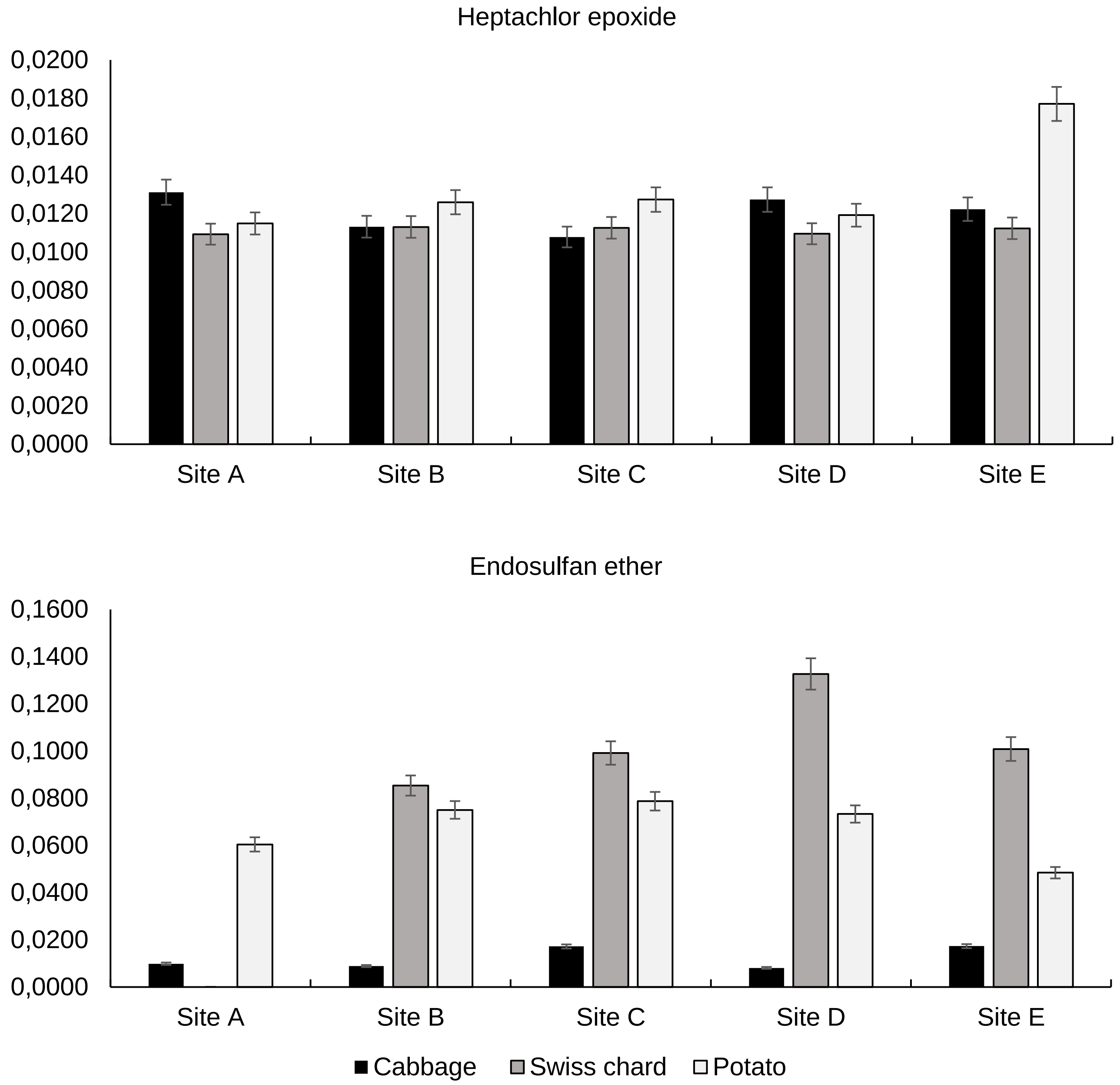


Figure 4.3: Variation between heptachlor epoxide and endosulfan ether residues on vegetable sites accession.

Variations were found in the concentrations of chlordane residues and the types of samples from Site B and Site E (Figure 4.4). Site E Cabbage had the highest detection of chlordane at 344.46%, followed by Site C Swiss chard at 107.58%, and Site E Potato at 28.61%. Additionally, *p,p'*-DDE was detected at 59.05% in Site E Potato, followed by 39.7% in Site A Cabbage and then 37.65% in Site B Swiss chard (see Figure 4.4).

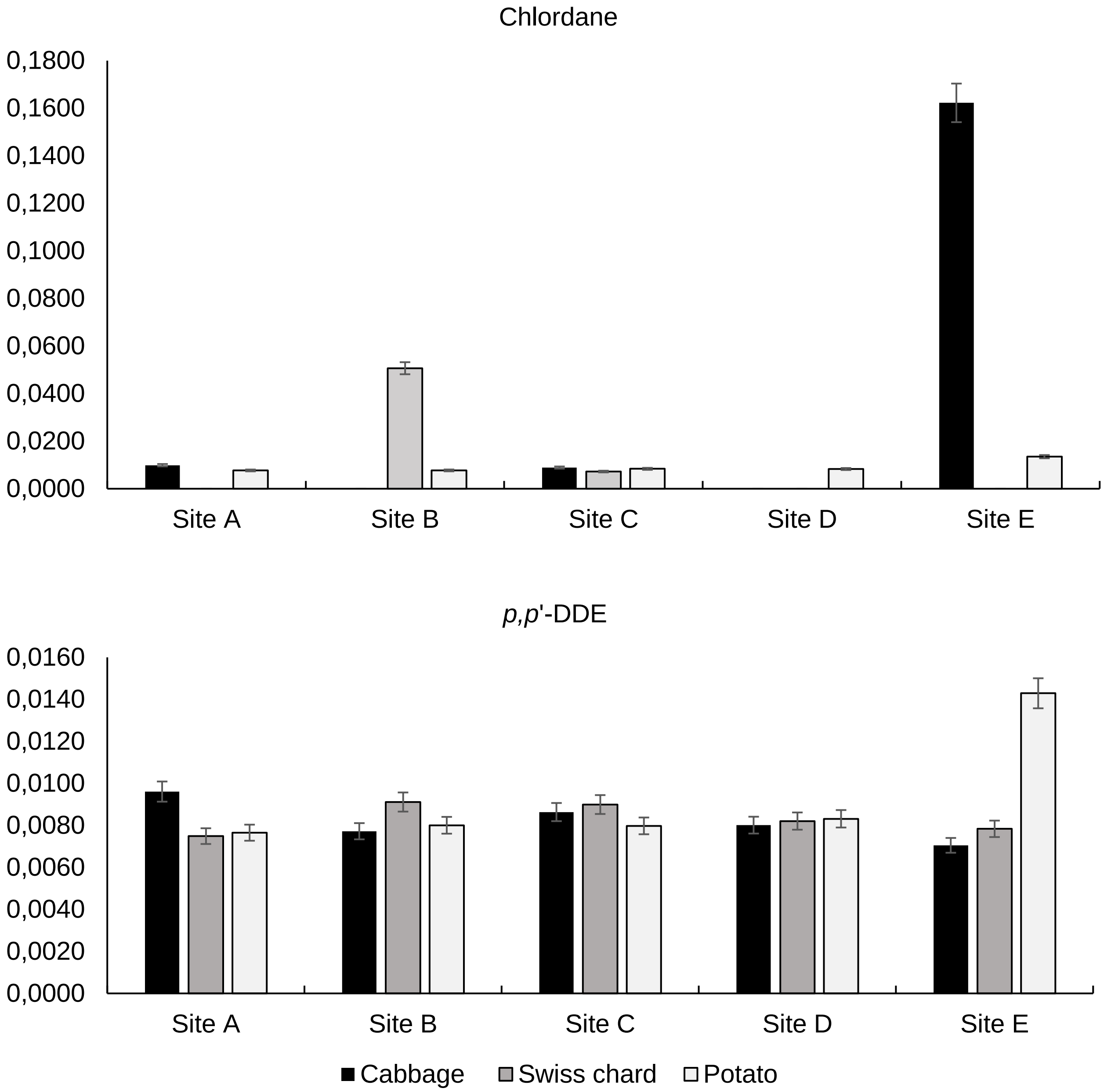


Figure 4.4: Variation between chlordane and *p.p'*-DDE residues on vegetable sites accession.

There were no variations among the concentration of dieldrin residues and the types of the samples from the sampling sites (see Figure 4.5). Dieldrin appeared in Site B Swiss chard at 44.75% followed by Site D Potato at 40.96% and Site C Cabbage at 34.18%. The same applied to endrin; it was detected in Site B Swiss chard at 44.75%, followed by Site D Potato at 40.79%, and Site C Cabbage at 34.04% (Figure 4.5).

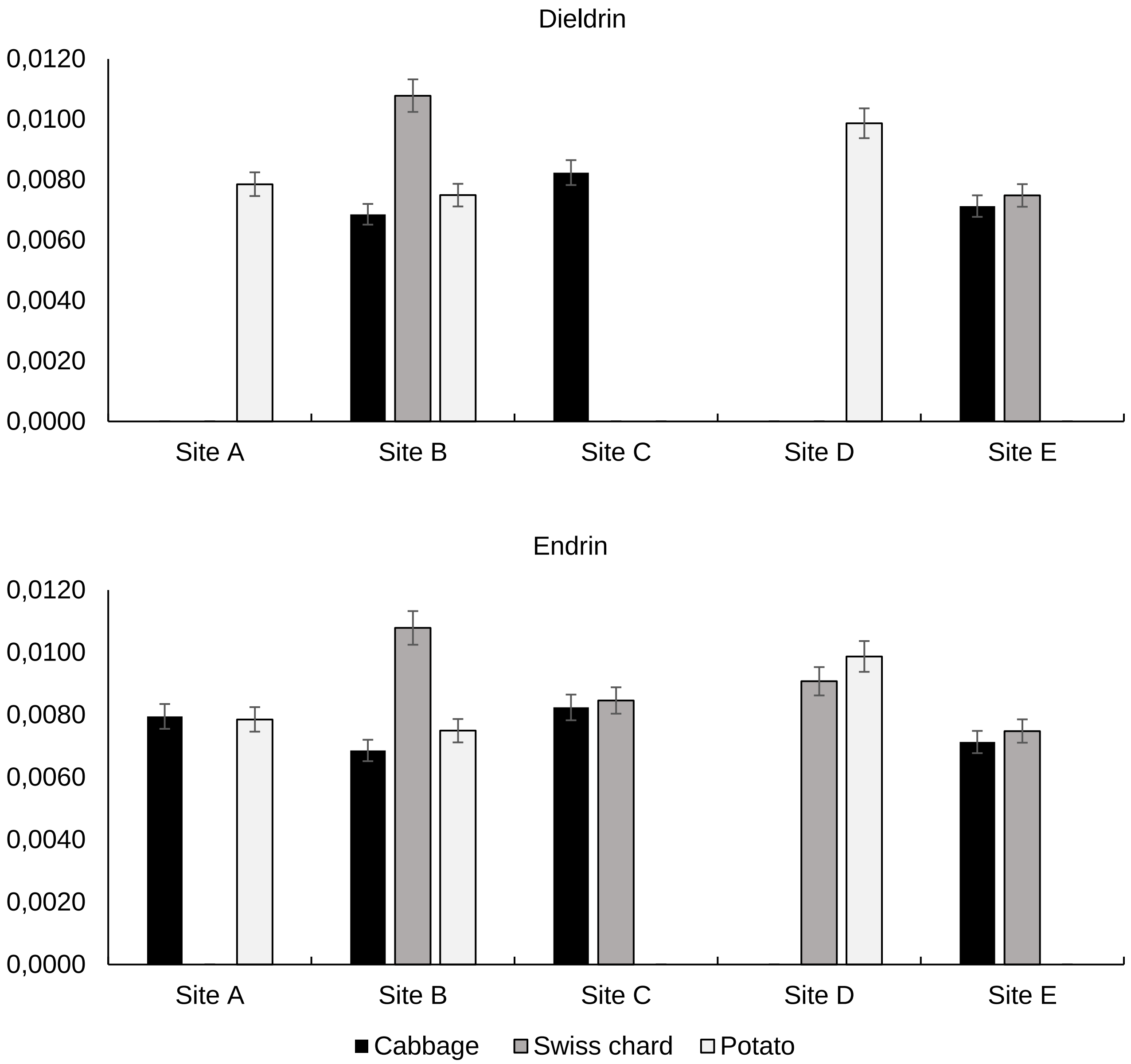


Figure 4.5: Variation between dieldrin and endrin residues on vegetable sites accession.

In terms of the presence of *o,p'*-DDD, no variations were detected between Swiss chard and potato samples from all sampling sites (see Figure 4.6). The detection of Site E Swiss chard was 34.89%, in Site E Potato 34.56%, and in Site C Swiss chard 33.96%. Furthermore, chlorbicyclen detection had no variation between Site A Cabbage at 53.94%, Site D Potato at 51.68% and Site B Potato at 51.17% (Figure 4.6).

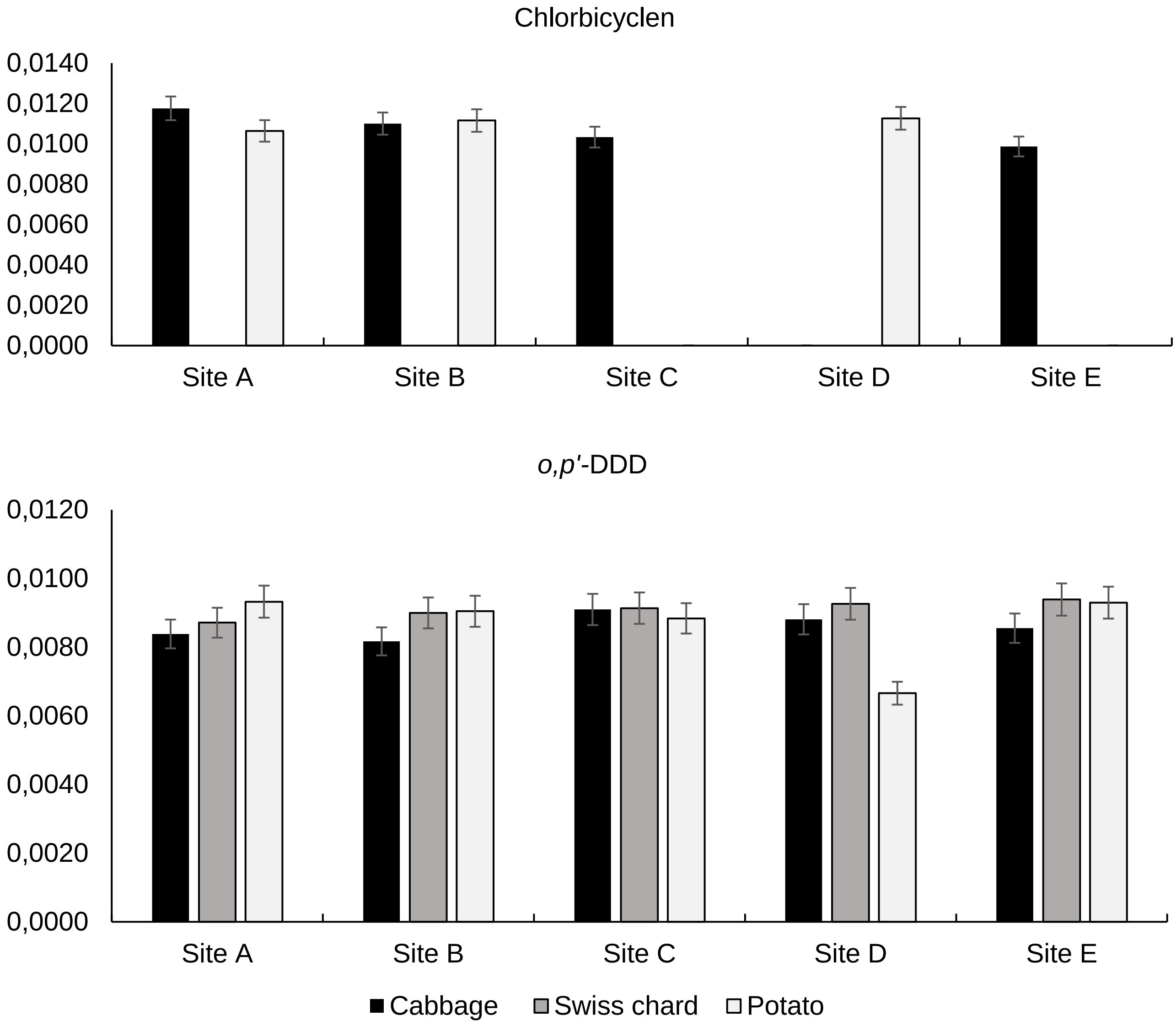


Figure 4.6: Variation between chlorbicyclen and *o.p′*-DDD residues on vegetable sites accession.

There were no variations in the occurrence of *o,p'*-DDT among the Swiss chard samples from all sampling sites (Figure 4.7). Residues of *o,p'*-DDT was detected in Site E Swiss chard at 69.78%, followed by Site D Swiss chard at 66.81%, and Site C Swiss chard at 63.76%. Additionally, there were no variations observed in the detection of methoxychlor residues in Swiss chard and Potato from all sampling sites. The detection of methoxychlor on Site A Potato was 40.75% and Site E Swiss chard at 37.99% (see Figure 4.7).

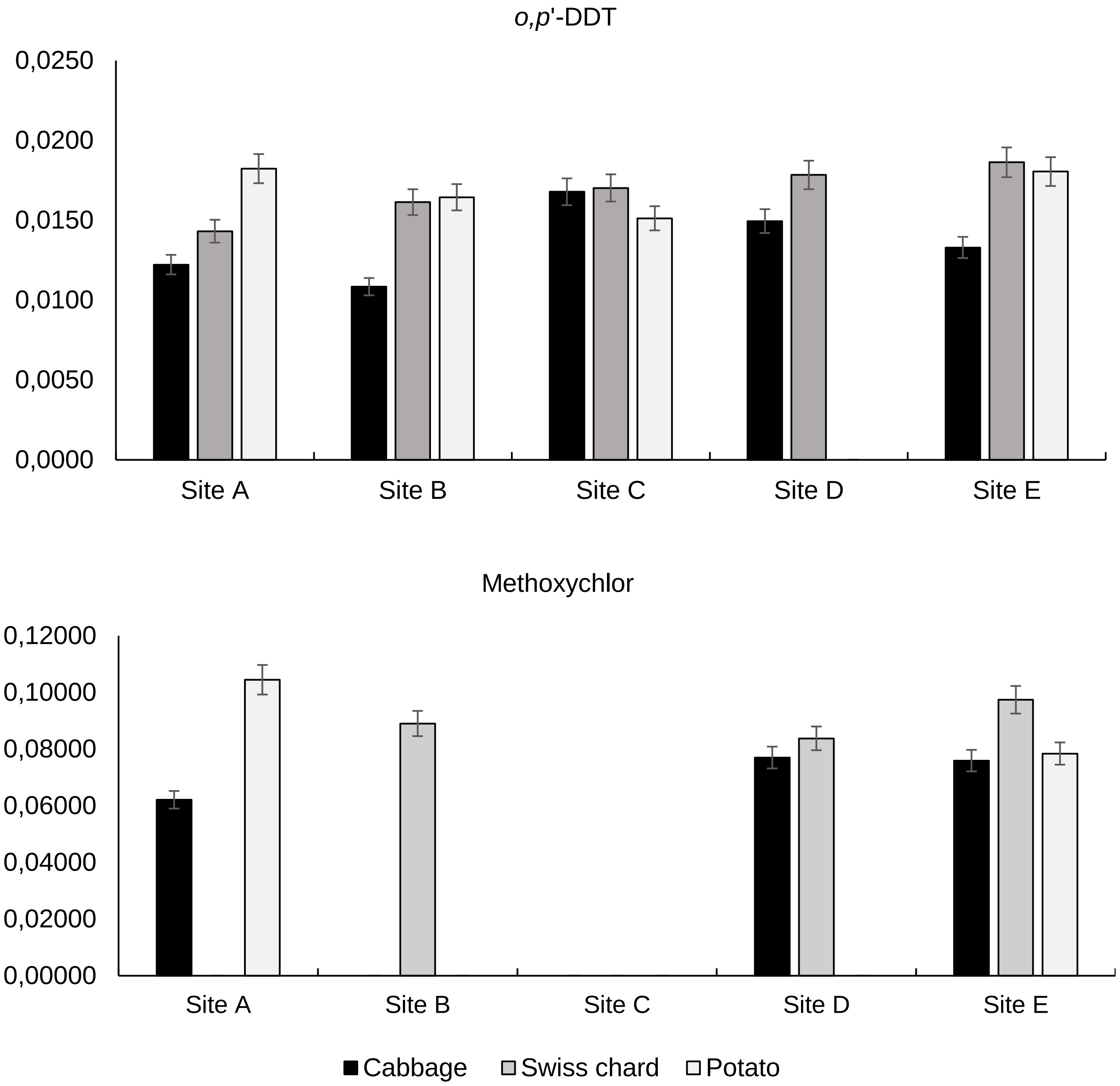


Figure 4.7: Variation between *o.p'*-DDT and methoxychlor residues on vegetable sites accession.

Generally, out of a total of 16 pesticide residues detected in 15 samples of cabbage, Swiss chards and potato, pesticide residues were not detected in 26.67% of the samples, while 73.33% of the samples did contain pesticide residues. Overall, 80% of cabbage, 60% of Swiss chard and 80% of potato samples contained one or more detectable residues (see Tables 4.1 to 4.3). This suggests that vegetable samples were contaminated with the compounds studied.

There were variations in the concentrations of total hexachlorobenzene, lindane, heptachlor and chlordane among all the sample types and sites. The highest mean concentration observed, was chlordane in Site E Cabbage (Figure 4.4). No variations were found in the levels of aldrin, heptachlor epoxide, endosulfan ether, dieldrin, endrin, *o,p*'-DDD, chlorbicyclen, *o,p*'-DDT, methoxychlor and *p,p'*-DDE among all the samples types and sites. This suggests that there were no differences in the farming conditions because the contamination patterns of the pesticides evaluated have similar pesticide absorption abilities. Therefore, the findings of this study indicate that most vegetables from all the markets have similar contamination sources.

Principal component analyses on vegetables and sites

The principal component analysis (PCA) was performed in order to find patterns in the distributions of the 14 pesticides among 15 vegetable samples obtained from different sampling sites. The patterns of diversity were determined using those variables with the highest square of cosines among accessions (Table 4.5). The PCA measures the contribution of each component to the total variance, while each factor loading specifies the amount of contribution of every trait with each principal component associated with that trait (Beaumont, 2012). The first two components accounted for 46.24% of the total variance. The PC1 accounted for 23.92% and PC2 for 22.32% of the variation (see Figure 4.8).

Vegetables from specific sites that contributed the most to the variability accessions in the first principal component (PC1) were Site B Cabbage, Site E Cabbage and Site B Swiss chard. Additionally, their commonality could indicate that they all contain *o,p'*-DDD, *o,p'*-DDT, methoxychlor, endosulfan ether, hexachlorobenzene, endrin, dieldrin, *p,p'*-DDE, lindane and chlorbicyclen. For PC2, the sites that mainly contributed to the variability among accessions were Site A Cabbage, Site E Swiss chard and Site A Potato (Figure 4.8). These sites were similar because of the traces of chlorbicyclen, *p,p'*-DDE and *o,p'*-DDT, *o,p'*-DDD pesticides. Site D Potato and Site B Potato were the main contributing factors in the third and fourth principal components, respectively.

Table 4.5: Principal component analysis (PCA) for quantitative traits of 15 vegetable sites accession.

Traits	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Eigenvalue	3.35	3.13	2.59	1.79	1.38
Variability (%)	23.92	22.32	18.49	12.78	9.87
Cumulative (%)	23.92	46.24	64.73	77.51	87.38
Variables					
Site A Cabbage	0.14	**0.57**	0.00	0.09	0.19
Site B Cabbage	**0.47**	0.00	0.06	0.08	0.15
Site C Cabbage	0.09	0.16	0.00	0.01	0.05
Site D Cabbage	0.20	0.03	0.00	0.03	0.02
Site E Cabbage	**0.62**	0.08	0.06	0.06	0.13
Site A Swiss chard	0.08	0.09	0.07	0.20	0.07
Site B Swiss chard	**0.52**	0.01	0.03	0.42	0.01
Site C Swiss chard	0.28	0.13	0.08	0.00	0.19
Site D Swiss chard	0.28	0.19	0.03	0.01	0.07
Site E Swiss chard	0.03	**0.49**	0.15	0.14	0.04
Site A Potato	0.04	**0.50**	0.10	0.07	0.01
Site B Potato	0.00	0.00	0.08	**0.63**	0.00
Site C Potato	0.09	0.08	0.01	0.31	0.19
Site D Potato	0.12	0.20	**0.52**	0.11	0.05

Values in bold correspond for each observation to the factor for which the squared cosine is the largest

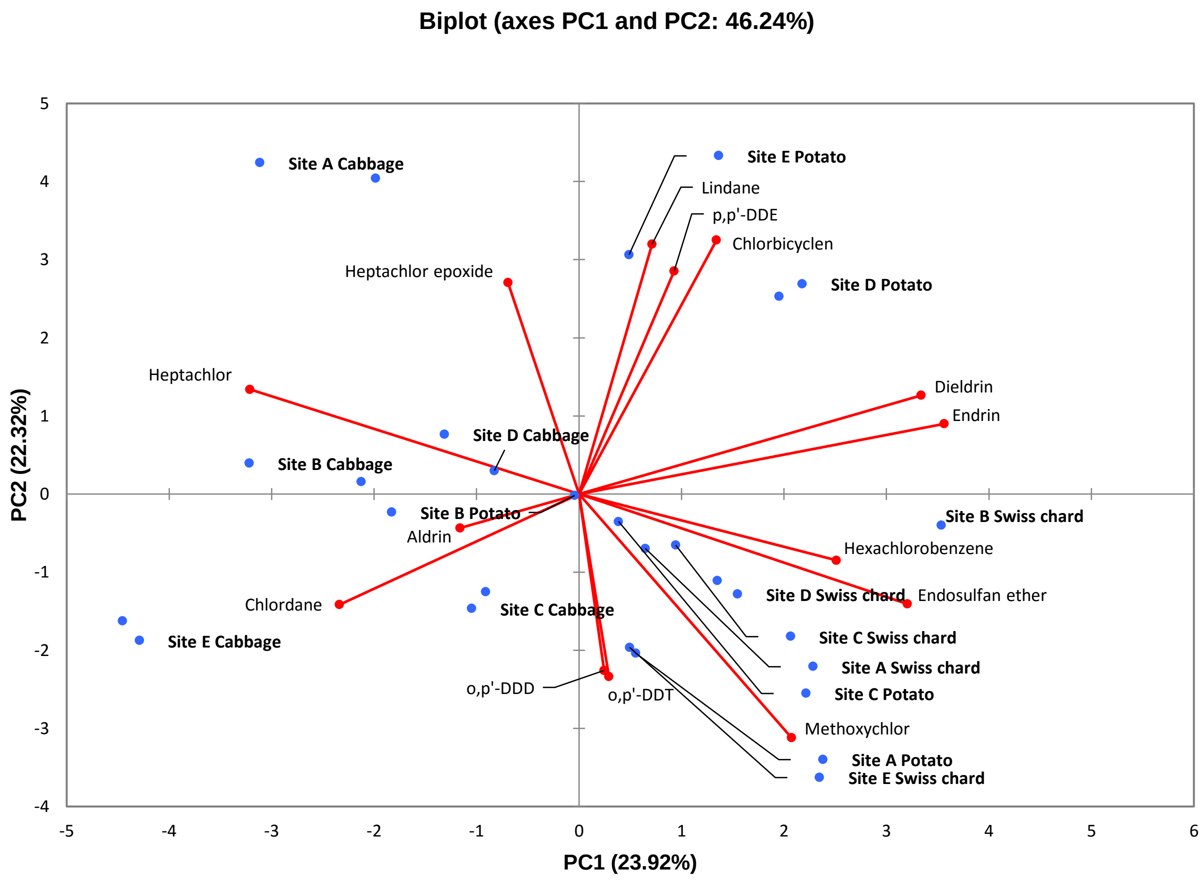


Figure 4.8: Principal component biplot showing variation between pesticide residues accessions by vegetable and site traits.

These results are similar to the findings reported by Lawrence *et al.* (2015), who reported the first two PCs in their study accounting for 49% variation with PC1 and PC2 of the total variance. Principal component one was distinguished by favourable loading for the variables; aldrin, endrin, dieldrin, DDT, endosulfan II and endosulfan sulphate. The PC2 was positively loaded for Alpha HCH, Gamma HCH, endosulfan aldehyde, atrazine and glyphosate. This implied that the distribution and degradation patterns of these pesticide residues in water samples obtained from Ogbesse River were highly correlated, while the occurrence of HCH, endosulfan alongside its isomers on the same group of PC1 and PC2 could suggest the same source of origin of these pesticides.

Results in this study were also similar to the findings of de Sousa *et al*. (2012) in their study in Brazil. The study used principal component analysis in evaluating the results obtained for the percentages of the matrix effect. The tomato, grape and pineapple matrices caused a more significant matrix effect and were grouped. It was observed that for most pesticides, the soil matrix caused a negative matrix effect. It also agrees with the findings of Kilulya and Mhinzi's (2012), who evaluated the patterns and spatial trends of pesticide residues on Vikuge farm, coast region, Tanzania, using principal components analysis. The PCA of the data sets for pesticide residues in water, soil and sediment samples has shown that the obsolete pesticides dumped at the farm for many years underwent degradation over time and the distribution pattern of the pesticides in the three environments was similar.

Cluster analyses on vegetables and sites

The hierarchical cluster analysis (CA) dendrogram displaying relationships among 15 vegetables and sites accessions using quantitative traits at 0.91 Euclidean distance, is illustrated in Figure 4.9. Cluster analysis is a class of techniques that classifies cases that are relatively homogeneous or heterogeneous within themselves (Norusis, 2010; Morissette and Chartiers, 2013). Observing the dendrogram from left to right, clusters that are more similar to each other are grouped, and the vertical lines represent the grouping of clusters. The lines joined together to indicate the distance between two joining clusters. As the clusters merge, they become more heterogeneous and, the vertical lines are located farther to the right side of the plot as they represent larger distance values (Yim and Ramdeen, 2015).

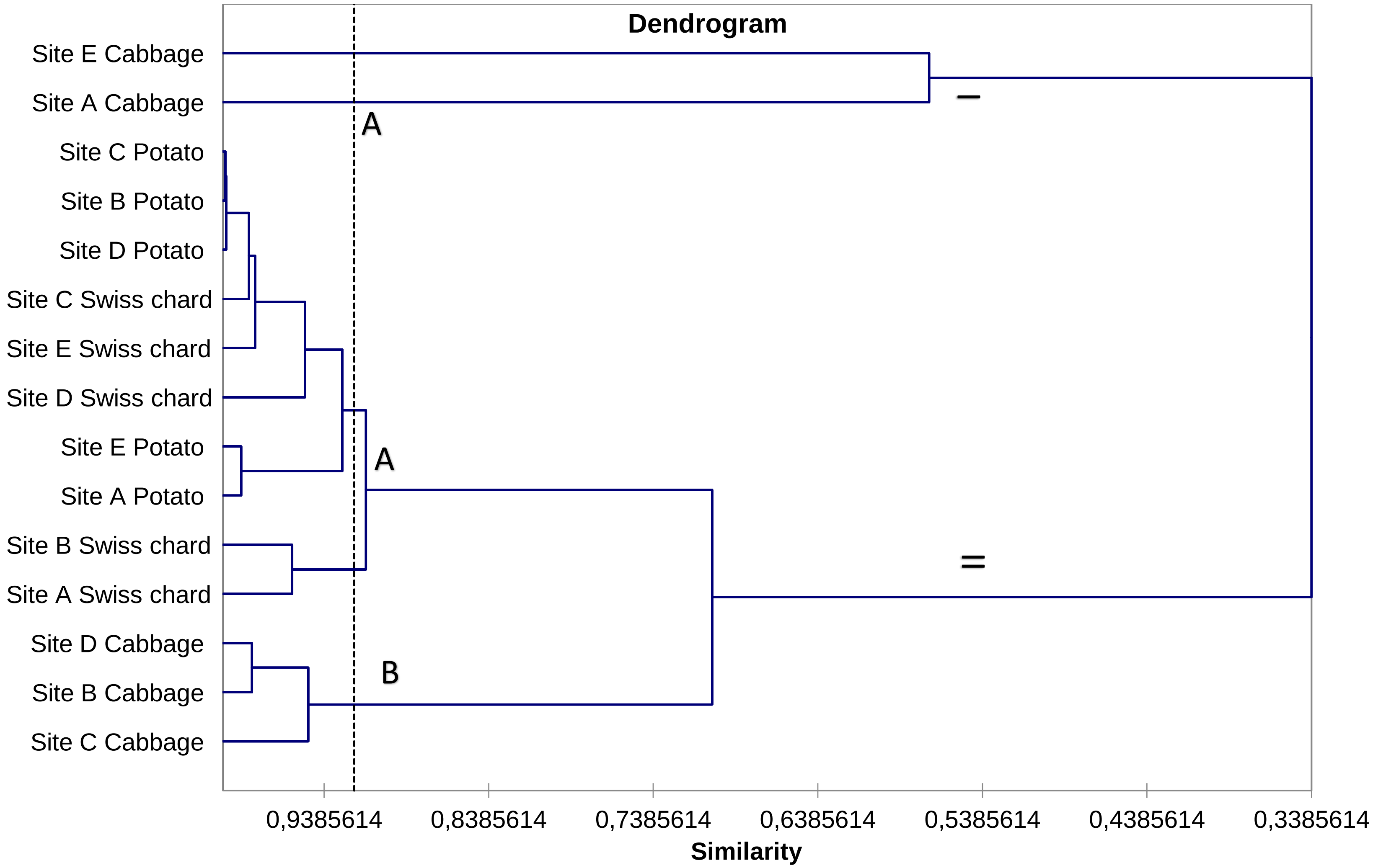


Figure 4.9: Hierarchical cluster analysis dendrogram displaying relationship among 15 vegetable sample and sites using quantitative traits.

The first main cluster (Cluster I) was subdivided into sub-cluster A, which contained Site A Cabbage and Site E Cabbage accessions. The two accessions (Site A Cabbage and Site E Cabbage) could have been more similar based on the highest number of pesticide residues found on cabbage. This is the same with PCA, which indicated Site E Cabbage and Site A Cabbage to both falls on the second principal component (PC2) and are associated with the same pesticide residues, namely heptachlor epoxide, heptachlor, aldrin and chlordane (see Figure 4.8).

The second major (Cluster II) was further subdivided into two main sub-clusters, A and B. Sub-cluster A contained accession Site A Swiss chard, Site B Swiss chard, Site A Potato, Site E Potato, Site D Swiss chard, Site E Swiss chard, Site C Swiss chard, Site D Potato, Site B Potato and Site C Potato whereas sub-cluster B consisted of accessions of Site C, Site B Cabbage and Site D Cabbage. Cluster II was grouped based on the levels of sites of the vegetables with more pesticide residues. The cluster analysis demonstrated the existence of pesticides among the 15 vegetable samples accessed on the sampling sites (Figure 4.9).

Therefore, the clustering pattern showed accessions from all sampling sites and were close together which can be similar to one another. The accessions clustered together because of their traits in the first and second quadrants had a high level of similarity and are regarded as closely related. The study conducted by Armah (2011) in Ghana, showed that cluster analysis grouped pesticide residues into two spatially different categories of six and four members; indicating high levels and a wide assortment of pesticide residues.

Correlation between pesticide residues on vegetables

Table 4.6 illustrates the associations that exist among pesticide residues at different levels of correlation. The strong positive correlation was observed between dieldrin and endrin at R^2 =0.97, as well as between heptachlor epoxide and *p,p'*-DDE at 0.86 levels. Furthermore, lindane was positively correlated with chlorbicyclen and *p,p'*-DDE at R^2 = 0.70 and R^2 = 0.67, respectively. Another positive correlation was observed between hexachlorobenzene and *p,p'*-DDE and endrin at the same level of R^2 = 0.58. Moreover, heptachlor was positively correlated with chlordane at R^2 = 0.58, suggesting a common origin. However, negative correlations were observed between heptachlor and methoxychlor at R^2 = -0.63 and between chlordane and chlorbicyclen at R^2 = -0.65.

A positive correlation is a relationship between two variables where if one variable increases, the other one also increases. The strong positive correlation was observed between dieldrin and endrin. Dieldrin is closely related to endrin; they are preliminarily identified as a persistent insecticide in the environment, and they can remain in the soil for a long time after application (EBI, 2018). Furthermore, repeated pesticide application and using mixtures of pesticides are highly linked with risk of exposure of pesticides in vegetables (Kariathi *et al*., 2016).

This study showed a positive correlation between heptachlor epoxide and *p,p'*-DDE. The National Health and Nutrition Examination Survey (NHANES) data derived have also shown that pesticide *p,p'*-DDT and pesticide metabolite heptachlor epoxide were significantly associated with diabetes with kidney disease in humans (Everett and Thompson, 2015). Lindane was positively correlated with chlorbicyclen and *p,p'*-DDE. A market survey conducted in Nigeria on the assessment of contamination by organochlorine pesticides in *Solanum lycopersicum* L. and *Capsicum annuum* L., a pair-

Table 4.6: Pearson's correlation coefficient between different pesticide residues in all sites and vegetables

Variables	HCB	Lin.	Hept.	Ald.	HepEp.	EnEth.	Chlord.	ppDDE	DieL.	Endr.	opDDD	ChlorBic	opDDT	Methoxy.
HCB	1													
Lin.	0.06	1												
Hept.	-0.18	0.16	1											
Ald.	0.23	0.00	0.39	1										
HepEp.	-0.23	0.47	0.12	-0.25	1									
EnEth.	0.31	0.06	**-0.53**	-0.32	-0.37	1								
Chlord.	0.09	-0.37	**0.58**	0.08	-0.08	-0.23	1							
p.p'-DDE	0.05	**0.67**	-0.07	-0.13	**0.86**	-0.03	-0.28	1						
ppDDE	**0.58**	0.07	-0.27	-0.07	-0.04	0.30	-0.19	0.22	1					
Endr.	**0.58**	0.04	-0.35	-0.07	-0.09	0.45	-0.20	0.20	**0.97**	1				
opDDD	0.22	0.07	-0.19	0.25	0.12	0.25	-0.02	0.19	-0.29	-0.22	1			
ChlorBic	-0.05	**0.70**	0.00	-0.04	0.05	0.10	**-0.63**	0.22	0.26	0.22	-0.35	1		
opDDT	0.21	0.07	-0.22	0.22	0.09	0.27	-0.04	0.16	-0.30	-0.23	**1.00**	-0.34	1	
Methoxy.	0.25	-0.31	**-0.65**	-0.25	-0.37	0.49	-0.16	-0.27	0.04	0.07	0.31	-0.33	0.33	1

Abbreviation: HCB= Hexachlorobenze. Lin.= Lindane. Hept.= Heptachlor. Ald.= Aldrin. HepEp.= Heptachlor epoxide. EnEth= Endosulfan ether. Chlord.= Chlordane. ppDDE= *p.p'*-DDE. DieL.= Dieldrin. Endr.= Endrin. opDDD= *o.p'*-DDD. ChlorBic.= Chlorbicyclen. opDDT= *o.p'*-DDT. Methoxy= Methoxychlor

-wise linear correlation among concentrations of OCPs in *S. lycopersicum* samples indicated statistically significant relations between *p,p'*-DDE and *trans*-nonachlor at $R^2 = 0.691$, *β*-HCH and *p,p'*-DDE at $R^2 = 0.269$ (Benson and Olufunke, 2011).

Moreover, hexachlorobenzene was positively correlated with and *p,p'*-DDE and endrin in this study. This is also comparable with Benson and Olufunke's (2011) because samples indicated a correlation between hexachlorobenzene and dieldrin at $R^2 = 0.99$. Subsequently, heptachlor was positively correlated with chlordane, similar to the finding of the study in Nigeria, namely that organochlorine pesticide residues in dried cocoa beans obtained from cocoa stores revealed that heptachlor was positively correlated with chlordane at $R^2 = 0.78$ (Oyekunle *et al*., 2017). This indicated that a positive and statistically significant relationship existed between these pesticides in vegetables.

However, a negative correlation existed between heptachlor and methoxychlor in this study, whereas Oyekunle *et al.* (2017) found heptachlor and methoxychlor to be positively correlated at $R^2 = 0.55$. Negative correlation between chlordane and chlorbicyclen was also observed in a study in the USA where chlordane was used in agriculture for vegetable crops, revealed the insignificant correlation at Pallas at $R^2 = 0.0029$ (Bidleman *et al*., 2002). This is comparable to the findings of Machekano *et al.* (2019) in their study of pesticides in Botswana using multivariate analysis. The detected quantity of pesticides was negatively correlated at $R^2 = -0.27$ with the length of time between the vendor or supermarket's date of receiving supply and the time of sampling.

There were no variations of all other pesticide residues among the vegetables. This suggests that there were similarities in the farming conditions as well as the application or contamination patterns of the pesticides and maybe the vegetables investigated had similar pesticide accumulation abilities. These results indicate that most vegetables from all the fresh produce markets have similar sources.

4.3 RISK ASSESSMENT

Pesticide-related health issues constitute a severe threat to development (Macharia*,* 2015; Jallow *et al.,* 2017); yet, data on public health risk assessment, detection and quantification of potentially harmful pesticide residues in vegetables or related products remain scarce. Hence, this study evaluated quantified pesticide residues and also assessed the potential risk of the consumption of vegetables from fresh produce markets in Bloemfontein with pesticide residues holds for human health. This information is critical in advising policy-makers, pesticide regulators, consumers and farmers on the potential health risks associated with exposure to high levels of toxic chemical residues in vegetables and the urgent need for appropriate intervention.

The estimated daily intake and hazard quotients of the pesticides due to the consumption of the vegetables (cabbage, Swiss chard and potato) are shown in Table 4.7. The acute consumer health risk (aHI) was highest in chlordane on cabbage from Site C market (127.09 x 10^{-4}) and lowest in hexachlorobenzene on cabbage from Site D (0.14 x 10^{-4}) (Table 4.8). All the vegetables showed hazard quotient (HQ) of less than one, and the highest HQ of 4.07 x 10^{-4} heptachlor epoxide in the cabbage from Site A and the lowest HQ value of 0.04 x 10^{-9} was the dieldrin in cabbage sampled from the Site C market (Table 4.9). This study is comparable with a study conducted in Turkey by Golge *et al*. (2018), which reported the outcome of the consumer risk assessment of pesticides for cucumber and green pepper. It was revealed that HQs for adults identified pesticides in green peppers and cucumbers ranged from 0.03 to 1.43 x 10^{-3} %, and from 0.01 to 1.03 x 10^{-3} %, respectively.

Table 4.7: Chronic and acute risk assessment of eight pesticides.

	MRLs (mg·kg^{-1})		Acute risk assessment			Chronic risk assessment		
Pesticides	**Highest residue**	**mean**	**ESTI**	**ARfD**	**% aHI**	**EDI**	**ADI**	**% HQ**
Hexachlorobenzene	2.90 x 10^{-5}	0.74 x 10^{-5}	1.14 x 10^{-6}	0.80 x 10^{-3}	1.42 x 10^{-3}	2.89 x 10^{-7}	0.25 x 10^{-3}	1.16 x 10^{-3}
Lindane	1.04 x 10^{-5}	6.2 x 10^{-5}	4.07 x 10^{-7}	0.03 x 10^{-3}	0.13 x 10^{0}	2.43 x 10^{-7}	0.8 x 10^{-3}	0.30 x 10^{-3}
Heptachlor	12.16 x 10^{-3}	3.45 x 10^{-4}	4.76 x 10^{-6}	0.05 x 10^{-3}	0.95 x 10^{0}	1.35 x 10^{-7}	0.01 x 10^{-3}	1.35 x 10^{0}
Heptachlor epoxide	1.77 x 10^{-4}	1.22 x 10^{-4}	6.93 x 10^{-7}	0.05 x 10^{-3}	0.14 x 10^{0}	4.78 x 10^{-7}	0.01 x 10^{-3}	0.48 x 10^{0}
Endosulfan ether	1.33 x 10^{-3}	5.82 x 10^{-4}	5.19 x 10^{-6}	1.5 x 10^{-3}	3.46 x 10^{-3}	2.28 x 10^{-6}	0.6 x 10^{-3}	3.79 x 10^{-3}
Chlordane	1.62 x 10^{-3}	2.85 x 10^{-4}	6.35 x 10^{-6}	0.05 x 10^{-3}	1.27 x 10^{0}	1.12 x 10^{-6}	0.05 x 10^{-3}	0.22 x 10^{0}
Dieldrin	1.08 x 10^{-4}	8.22 x 10^{-5}	4.23 x 10^{-8}	0.05 x 10^{-4}	0.85 x 10^{0}	3.21 x 10^{-7}	10.00	3.21 x 10^{-6}
Chlorbicyclen	1.18 x 10^{-4}	1.09 x 10^{-4}	4.62 x 10^{-7}	1.50 x 10^{-3}	3.08 x 10^{-4}	4.26 x 10^{-7}	0.6 x 10^{-3}	0.71 x 10^{-3}

ESTI= Acute consumer health risk ARfD= Acute Reference Dose, % aHI= Acute consumer health risk, EDI=Estimated daily intake, ADI= Acceptable daily intake, %HQ= Chronic health risk

Table 4.8: Health risk estimation for acute effects associated with the highest pesticide residues

		Pesticide commodity								
		Cabbage (x 10^{-4} mg•kg^{-1})			**Swiss chard** (x 10^{-4} mg•kg^{-1})			**Potato** (x 10^{-4} mg•kg^{-1})		
	ARfD	**C. Max**	**MRL**	**aHI**	**C. Max**	**MRL**	**aHI**	**C. Max**	**MRL**	**aHI**
Hexachlorobenzene	0.80	0.42	0.35	0.21	0.29	0.26	0.14	0.68	0.28	0.33
Lindane	0.03	1.95	0.45	25.51	ND	ND	0.00	1.04	0.79	13.60
Heptachlor	0.05	12.16	6.98	95.28	2.87	1.92	22.47	2.23	1.86	17.48
Heptachlor epoxide	0.05	1.31	1.27	10.28	1.13	1.10	8.86	1.77	1.19	13.87
Endosulfan ether	1.50	1.73	0.99	0.45	13.27	10.00	3.46	7.87	7.33	02.06
Chlordane	0.05	16.22	0.99	127.09	5.07	2.89	39.69	1.35	0.83	10.56
Dieldrin	0.01	0.82	0.71	64.55	1.08	0.91	84.52	0.99	0.79	77.32
Chlorbicyclen	1.50	1.18	1.07	0.31	0.00	ND	ND	1.13	1.12	0.29

ARfD= Acute Reference Dose, MRL= Maximum Residue Limit (in mg·kg^{-1}), C. Max= Maximum concentration (in mg·kg^{-1}), Acute consumer health risk (aHI), ND= Not detected

Table 4.9: Health risk estimation for chronic effects associated with the highest pesticide residues

	Pesticide commodity (in mg•kg^{-1})									
		Cabbage			Swiss chard			Potato		
	ADI (x10^{-3})	**C. Max**	**MRL**	**HQ**	**C. Max**	**MRL**	**HQ**	**C. Max**	**MRL**	**HQ**
Hexachlorobenzene	0.25×10^{-3}	0.42×10^{-4}	0.35×10^{-4}	5.48×10^{-8}	0.29×10^{-4}	0.26×10^{-4}	4.07×10^{-4}	0.68×10^{-4}	0.28×10^{-4}	4.39×10^{-8}
Lindane	0.8×10^{-3}	01.95×10^{-4}	0.45×10^{-4}	2.20×10^{-8}	ND	ND	ND	1.04×10^{-4}	0.79×10^{-4}	3.87×10^{-8}
Heptachlor	0.01×10^{-3}	12.16×10^{-4}	6.98×10^{-4}	2.74×10^{-5}	2.87×10^{-4}	1.92×10^{-4}	7.52×10^{-6}	2.23×10^{-4}	1.86×10^{-4}	7.28×10^{-6}
Heptachlor epoxide	0.01×10^{-3}	1.31×10^{-4}	1.27×10^{-4}	4.9×10^{-6}	1.13×10^{-4}	1.10×10^{-4}	4.31×10^{-6}	1.77×10^{-4}	1.19×10^{-4}	4.66×10^{-6}
Endosulfan ether	0.6×10^{-3}	1.73×10^{-4}	0.99×10^{-4}	6.46×10^{-8}	13.27×10^{-4}	0.01×10^{0}	6.53×10^{-7}	7.87×10^{-4}	7.33×10^{-4}	4.78×10^{-7}
Chlordane	0.05×10^{-3}	16.22×10^{-4}	0.99×10^{-4}	7.75×10^{-7}	5.07×10^{-4}	2.89×10^{-4}	2.26×10^{-6}	1.35×10^{-4}	0.83×10^{-4}	6.50×10^{-7}
Dieldrin	10.00×10^{0}	0.82×10^{-4}	0.71×10^{-4}	2.78×10^{-7}	1.08×10^{-4}	0.91×10^{-4}	0.04×10^{-9}	0.99×10^{-4}	0.79×10^{-4}	3.09×10^{-7}
Chlorbicyclen	0.6×10^{-3}	1.18×10^{-4}	1.07×10^{-4}	6.98×10^{-8}	ND	ND	ND	1.13×10^{-4}	1.12×10^{-4}	7.31×10^{-8}

ADI= Acceptable daily intake, MRL= Maximum Residue Limit (in mg·kg^{-1}), C. Max= Maximum concentration (in mg·kg^{-1}), Chronic consumer health risk (HQ)

The results of this study reported here show that the risk analysis had no risk at the time of the study in the consumption of those vegetables in the samples, as the hazard quotient values were less than 0.2 and the acute health risk values were less than one (1) for pesticides in all the vegetables. This finding implies that individuals are not at any health risk from the consumption of any of the vegetables analysed. This also means that although the vegetables assessed in this study contained pesticides, the levels were still too low to pose any risk to the consumers of these vegetables at the time of the study. This, however, does not exclude the possible health risk of the consumption of vegetables from the same sources in future. The current contamination is because some pesticides are persistent and continuous application of such pesticides can lead to higher pesticide residue levels in the soil and subsequent uptake by plants which possibly will ensue in pesticide residue levels causing health hazards to be manifested (Njoku *et al*., 2017).

In the light of possible health risks, regulatory policy frameworks, consumer training about the human health risks posed by pesticide residues, and changing farmers' perceptions about pesticide use will be useful in preventing and reducing the risk of pesticide exposure. The South African Fertilizers, Farm Feeds, Seeds and Remedies Act No. 36 of 1947 (Fertilizers Act) has regulations on the proper handling of pesticides and human and environmental protection. However, limitations are present in (i) the lack of the country's pesticide monitoring programme and registration; (ii) the regulations of the Fertilizers Act, which need to be revised to reflect the current laws on pesticides management; (iii) the penalty for breaching the regulations, which are not prohibitive enough to enforce compliance, and (iv) the free use of banned and restricted pesticides.

These deficiencies or gaps need to be addressed to comply with the countries and global requirements. Furthermore, the pesticides detected by this study need further investigation in terms of the assessment of the exposure that might be posed to humans and the environment. Based on the results reported here, long-term epidemiological studies may be needed to quantify the human health risk by establishing the human health risk assessment tools in the country and have records on the degree of correlation between acute and human health exposures including accumulation of pesticide exposure.

4.4 CONCLUSION

The hazard index values less than one for pesticides in all the vegetables analysed (cabbage, Swiss chard and potato) are an indication that individuals are not at any health risk from the consumption of these vegetables. This suggests that although the vegetables assessed in this study contained pesticides residues, the levels are still too low to pose any risk to the consumers of such vegetables as at the time of the study. This, however, does not exclude the possible imminent accumulation and risks of the consumption of these vegetables from the same site. This is possible in the sense that some pesticides are persistent and continuous application of these pesticides can lead to high levels of pesticide residue levels in the soil and subsequent uptake by plants with the possibility of rising to levels at which health risks will become a reality.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 RECAPITULATION

Pesticides were manufactured to benefit humanity through an increase in agricultural productivity by controlling pests and disease; however, their adverse effects often contradict the benefits associated with their use. Pesticides have entered into food chains and affected humans. Some of the acute and chronic human illnesses now emerging is a consequence of the intake of contaminated food, water and air. The risk caused by pesticides used in agriculture is associated not only with those applying the pesticide but also affects the consumers of the products to which the pesticides are applied.

The study highlighted that the consumers of the vegetables sampled (cabbage, Swiss chard and potato) in Bloemfontein are not necessarily at risk of being exposed to the pesticides studied. The findings from this study indicated good pesticide-use practices, mainly because there were low levels of residues detected in these staple vegetables. However, improper pesticide application and the use of pesticides are highly linked with risk of exposure to pesticides in agricultural production.

Hence the findings of the study suggest the proper use of pesticides to protect humans and the environment and reduce health risks associated with pesticide use. Continuous monitoring of pesticide residues in food, commercial methods to reduce excess residues in food, and rational use of pesticides will reduce the risks linked to pesticide applications. Further, informed consumers, public development, and extension programmes that educate and encourage farmers to adopt the Good Agricultural Practices (GAPs) hold the key to reducing the harmful impact of pesticides on the environment and eventually on human health. GAP, in the use of pesticides, refers to the officially recommended or nationally authorised uses of pesticides under the actual conditions prescribed for effective and reliable pest control. This entails a variety of levels of pesticide applications, applied in an effective and efficient way which leaves a residue which is the smallest practicable amount (FAO of the UN, 2020).

Some studies conducted so far in the RSA reveal levels of pesticides in water, sediments, food, fruits and vegetables from past use of pesticides chemicals (Barnhoorn *et al.,* 2015; Dalvie *et al.,* 2014; Keikotlhaile and Spanoghe, 2011). Research conducted worldwide over the past decade points to the presence of pesticide residues in vegetables, specifically spinach, lettuce, cabbage, tomato and onion (Mahungija *et al.,* 2017; Kolani *et al.,* 2016). In these studies, residue levels of organochlorine pesticides, organophosphorus pesticides and pyrethroids were found in fresh cabbage, spinach, and onion samples from the markets. Pesticides and metabolites were detected in 72.2% of the samples. The detected pesticide residues and their highest mean concentrations were *p,p'* -DDT 4.00×10^{-3} mg·kg^{-1}; *p,p'* -DDD 6.40×10^{-1} mg·kg^{-1}; *o,p'* -DDD 1.00×10^{-2} mg·kg^{-1}; α-endosulfan 6.00×10^{-1} mg·kg^{-1}; β-endosulfan 2.10×10^{-1} mg·kg^{-1}.

In 2017, 11,158 samples of cereal, animal fat, fruit and vegetables were analysed as routine samples in the coordinated national pesticide monitoring programme of the European Food Safety Authority (EFSA, 2019e). Samples without quantifiable levels of residues were 7,236 or 64.9% (residues < LOQ); 743 or 33.5% contained one or more pesticide residues in concentrations below the legally permitted maximum residue levels (MRLs), and 179 or 1.6% contained residue concentrations exceeding the legally permitted MRLs. Among these, 80 or 0.7% of the total samples were considered non-compliant (EFSA, 2019e). This risk assessment indicated that as far as the sample foods analysed are concerned, the probability was low of European citizens being exposed to pesticide residue levels that could ensue in negative health outcomes.

Pesticide-use practices of vegetable farmers were investigated in major vegetable production zones of the humid tropical region of Cameroon Abang *et al., 2013)*. It was found that the weekly spraying of pesticides was the most common practice: 40% of farmers sprayed insecticides, and 28% sprayed fungicides, yet 45% and 59% respectively could not identify the insect pests and diseases they were striving to control. Thirty-two per cent of farmers applied up to 9 litres of pesticide per year; in terms of kilograms, 18% indicated that they used 10 to 49 kg of pesticides per year, and about 9% used 10 to 49 packets of chemicals per year, depending on the size of the farm. Ninety per cent of farmers used a knapsack sprayer, and 20% of farmers noticed that their health was affected by pesticides. About 25% of the farmers stored chemicals at home. Seventy-five per cent received information about agricultural products from other farmers and had never received any training on pesticide use practices and the health effects of pesticides (Abang *et al.,* 2013).

A study conducted in Ghana investigated the potential health risk associated with vegetables due to pesticide residues (Bolor *et al.,* 2018). Methoxychlor was found in cabbage at the mean concentration of $184.10 \pm 12.11\ \mu g \cdot kg^{-1}$, and beta-hexachlorocyclohexane (beta-HCH) in cabbage at a mean concentration of $0.20 \pm 0.00\ \mu g \cdot kg^{-1}$. The results indicated that the consumption of these vegetables by children could present both carcinogenic and noncarcinogenic health risks.

The findings of studies conducted worldwide over the past decade point to the presence of pesticide residues in vegetables, specifically spinach, lettuce, cabbage, tomatoes and onions (Mahungija *et al.,* 2017; Kolani *et al.,* 2016). In these studies, residue levels were found to be above the maximum residue limits (MRLs). However, each country has its own rules, and different laws apply in order to keep hazardous and toxic chemicals away from humans and the environment, but banned pesticides still are found in food products.

Agricultural residue pesticides such as dichlorodiphenyltrichloroethane (DDT), malathion, cypermethrin, aldrin, endrin, chlordane, heptachlor, dieldrin, and endrin are currently banned globally due to bio-concentration and bio-magnification of food chain consequences to human health (Gyawali, 2018). This is due to the chemical toxicity residues present in the food humans consume, as well as the chemicals' persistence in the environment and toxicity to non-human biota (Deribe *et al.,* 2013).

Negative impacts of pesticides also can be reduced by adequately educating farmers regarding the undesired results of pesticide usage and handling, and also by training them on how to avoid undesired outcomes (Syed *et al.,* 2014). In some cases, the control programmes for pesticide residues in developing countries are often limited if not absent because of the lack of adequate resources and non-enforcement of legislation. The pesticide-related laws must be implemented strictly and amended when required to reduce the cases of pesticide residues in vegetables. Therefore, periodical and free monitoring of pesticide residues are essential for producers, consumers, and food quality control and appropriate agricultural legislation to be applied (Ahmed *et al.,* 2014).

5.2 RECOMMENDATIONS

Proper use of pesticides will improve when the standard of education at various community levels is improved. Added to this, routine monitoring of pesticide residues is necessary for the prevention, control and reduction of health risks (Okoffo *et al.,* 2017). Therefore, an urgent need exists for the development of pesticide monitoring programmes to assess the extent of pesticide contamination on food in the RSA. Regular monitoring of pesticide residues in food will contribute to alleviating human health risk exposures. Proper pesticide use decreases associated risks to a level deemed acceptable by pesticides regulatory agencies such as the Department of Agriculture, Forestry and Fisheries of South Africa and the World Health Organization (WHO).

The Fertilizers Act (RSA, 1996) should encourage the generation of health risk assessment data, despite these being very costly. The registration process is crucial to human health and environmental risk assessment, and the regulations regarding registering fertilizers should be strictly observed. The Fertilizers Act compels registrants to conduct comprehensive tests (RSA, 2012) despite the presumed lack of expertise in the country. Peer reviews should be used, for example, by involving the European Food Safety Authority to assess the pesticide before the decision to accept or decline a registration. Pesticides safety must be re-evaluated every 15 years, taking into consideration any new data. In South Africa research is essential and it should be a priority to invest more in research to develop non-persistent active chemicals for pest control and to make available convenient access to updated information on pesticides to ensure that all interested are kept informed of developments. Such actions will be of great help in reducing the health risks associated with pesticide residues.

Considering registration, application costs, resistance, and toxicity-related impacts in a consistent way, it is crucial to align farmers' practices with the safe use of pesticides. A screening framework is required that aids farmers and other relevant stakeholders in identifying the most sustainable pesticides under specific conditions. Such a framework must apply to a wide range of pesticide-crop combinations and settings (Steingrímsdorrír *et al.,* 2018). The appropriate practices are crucial regarding the use and application of pesticides such as suitable spraying equipment, protective clothing and knowledge of the dangers to human health and the environment to prevent the risks of pesticides (Damalas and Eleftherohorinos, 2011).

To limit the risks associated with pesticides, farmers should be provided with more training about health effects associated with exposure to pesticides (Jallow *et al*., 2017; Lekei *et al*., 2014). Farmers who are directly involved in the handling of pesticides are at a high risk of exposure to pesticides through contact with pesticide residues on treated crops, unsafe handling, storage and disposal practices, poor maintenance of spraying equipment, and the lack of protective equipment or failure to use it properly. Hence, when using a pesticide, good agricultural practices (referred to as GAPs), are recommended. Good agricultural practices (GAPs) include the recommended application dosage, applied using a specific method to a crop or crop class, together with other information, such as minimum pre-harvest intervals and application counts per season (Steingrimsdóttir *et al.,* 2018).

It is therefore recommended that the Fertilizer’s Act (RSA, 1996; 2012), be reviewed, as it is responsible for reducing the risk posed by pesticide residues for consumers and the management practices in vegetable production; the safety approach as stated by the Act should be applied and followed to the letter. The Act should contain clear regulations containing directions for proper use; restriction for pesticides users and continuous monitoring programmes must be implemented. Consumers should be protected and safeguarded by alleviating the risk of pesticide contamination by regulating the management of pesticide usage and preventing consumption of contaminated vegetables at all costs (Mutengwe *et al.,* 2016b). The national pesticide policy should rule the usage and management of pesticides, and users, managers and workers must abide by the regulations of the law.

It is recommended that higher education institutions in the RSA should incorporate risk assessment in general, and pesticide toxicity and exposure models in particular, in their curricula. Farmers should be subjected to training by the Agricultural Extension Officer on how to manage and control the use of pesticides and about the preventive measures to be taken on farms so that they and farm workers can remain healthy. Training on pesticide management will generate skills of analysis, decision making and facilitation at the national and local level.

To prevent harm and protect the health of the public against pesticides will require the raising of public awareness on good practices for pesticide application, and strengthening food safety control services for pesticide control (Wanwimolruk *et al*., 2015). This indication is also supported by Ahmed *et al.* (2014) in the study of dietary intake based on vegetable consumption conducted in Ismailia, Ghana. Consumers should be taught that merely washing their vegetables under tap water will remove pesticides on vegetables. Furthermore, peeling, frying, and freezing contaminated vegetables have been found to result in a marked reduction in pesticide residues (Syed *et al.,* 2014; Keikotlhaile and Spanoghe, 2011), while treatment of vegetables with acidic and alkaline solutions can effectively minimise the pesticide residues (Ahmed *et al.,* 2011). In the final instance, it is the responsibility of the consumer to ensure the safe consumption of food by ensuring that all consumables derive from safe sources and by abiding by safe food-preparation techniques.

5.3 CONCLUSION

Pesticides are used worldwide to ensure better crops, but despite their usefulness, pesticides pose potential risks to food safety, the environment, and all living things as they contaminate soil, water, and other vegetation. Concern about the impact of repeated pesticide use has prompted this research. In addition to killing insects or weeds, pesticides can be toxic to all living creatures, and unfortunately, its use has ensued in unintended and fatal consequences despite being useful in the provision of food. Thus, food monitoring programmes have been enacted worldwide to ensure consumer health, improve the management of agricultural resources, and prevent economic losses. The South African government also now needs to act in order to control pesticide application better and prevent some of its harmful and increasingly common side effects.

It is believed that this study will shed more light on the issue of pesticide contamination and make a contribution to a better understanding of the dual impact of pesticides – on the one hand, we need pesticides for the sustainability of food sources, but on the other hand, pesticide use may destroy lives and the environment.

REFERENCES

Abang, A.F., Kouame, C.M., Abang, M., Hannah, R. & Fotso, A.K. (2013). Vegetable growers' perception of pesticide use practices, cost, and health effects in the tropical region of Cameroon. *International Journal of Agronomy and Plant Production*, 4: 873-883.

Abbassy, M.M.S. (2017). Farmers' knowledge, attitudes and practices, and their exposure to pesticide residues after application on the vegetable and fruit crops. Case study: North of Delta, Egypt. *Journal of Environmental and Analytical Toxicology*, 7: 1-6.

Abdulhamid, Z., Bolanle, E.A., Gimba, C.E. & Abel, S.A. (2015). Determination of organochlorine and pyrethroid pesticide residues in some vegetables by QuEChERS method and Gas Chromatography Triple Quadrupole Mass Spectrometry. *Journal of Environmental Science, Toxicology and Food Technology,* 9: 14-20.

Abubakar, M., Mala, M.A., Mumin, A., Zainab, T. & Fatima, A.A. (2015). Perceptions of Environmental Effects of Pesticides use in Vegetable Production by Farmers along River Ngadda of Maiduguri, Nigeria. *Journal of Agriculture and Environmental Sciences*, 4: 212-215.

Adewunmi, A.A. & Fapohunda, S.O. (2018). Pesticides and food safety in Africa. *European Journal of Biological Research,* 8: 70-83.

AHA (American Heart Association). (2017). Lack of fruits and vegetables increases global heart disease burden. Retrieved from https://medicalxpress.com/news/2017-03-lack-fruits-vegetables-global-heart.html.

Ahmed, A., Randhawa, M.A., Yusuf, M.J. & Khalid, N. (2011). Effect of processing on pesticide residues in food crops: A review. *Journal of Agricultural Research*, 49: 379-390.

Ahmed, M.A.I., Khalil, N.S. & El Rahman, T.A.A. (2014). Determination of Pesticide Residues in Potato Tuber Samples using QuEChERS Method with Gas Chromatography. *Australian Journal of Basic and Applied Sciences,* 8: 349-353.

Akan, J.C., Jafiya, L., Mohammed, Z. & Abdulrahman, F.I. (2013). Organophosphorus pesticide residues in vegetables and soil samples from Alan Dam and Gongulong Agricultural Areas, Borno State, Nigeria. *International Journal of Environmental Monitoring and Analysis,* 1: 58.

Akter, S., Islam, M.S. & Rahman, M.S. (2011). An economic analysis of winter vegetables production in some selected areas of Narsingdi district. *Journal of the Bangladesh Agricultural University*, 9: 241-246.

AL-Ahmadi, M.S. (2019). Pesticides, Anthropogenic Activities and the Health of our Environment Safety. In *Pesticides, Anthropogenic Activities and the Health of our Environment*. IntechOpen. https://www.intechopen.com/

Alasfoor, D., Rajab, H. & Al-Rassasi, B. (2013). Task force for the development and implementation of the Omani Food Based Dietary Guidelines. Food Based Dietary Guidelines: Technical background and description. *Health Psychology Research,* Sep 24;1(3).

Alavanja, M.C. & Bonner, M.R., (2012). Occupational pesticide exposures and cancer risk: a review. *Journal of Toxicology and Environmental Health, 15*: 238-263.

Alavanja, M.C., Ross, M.K. & Bonner, M.R. (2013). Increased cancer burden among pesticide applicators and others due to pesticide exposure. *CA: A Cancer Journal for Clinicians*, 63: 120-142.

Amaral, A.F. (2014). Pesticides and asthma: Challenges for epidemiology. *Frontiers in Public Health*, 2: 6.

Amir, R.M., Anjum, F.M., Randhawa, M.A. & Sarwar, M. (2015). Multiple pesticide residues in spinach and associated health risk. *Professional Medical Journal*, *22*: 596-602.

Anand, S.S., Hawkes, C., De Souza, R.J., Mente, A., Dehghan, M., Nugent, R., Zulyniak, M.A., Weis, T., Bernstein, A.M., Krauss, R.M. & Kromhout, D. (2015). Food consumption and its impact on cardiovascular disease: Importance of solutions focused on the globalized food system: A report from the workshop convened by the World Heart Federation. *Journal of the American College of Cardiology*, 66: 1590-1614.

Andriukaitis, V. (2019). Pesticides in the European Union authorization and use. European Commission. Retrieved on 14 January 2020 from file:///G:/Topics/Pesticides/Banned%20pesticides/Pesticides_factsheet%20(1).pdf.

Apeh, C.C. (2018). Farmers' Perception of the Health Effects of Agrochemicals in Southeast Nigeria. *Journal of Health and Pollution*, 8: 180901.

ARC (Agricultural Research Council). (2013a). Production Guidelines for Summer Vegetables. Retrieved from http://www.arc.agric.za/arc-sgi/Documents/2019 Production Guidelines.

ARC (Agricultural Research Council). (2013b). Production Guidelines for Winter Vegetables. Retrieved from http://www.arc.agric.za/arc-sgi/Documents/2019 Production Guidelines.

ARC (International Agency for Research on Cancer). (1991). Chlordane and heptachlor: Occupational exposure in insecticide application, and some pesticides. Monographs on the evaluation of carcinogenic risk to humans. Lyon (FR): No. 53.

Arias-Estévez, M., López-Periago, E., Martínez-Carballo, E., Simal-Gándara, J., Mejuto, J.C. & García-Río, L. (2008). The mobility and degradation of pesticides in soils and the pollution of groundwater resources. *Agriculture, Ecosystems & Environment*, 123: 247-260.

Armah, FA. (2011). Assessment of pesticide residues in vegetables at the Farm Gate: Cabbage (Brassica oleracea) cultivation in Cape Coast, Ghana. *Research Journal of Environmental Toxicology,* 5: 180-202.

ATSDR (Agency for Toxic Substances and Disease Registry). (2007). Toxic guide for Heptachlor and Heptachlor Epoxide. Public Health Service, US Department of Health and Human Services, Atlanta, GA.

ATSDR (Agency for Toxic Substances and Disease Registry). (2014). Toxic substances portal. Medical management guidelines for chlordane. Atlanta, GA: US Department of Health and Human Services. Public Health Services.

ATSDR (Agency for Toxic Substances and Disease Registry). (2015). Public health statement for Methoxychlor. Public Health Service, US Department of Health and Human Services, Atlanta, GA.

ATSDR (Agency for Toxic Substances and Disease Registry). (2000). Toxicological Profile for Chlordane (Update). Public Health Service, US Department of Health and Human Services, Atlanta, GA.

Aune, D., Giovannucci, E., Boffetta, P., Fadnes, L.T., Keum, N., Norat, T., Greenwood, D.C., Riboli, E., Vatten, L.J. & Tonstad, S. (2017). Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality: A systematic review and dose-response meta-analysis of prospective studies. *International Journal of Epidemiology*, 46: 1029-1056.

AZchemistry. (2017). Nine restricted lists of banned chemicals in South Africa. Chemistry, study and research. Retrieved on 31 July 2018 from https://azchemistry.com/list-of-banned-chemicals-in-south-africa.

Badr, A.N., Ahmed, M.B.M., Amer, M.M., Thang, V.N. & Fouzy, A.S. (2019). Pesticides Evaluation in Egyptian Fruits and Vegetables: A Safety Assessment Study. *Science and Technology*, 12: 81-91.

Bailey, H.D., Fritschi, L., Infante-Rivard, C., Glass, D.C., Miligi, L., Dockerty, J.D., Lightfoot, T., Clavel, J., Roman, E., Spector, L.G. & Kaatsch, P. (2014). Parental occupational pesticide exposure and the risk of childhood leukemia in the offspring: Findings from the Childhood Leukemia International Consortium. *International Journal of Cancer*, 135: 2157-2172.

Bakırcı, G.T., Acay, D.B.Y., Bakırcı, F. & Ötleş, S. (2014). Pesticide residues in fruits and vegetables from the Aegean region, Turkey. *Food Chemistry*, 160: 379-392.

Balme, K.H., Roberts, J.C., Glasstone, M., Curling, L., Rother, H.A., London, L., Zar, H. & Mann, M.D. (2010). Pesticide poisonings at a tertiary children's hospital in South Africa: An increasing problem. *Clinical Toxicology*, 48: 928-934.

Baltazar, M.T., Dinis-Oliveira, R.J., de Lourdes Bastos, M., Tsatsakis, A.M., Duarte, J.A. & Carvalho, F. (2014). Pesticides exposure as etiological factors of

Parkinson's disease and other neurodegenerative diseases: A mechanistic approach. *Toxicology Letters*, 230: 85-103.

Barnhoorn, I.E.J., van Dyk, J.C., Genthe, B., Harding, W.R., Wagenaar, G.M. & Bornman, M.S. (2015). Organochlorine pesticide levels in *Clarias gariepinus* from polluted freshwater impoundments in South Africa and associated human health risks. *Chemosphere,* 120: 391-397.

Barrientos, S. & Visser, M. (2013). South African horticulture: Opportunities and challenges for economic and social upgrading in value chains. Available at SSRN 2209718.

Bateman, R. (2010). Pesticides use in cocoa. *A guide for training administrative and research staff.* Second edition, ICCO, London, pp.33-38.

Bazzano, L.A. (2005). Dietary intake of fruit and vegetables and risk of diabetes mellitus and cardiovascular disease. *Department of Medicine*, (pp. 66-66). Geneva: WHO.

Beaumont, R. (2012). An introduction to principal component analysis & factor analysis using SPSS 19 and R (psych package). *Factor Analysis and Principal Component Analysis (PCA)*, 24.

Beiras, R. (2018). (Chapter 8). Marine pollution. In *Sources: Fate and Effects of Pollutants in Coastal Ecosystems*, (pp. 107-135). Amsterdam: Elsevier

Bellavia, A., Larsson, S.C., Bottai, M., Wolk, A. & Orsini, N. (2013). Fruit and vegetable consumption and all-cause mortality: A dose-response analysis. *The American Journal of Clinical Nutrition*, 98: 454-459.

Benford, D.J. (2013). Risk assessment of chemical contaminants and residues in foods. In *Persistent Organic Pollutants and Toxic Metals in Foods,* (pp. 173-187). Woodhead Publishing.

Benson, N.U. & Olufunke, A.I. (2011). Assessment of contamination by organochlorine pesticides in *Solanum lycopersicum* L. and *Capsicum annuum* L.: A market survey in Nigeria. *African Journal of Environmental Science and Technology*, 5: 437-442.

Berry, K. (2016). Codex MRLs Use and Trends. Global MRLs Database. *Bryant Christie Incorporation*. Retrieved on 09 December 2019 from https://bcglobal.bryantchristie.com/downloads/whitepaper_Codex.

Betarbet, R., Sherer, T.B., MacKenzie, G., Garcia-Osuna, M., Panov, A.V. & Greenamyre, J.T. (2000). Chronic systemic pesticide exposure reproduces features of Parkinson’s disease. *Nature Neuroscience* 3.

Betterhealth. (2019). Retrieved on 09 December 2019 from https://www.betterhealth.vic.gov.au/health/healthyliving/food-poisoning-prevention.

Bidleman, T.F., Jantunen, L.M., Helm, P.A., Brorström-Lundén, E. & Juntto, S. (2002). Chlordane enantiomers and temporal trends of chlordane isomers in arctic air. *Environmental Science & Technology*, 36: 539-544.

Bolor, V.K., Boadi, N.O., Borquaye, L.S. & Afful, S. (2018). Human risk assessment of organochlorine pesticide residues in vegetables from Kumasi, Ghana. *Journal of Chemistry,* 2018: 11.

Borokini, F.B., Olaleye, M.T. & Lajide, L. (2017). Nutritional and chemical compositions of two underutilized vegetables in Nigeria. *Bangladesh Journal of Scientific and Industrial Research*, 52: 201-208.

Boyd, C. (2014). Effects of methoxychlor felt for generations. *Industry News.* Retrieved from https://www.chemservice.com/news/2014/07/effects-of-methoxychlor-felt-for-generations/.

CAC (Codex Alimentarius Commission). (2019). Pesticides. Food Standards, FAO and WHO of the United Nations. Retrieved from http://www.fao.org/fao-who-codexalimentarius/thematic-areas/pesticides/en/ on 02 September 2019.

Carvalho, M.M.X.D., Nodari, E.S., & Nodari, R.O. (2017). “Defensives” or “pesticides”? A history of the use and perception of pesticides in the State of Santa Catarina, Brazil, 1950-2002. *História, Ciências, Saúde-Manguinhos*, 24: 75-91.

CEDAC, SAEDA & PANAP (Community Economic Development Assistance Cooperation, Subversion and Espionage Directed Against the US Army &

Pesticide Action Network Asia Pacific). (2013). Illegal pesticide trade in the Mekong countries: Case studies from Cambodia and Lao PDR. Retrieved on 03 March 2020 from http://files.panap.net/resources/Illegal-pesticide-trade-in-Lao-and-Cambodia.pdf.

Chemicals in Agriculture. (2019, April 11) Digital Agriculture and Farming Handbook. Retrieved from https://agribook.co.za/inputs/chemicals-in-agriculture/

Chen, Z.L., Dong, F.S., Jun, X.U., Liu, X.G. & Zheng, Y.Q. (2015). Management of pesticide residues in China. *Journal of Integrative Agriculture*, 14: 2319-2327.

Chepkemoi, J. (2017). The world leaders in cabbage production. *Worldatlas*. Retrieved on 24 September 2019 from https://www.worldatlas.com/articles/the-world-leaders-in-cabbage-production.html.

Chong, L.Y., Bo, J., Mei, Z., Jing, H.Z., Qian, D., Geng, Z.M., Ping, Z.Z., Fa, W.Y. & Min, W.L. (2017). Vegetable and fruit consumption among Chinese adults and associated factors: A nationally representative study of 170,847 adults. *Biomedical and Environmental Sciences,* 30: 863-874.

Chowdhury, M.A.Z., Fakhruddin, A.N.M., Islam, M.N., Moniruzzamana, M., Ganc, S.H. & Alama M.K. (2013). Detection of the residues of nineteen pesticides in fresh vegetable samples using gas chromatography mass spectrometry. *Food Control.* 34: 457-465.

Colerangle, J.B. (2017). Preclinical development of nononcogenic drugs (small and large molecules). In *A Comprehensive Guide to Toxicology in Nonclinical Drug Development* (pp. 659-683). Academic Press.

Cooper, A.J., Forouhi, N.G., Ye, Z.A., Buijsse, B., Arriola, L., Balkau, B., Barricarte, A., Beulens, J.W., Boeing, H., Büchner, F.L. & Dahm, C.C. (2012). Fruit and vegetable intake and type 2 diabetes: EPIC-InterAct prospective study and meta-analysis. *European Journal of Clinical Nutrition*, 66: 1082.

Covello, V.T. & Merkhoher, M.W. (2013). Chapter1. *Risk assessment methods: Approaches for assessing health and environmental risks*. Introduction to risk assessment (pp. 1-5). Springer Science & Business Media.

Cox, J.R. (2000). Pesticide residue analysis facilities: Experiences from the Natural Resource Institute's Support Program. In *International Workshop, CIRAD-FAO*, p. 13.

Crawford, C.B. & Quinn, B. (2017). The interactions of microplastics and chemical pollutants. In *Microplastic Pollutants* (pp. 131-157). Elsevier Science.

da Silva, J.G. & Chan, M. (2014). The International Code of Conduct on Pesticide Management. Food and Agriculture Organization and World Health Organization (FAO/WHO), Rome.

Dabrowski, J.M., Shadung, J.M. & Wepener, V. (2014). Prioritizing agricultural pesticides used in South Africa based on their environmental mobility and potential human health effects. *Environment International*, 62: 31-40.

DAFF (Department of Agriculture Forestry and Fisheries). (2014). Department of Agriculture. South African Government. Retrieved on 09 December 2019 from https://www.gov.za/sites/default/files/gcis_document/201409/agricanrep0607**.**

DAFF (Department of Agriculture, Forestry and Fisheries). (2010). Adoption of a Pesticide Management Policy for South Africa. Republic of South Africa. Notice No.33899 37. Retrieved on 09 December 2019 from https://www.nda.agric.za/docs/Policy/PesticideManag.pdf.

DAFF (Department of Agriculture, Forestry and Fisheries). (2015). Guidelines on the registration process for agricultural remedies. Republic of South Africa. Retrieved from https://www.daff.gov.za/daffweb3/Branches/Agricultural-Production.

DAFF (Department of Agriculture, Forestry and Fisheries). (2018). Guidelines on the data and documents required for the registration of agricultural remedies used in non-crop situations in South Africa. Republic of South Africa. Retrieved from https://www.nda.agric.za/doaDev/sideMenu/ActNo36_1947/AIC/Guidelines.

DAFF (Department of Agriculture, Forestry and Fisheries). (2019). Programmes. Republic of South Africa. Retrieved from https://www.daff.gov.za/daffweb3/Programme/National-Regulatory-Services.

Dalvie, M.A., Sosan, M.B., Africa, A., Cairncross, E. & London, L. (2014). Environmental monitoring of pesticide residues from farms at a neighbouring primary and pre-school in the Western Cape in South Africa. *Science of the Total Environment*, 466: 1078-1084.

Damalas, C.A. & Eleftherohorinos, I.G. (2011). Pesticide exposure, safety issues, and risk assessment indicators. *International Journal of Environmental Research and Public Health*, 8: 1402-1419.

de Bon, H., Huat, J., Parrot, L., Sinzogan, A., Martin, T., Malezieux, E. & Vayssieres, J., de Sousa, F.A., Costa, A.I.G., de Queiroz, M.E.L.R., Teófilo, R.F., Neves, A.A. & de Pinho, G.P. (2012). Evaluation of matrix effect on the GC response of eleven pesticides by PCA. *Food Chemistry*, 135: 179-185.

De Fouloy, C.D. (2016). Public participation in decision-making process. Association of Accredited Public Policy Advocates to European Union. Retrieved from http://www.aalep.eu/public-participation-decision-making-processes.

DEA (Department of Environmental Affairs). (2010). South African Country Report for the Eighteenth Session of the United Nations Commission on Sustainable Development. Country Report. South Africa. https://www.environment.gov.za/sites/default/files/reports/annual.

Dearsouthafrica (2019). Public Participation in Decision-Making Processes. Retrieved on 24 December 2019 from https://dearsouthafrica.co.za/2019/12/24/media-release-23-december-2019-for-immediate-distribution/

Delcour, I., Spanoghe, P. & Uyttendaele, M. (2015). Literature review: Impact of climate change on pesticide use. *Food Research International*, *68*: 7-15.

Deribe, E., Rosseland, B.O., Borgstrom, R., Salbu, B., Gebremariam, Z, Dadebo, E. & Eklo, O.M. (2013). Biomagnification of DDT and its metabolites in four fish species of a tropical lake. *Ecotoxicology and Environmental Safety*, 95:10-18.

Dias, J.S. (2012a). Nutritional quality and health benefits of vegetables: A review. *Food and Nutrition Sciences*, 3*:* 1354.

Dias, J.S. (2012b). Major classes of phytonutriceuticals in vegetables and health benefits: A review. *Journal of Nutritional Therapeutics*, 1: 31-62.

Díaz-Resendiz, K.J.G., Toledo-Ibarra, G.A. & Girón-Pérez, M.I. (2015). Modulation of immune response by organophosphorus pesticides: fishes as a potential model in immunotoxicology. *Journal of Immunology Research,* 2015: 10.

Directorate-General for Environment (European Commission). (2013). Interpretation of the WSSD 2020 chemicals: Goal and assessment of EU efforts to meet the WSSD commitment. Retrieved on 03 September 2019 from

DoH (Department of Health, RSA). (2019). Maximum Residue Limit (MRL). Retrieved from https://www.doh.gov.za/department/dir_foodcontr.html.

DoH (Department of Health, RSA. (2012). Regulations governing the maximum limits for pesticide residues that may be present in foodstuffs: amendment. Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972). No.34958 3. Government notice. No. R. 46 19.

Donga, T.K. & Eklo, O.M. (2018). Environmental load of pesticides used in conventional sugarcane production in Malawi. *Crop Protection*, 108: 71-77.

Drogué, S. & DeMaria, F. (2012). Pesticide residues and trade, the apple of discord? *Food Policy*, 37: 641-649.

DTI (Department of Trade and Industry). (2016). Agricultural remedies that are banned or restricted for use in the Republic of South Africa. Retrieved on 03 September 2019 from https://www.thedti.gov.za/industrial_development/doc/Agricultural_Remedies.pdf.

EBI (European Bioinformatics Institute). (2018). Dieldrin. Retrieved from https://www.ebi.ac.uk/chebi/searchId.do?chebiId=CHEBI:34696.

ECHA (European Chemicals Agency). (2016). Acceptable daily intake (ADI) and Acute reference dose (ARfD) derivation for biocidal active substances. Meeting with Human Health Working Group. Retrieved from https://echa.europa.eu/documents/10162/4221979/adi_arfd_derivation_en.pdf/9cf8371e-2ce7-b62a-1089-04b7a63c2aa1.

EFSA (European Food Safety Authority). (2013). The 2010 European Union Report on Pesticide Residues in Food. Scientific Report. European Food Safety Authority. Italy. *European Food Safety Authority Journal,* 11: 3130.

EFSA (European Food Safety Authority). (2016). National summary reports on pesticide residue analysis performed in 2014. *EFSA Supporting Publications*, 13: 1107E.

EFSA (European Food Safety Authority). (2017). Scientific Opinion of the PPR Panel on the follow-up of the findings of the External Scientific Report. Literature review of epidemiological studies linking exposure to pesticides and health effects. *European Food Safety Authority Journal,* 15: 5007.

EFSA (European Food Safety Authority). (2019a). Pesticide evaluations: overview and procedure. Retrieved on July 1 2019 from https://www.efsa.europa.eu.

EFSA (European Food Safety Authority). (2019b). EU legislation on MRLs. Retrieved on September 09 2019 from https://ec.europa.eu/food/plant/pesticides/max_residue_levels/eu_rules_en.

EFSA (European Food Safety Authority). (2019c). How European Union ensures pesticides are safe. Retrieved on July 1 2019 from https://www.efsa.europa.eu/en/interactive-pages/pesticides-authorisation/PesticidesAuthorisation.

EFSA (European Food Safety Authority). (2019d). The 2017 European Union report on pesticide residues in food. *EFSA Journal,* 17: 574

EFSA (European Food Safety Authority). (2019e). The 2017 European Union report on pesticide residues in food. Scientific report. Retrieved on October 10 2019 from https://efsa.onlinelibrary.wiley.com/doi/10.2903/j.efsa.2019.5743.

EPA (Environment Protection Authority). (2017a). Guidelines for Responsible Pesticide Use. South Australia. Retrieved from https://www.epa.nsw.gov.au.

EPA (Environment Protection Authority). (2017b). Summary of the Federal Insecticide, Fungicide, and Rodenticide Act USA. Retrieved from https://www.epa.gov/laws-regulations/summary-federal-insecticide-fungicide-and-rodenticide-act.

EPA (Environment Protection Authority). (2018). Registration review process (USA). Retrieved from https://www.epa.gov/pesticide-reevaluation/registration-review-process.

EPA (Environment Protection Authority). (2019). Food and Pesticides. Retrieved from https://www.epa.gov/safepestcontrol/food-and-pesticides on 03 June 2019.

Eskola, M., Elliott, C.T., Hajšlová, J., Steiner, D. & Krska, R. (2019). Towards a dietary-expo: Some assessment of chemicals in food: An update on the chronic health risks for the European consumer. *Critical Reviews in Food Science and Nutrition*, pp. 1-22.

Esturk, O., Yakar, Y. & Ayhan, Z. (2014). Pesticide residue analysis in parsley, lettuce and spinach by LC-MS/MS. *Journal of Food Science and Technology,* 51: 458-466.

EUR-LEX. (2019). Document, September 04. Retrieved from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX

EUROPA. (2019). Sustainable use of pesticides. Food safety. European Commission. Retrieved on 03 September 2019 from https://ec.europa.eu/food/plant/pesticides/sustainable_use_pesticides_en.

Everett, C.J. & Thompson, O.M. (2015). Association of DDT and heptachlor epoxide in human blood with diabetic nephropathy. *Reviews on Environmental Health*, 30: 93-97.

Faber, M., Witten, C. & Drimie, S. (2011). Community-based agricultural interventions in the context of food and nutrition security in South Africa. *South African Journal of Clinical Nutrition*, 24*:* 21-30.

Facts Network. (2017). Frequently asked questions on pesticides and food safety. *International Food Information Council Foundation*. Retrieved from https://foodinsight.org/frequently-asked-questions-on-pesticides-and-food-safety/

FAO (Food and Agriculture Organization of the United Nations). (2020). Comparison of GAPs. Downloaded on 21 February 2020 from www.fao.org/pesticide-registration-toolkit/registration-tools/assessment-methods/method-detail/en/c/1187111/.

FAO (Food and Agriculture Organization). (2016). A scheme and training manual on Good Agricultural Practice (GAP) for fruits and vegetables. *FAO of the United Nations*. Bangkok.

FAO (Food and Agriculture Organization). (2019a). Prevention and disposal of obsolete pesticides. Retrieved from http://www.fao.org/agriculture/crops/obsolete-pesticides/why-problem/pesticide-bans/en/

FAO (Food and Agriculture Organization). (2019b, April 11). Overview of the situation. Estimated size and geographical distribution of obsolete pesticide stocks. Retrieved from http://www.fao.org/3/x8639e/x8639e02.htm

FAO (Food and Agriculture Organization). (2019c, April 11). AGP: The Joint FAO/WHO Meeting on Pesticide Residues (JMPR). Retrieved from http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/jmpr/en/

FAO (Food and Agriculture Organization). (2019d). The crops. FAO STAT. Retrieved from http://www.fao.org/faostat/en/#data/QC/visualize.

FAO/WHO (Food and Agriculture Organization & World Health Organization). (2010). International Code of Conduct on the Distribution and Use of Pesticides. Guidelines for the Registration of Pesticides. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/70293/WHO_HTM_NTD_WHOPES_2010.7_eng.pdf;sequence=1.

FAO/WHO (Food and Agriculture Organization & World Health Organization). (2011). International Code of Conduct of the distribution and use of pesticides. Guidelines for quality control of pesticides. Retrieved from www.fao.org/pesticide-registration-toolkit/special-topics/highly-hazardous-pesticides-hhp/introduction/en/

FAO/WHO (Food and Agriculture Organization & World Health Organization) (2013). *Pesticide residues in food and feed. Codex Alimentarius Commission. Food Standard Programme*. Rome, Italy.

FAO/WHO (Food and Agriculture Organization & World Health Organization). (2015). International Code of Conduct on Pesticide Management Guidelines on Pesticide Legislation. Retrieved from WHO/HTM/NTD/WHOPES/2015.4.

FAO/WHO (Food and Agriculture Organization & World Health Organization). (2019). Pesticides residues in food. FAO Plant Production and Protection. FAO of the United Nations Report. Rome. Paper 234.

Farha, W., Abd El-Aty, A.M., Rahman, M.M., Jeong, J.H., Shin, H.C., Wang, J., Shin, S.S. & Shim, J.H. (2018). Analytical approach, dissipation pattern and risk assessment of pesticide residue in green leafy vegetables: A comprehensive review. *Biomedical Chromatography*, 32: 4134.

FDA (Food and Drug Administration). (2016). Pesticide Residue Monitoring Program Fiscal Year 2016 Pesticide Report U.S. Food and Drug Administration. Retrieved from https://www.fda.gov/food/pesticides/pesticide-residue-monitoring-2016-report-and-data.

FDA (Food and Drug Administration). (2019). Pesticide Residue Monitoring Program Questions and Answers. Retrieved on 20 February 2019 from https://www.fda.gov/food/foodborneillnesscontaminants/pesticides/ucm583711.htm.

FDC (Free State Development Cooperation). (2019). Agriculture and agro processing. Retrieved from https://www.fdc.co.za/index.php/addons/fs-economic-sectors/agriculture-agro-processing.

Fenik, J., Tankiewicz, M. & Biziuk, M. (2011). Properties and determination of pesticides in fruits and vegetables. *Trends in Analytical Chemistry*, 30: 814-826.

Fenner-Crisp, P.A. (2010). Risk assessment and risk management: The regulatory process. In *Hayes' Handbook of Pesticide Toxicology*, edited by Krieger, R. (pp. 1371-1380). Elsevier: Academic Press.

Fothergill, A. & Abdelghani, A. (2013). A review of pesticide residue levels and their related health exposure risks. *WIT Transactions on Ecology and the Environment*, 170: 195-205.

FPM (Fresh Produce Market). (2008). The role of fresh produce markets in SA. Regoverning markets. University of Pretoria.

FRC (Fresh Water Research Centre). (2018). Managing pesticides in South African waters. Retrieved on 02 July 2019 from http://frcsa.org.za/news/managing-pesticides-in-south-african-waters/

Gaber, S. & Abdel-Latif, S.H. (2012). Effect of education and health locus of control on safe use of pesticides: A cross sectional random study. *Journal of Occupational Medicine and Toxicology*, 7*:* 3.

Gama, S. (2015). Benchmarking of ports: Pricing systems an art. IOL. Retrieved from https://www.iol.co.za/business-report/opinion/benchmarking-of-ports-pricing-systems-an-art-1884151.

Gana, S. (2014). *Evaluation of implementation of food safety legislation in the red meat abattoirs of Mopani District, Limpopo Province, South Africa* (Doctoral dissertation, University of Limpopo).

Garcia, F.P., Ascencio, S.Y.C., Oyarzun, J.G., Hernandez, A.C. & Alavarado, P.V. (2012). Pesticides: classification, uses and toxicity. Measures of exposure and genotoxic risks. *Journal of Research in Environmental Science and Toxicology*, 1: 279-293.

Genuis, S.J., Lane, K. & Birkholz, D. (2016). Human elimination of organochlorine pesticides: blood, urine, and sweat study. *BioMed research international*, *2016*.

Gerage, J.M., Meira, A.P.G. & da Silva, M.V. (2017). Food and nutrition security: Pesticide residues in food. *Nutrire*, 42: 3.

Gerba, C.P. (2015). Risk assessment. In I. Pepper, C. Gerba & T Gentry (Eds). *Environmental microbiology* (pp. 565-579). Elsevier: Academic Press.

Gerber, R., Smit, N.J., van Vuren, J.H.J., Nakayama, S.M.M., Yohannes, Y.B., Ikenaka, Y. & Wepener, V. (2016). Bioaccumulation and human health risk assessment of DDT and other organochlorine pesticides in an apex aquatic predator from a premier conservation area. *Science of the Total Environment,* 550: 522-533.

Gill, H.K. & Garg, H. (2014). Pesticides: Environmental impacts and management strategies. In *Pesticides-toxic aspects*. IntechOpen.

Glucker, A.N., Driessen, P.P., Kolhoff, A. & Runhaar, H.A. (2013). Public participation in environmental impact assessment: Why, who and how. *Environmental Impact Assessment Review*, 43: 104-111.

Golge, O., Hepsag, F. & Kabak, B. (2018). Health risk assessment of selected pesticide residues in green pepper and cucumber. *Food and Chemical Toxicology,* 121: 51-64.

Goudarzi, S. (2018). Good Laboratory Practice: Cornerstone of laboratory compliance. Retrieved on 28 July 2018 from https://www.labmanager.com/business-management/2018/03/good-laboratory-practice-the-cornerstone-of-laboratory-compliance.

Grace, D. (2015). Food safety in developing countries: An overview. *Department for International Development.* Retrieved from https://www.gov.uk/dfid-research-outputs/food-safety-in-developing-countries-an-overview.

Grandjean, P. & Landrigan, P.J. (2014). Neurobehavioural effects of developmental toxicity. *The Lancet Neurology*, 13: 330-338.

Grewal, A.S., Singla, A., Kamboj, P. & Dua, J.S. (2017). Pesticide residues in food grains, vegetables and fruits: A hazard to human health. *Journal of Medicinal Chemistry and Toxicology,* 2: 1-7.

Gunier, R.B., Kang, A., Hammond, S.K., Reinier, K., Lea, C.S., Chang, J.S., Does, M., Scelo, G., Kirsch, J., Crouse, V. & Cooper, R. (2017). A task-based assessment of parental occupational exposure to pesticides and childhood acute lymphoblastic leukemia. *Environmental Research*, 156: 57-62.

Gyawali, K. (2018). Pesticide Uses and its Effects on Public Health and Environment. *Journal of Health Promotion*, 6: 28-36.

Gyenwali, D., Vaidya, A., Tiwari, S., Khatiwada, P., Lamsal, D.R. & Giri, S. (2017). Pesticide poisoning in Chitwan, Nepal: A descriptive epidemiological study. *BMC Public Health*, 17: 619.

Handford, C.E., Elliott, C.T. & Campbell, K. (2015). A Review of the Global Pesticide Legislation and the Scale of Challenge in Reaching the Global Harmonization of Food Safety Standards. *Integrated Environmental Assessment and Management,* 11: 525-536.

Harada, T. Takeda, M., Kojima, S. & Tomiyama, N. (2016). Toxicity and carcinogenicity of dichlorodiphenyltrichloroethane (DDT). *Toxicological Research,* 32: 21.

Hart, A., Maxim, L., Siegrist, M., Von Goetz, N., da Cruz, C., Merten, C., Mosbach-Schulz, O., Lahaniatis, M., Smith, A. & Hardy, A. (2019). Guidance on communication of uncertainty in scientific assessments. *European Food Safety Authority Journal,* 17: e05520.

Hartley, L., Igbinedion, E., Holmes, J., Flowers, N., Thorogood, M., Clarke, A., Stranges, S., Hooper, L. & Rees, K. (2013). Increased consumption of fruit and vegetables for the primary prevention of cardiovascular diseases. *Cochrane Database of Systematic Reviews*, 6.

Hau, M., Cole, D., Vanderlinden, L., Farlane, R., Mee, C., Archbold, J. & Campbell, M. (2014). Development of a guide to applying precaution in local public health. Education and Practice. *International Journal of Occupational and Environmental Health,* 20: 174-184.

Herr, I. & Büchler, M.W. (2010). Dietary constituents of broccoli and other cruciferous vegetables: Implications for prevention and therapy of cancer. *Cancer Treatment Reviews*, 36: 377-383.

HSE (Health and Safety Executive). (2019). Retrieved from http://www.hse.gov.uk/pesticides/topics/pesticide-approvals/pesticides-registration/general/fepa-and-copr.htm.

https://op.europa.eu/en/publication-detail/-/publication/e636b772-1164-4a91-b024-069000bf5626.

https://www.environment.gov.za/sites/default/files/docs/remedies_stockremedies_act36_of1947.pdf.

Hu, D., Huang, J., Wang, Y., Zhang, D. & Qu, Y. (2014). Fruits and vegetables consumption and risk of stroke: A meta-analysis of prospective cohort studies. *Stroke*, 45: 1613-1619.

Huong, P.T.T., Everaats, A.P., Neeteson, J.J. & Struik, P.C. (2013). Vegetable production in the Red River Delta of Vietnam. II. Profitability, labor requirements and pesticide use. *NJAS-Wageningen Journal of Life Sciences,* 67: 37-46.

IAS (International Accreditation Service). (2015). Guidelines for food testing laboratories. Retrieved from https://portal.iasonline.org/about-us/.

Ibanez, J.G., Hernandez-Esparza, M., Doria-Serrano, C., Fregoso-Infante, A. & Singh, M.M. (2010). *Environmental chemistry: Fundamentals*. Springer Science & Business Media.

IOL News (Independent Online News). (2010). Harmful pesticide banned in SA. South Africa. Retrieved from https://www.iol.co.za/news/south-africa/harmful-pesticide-banned-in-sa-485733.

Jallow, M.F., Awadh, D.G., Albaho, M.S., Devi, V.Y. & Ahmad, N. (2017). Monitoring of pesticide residues in commonly used fruits and vegetables in Kuwait. *International Journal of Environmental Research and Public Health*, 14: 833.

Jayaraj, R., Megha, P. & Sreedev, P. (2016). Organochlorine pesticides, their toxic effects on living organisms and their fate in the environment. *Interdisciplinary Toxicology.* 9(3-4): 90-100.

Jensen, H.K., Konradsen, F., Jørs, E., Petersen, J.H. & Dalsgaard, A. (2011). Pesticide use and self-reported symptoms of acute pesticide poisoning among aquatic farmers in Phnom Penh, Cambodia. *Journal of Toxicology,* 2011: 1-9.

JMPR (Joint FAO/WHO Meeting on Pesticide Residues). (2017). Pesticide Residues in Food. Organization (FAO/WHO). 2017. *FAO Plant Production and Protection Paper 232*. Rome.

JMPR (Joint FAO/WHO Meeting on Pesticide Residues). (2018). Acceptable daily intakes, acute reference doses, acute and long-term dietary exposures, recommended maximum residue limits, supervised trials median residue values and other values recorded by the 2018 meeting. Summary report. Berlin.

Kariathi, V., Kassim, N. & Kimanya, M. (2016). Pesticide exposure from fresh tomatoes and its relationship with pesticide application practices in Meru District. *Cogent Food & Agriculture*, *2*: 1196808.

Keikotlhaile, B.M. & Spanoghe, P. (2011). Pesticide residues in fruits and vegetables. In Margarita Stoytcheva (Ed.) *Pesticides: Formulations, effects, fate* (pp. 243-252). Rijeka, Croatia: InTech. Retrieved from https://biblio.ugent.be/publication/4241571.

Keikotlhaile, B.M. (2011). Influence of the processing factors on pesticide residues in fruits and vegetables and its application in consumer risk assessment. Doctoral dissertation. Ghent University.

Khatri, N. & Tyagi, S. (2015). Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Frontiers in Life Science*, 80: 23-39.

Kilulya, K.F. & Mhinzi, G.S. (2012). Evaluation of patterns and spatial trends of pesticide residues from Vikuge Farm, Coast Region, Tanzania by principal components analysis. *Tanzania Journal of Science*, 38: 184-200.

Kim, K., Kabir, E. and Jahan, S.A. 2017. Exposure to Pesticides and the Associated Human Health Effects. *Science of the Total Environment*, 575: 525-535.

Kolani, L., Mawussi, G. & Sanda, K. (2016). Assessment of Organochlorine Pesticide Residue in Vegetable Samples from some Agricultural Areas in Togo. *American Journal of Analytical Chemistry*, 7: 332-341.

Koutros, S., Alavanja, M.C.R., Lubin, J.H., Sandler, D.P., Hoppin, J.A., Lynch, C.F., Knott, C., Blair, A. & Freeman, L.E.B. (2010). An Update of Cancer Incidence in the Agricultural Health Study. *Journal of Occupational and Environmental Medicine,* 2: 1098–1105.

Kushi, L.H., Doyle, C., McCullough, M., Rock, C.L., Demark-Wahnefried, W., Bandera, E.V., Gapstur, S., Patel, A.C., Andrews, K., & Gansler, T. (2012). The American Cancer Society 2010 Nutrition and Physical Activity Guidelines Advisory Committee. American Cancer Society Guidelines on Nutrition and

Physical Activity for Cancer Prevention Reducing the Risk of Cancer with Healthy Food Choices and Physical Activity. *CA Cancer Journal for Clinicians,* 62: 30-67.

Lawrence, E., Ozekeke, O. & Isioma, T. (2015). Distribution and ecological risk assessment of pesticide residues in surface water, sediment and fish from Ogbesse River, Edo State, Nigeria. *Journal of Environmental Chemistry and Ecotoxicology*, 7: 20-30.

Lehotay, S.J. (1996). Supercritical fluid extraction of pesticide residues in fruit and vegetables. *Seminars in Food Analysis,* 1: 73-84.

Lehotay, S.J., Son, K.A., Kwon, H., Koesukwiwat, U., Fu, W., Mastovska, K., Hoh, E., Leepipatpiboon, N. (2010). Comparison of QuEChERS sample preparation methods for the analysis of pesticide residues in fruits and vegetables. *Journal of Chromatography* A, 1217: 2548-2560.

Lekei, E.E., Ngowi, A. & London, L. (2014). Farmers' knowledge, practices and injuries associated with pesticide exposure in rural farming villages in Tanzania. *BMC Public Health*, 14: 389

Lerro, C.C., Koutros, S., Andreotti, G., Friesen, M.C., Alavanja, M.C., Blair, A., Hoppin, J.A., Sandler, D.P., Lubin, J.H., Ma, X. & Zhang, Y. (2015). Organophosphate insecticides use and cancer incidence among spouses of pesticide applicators in the Agricultural Health Study. *Occupational Environmental Medicine*, 72(10): 736-744.

Li, M., Fan, Y., Zhang, X., Hou, W. & Tang, Z. (2014). Fruit and vegetable intake and risk of type 2 diabetes mellitus: Meta-analysis of prospective cohort studies. *BMJ Open:* e005497*.*

Li, Z. (2018). Health risk characterization of maximum legal exposures for persistent organic pollutant (POP) pesticides in residential soil: An analysis. *Journal of Environmental Management*, 205:163-173.

Liu, P. & Guo, Y. (2019). Current situation of pesticide residues and their impact on exports in China. In *IOP Conference Series: Earth and Environmental Science,* 227: 052027

Loha, K.M., Lamoree, M., Weiss, J.M. & de Boer, J. (2018). Import, disposal, and health impacts of pesticides in the East Africa Rift (EAR) zone: A review on management and policy analysis. *Crop Protection* 112: 322-331.

Lötvall, J., Akdis, C.A., Bacharier, L.B., Bjermer, L., Casale, T.B., Custovic, A., Lemanske Jr, R.F., Wardlaw, A.J., Wenzel, S.E. & Greenberger, P.A. (2011). Asthma endotypes: a new approach to classification of disease entities within the asthma syndrome. *Journal of Allergy and Clinical Immunology*, 127: 355-360.

Łozowicka, B., Kaczyński, P., Rutkowska, E., Jankowska, M. & Hrynko, I. (2013). Evaluation of pesticide residues in fruit from Poland and health risk assessment. *Agricultural Sciences*, 4: 106-111.

Macharia, I. (2015). Pesticides and Health in Vegetable Production in Kenya. *BioMed Research International,* Special Issue. Retrieved from https://www.hindawi.com/journals/bmri/2015/241516/.

Machekano, H., Masamba, W., Mvumi, B.M. & Nyamukondiwa, C. (2019). Cabbage or 'pesticide'on the platter? Chemical analysis reveals multiple and excessive residues in African vegetable markets. *International Journal of Food Contamination*, 6: 2.

Mahmood, I., Imadi, S.R., Shazadi, K., Gul, A., & Hakeem, K.R. (2016). Effects of pesticides on environment. In *Plant, soil and microbes* (pp. 253-269). Springer, Cham.

Mahugija, J.A.M., Khamis. F.A. & Lugwisha, E.H.J. (2017). Determination of levels of organochlorine, organophosphorus, and pyrethroid pesticide residues in vegetables from markets in Dar es Salaam by GC-MS. *International Journal of Analytical Chemistry.* Article ID 4676724, 9 pages. Retrieved from https://doi.org/10.1155/2017/4676724.

Makhafola, B. (2010). Quality Assurance Regulations Applicable to Agricultural Products in the Republic of South Africa. Department of Agriculture Forestry and Fisheries. Slideshow. Retrieved from https://www.nda.agric.za/doaDev/sideMenu/internationalTrade/docs/QualityAssuranceRegToAgricProductsInSA16March2010.pdf.

Malagoli, C., Costanzini, S., Heck, J.E., Malavolti, M., De Girolamo, G., Oleari, P., Palazzi, G., Teggi, S. & Vinceti, M. (2016). Passive exposure to agricultural pesticides and risk of childhood leukaemia in an Italian community. *International Journal of Hygiene and Environmental Health*, 219: 742-748.

Maliwichi, L.L., Pfumayaramba, T.K. & Katlego, T. (2014). An analysis of constraints that affect smallholder farmers in the production of tomatoes in Ga-Mphahlele, Lepelle Nkumbi Municipality, Limpopo Province, South Africa. *Journal of Human Ecology*, 47: 269-274.

Marketing, D. (2011). A profile of the South African Tobacco Market Value Chain. *Organizational Analysis*, 48: 48.

Mathieu, V., Marie-Hélène B., Louis R., Louise, N., Onil, S., Denis, B., Carole, B. & Denise, P. (2017). Human health risk assessment on the consumption of fruits and vegetables containing residual pesticides: A cancer and non-cancer risk/benefit perspective. *Environment International,* 108: 63-74.

Matsei, E. (2017). *Economic Review of the South African Agriculture*. Pretoria: DAFF.

Matsoso, M.P. (2015). *National environmental health norms and standards for premises and acceptable monitoring standards for environmental health practitioners.* Pretoria: Department of Health.

Matthews, G., Zaim, M., Yadav, R.S., Soares, A., Hii, J., Ameneshewa, B., Mnzava, A., Dash A.P., Ejov M., Tan, S.H. & van den Berg, H. (2011). Status of legislation and regulatory control of public health pesticides in countries endemic with or at risk of major vector-borne diseases. *Environmental Health Perspectives,* 119: 517-1522.

Mbhenyane, X. & Labuschagne, I. (2017). South Africa's twin malnutrition challenges: Hunger and obesity. Retrieved from https://www.sun.ac.za/english/Lists/news/DispForm.aspx?ID=5353.

McDaniel College. (2019). Pesticide health effects. Retrieved from https://www2.mcdaniel.edu., 17 July 2019.

Mengistie, B.T., Mol, A.P. & Oosterveer, P. (2016). Private environmental governance in the Ethiopian pesticide supply chain: Importation, distribution and use. *NJAS-Wageningen Journal of Life Sciences*, 76: 65-73.

Modjadji, P. & Madiba, S. (2019). The double burden of malnutrition in a rural health and demographic surveillance system site in South Africa: A study of primary school children and their mothers. *BMC Public Health,* 19: 1087.

Mogala, M. (2017). A Profile of the South African Potato Market Value Chain. *Department of Agriculture, Fisheries and Forestry.* RSA: Pretoria.

Moradhaseli, S., Sadighim, H. & Ataei, P. (2017). Investigation of the Farmers' Safety and Protective Behaviour to use Pesticides in the Farms. *Health Education & Health Promotion*, 5: 53-65.

Mordorintelligence. (2018). Fruits and Vegetables Market in South Africa: Major Fruits and Vegetables with Production, Trade, and Consumption Analysis, Trends, and Forecast (2018 - 2023). Retrieved on 14 February, 2018 from http://www.mordorintelligence.com.

Morissette, L. & Chartier, S. (2013). The *k*-means clustering technique: General consideration and implementation in Mathematica. *Tutorials in Quantitative Methods for Psychology,* 9: 15-21.

Mostafalou, S. & Abdollahi, M. (2013). Pesticides and human chronic diseases: Evidences, mechanisms and perspectives. *Toxicology and Applied Pharmacology*, 268: 157-177.

Mubushar, M., Aldosari, F.O., Baig, M.B., Alotaibi, B.M. & Khan, A.Q. (2019). Assessment of farmers on their knowledge regarding pesticide usage and biosafety. *Saudi Journal of Biological Sciences*.

Mudzunga, J. (2015). *Regulatory Framework for Pesticides in South Africa*. Department of Agriculture, Forestry and Fisheries. Pretoria: DAFF.

Munawar, A. & Humeed, S.W. (2013). Quantification of Pesticide Residues in Vegetables by different Chromatographic Techniques. *Journal of Chromatography and Separation Techniques,* 4: 8-11.

Mutengwe, M.T., Aneck-Hahn, N.H., Korsten, L., Van Zijl, M.C. & De Jager, C. (2016a). Pesticide residues and estrogenic activity in fruit and vegetables sampled from major fresh produce markets in South Africa. *Food Additives & Contaminants: Part* A, 33: 95-104.

Mutengwe, M.T., Chidamba, L. & Korsten, L. (2016b). Monitoring pesticide residues in fruits and vegetables at two of the biggest fresh produce markets in Africa. *Journal of Food Protection*, 79: 1938-1945.

Mutengwe, M.T., Chidamba, L. & Korsten, L. (2016c). Pesticide residue monitoring on South African fresh produce exported over a 6-year period. *Journal of Food Protection,* 79: 1759-1766.

Mwabu, G. (2016). Agriculture, productivity and poverty eradication in Africa. United *Nations Conference*. Bangkok.

Mwabulambo, S.G., Mrema, E.J., Ngowi, A.V. & Mamuya, S. (2018). Health Symptoms Associated with Pesticides Exposure among Flower and Onion Pesticide Applicators in Arusha Region. *Annals of Global Health,* 84: 369-379.

Mwanja, M., Jacobs, C., Mbewe, A.R. & Munyinda, N.S. (2017). Assessment of pesticide residue levels among locally produced fruits and vegetables in Monze District, Zambia. *International Journal of Food Contamination*, 4: 11.

Mwatawala, M.W. & Yeyeye, G.E. (2016). Education, training and awareness of laws as determinants of compliance with plant protection law: The case of pesticide use practices in Tanzania. *African Journal of Food Agriculture, Nutrition and Development*, 16: 10682-10696.

Naidoo, S., Rother, H., London, L. & Burdorf, A. (2010). Pesticides safety training and practices in woman working in small- scale agriculture in South Africa. *Occupational and Environmental Medicine,* 67: 823-828.

Naidoo, V. & Buckley, C. (2003). Survey of Pesticide Wastes in South Africa and Review of Treatment Options. *Report to the Water Research Commission.* Retrieved from www.wrc.org.za/about-us/annual-reports/.

Naik, G. & Suresh, D.N. (2018). Challenges of creating sustainable Agri-retail supply chains. *IIMB management review*, 30: 270-282.

NDA (National Department of Agriculture). (2015). *Guideline of the registration process for agricultural remedies.* The Department of Agriculture, Forestry and Fisheries. Republic of South Africa.

NDA (National Department of Agriculture). (2018). Banned and Restricted Substances in the Republic of South Africa. Retrieved on 19 September 2018 from http://www.nda.agric.za/doaDev/sideMenu/ActNo36_1947/bannedAndRestricted.htm

NDoH (National Department of Health, South Africa). (2010). Maximum Residue Limit. Retrieved form http://www.doh.gov.za/department/dir_foodcontr.html.

Neves, J.D., Barnhoorn, I.E.J. & Wagenaar, G.M. (2018). The effects of environmentally relevant concentrations of aldrin and methoxychlor on the testes and sperm of male *Clarias gariepinus* (Burchell, 1822) after short-term exposure. *Fish physiology and biochemistry,* 44: 1421-1434.

Ngobese, N.Z., Workneh, T.S., Alimi, B.A. & Tesfay, S. (2017). Nutrient composition and starch characteristics of eight European potato cultivars cultivated in South Africa *Journal of Food Composition and Analysis*, 55*:* 1-11. Retrieved from https://www.sciencedirect.com/science/article/pii/S0889157516301922.

Nguyen, K.A., De Villiers, A., Fourie, J.M. & Hendricks, M. (2017). Challenges to implementing the food-based dietary guidelines in the South African primary school curriculum: A qualitative study exploring the perceptions of principals and curriculum advisors. *South African Journal of Clinical Nutrition,* 30: 15-20.

Nicolopoulou-Stamati, P., Maipas, S., Kotampasi, C., Stamatis, P. & Hens, L. (2016). Chemical pesticides and human health: The urgent need for a new concept in agriculture. *Frontiers in Public Health*, 4: 148.

Ninfali, P. & Angelino, D. (2013). Nutritional and Functional Potential of *Beta vulgaris acla* and *rubra*. *Fitoterapia*, pp 188-199.

Njaya, T. (2014). The Economics of Fruit and Vegetable Marketing by Smallholder Farmers in Murehwa and Mutoko Districts in Zimbabwe. *International Journal of Research in Humanities and Social Sciences*, 1: 35-43.

Njoku, K.L., Ezeh, C.V., Obidi, F.O. & Akinola, M.O. (2017). Assessment of Pesticide Residue Levels in Vegetables sold in some Markets in Lagos State, Nigeria. *Nigerian Journal of Biotechnology, 32*: 53-60.

Nnamonu, L.A. & Onekutu, A. 2015. Green Pesticides in Nigeria: An Overview. *Journal of Biology, Agriculture and Healthcare* 5(9): 4862.

Norusis, M.J. (2010). Cluster analysis. Chapter 6. *PAW Statistics 18 Statistical Procedures Companion (*pp 361-391). NJ: Prestige Hall.

NPIC (National Pesticide Information Centre, US). (2016). Regulating pesticides. Federal pesticide regulation. Retrieved from http://npic.orst.edu/reg/regfed.html

NPIC (National Pesticide Information Centre, US). (2019, July 26). International Pesticide Regulations. Retrieved from http://npic.orst.edu/reg/intreg.html.

Nuapia, Y., Chimuka. L. & Cukrowska. E. (2016). Assessment of organochlorine pesticide residues in raw food samples from open markets in two African cities. *Chemosphere 164*.

OECD (Organization for Economic Co-operation and Development). (2019a). Agricultural pesticides: Testing of chemicals: Better policies for better lives. Retrieved on July 18, 2019 from http://www.oecd.org/chemicalsafety/testing/

OECD (Organization for Economic Co-operation and Development). (2019b). Agricultural Chemical Pesticide Registration. (2019, July 22). Retrieved from https://www.oecd.org/env/ehs/pesticides-biocides/agricultural-chemical-pesticide-registration.htm.

OECD (Organization for Economic Co-operation and Development). (2019c). Evaluating Public Participation in Policy Making Retrieved on 30 July 2019 from https://www.oecd.org/gov/evaluatingpublicparticipationinpolicymaking.htm.

OECD (Organization for Economic Co-operation and Development). (2019d). Good Laboratory Practice (GLP). (2019, September 04). Retrieved from https://www.oecd.org/countries/argentina/good-laboratory-practiceglp.htm.

Okoffo, E.D., Fosu-Mensah, B.Y. & Gordon, C. (2017). Contamination levels of organophosphorus and synthetic pyrethroid pesticides in cocoa beans from Ghana. *Food Control*, 73: 1371-1378.

Okop, K.J., Ndayi, K., Tsolekile, L., Sanders, D. & Puoane, T. (2019). Low intake of commonly available fruits and vegetables in socio-economically disadvantaged communities of South Africa: influence of affordability and sugary drinks intake. *BMC public health*, 19: 940.

Oloo, B., Daisy, L. & Oniang'o, R. (2018). Food safety legislation in some developing countries. El-Samray, Y. (Ed) *Food safety*, 3: 21-35. Some Global Trends. IntechOpen.

Omeroglu, P.Y., Ambrus, Á. & Boyacioglu, D. (2018). Uncertainty of pesticide residue concentration determined from ordinary and weighted linear regression curve. *Food Additives & Contaminants: Part A*, 35: 1324-1339.

Oyebode, O., Gordon-Dseagu, V., Walker, A. & Mindell, J.S. (2014). Fruit and vegetable consumption and all-cause, cancer and CVD mortality: Analysis of Health Survey for England data. *Journal of Epidemiology and Community Health*, 68: 856-862.

Oyekunle, J.A.O., Akindolani, O.A., Sosan, M.B. & Adekunle, A.S. (2017). Organochlorine pesticide residues in dried cocoa beans obtained from cocoa stores at Ondo and Ile-Ife, Southwestern Nigeria. *Toxicology Reports*, 4: 151-159.

Palmquist, K., Salatas, J. & Fairbrother, A. (2012). Pyrethroid insecticides: Use, environmental fate, and ecotoxicology. In *Insecticides-advances in integrated pest management*. IntechOpen. Retrieved from https://www.intechopen.com/books/insecticides-advances-in-integrated-pest-management/pyrethroid-insecticides-use-environmental-fate-and-ecotoxicology.

Pandya, C.V., Pandya, A.C. & Joshi, D.S. (2014). Insecticide residues in fruits, vegetables and crops. Movement of pesticides in the environment, soil. *LAP Lambert.* India.

PANEurope (Pesticides Action Network Europe). (2018). Neonicotinoids: A historic day for the European Union. Retrieved from http://www.pan-europe.info/press/2018/04/neonicotinoids-historic-day-european-union

PANUK (Pesticides Action Network, UK). (2019). Promoting safe and sustainable alternatives to hazardous pesticides. Retrieved from http://www.pan-uk.org/how-are-pesticides-regulated/

Panuwet, P., Siriwong, W., Prapamontol, T., Ryan, P.B., Fiedler, N., Robson, M.G. & Barr, D.B. (2012). Agricultural pesticide management in Thailand: Status and population health risk. *Environmental Science and Policy*, 17: 72-81.

Patočka, J., Wu, Q., França, T.C., Ramalho, T.C., Pita, R. & Kuča, K. (2016). Clinical aspects of the poisoning by the pesticide endosulfan. *Química Nova*, 39: 987-994.

Pem, P.E.M. & Jeewon, R. (2015). Fruit and vegetable intake: Benefits and progress of nutrition education interventions: Narrative review article. *Iranian Journal of Public Health*, 44: 1309.

Phung, D.T., Connell, D., Miller, G., Rutherford, S. & Chu, C. (2012). Pesticide regulations and farm worker safety: The need to improve pesticide regulations in Viet Nam. *Bulletin of the World Health Organization*, 90: 468-473.

PMA (Produce Market Association). (2014). The changing trends in African vegetable consumption: PMA Fresh connections. *Euromonitor International***.** Retrieved from https://www.pma.com/~/media/pma-files/fc-south-africa-2014/protea-hirschel.pdf?la=en&la=en.

PPECB (Perishable Products Export Control Board). (2016). *Statutory operations.* Retrieved from PPECB Annual Report 2015/2016. pmg-assets.s3-website-eu-west-1.amazonaws.com/161020ppecb.pdf.

PPECB (Perishable Products Export Control Board). (2019, March 27). Laboratory and Analytical Services. Retrieved from https://ppecb.com/services/laboratory-and-analytical-services/.

Prosekov, A.Y. & Ivanova, S.A. (2018). Food Security: The Challenge of the Past. *Geoforum*, 91*:* 73-77.

Pujeri, U.S., Pujar, A.S., Hiremath, S.C., Pujari, K.G. & Yadawe, M.S. (2015). Analysis of pesticide residues in vegetables in Vijayapur, Karnataka, India. *World Journal of Pharmacy and Pharmaceutical Sciences*, 4*:* 1743-1750.

Quinn, L.P., de Vos, J., Fernandes-Whaley, M., Roos, C., Bouwman, H., Kylin, H., Pieters, R. & van den Berg, J. (2011). Pesticide use in South Africa: One of the largest importers of pesticides in Africa. In *Pesticides in the Modern World: Pesticides Use and Management* (pp. 49-96) Intech Open.

Raanan, R., Harley, K.G., Balmes, J.R., Bradman, A., Lipsett, M. & Eskenazi, B. (2014). Early-life exposure to organophosphate pesticides and paediatric respiratory symptoms in the CHAMACOS cohort. *Environmental Health Perspectives*, 123: 179-185.

Reeves, W.R., McGuire, M.K., Stokes, M. & Vicini, J.L. (2019). Assessing the Safety of Pesticides in Food: How Current Regulations Protect Human Health. *Advances in Nutrition,* 10: 80-88.

Richter, A., Sieke, C., Reich, H., Ossendorp, C., Breiysse, N., Lutze, J., Mahieu, K., Margerison, S., Rietveld, A., Sarda, X., Vial, G. & van der Velde-Koerts. (2018). Setting the stage for the review of the international estimate of short-term intake (IESTI) equation. *Journal of Environmental Science and Health, Part B,* 53: 345-351.

Rodrigues, D., Carvalho, T., Sousa, A., Neto, V.S., Fechine, P. & Nascimento, R. (2011). Determination of Insecticide Residues in Vegetal Fruits**.** *Chromatography Research International*, Volume 2011, ArticleID 713256, 6 pages. doi:10.4061/2011/713256. Retrieved from downloads.hindawi.com/archive/2011/713256.pdf.

Rodrigues, E.T., Alpenduradab, M.F., Ramos, F.M. & Pardala, M.Â. (2018). Environmental and human health risk indicators for agricultural pesticides in Estuaries Elsa Teresa. *Ecotoxicology and Environmental Safety*, 150: 224–231.

Rowley, W.R., Bezold, C., Arikan, Y., Byrne, E. & Krohe, S. (2017). Diabetes 2030: Insights from yesterday, today, and future trends. *Population Health Management, 20*.

RSA (Republic of South Africa). (1996). Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act No. 36 of 1947 (Fertilizers Act) (as amended) General Law Amendment Act 49 of 1996. Retrieved on 03 February 2020 from

RSA (Republic of South Africa). (2003). Medicines and Related Substances Control Act No. 101 of 1965. Retrieved on 03 March 2020 from https://www.nda.agric.za/doadev/sidemenu/fisheries/03_areasofwork/Aquaculture/AquaPolGuidLeg/Legislation/MedicinesRelatedSubstancesControlAct101of1965.pdf.

RSA (Republic of South Africa). (2012). Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act, 1947 (Act No. 36 of 1947). Regulations Regarding Fertilizers. *Staatskoerant, No. 35666 3 Government Notice*. Department of Agriculture, Forestry and Fisheries No. R. 732 10 September 2012.

Saillenfait, A.M., Ndiaye, D. & Sabaté, J.P. (2015). Pyrethroids: Exposure and health effects: An update. *International Journal of Hygiene and Environmental Health*, 218: 281-292.

Samsidar, A., Siddiquee, S. & Md Shaarani, S. (2018). A review of extraction, analytical and advanced methods for determination of pesticides in environment and foodstuffs. *Trends in Food Science and Technology.* Retrieved from https://www.researchgate.net/publication/328341168_

Sarwar, M. (2015). The Dangers of Pesticides Associated with Public Health and Preventing of the Risks. *International Journal of Bioinformatics and Biomedical Engineering* 2: 130-136.

Saxena, S. (2016). Safer access to pesticides for suicide prevention: Experiences from community interventions. *World Health Organization*, WHO/MSD/MER/16.3.

Schleier, J.J. & Peterson, R.K. (2011). Pyrethrins and pyrethroid insecticides. *Green Trends in Insect Control*, 94: 131.

Schreinemachers, P. & Tipraqsa, P. (2012). Agricultural pesticides and land use intensification in high-, middle- and low-income countries. *Food Policy,* 37: 616-626.

Schreinemachers, P., Simmons, E.B. & Wopereis, M.C.S. (2018). Tapping the economic and nutritional power of vegetables: Review Article. *Global Food Security,* 16: 36-45.

Schrimpf, W. & Morgan, N. (2017). Obsolete and unwanted pesticide stocks. Practical guidance on safeguarding, disposal and preparation. *Crop Life International*. http://www.croplife.org/

Sharaf, N.E., Amer, N.M., Ibrahim, K.S., El-Tahlawy, E.M. & Abdelgelil, K.S. (2013). Pesticides usage in agriculture among rural women in Egypt: Association between serum organo-chlorine pesticide residues and occurrence of diabetes. *World Journal of Medical Sciences*, 1: 8-15.

Sharifzadeh, M., Abdollahzadeh, G., Damalas, C. and Rezaei, R. (2018). Farmers' criteria for pesticide selection and use in the pest control process. *Agriculture*, 8: 24.

Sharma, B.M., Bharat, G.K., Tayal, S., Nizzetto, L., Čupr, P. & Larssen, T. (2014). Environment and human exposure to persistent organic pollutants (POPs) in India: A systematic review of recent and historical data. *Environment International*, 66: 48-64.

Shields, W.J., Saba, T., Boehm, P.D. & Pietari, J. (2015). Congeners: A forensics analysis. In Murphy BL, Morrison RD (Eds). *Introduction to Environmental Forensics* (pp. 347-393). Elsevier: Academic Press.

Shogren, J. (2013). *Encyclopedia of energy, natural resource, and environmental economics*. Newnes, Elsevier.

Siegel, K.R., Ali, M.K., Srinivasiah, A., Nugent, R.A. & Narayan, K.V. (2014). Do we produce enough fruits and vegetables to meet global health need? *PloS One*, 9: 104059.

Sikuka, W. (2016). Global agricultural information network. Food and agricultural import regulations and standards (FAIRS). South Africa. *Gain Report*, 54: 1-23.

Skovgaard, M., Encinas, S.R., Jensen, O.C., Andersen, J.H., Condarco, G. & Jørs, E. (2017). Pesticide residues in commercial lettuce, onion, and potato samples from Bolivia: A threat to public health. *Environmental Health Insight,* 11:1-8.

Slavin, J.L. & Lloyd, B. (2012). Health benefits of fruits and vegetables. *Advances in Nutrition*, 3: 506-516.

Smart, J., Snyder, J., Goeb, J. & Tschirley, D. (2018). High pesticides use among smallholders in Africa south of the Sahara poses risks for health, environment. Retrieved from http://www.ifpri.org/blog/high-pesticide-use-among-smallholders-africa-south-sahara-poses-risks-health-environment

Smegal, D.C. (2000). *Human health risk assessment chlorpyrifos*. US Environmental Protection Agency, Office of Prevention, Pesticides and Toxic Substances, Office of Pesticide Programs, Health Effects Division, US Government Printing Office: Washington, DC, pp.1-131.

Smith, S. (2014). Global horticulture (2014-2018). Pink and healthy PR Newswire. Reportbuyer. Retrieved from https://www.prnewswire.com/news-releases/global-horticulture-2014--2018---pink-and-healthy-271781701.html.

Sola, P., Mvumi, B.M., Ogendo, J.O., Mponda, O., Kamanula, J.F., Nyirenda, S.P., Belmain, S.R. & Stevenson, P.C. (2014). Botanical pesticide production, trade and regulatory mechanisms in Sub-Saharan Africa: Making a case for plant-based pesticidal products. *Food Security,* 6: 369-384.

South African Government. (2006, May 27). Agriculture on pesticides management policy for South Africa. Retrieved from https://www.gov.za/agriculture-pesticides-management-policy-south-africa.

Sparks, T.C. & Nauen, R., 2015. IRAC: Mode of action classification and insecticide resistance management. *Pesticide Biochemistry and Physiology*, 121: 122-128.

Steingrímsdóttir, M.M., Petersen, A. & Fantke, P. (2018). A screening framework for pesticide substitution in agriculture. *Journal of Cleaner Production*, 192: 306-315.

Syed, J.H., Alamdar, A., Mohammad, A., Ahad, K., Shabir, Z., Ahmed, H., Ali, S.M., Sani, S.G.A.S., Bokhari, H., Gallagher, K.D. & Ahmad, I. (2014). Pesticide residues in fruits and vegetables from Pakistan: A review of the occurrence and associated human health risks. *Environmental Science and Pollution Research*, 21: 13367-13393.

Tago, D., Andersson, H. & Treich, N. (2014). Pesticides and health: A review of evidence on health effects, valuation of risks and benefit-cost analysis. In *Preference Measurement in Health* (pp. 203-295). Emerald Group Publishing Limited.

Tanner, C.M., Kamel, F., Ross, G.W., Hoppin, J.A., Goldman, S.M., Korell, M., Marras, C., Bhudhikanok, G.S., Kasten, M., Chade, A.R. & Comyns, K. (2011). Rotenone, paraquat, and Parkinson's disease. *Environmental Health Perspectives*, 119: 866.

Tapia, M.R., Gutierrez-Pacheco, M.M., Vazquez-Armenta, F.J., Aguilar, G.G., Zavala, J.A., Rahman, M.S. & Siddiqui, M.W. (2015). Washing, peeling and cutting of fresh-cut fruits and vegetables. In *Minimally processed foods* (pp. 57-78). Springer, Cham. Retrieved from https://link.springer.com/chapter/10.1007/978-3-319-10677-9_4.

Taylor, K.W., Novak, R.F., Anderson, H.A., Birnbaum, L.S., Blystone, C., DeVito, M., Jacobs, D., Köhrle, J., Lee, D.H., Rylander, L. & Rignell-Hydbom, A. (2013). Evaluation of the association between persistent organic pollutants (POPs) and diabetes in epidemiological studies: A national toxicology program workshop review. *Environmental Health Perspectives*, 121: 774.

Tiryaki, O. & Temur, C. (2010). The fate of pesticide in the environment. *Journal of Biological and Environmental Sciences,* 4: 29-38.

Tsai, W.T. (2010). Current status and regulatory aspects of pesticides considered to be persistent organic pollutants (POPs) in Taiwan. *International Journal of Environmental Research and Public Health,* 7: 3615-3627.

UFPA (United Fresh Produce Association). (2017). Background Facts on Chlorpyrifos Use and Safety. Retrieved from https://www.unitedfresh.org/content/uploads/2017/11/Chlorpyrifos-Use-and-Safety.pdf.

UNEP (United Nations Environment Programme). (2015). Report on the implementation of joint and convention-specific activities contained in the 2014-2015 programme budgets of the Basel, Rotterdam and Stockholm Conventions.

UNEP/CHW.12/INF/45-UNEP/FAO/RC/COP.7/INF/31-UNEP/POPS/COP.7/INF/51.

UNEPA (United Nations Environmental Protection Agency). (2016). Health effects assessment for existing chemical and radionuclide national primary drinking water regulations. Six-year review 3: Summary report. EPA 822-R-16-008.

United States Environment Protection Authority (USEPA). (2018, May 28). Pesticide Registration. USEPA. Retrieved from https://www.epa.gov/pesticide-registration/about-pesticide-registration

US Food and Drug Administration (USFDA). (2012). Bacteriological analytical manual, Chapter 1, Food sampling/Preparation of sample homogenate. Retrieved from https://www.fda.gov/food/laboratory-methods-food/bacteriological-analytical-manual-bam.

USDA (United States Department of Agriculture). (2019). Pesticide Data Program (PDP). Agricultural Marketing Service. Retrieved on 30 July 2019 from https://www.ams.usda.gov/datasets/pdp on July 2019.

Utembe, W. & Gulumian, M. (2015). Challenges and research needs for risk assessment of pesticides for registration in Africa. *Human and Ecological Risk Assessment: An International Journal*, 21: 1518-1541.

Vale, A. (2015). Organophosphorus insecticide poisoning. *BMJ Clinical Evidence*, 11: 2102. Elsevier.

van den Berg, H., Hii, J., Soares, A., Mnzava, A., Ameneshewa, B., Dash, A. P., Ejov, M., Tan S.H., Matthews, G., Yadav, R.S. & Zaim, M. (2011). Status of pesticide management in the practice of vector control: A global survey in countries at risk of malaria or other major vector-borne diseases. *Malaria Journal*, 10: 125.

Van den Berg, H., Manuweera, G. & Konradsen, F. (2017). Global trends in the production and use of DDT for control of malaria and other vector-borne diseases. *Malaria Journal*, 16: 401.

Veale, D.J.H., Wium, C.A. & Müller, G.J. (2013). Toxicovigilance I: A survey of acute poisonings in South Africa based on Tygerberg Poison Information Centre data. *South African Medical Journal*, 103: 293-297.

Vega, M., Romano, D. & Uotila, E. (2016). Policy Department C: Citizen’s rights and Constitutional affairs. Lindane (Persistent Organic Pollutant). *European Parliament*.

Vorster, H.H., Badham, J.B. & Venter, C.S. (2013). An introduction to the revised food-based dietary guidelines for South Africa. *South African Journal of Clinical Nutrition*, 26: S5-S12.

Wang, N., Jiang, Q., Han, L., Zhang, H., Zhu, B. & Liu, X. (2019). Epidemiological characteristics of pesticide poisoning in Jiangsu Province, China, from 2007 to 2016. *Scientific Reports*, 9: 8604.

Wang, X., Ouyang, Y., Liu, J., Zhu, M., Zhao, G., Bao, W. & Hu, F.B. (2014). Fruit and vegetable consumption and mortality from all causes, cardiovascular disease, and cancer: Systematic review and dose-response meta-analysis of prospective cohort studies. *British Medical Journal,* 349*:* 4490.

Wang, Y., Wang, Y., Huo, X. & Zhu, Y. (2015). Why some restricted pesticides are still chosen by some farmers in China: Empirical evidence from a survey of vegetable and apple growers. *Food Control*, 51: 417-424.

Wanwilmolruk, S., Kanchanamayoon, O., Phopin, K. & Prachayasittikul, V. (2015). Food safety in Thailand 2: Pesticide residues found in Chinese kale (Brassica oleracea), a commonly consumed vegetable in Asian countries. *Science of the Total Environment,* 532: 447-455.

Warid, A. (2019, October 28). Vegetable farming, history, methods, equipment and facts. Encyclopaedia. Britannia. Retrieved from https://www.britannia.com/topic/vegetable-farming/Climate.

Watkins, J.B. & Klaasen, C.D. (2010). *Essentials of toxicology*. US: Chapter 4. Risk assessment, pp.48-55. New York: McGraw-Hill.

Weimer, M., Vos, E. & Zeitlin, J. (2015). The role of the EU in transnational regulation of food safety: Extending experimentalist governance? In Jonathan Zeitlin (Ed) *Extending Experimentalist Governance? The European Union and Transnational Regulation,* p.51. Oxford University Press.

WHO (World Health Organization). (2010a). *Handbook: Good Agricultural Practice (GLP). Quality practices and regulated non-clinical research and development. UNICEF, UNDP, World Bank, WHO.*

WHO (**World Health Organization).** (2010b). *WHO human health risk assessment toolkit: Chemical hazards.* International Programme on Chemical Safety. World Health Organization, the International Labour Organization and the United Nations Environment Programme, and produced within the framework of the Inter-Organization Programme for the Sound Management of Chemicals https://www.who.int/ipcs/publications/methods/harmonization/exposure_assessment.pdf?ua=1.

WHO (World Health Organization). (2016). *Safer access to pesticides for suicide prevention. Experiences from community interventions.* WHO/MSD/MER/16.3. Switzerland.

WHO (World Health Organization). (2018, June 3). *Pesticide residues in food.* Retrieved from https://www.who.int/news-room/fact-sheets/detail/pesticide-residues-in-food*.*

WHO/FAO (World Health Organization & Food and Agriculture Organization) Meeting on Pesticide Residues (JMPR). (2017). Pesticide Residues in Food. *FAO Plant Production and Protection,* Paper, 232. Rome: WHO.

WHO/FAO (World Health Organization and Food and Agriculture Organization). (2017) *Integrated vector management: Strategic framework for the Eastern Mediterranean Region 2016–2020* (No. WHO-EM/MAL/386/E). World Health Organization. Regional Office for the Eastern Mediterranean.

WHO/FAO (World Health Organization and Food and Agriculture Organization). (2010). *International Code of Conduct on the Distribution and Use of Pesticides. Guidelines for the Registration of Pesticides*. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/70293/WHO_HTM_NTD_WHOPES_2010.7_eng.pdf;sequence=1.

WHOPES (World Health Organization Pesticide Evaluation Scheme). (2010). Guidelines for the Registration of Pesticides. International Code of Conduct on the Distribution and Use of Pesticides.

https://apps.who.int/iris/bitstream/handle/10665/70293/WHO_HTM_NTD_WHOPES_2010.7_eng.pdf;sequence=1.

Wong, C.T., Wais, J. & Crawford, D.A. (2015). Prenatal exposure to common environmental factors affects brain lipids and increases risk of developing autism spectrum disorders. *European Journal of Neuroscience*, 42: 2742-2760.

Wood, R. (1996). *Food labelling and standard division, MAFF: Survey of European Commission and Codex Regulations and Directives. Sampling for food analysis training course*. Food Regulation Agency. Leatherhead. United Kingdom.

Woyessa, Y.E., Hensley, M. & Van Rensburg, L.D. (2006). Catchment management in semi-arid area of central South Africa: Strategy for improving water productivity. *Water South Africa*, 32*: 5*.

Wright, C.Y., Mathee, A. & Oosthuizen, M.A. (2014). Challenging times for environmental health in South Africa: The role of the Environmental Health Research Network. *South African Medical Journal*, 104: 20-21.

Wu, Q.J., Yang, Y., Wang, J., Han, L.H. & Xiang, Y.B. (2013). Cruciferous vegetable consumption and gastric cancer risk: A meta-analysis of epidemiological studies. *Cancer Science*, 104: 1067-1073.

Yadav, I.C. & Devi, N.L. (2017). Pesticides classification and its impact on humans and environment. *Environment Science and Engineering,* 6*.*

Yang, T., Doherty, J., Zhao, B., Kinchla, A.J., Clark, J.M. & He, L. (2017). Effectiveness of commercial and homemade washing agents in removing pesticide residues on and in apples. *Journal of Agricultural and Food Chemistry*, 65: 9744-9752.

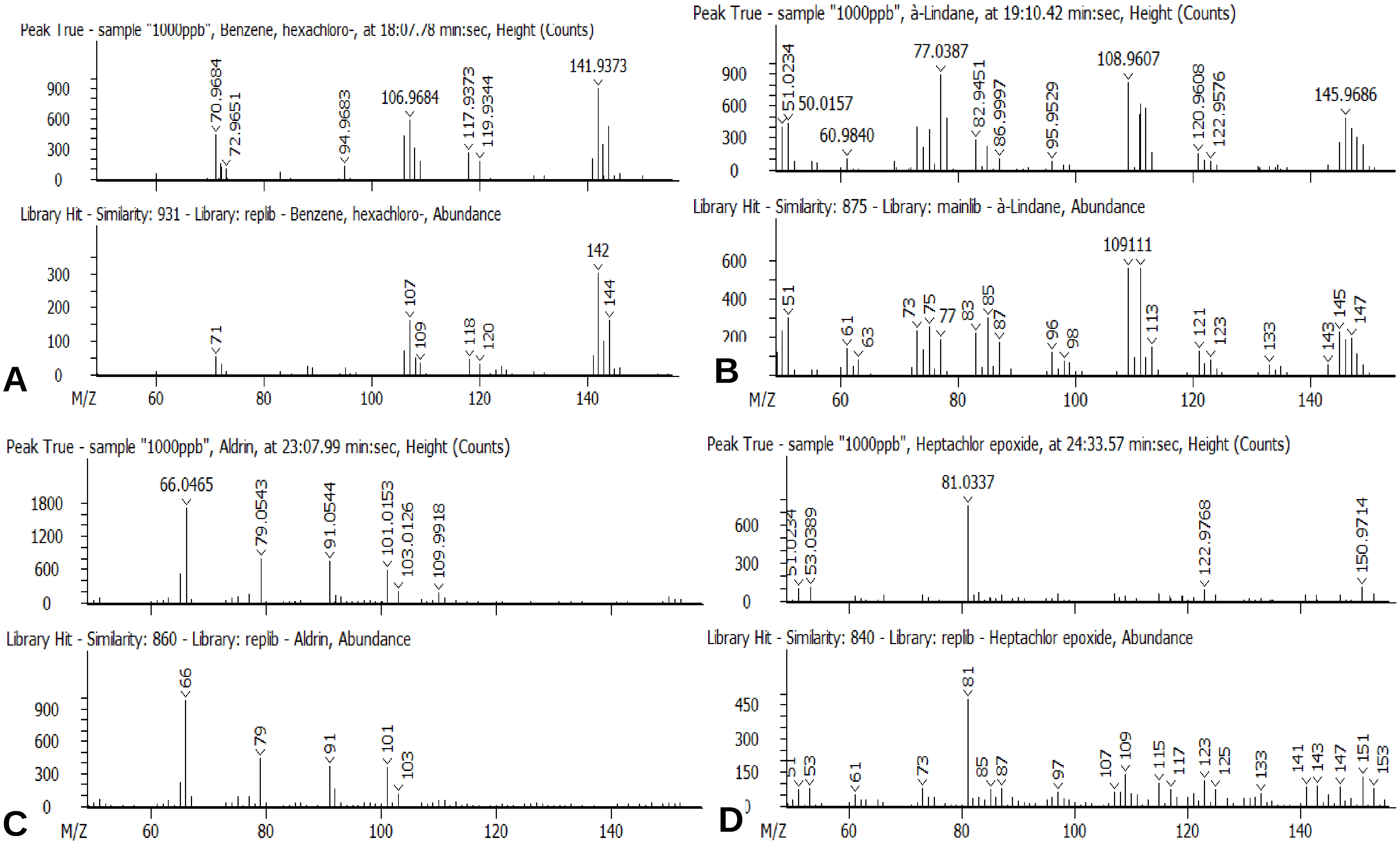
Yim, O. & Ramdeen, K.T. (2015). Hierarchical cluster analysis: Comparison of three linkage measures and application to psychological data. *The Quantitative Methods for Psychology,* 11: 8-21.

Zach, L., Doyle, M.E., Bier, V. & Czuprynski, C. (2012). Systems and governance in food import safety: A US perspective. *Food Control,* 27: 153-162.

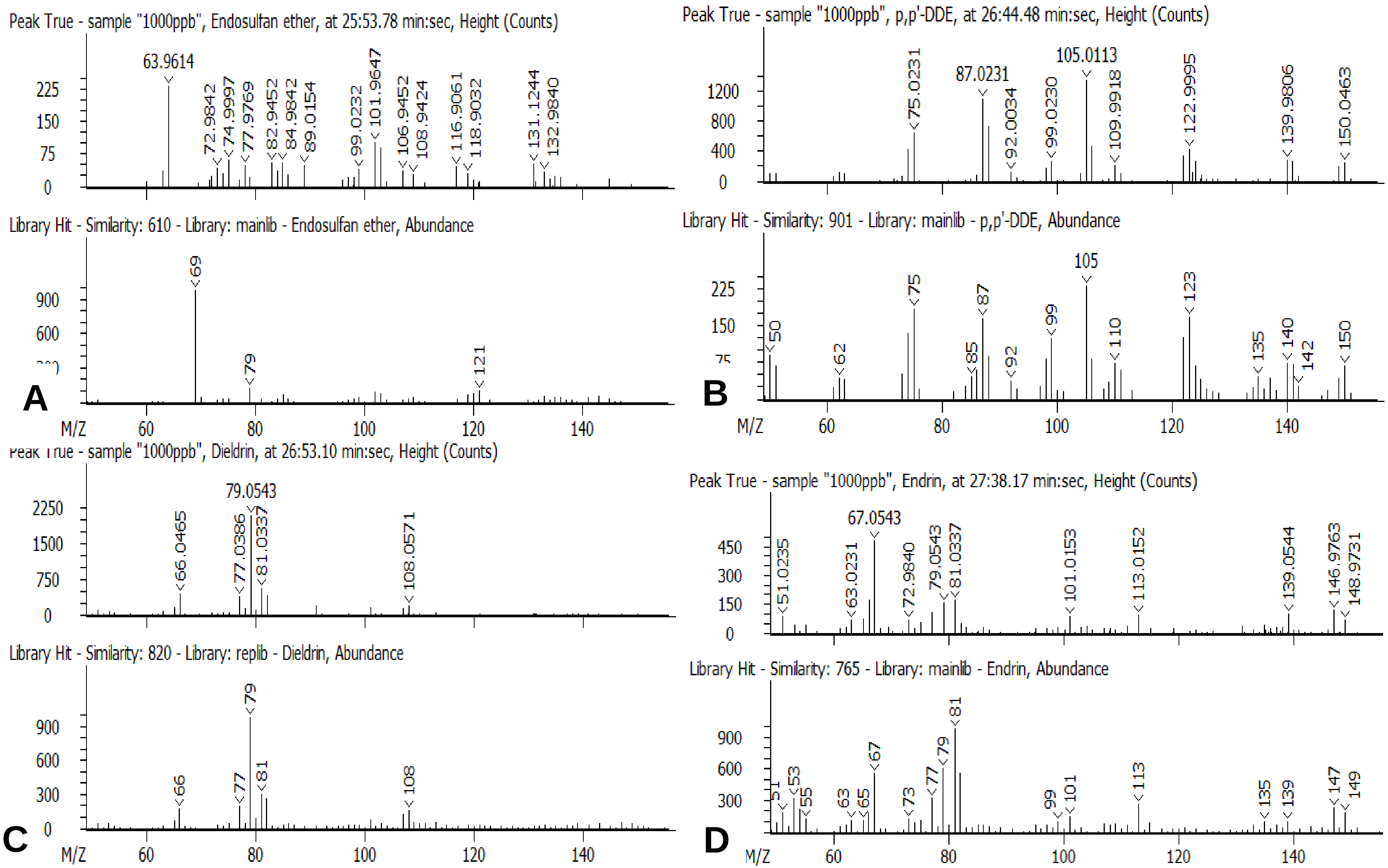
Zarn, J.A. & O'Brien, C.D. (2018). Current pesticide dietary risk assessment in light of comparable animal study: NOAEL's after chronic and short-termed exposure durations. *Archives of Toxicology*, 92: 157-167.

Zikankuba, V.L., Mwanyika, G., Ntwenya, J.E. & James, A. (2019). Pesticide regulations and their malpractice implications on food and environment safety. *Cogent Food and Agriculture* 5: 1601544.

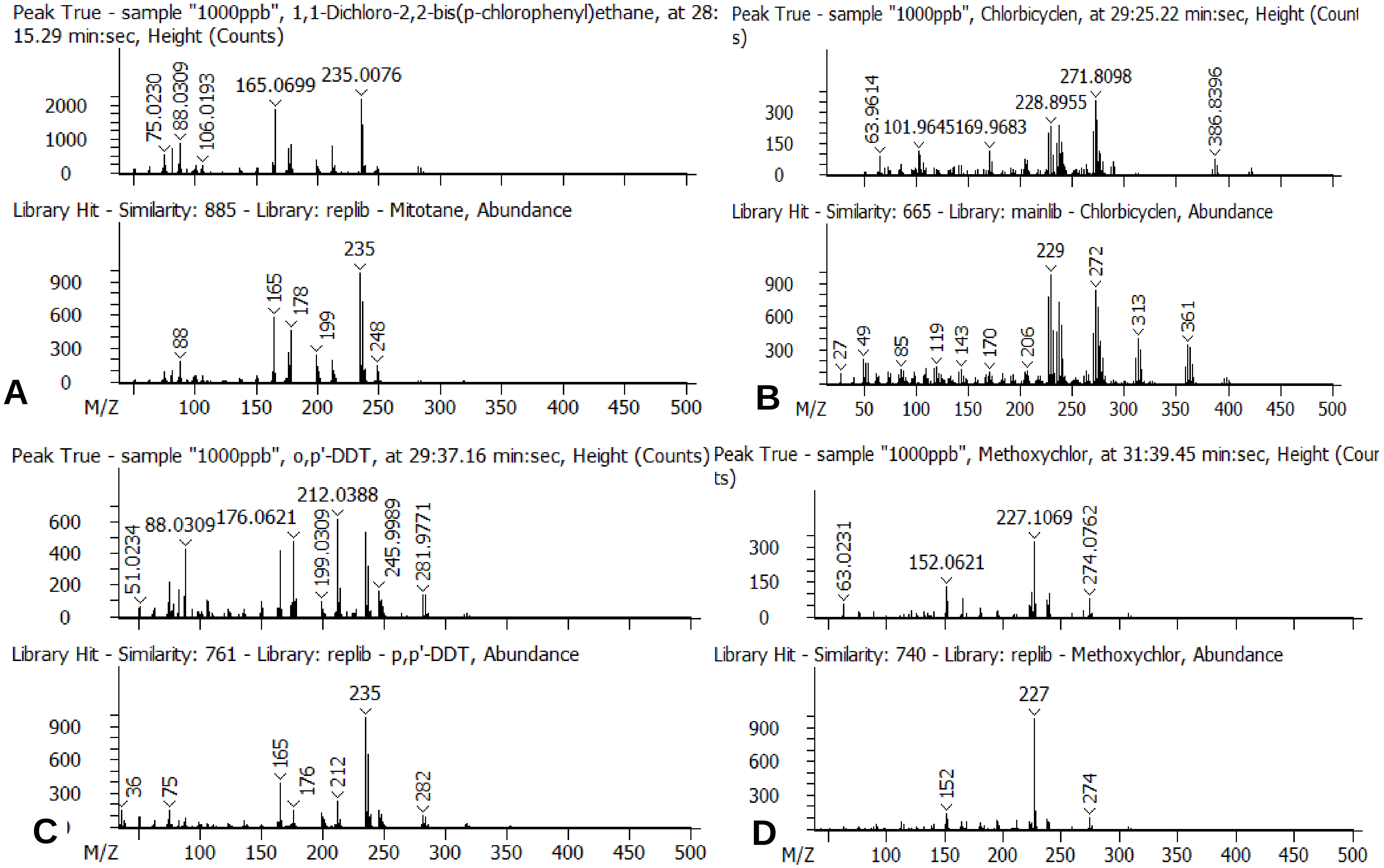
APPENDIX



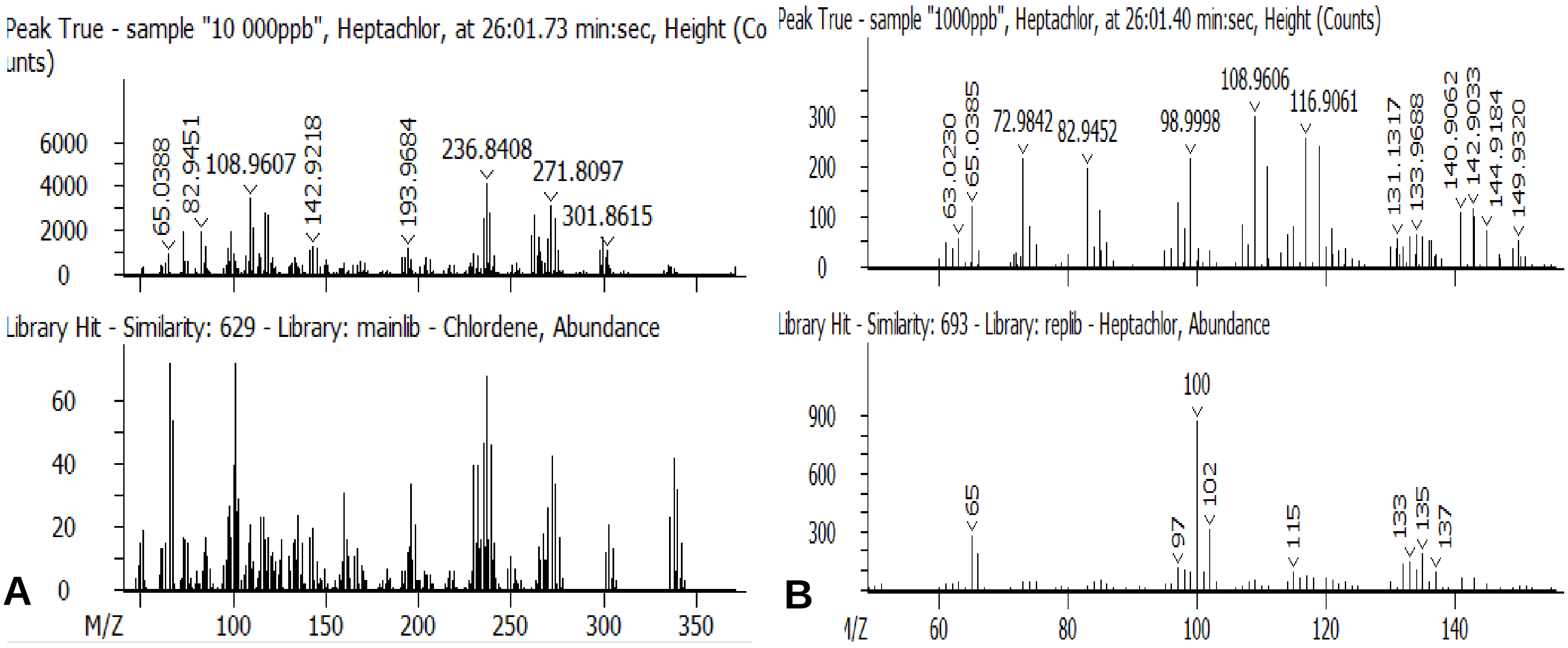
Comparative of peak areas between hexachlorobenzene (A), lindane (B) , aldrin (C), heptachlor epoxide (D) and sample.



Comparative of peak areas between endosulfan ether (A), *p,p'*-DDE (B), dieldrin (C), endrin (D) and sample.


Peak True - sample "1000ppb", 1,1-Dichloro-2,2-bis(p-chlorophenyl)ethane, at 28:15.29 min:sec, Height (Counts)
2000
1000
0
75.0230
88.0309
106.0193
165.0699
235.0076
Library Hit - Similarity: 885 - Library: replib - Mitotane, Abundance
900
600
300
0
88
165
178
199
235
248
A
M/Z
100
150
200
250
300
350
400
450
500
Peak True - sample "1000ppb", Chlorbicyclen, at 29:25.22 min:sec, Height (Counts)
300
150
0
63.9614
101.9645
169.9683
228.8955
271.8098
386.8396
Library Hit - Similarity: 665 - Library: mainlib - Chlorbicyclen, Abundance
900
600
300
27
49
85
119
143
170
206
229
272
313
361
B
M/Z
50
100
150
200
250
300
350
400
450
500
Peak True - sample "1000ppb", o,p'-DDT, at 29:37.16 min:sec, Height (Counts)
600
400
200
0
51.0234
88.0309
176.0621
199.0309
212.0388
245.9989
281.9771
Library Hit - Similarity: 761 - Library: replib - p,p'-DDT, Abundance
900
600
300
36
75
165
176
212
235
282
C
M/Z
100
150
200
250
300
350
400
450
500
Peak True - sample "1000ppb", Methoxychlor, at 31:39.45 min:sec, Height (Counts)
300
150
0
63.0231
152.0621
227.1069
274.0762
Library Hit - Similarity: 740 - Library: replib - Methoxychlor, Abundance
900
600
300
152
227
274
D
M/Z
100
150
200
250
300
350
400
450
500

Comparative of peak areas between *o,p'*-DDD (A), chlorbicyclen (B), *o,p'*-DDT (C), methoxychlor (D) and sample.



Comparative of peak areas between Chlordane (A) and Heptachlor and sample.