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RISK ASSESSMENT FOR DIETARY EXPOSURE OF PESTICIDES AMONG VEGETABLES CONSUMERS IN ARUSHA, TANZANIA

Purificator Andrew Kiwango

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy in Life sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Information on the extent of pesticide residues in vegetables from Tanzania and risk of dietary exposure to these residues among vegetable consumers is limited. This research assessed the risk of dietary exposure of pesticide residues in vegetable farmers and individuals with non-communicable disorders in Arusha. Face-to-face interviews were conducted to assess pesticide application practices. Observations were made to assess effectiveness of vegetable processing practices at household level, in reducing pesticide residues. Two-point 24 hour recalls and food frequency questionnaire techniques were used to determine vegetable consumption. Raw and ready-to-eat vegetables were sampled and analyzed for pesticide residues using Gas Chromatography-Mass Spectroscopy. Dietary exposure to pesticide residues was estimated. The results showed that vegetables were contaminated with organophosphates, pyrethroids organochlorines, carbamates and benzoic acid pesticides. Endosulfan and dieldrin which are banned for use in agriculture in Tanzania were quantified in the vegetables at levels above their respective Maximum Residue Levels. Exposure estimations showed that 18.6% of vegetable farmers are at risk of exposure to organophosphates [Hazard index (HI); 1.19], mainly contributed by dimethoate. Individuals with NCDs are at risk of exposure to organophosphates (HI; 1.12) and organochlorines (HI; 1.08) mainly attributed to exposure to chlorpyrifos and endosulfan, respectively. Dietary exposures of pesticides are significantly associated with lack of advice from agricultural extension officers (adjusted odds ratio (AOD) = 6.56; $P = 0.031$), over-dosage of pesticides in vegetables (AOD = 3.751; $P = 0.038$) and lack of professional training on pesticide application practices (AOD = 3.37; $P = 0.043$). Washing vegetables in a bowl two or more times with changing the washing water after one use, ($\chi^2(1) = 6.56$; $P = 0.01$) or peeling ($\chi^2(1) = 6.949$; $P = 0.008$ is significantly associated with low levels of pesticides in ready to eat vegetables. Poor practices in washing of minor ingredients (tomato, carrot, sweet pepper and onions) such as washing by water that was previously used to wash the major ingredients has significant association with the occurrence of pesticide residues in vegetables ($\chi^2(1) = 25.55$; $P = 0.001$. Based on the findings of this study it is necessary to ensure continuous monitoring of pesticide residues in vegetables and training growers on good agricultural practices and best practices on vegetable handling at household level.

DECLARATION

I, Purificator Andrew Kiwango do hereby declare to the Senate of Nelson Mandela African Institutition of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

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CERTIFICATION

The undersigned certify that they have read and hereby recommends for acceptance of the dissertation entitled 'Risk assessment for dietary exposure of pesticides among vegetables consumers in Arusha, Tanzania' by Purificator Andrew Kiwango in fulfilment of the Award of Doctor of Philosophy in Food and Nutrition Sciences at The Nelson Mandela African Institution of Science and Technology

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DEDICATION

This work is dedicated to my lovely family.

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LIST OF ABBREVIATIONS AND SYMBOLS

ADIs	Acceptable daily intakes
AICC	Arusha International Conference Centre
ARfD	Acute reference dose
bwt	body weight
BPPM	Best practices of pesticide management
EDIs	Estimated daily intakes
EPA	Environmental protection agency
EU	European union
FAO	Food and Agriculture Organization of the United Nations
GAP	Good agricultural practices
HI	Hazard index
HQ	Hazard quotient
IPCS	International Programme on Chemical Safety
kg	kilogram
LMCA	Lutheran Medical Center, Arusha
LOD	Limit of detection
LOQ	Limit of quantification
mg	miligram
MRLs	Maximum residue limits
NCDs	Non communicable disorders
PHI	Pre-harvest interval
RLDC	Rural Livelihood Development Company
SCF	Small and Medium Enterprise Competitiveness Facility
SPSS	Statistical Package for the Social Sciences
UNEP	United Nations Environment Programme
URT	United Republic of Tanzania
USEPA	United States Evironmental Protection Agency
WHO	World Health Organization

CHAPTER ONE

1.1 Introducation

This chapter describes the background of the study. Specifically, it describes the current status of pesticide application practices which predispose the vegetable consumers to the risks associated with the exposure to pesticide residues. It also describes the rationale, justification, objectives and the conceptual framework of the study.

1.2 Background information

Vegetable production requires extensive application of pesticides for the control of pests and diseases to improve crop yield that would otherwise be lost (Jang *et al.,* 2011; Ngowi *et al.,* 2007). When pesticides are not properly managed and their residues in food controlled, they can cause threats to public health. Exposure to pesticide residues is associated with risks of cancer development, genetic and immune system defects and neurological system disorders (Keifer, 2008).

The most vulnerable individuals to the risks of pesticide exposure are those who consistently consume high amounts of these vegetables (EFSA, 2012a; FAO/WHO, 2009a). Vegetable farmers who are involved in vegetable production may be exposed to pesticide residues through vegetable consumption as vegetables are readly available at their household premise thus consuming vegetables more frequently. Individuals with non-communicable disorders (NCDs) such as cancer, cardiovascular disorders, diabetes mellitus and respiratory disorders are also among these vulnerable groups (Pronczuk *et al.,* 2002). This is due to the fact that, they are advised to consume more of vegetables to supply the body with micronutrients and phytochemicals which help to control the health disorder such as cancer cell proliferation and oxidative stress (Mayne, 2003). It is therefore important to ensure that these vegetables are safe for consumption in order to protect consumers from exposure to pesticide residues.

To ensure the safety of vegetables and other foods, Codex Alimentarius Commission in collaboration with Environmental Protection Agency (EPA) has set maximum tolerable residual levels (MRLs) of particular pesticides in food. MRL is a lawfully amount of pesticide that can remain in a food commodity after applying good agricultural practices (GAPs). The MRL has an added margin of safety to ensure that the pesticide residues

remaining in the food are much lower than the amounts that can cause adverse health effects. However, reports reveal that, these limits have been exceeded in some foods (EFSA, 2012a).

A research done in Denmark realized that 2.6% of food samples collected and analyzed had pesticide residues higher than the MRLs (Petersen and Nielsen, 2013). Another research which was conducted in European Union (EU) in 2010 revealed that 1.6% of the collected food samples had pesticides levels higher than the MRLs. Samples analyzed in the EU report of 2010 included apples, pears, cabbage, leek, lettuce and tomatoes (EFSA, 2012a).

In Tanzania studies show that there is a malpractice of pesticides application (Busindi, 2012; Maerere *et al.*, 2010; Ngowi *et al.*, 2007). The pesticide application malpractice is observed in Arusha, Iringa, Lushoto and Kilimanjaro which are high potential regions for vegetable production (Maerere *et al.*, 2010; Putter and Koesveld, 2007). Busindi (2012) reported that, there is improper application of pesticides in tomato by farmers in Iringa whereby Caratel is applied every seven days instead of 14 days and 1 day instead of 7 days before harvest. After harvesting, the tomatoes are sprayed with Selecron to enhance shinness and ripening a week before tomatoes are ready for marketing (Busindi, 2012). Also, farmers tend to mix more than one pesticide in a single spray such as "dume" + "clax" + "actellic" to control pests and diseases. The situation is enhanced where farmers rely on personal judgment and pesticide suppliers' judgment rather than technical advice from extension officers (Anderson and Morales, 2005; Busindi, 2012). It is reported in Anderson and Morales, (2005) that 17% of farmers rely on their own decision on what pesticide to apply and when to apply (Anderson and Morales, 2005). All pesticides have adverse health effect to human when they are used improperly.

A survey done in Northern Tanzania revealed that, about 53% of farmers interviewed had increased trend of applying pesticides to vegetables (Ngowi *et al.*, 2007). Pesticides mostly applied to vegetables include insecticides (59%), fungicides (29%) and herbicides (10%) (Ngowi *et al.*, 2007)

Surveys which were done in Arusha region in Karatu and Arumeru districts show that, most of farmers don't have adequate knowledge on safe handling, storage, doses and effectiveness of pesticides. Due to this they use pesticides inappropriately, for example mixing more than one pesticide of the same active ingredient in the same tank. In addition some of the farmers don't use appropriate measuring equipment which may lead to overdose of the pesticide.

Other farmers do not follow the pre-harvest withdraw interval (Mkindi, 2012). Furthermore it was realized that, the farmers use pesticides not registered for use to a particular crop (Ngowi *et al.*, 2007). All these may have significant effect on the pesticide residue levels of such particular pesticides in the vegetables.

Studies have been done on ways of reducing pesticide residue content in vegetables at household level (Kiwango *et al.*, 2018b). Such works studied the influence of various household practises for vegetable preparation on pesticide residues and found that, washing, peeling and cooking of vegetables have significant influence on reduction of pesticide residues, although some of the processes such as sauce preparation could concentrate the residues (Keikotlhaile *et al.*, 2010). However, these studies were performed at laboratory level, which may not reflect the real practice at community level suggesting a need of assessing the influence of vegetable handling to the pesticide residues in the vegetables at community level.

Arusha district is one of the potential areas for vegetable production in Arusha. Although pesticide application practices have been reported in other districts such as Arumeru and Karatu, such records are not available in Arusha district. Further, the association of these practices and dietary exposure to these residues is not yet established. Therefore, it is important to assess pesticide application practices and their association to pesticide residues to vegetables in Arusha district. Furthermore, studies show that about 50 % of vegetables produced are consumed by the farmers' households while the other 50 % are mostly sold to consumers through various outlets including the Central market in Arusha, Kilombero and Tengeru (Weinberger and Msuya, 2004). This implies that, if the vegetables are contaminated with pesticide residues, the consumers may be at risk of dietary exposure to pesticide residues which may lead to adverse health effects to the farmers, their household members and other consumers in Arusha city. Therefore it is important to assess dietary exposure of pesticide residues to consumers in Arusha city. This work aimed at investigating human exposure of pesticide residues through vegetable consumption in Tanzania, focusing on population in Arusha particularly on individuals with non-communicable diseases and vegetable farmers.

1.3 Problem statement and justification of the study

Like in other developing countries, vegetable farmers in Tanzania apply pesticides to vegetables indiscriminately. As a result, vegetables are likely to contain high levels of

pesticide residues which could increase the risk of human exposure to pesticide residues. The exposure to pesticide residues may lead to both acute and chronic health effects. The acute ones include abdominal pain, dizziness, vomiting, headache, nausea and skin and eye problems while chronic ones include risk of cancer, neurological, immune and reproductive effects (Bassil *et al.*, 2007; Sanborn *et al.*, 2012). Frequency and quantity of vegetable consumed have influence on the exposure. Individuals with non-communicable disorders (NCDs) are among the vulnerable groups to pesticides residues exposure through vegetable consumption (FAO/WHO, 2004). This is due to the current strategies on preventing and controlling NCDs through healthy eating and physical exercises where by this group of people are strongly advised to eat more of vegetables and fruits. It is reported that Arusha, among other potential regions for vegetable production including, Iringa, Tanga, Morogoro and Kilimanjaro leads in pesticide trading and use (Agenda, 2006; Putter and Koesveld, 2007). Thus, vegetable farmers in Arusha are likely to be at high risk of both occupational and dietary exposure to pesticide residues. Since they cultivate vegetables, it is presumed that, the vegetables are readily available therefore consuming vegetables more frequently.

Although pesticide application practices to vegetables are well reported, the practices that are more associated with the exposure to pesticide residues are not identified. Also, studies on the assessment of the risk of exposure to the pesticide residues in Tanzania are limited. This raised the need of assessing the association of pesticide application practices with the risk of exposure to pesticide residues and investigation of the risk of human exposure to pesticide residues through vegetable consumption in Arusha focusing on the vegetable farmers and individuals with non-communicable diseases. Exposure assessment of pesticide residues through vegetable consumption requires data on the amount of vegetables consumed and, types and amount of pesticide residues in the vegetables. Vegetable consumption pattern for people with non communicable diseases and vegetable farmers in Tanzania is yet to be established (Mayige *et al.*, 2012) thus raising the need to assess vegetable consumption among vegetable farmers and individuals with NCDs.

Data on the extent of pesticide residues contamination in ready to eat vegetables commonly consumed in Tanzania is limited. Only few studies determined contamination in spinach (Ndengerio-Ndossi and Cram, 2005), tomato (Kariathi *et al.*, 2016), cabbage and onion (Mahugija *et al.*, 2017). However, there are more vegetables which are consumed but their

extent of pesticide residues contamination is not known indicating a need of determining pesticide residues in the commonly consumed vegetables in Arusha.

Household vegetable processing may influence pesticide residues in the vegetables. These processes have been studied at experimental level in other countries but not in Tanzania. The studies at experimental level may not necessarily reflect the actual influence at household level. Therefore there was a need of determining the influence of household vegetable processing on the pesticide residues in the vegetables at household level.

This study aimed at investigating the risk of exposure to pesticides in human consuming vegetables in Arusha. It characterized the risks associated with exposure to pesticide residues via vegetable consumption and determined the influence of household vegetable processing on the reduction of pesticide residues in the vegetables. The study identified the potential pesticide application practices that are significantly associated with risk of exposure to pesticide residues among vegetable consumers. Assessment of the risk of exposure to pesticide residues to vegetable consumers provided information on the extent of exposure to pesticide residues for regulatory decision making for public health protection. Further, the study provided data on the vegetable consumption pattern among individuals with NCDs and vegetable farmers in Arusha and the extent of vegetable contamination with pesticides for policy makers. The identification of pesticide application practices with significant association with the risk of exposure allows a focussed allocation of resources in controlling pesticide residues in the vegetables. Also, best household vegetable practices to reduce pesticide residue contamination were identified in this study.

1.4 Objectives

1.4.1 Main objective

To assess the risk of dietary exposure of pesticide residues among vegetable farmers and individuals with non-communicable disorders consuming vegetables in Arusha Region.

1.4.2 Specific objectives

(i) To assess pesticide application practices in vegetables cultivated in Arusha district and their influence to the risk of dietary exposure of pesticide residues among vegetable farmers in Arusha district.

(ii) To determine extent of pesticides residues in vegetables commonly consumed in Arusha.

(iii) To assess the vegetable processing practices at household level and their influence to pesticide content in ready to eat food in Arusha.

(iv) To assess the risk of dietary exposure of pesticides residues through vegetable consumption among individuals with non communicable disorders and vegetable farmers in Arusha.

1.4.3 Research questions

(i) What is the influence of pesticide application practices in vegetables to dietary pesticide residues exposure to the farmers in Arusha district?

(ii) To what extent are vegetables commonly consumed in Arusha contaminated with pesticide residues?

(iii) What is the influence of vegetable processing at household level to the amounts of pesticide residues?

(iv) To what extent are individuals with non communicable disorders and vegetable farmers in Arusha at risk of exposure to pesticide residues?

1.5 Outline of the study

This dissertation is paper-based with three original papers and one review paper. Two papers (original and a review) are published in accredited research journals whereas the other 2 papers are draft manuscripts ready for submission and possibly publication in scientific journals. The outline of the dissertation is presented in Fig. 1. Chapter one presents the background information of the study, followed by the research problem and justification and the objectives of the study. Chapter two is a review of similar studies on the pesticide application practices among vegetable farmers, pesticide residues in vegetables, the risk of exposure and practical interventions on how to reduce the pesticide residues in vegetables. Chapter three is the results of the extent of pesticide residues content in ready-to-eat vegetables from Arusha district, the risk of exposure to pesticide residues in vegetable farmers and the association of the risk to pesticide application practices, whereby the significant practices are identified by logistic regression. Chapter four repeals the extent of pesticide residues in raw and ready to eat vegetables from Arusha city and assesses the influence of household vegetable handling practices on the reduction of pesticide residues. The practices that have significant influences on the reduction of the residues are identified by chi-square statistical tool. The risk of dietary exposure to pesticide residues among individuals with NCDs are presented in chapter five. Lastly, the general discussion, conclusion and recommendations for the study are presented in chapter six, followed by references and appendices.

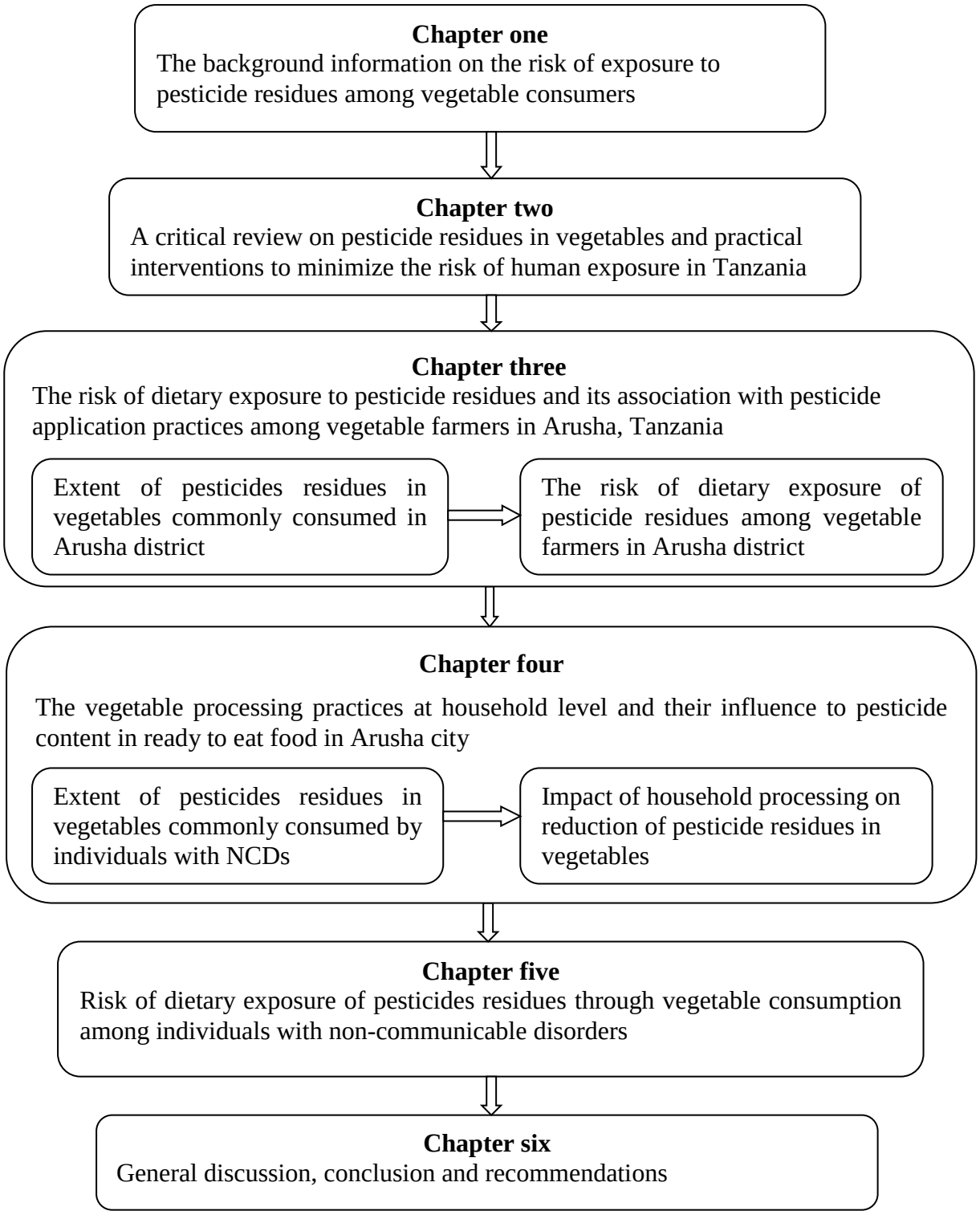

Figure 1: Outline of the study

CHAPTER TWO

A CRITICAL REVIEW OF LITERATURE ON PESTICIDE RESIDUES IN VEGETABLES: MAGNITUDE OF THE PROBLEM AND PRACTICAL INTERVENTIONS TO MINIMIZE THE RISK OF HUMAN EXPOSURE IN TANZANIA[1]

Abstract

Malpractices of pesticides use in vegetables production have been reported in horticultural industry in developing countries. This can result in excessive use of pesticides and subsequently unacceptable levels of pesticide residues in foods of horticultural origin. Consumption of vegetables containing unacceptable levels of pesticide residues is of public concern as can result in harmful effects in human health. In this study, the current status of pesticide application, the occurrence and exposure of pesticide residues in vegetables as well as factors influencing the problem of pesticide exposure in Tanzania is reviewed. The review found that pesticides are applied to vegetables seldom following good agricultural practices. However, pesticide residues in vegetables are not monitored and exposure studies are limited. Studies on vegetable processing at household level have been done at laboratory scale. Nevertheless the potential of these processes at community level is unknown. This review suggests a broader research on the pesticide application practices to establish the important practices that have significant influence on the occurrence of pesticide residues in vegetables so that the allocation of resources can be streamlined towards improvement, monitoring and control of these practices to minimize pesticide residues in the vegetables. Continuous monitoring of pesticide residues in food as well as the subsequent human dietary exposure is highly recommended in order to inform policy makers and risk managers on the status of the risk of exposure to pesticide residues for risk management.

Keywords: pesticide residues, application practices, household vegetables processing, exposure assessment.

[1] This review is published in the 'Current Journal of Applied Science and Technology' Vol. 26(1), 2018

2.1 Introduction

The occurrence of pesticide residues in horticultural produce has been a growing public health concern worldwide. High pest infestation forces farmers to apply pesticides intensively to rescue crop loss. It is reported that the crop loss due pest infestation can be as high as 100%, if they are not controlled (Rajabu *et al.,* 2017). However, good pesticide application practices have to be observed to protect and promote public health. If not well controlled, pesticides use may result in pesticide residues in agricultural produce in levels above the maximum residue levels (MRLs) recommended, which in turn results in pesticide exposure in human and animals. Consumption of pesticide containing food is the major route of chronic exposure to pesticides. It is estimated that dietary pesticide exposure is five times higher than exposure through other routes which include inhalation and contact (Fothergill and Abdelghani, 2013; Thatheyus and Selvam, 2013). Health risks associated with exposure to pesticide residues range from acute characterized with coughing, headache, nausea, stomachache, diarrhoea and vomiting to chronic in the form of endocrine disruption, reproduction and immune systems malfunctioning and development of some cancers (Ndengerio-Ndossi and Cram, 2005).

Several initiatives have been taken to ensure pesticide safety in vegetables and other foods. Some of these include the establishment and enforcement of MRLs. Countries and/or the Codex Alimentarius Commission set MRLs based on reference limits such as acceptable daily intakes (ADI) and acute reference dose (ARfD) prescribed by the Joint Meeting of Food and Agriculture Organization (FAO) and World Health Organization (WHO) on Pesticide Residues (JMPR). MRLs are established based on data obtained from field supervised trials following good agricultural practices (GAPs) whereas ADI and ARfD are established based on international dietary risk assessment data (WHO, 1997). The MRLs are set much higher above the ADI to ensure that if the food produced under GAPs is consumed in the entire lifetime of the consumer, the adverse health risks associated with the particular pesticide will not be manifested (Claeys *et al.,* 2008).

Furthermore, international treaties and codes on pesticides trade encourages governments to establish and/or review regulations and policies related to chemical trading, use and disposal to ensure protection of human, animal and environment. Of these, the FAO code of conduct on the distribution and use of pesticides was adopted in 2002 (FAO, 2005), The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and

Pesticides in International Trade was adopted in 1998 in Rotterdam, Netherlands and The Stockholm Convention on Persistent Organic Pollutants (POPs) was adopted in 2001 in Stockholm Sweden (UNEP, 2009). Countries establish pesticide policies and regulations to manage transportation, storage, use and disposal of pesticides, based on the international treaties and codes of practices. For instance, Tanzania has established policies and legislation for that purpose. Among others, these are the Agricultural and Livestock Policy of 1997, Pesticide Control Regulation of 1984 and Plant Protection Act number 13 of 1997. Establishment of the Tropical Pesticide Research Institute under the Act number 18 of 1979 was also done objectively to ensure safe and effective use of pesticides for the public health protection in Tanzania (Agenda, 2006).

Nonetheless, presence of policies, regulations and codes of practices in subsistence communities of developing countries like Tanzania cannot guarantee presence of acceptable levels of pesticides in food. Surveys in the developing countries such as Nigeria and Ghana (Afari-sefa *et al.,* 2015; Amoabeng *et al.,* 2017), Zimbabwe (Zimba and Zimba, 2016), Palestine (Zyoud *et al.,* 2010) and Tanzania (Mdegela *et al.,* 2013; Ngowi *et al.,* 2007) reported misuse and overuse of pesticides, non-adherence to the pre-harvest interval, poor storage and disposal of pesticide containers and use of banned and counterfeit pesticides. In the foregoing, indiscriminate use of pesticides may result in excessive pesticide residues in food and the environment. Levels of pesticide residues in food may be altered during household operations or industrial processing. However, most of the studies reporting pesticide reduction in food were conducted at laboratory level (Keikotlhaile *et al*., 2010). This implies that the alteration may not necessarily happen under real life situation at household level.

It is therefore imperative to gather, analyse and document farmers' and householders' practices that can influence presence and exposure of pesticides in developing countries. The information can be used by agricultural extension agents and food safety regulatory authorities to amend policies, regulations and codes of practices with a view to minimizing the problem of pesticides exposure in those countries.

This is a critical review of reports to unveil pesticide application or handling practices leading to residues and exposure in vegetables and recommend practical interventions to mitigate the problem among subsistence communities in Tanzania.

2.2 Vegetable production in Tanzania

In Tanzania vegetables are produced by small, medium and large scale growers mainly for commercial purposes. It is reported that of the vegetables produced in the country, 10% is for household consumption (SCF, 2008). Vegetable production subsector contributes about 7% of the GDP (Putter and Koesveld, 2007). Major vegetables cultivated in the country include tomato, cabbage, carrot, onions, kale, spinach, amaranth, nightshade and pumpkin leaves (SCF, 2008). Vegetable production is mainly concentrated in Northern zone regions of Arusha and Kilimanjaro, Coastal zone region of Tanga and Southern corridor zone regions of Morogoro and Iringa but 85% of the production is from the Northern zone (Lema *et al.*, 2014; Putter and Koesveld, 2007; SCF, 2008).

2.3 Health benefits of vegetables consumption

Vegetables are important sources of macro- and micro-nutrients and phytochemicals necessary for boosting body immunity thus maintaining health and prevent diseases in human. It is in this context that nutrition guidelines contain a recommendation that a balanced diet should include vegetables. Beyond advocacy of vegetable consumption for general health promotion and prevention of diseases (WHO, 2003), dietician prescribe higher amounts of vegetable and fruits consumptions for people suffering from non-communicable diseases (NCDs). As a result there is an increase in awareness about health benefits of vegetables in diet.

The increased awareness of health benefits of vegetables and fruits has contributed to the increased consumption and demand of these products (Horticultural Development Council of Tanzania, 2012). Since the risk of pesticide exposure is higher in heavy consumers compared to the moderate consumers of vegetables, there is an urgent need to ensure the pesticide safety of vegetables.

2.4 Pesticides use in Tanzania

Pesticide use in the country increased rapidly from the year 1992 (when the Tanzania adopted the trade liberalization policy). From that time, the Government suspended subsidies in agricultural inputs and allowed importation and distribution of agrochemicals through trade dealers (Bee and Mosh, 1997). Removal of subsidies in agricultural inputs resulted in decreased returns from cash crops due to increased production costs (de Bon *et al.,* 2014). Consequently, there was a paradigm shift of farmers from cash crops to vegetables and other food crops offering short duration of investment and realization of the earnings (Bee and Mosh, 1997). Also, trade liberalization has increased pesticide availability locally and in retail shops and therefore increased accessibility and rate of use (Ngowi *et al.,* 2007; Nonga *et al.,* 2011). This has been resulted in the increased volume of pesticides importation from 500 MT in 2000 to 2500 MT in 2003 (Lema *et al.,* 2014) and then from 2500 MT in 2003 to 11 482 MT in 2014. A number of formulations registered for use in Tanzania also increased from 450 (Mununa *et al.,* 2014) in 2012 to 1182 in 2014 (Lekei *et al.,* 2014c). Lekei *et al.* (2014c) reported that, of the 1182 formulations registered for use in Tanzania in the financial year 2013/2014, 83.4% (986) is for use in agriculture whereby horticulture, a sub-sector in agriculture consumes the largest proportion of 41.2% (406).

The pesticides registered for use in Tanzania are mostly pyrethroids 230 (27.2%) and organophosphates 135 (15.9%) as reported by Lekei *et al.* (2014c), whereas the organochlorine pesticides (endosulfan) previously (2011) listed as provisionally registered pesticides were no longer in this categorization. Organochlorines are among the persistent organic pollutants which were banned from use in agriculture in the country since 1997 due to their bio-accumulating property in environment, mammalian and other non-target organisms body tissues (Agenda, 2006), associated with adverse effect on human and animal health. Based on target pest, most of the registered pesticides are 493 (41.7%) brands of insecticides, 321 (27.2%) fungicides and 289 (24.4%) herbicides (Lekei *et al.,* 2014c) (Table 1).

Table 1: Registered pesticides, their categories and respective uses in Tanzania

Category	n	%	Use
Insecticides	493	41.7	Manage insects
Fungicides	321	27.2	Manage fungi
Herbicides	289	24.5	Manage weeds
Acaricides	56	4.70	Manage mites
Growth regulators	10	0.80	Enhance growth
Rodenticides	8	0.70	Manage rodents
Nematicides	3	0.30	Manage nematodes
Avicides	2	0.20	Manage birds

Source: (Lekei *et al.*, 2014c; Marčić *et al*., 2011; Śpiewak, 2001)

In horticultural farming, insecticides are mostly applied followed by fungicides and herbicides, a trend which is reflected in pesticide registration (Table 1). A survey done in 2007 by Ngowi *et al.* (2007) reported that 59% of farmers interviewed applied insecticides; 29% fungicide and 2%, herbicides. It was also documented by Nonga *et al.* (2011) that 50% of vegetable farmers applied insecticides 37.5%, fungicides and 12.5% herbicides. This trend implies that insects are the main challenge in horticultural farming as compared to other types of pests. According to WHO, pesticides have been classified into classes Ia – extremely hazadous, Ib - highly hazardous, II - moderately hazardous, III - slightly hazardous and U - unclassified (International Programme for chemical safety (IPCS), 2010). Most of the pesticides applied in vegetable farming in Tanzania are in the moderately (II) and slightly hazardous (III) classification, though highly hazardous pesticides have also been reported at a lower proportion (Nonga *et al.*, 2011). Extremely and highly hazardous pesticides are registered for restricted use and must be used by specifically trained personnel or under supervision of specifically trained personnel (United republic of Tanzania (URT), 2011). Most of these pesticides are cholinesterase inhibitors (16%) and classified as WHO class I and II (50%) (Lekei *et al.*, 2014c). The use of these pesticides in horticulture industry indicates potential risk of dietary exposure through vegetable consumption if good agricultural practices (GAPs) are not well observed. This review therefore, calls for the need for monitoring of pesticide residues and analyze for the risk of exposure among consumers.

Number of active ingredients applied in vegetables farming in the country have been well documented in various studies (IPCS, 2010; Lema *et al.*, 2015; Ngowi *et al.*, 2007; Nonga *et al.*, 2011) of which majority are in the groups of organophosphates (profenofos, dimethoate, chlorpyrifos, pirimiphos-methyl and fenitrothion), pyrethroids (cypermethrin, lambda-cyhalothrin, permethrin and deltamethrin), mancozeb and metalaxyl and organochlorines

(endosulfan). Endosulfan which is an endocrine disruptor is also reported as the most frequently applied pesticides to vegetables (Mhauka, 2014; Nonga *et al.,* 2011), whereas carbamate (carbofuran) are reported at lower extent. Bio-pesticides which are regarded as safer and biodegradable are limited in use (Moshi and Matoju, 2017). The pesticides that are more frequently used are associated with potential health risks to human and non target organisms. Their use in horticultural crops should carefully be controlled and minimized by including integrated pest management approach so that their residues are minimized below their MRLs for consumer protection. There is a need to perform more research on biodegradable pesticides in order to provide safer pest management options.

2.5 Malpractices in pesticide application in Tanzania

Poor pesticide application practices in vegetable production have been reported. These include use of unregistered pesticides, inappropriate dosage, lack of adherence to pre-harvest interval, use of banned pesticides, inappropriate use of pesticides such as inappropriate pesticide/crop combination and the use of cocktail mix of pesticides in single spray (Lema *et al.,* 2015; Ngowi, *et al.,* 2016; Ngowi *et al.,* 2007; Nonga *et al.,* 2011).

Plant Protection Act of 1997 and Plant Regulation Act of 1999 requires all pesticides to be registered by the Pesticide Registrar before they can be used in Tanzania (Mushobozi, 2010). However, surveys show that, unregistered pesticides are sold and used in vegetable production in various regions across the country. A post-registration surveillance of pesticides towards best practices of pesticide management (BPPM) for environmentaland human health protection in Tanzania done in Mtwara and Lindi regions in 2012 revealed 39.4% of pesticide shops selling unregistered pesticides (Mununa *et al.,* 2014). Also, a survey by Ngowi *et al.* (2007) found out that 19% of the pesticides applied on vegetables by smallholder farmers in Northern Tanzania were not registered. Of a special concern on unregistered pesticides, the application rates, pre-harvest intervals and crop/pesticide combination have not been validated in the country. This may create a risk of overdosing and harvesting of crops before pre-harvest intervals resulting into unacceptable pesticide residues in vegetables which may increase the risk of human exposure to pesticide residues.

Another survey observed misuse of pesticides in Mindu dam (Mdegela *et al.,* 2013) whereby sumithrin-piperonylbutoxide registered for control of mosquitoes was used to control fungi in tomato. Diazinon for ectoparasites in animals was used for armyworms in maize and

chlorfenvinphos for control of ticks was used to control aphids in tomatoes and onions. Misuse of pesticides could be due to ignorance or limited pesticide options. Since there are no studies on the important safety measures and limits for such product/crop combinations there might be a potential risk of high residues in the crop that can be exposed to the consumer. It is suggested to create awareness to the farmers on the importance of adherence to the directives of pesticide uses as per label for protection of their own and consumer health.

Adherence to the recommended dosage and frequency of application of pesticides is one of the requirements of GAPs that would ensure acceptable pesticide residues in food crops and the environment and hence protecting consumer and farmer's health. However, inappropriate dosages and application rates of pesticides in vegetables farming have been reported in most of the vegetable production areas. For instance, a study in Mang'ola district reports that, farmers apply pesticides on vegetables at an over-dosage (Mhauka, 2014). Other studies in Manyara basin and Arumeru district showed that, farmers applied pesticides on vegetables on a routine basis as a means of protection even though no pest had been observed on the plants (Ngowi *et al.,* 2007; Nonga *et al.,* 2011). This can result in unnecessary production costs and/or unacceptable pesticide residues in the vegetables. It is also reported that farmers mix two or more pesticides in the same spray with the aim of increasing efficacy though not recommended. For instance, the study in Northern Tanzania by Ngowi *et al.* (2007) reported that 33.3 % of the farmers do mix two or more pesticides in the same spray tank whereas about 90% of them mix three or more pesticides. In Mang'ola district it is reported that farmers mix two or more pesticides of different brand but the same active ingredients (Mhauka, 2014). Depending on the nature of the pesticides, mixing of pesticides in the same spray tank can result into more or less effective pesticide mixture which can affect plant health, reduce yield and result into multiple pesticide residues in vegetables (Mushobozi, 2010; Ngowi *et al.,* 2007) as well as high production costs. Codes of best practices prohibit use of cocktails of pesticides unless advised by the manufacturer or are inherent in the formulation (Mdegela *et al.,* 2013; Moshi and Matoju, 2017). Farmers mix pesticides in the same sprayer to save money and reconstitution water (Manyilizu and Mdegela, 2015). Other farmers think that by mixing pesticides they become more effective. Since the manufacturers include inert materials in the formulation of the pesticide which are usually unknown to the end user, it is difficult to understand the compatibility of the pesticides being mixed. It is recommended that the agricultural extension officers should establish demonstration farms among the vegetable farmers so that they can demonstrate to the farmers on best pesticide

application practices so that the farmers can learn practically from these agricultural extension officers.

It is further reported that majority of the farmers stored remaining pesticides in the kitchen or general stores with food (Lekei *et al.,* 2014a; Ngowi *et al.,* 2007; Nonga *et al.,* 2011; URT, 2011) and dispose empty pesticide containers on the farms. This may result into pesticide contamination of food and the environment which may affect food consumers, farmers as well as non-target organisms. For instance, the long persistent pesticides like dichlorodiphenyltrichloroethane (DDT) can be absorbed by the crop during growth and end up to be consumed (Mahugija *et al.,* 2017). In addition, farmers use own experience or advice from pesticide retailers on the choice and application of pesticides to vegetables rather than guidance from agricultural extension officers. Majority of pesticide retailers are business oriented and have low knowledge on GAP which may result in provision of wrong advice to farmers (Lekei *et al.,* 2014b). Farmers have been reported to have low level of education and limited professional pesticide application training. These limitations are linked to the poor pesticide handling practices which contributes to the increased risk of human exposure through occupation and food consumption (Kapeleka *et al.,* 2016; Ngowi *et al.,* 2007; Nonga *et al.,* 2011; URT, 2011). However, association of the poor pesticide handling practices and dietary exposure is not well established in these studies. It is recommended to establish the association between various pesticide application practices and the pesticide exposure levels so that the most important practices are identified. This will enable a more focused allocation of resources on management of these practices and eventually control pesticide residues in the vegetables and food crops at large.

2.6 Occurrence of pesticide residues in vegetables

Despite well documented poor pesticide handling and application practices in vegetable farming, monitoring of pesticide residues in vegetables is not a common practice in Tanzania. Only limited studies have evaluated pesticide residues in vegetables. Mahugija *et al.* (2017) evaluated pesticide residues in raw cabbage, onions and spinach whereas Ndengerio-Ndossi and Cram (2005) analyzed pesticide residues in ready-to-eat amaranths (spinach) from markets in Dar es Salaam. Kariathi *et al.* (2016) analyzed pesticide residues in raw tomatoes from farmers in Ngarenanyuki-Arumeru district. With exception of the residues detected by

Ndengerio-Ndossi and Cram (2005), one or more types of pesticide residues reported in these studies were above MRLs.

Ndengerio-Ndossi and Cram (2005) analyzed 33 amaranths samples for pesticide residues in Dar es Salaam markets and quantified gamma-hexachlorocyclohexane (g-HCH) 1,1-dichloro-2,2-bis (p-chlorophenyl) ethylene (pp-DDE), dichlorodiphenyltrichloroethane (pp-DDT), and chlorpyrifos residues in 72.7% of the samples. All the residues were well below their Codex MRL of 0.01 mg kg^{-1} g-HCH, pp-DDE, (pp-DDT) and 1 mg kg^{-1} for chlorpyrifos. The study by Mahugija *et al.* (2017) analyzed 72 vegetable samples of cabbage, spinach and onions and found pesticide contamination in 83.3%, 75% and 50% of the samples, respectively. The detected pesticide residues were α and β endosulfan, p,p'-DDD o,p'-DDD, p,p'-DDT, chlorpyrifos and cypermethrin. The residue concentrations in cabbage, spinach and onion exceeded their respective MRLs in 41.7%, 50% and 33.3% of samples, respectively. Kariathi *et al.* (2016) analyzed 50 samples of tomato from farmers in Ngarenanyuki and quantified chlorpyrifos and permethrin in 46.15% of the samples. This study also quantified Ridomil in four percent of the samples though it did not confirm the active ingredients as metalaxyl or mancozeb as ridomil registered for use in the country is formulated from these two active ingredients (URT, 2011). All quantified pesticide residues in this study were above their respective MRLs. However these analyses were done targeting fewer vegetables thus giving limited information on the status of pesticide residues in the vegetables. There is therefore a need for monitoring of pesticide residues in vegetables and conduct risk of exposure to the pesticide residues. This will enable policy makers and risk managers to formulate measures for management of the risks associated with pesticide residues exposure.

High pesticide residues levels above MRLs are also reported in other developing countries. For instance, Darko and Akoto (2008) analyzed pesticide residues in tomato, eggplant and pepper from Kumasi markets and found dichlorvos residues above MRLs in 48% of tomato, 42% of eggplant and 26% pepper. The dichlorvos residues were also quantified in spinach, parsley and lettuce obtained from markets in Turkey whereby 85% of spinach, 70% of parsley and 40% of lettuce samples were contaminated with dichlorvos residues at concentration levels above their corresponding EU-MRLs (Esturk *et al.,* 2011). Another study in Togo analyzed pesticide residues in cabbage, lettuce and tomato and found 100% of the vegetables contaminated with one or more organochlorine pesticides whereby 16.68% of

the residues were above their respective EU MRLs (Kolani *et al.*, 2016) although none was above the Codex MRLs.

Contrary to the high prevalence of pesticide residues above MRLs reported in Tanzania and other developing countries, reports by European Union monitoring programme show a very low prevalence of pesticide residues above their corresponding MRLs. For instance, the 2015 and 2014 reports showed that 1.6% of the food samples contained residues above the MRLs.

Based on the fact that monitoring of pesticide residues in the potential vegetable production areas where poor pesticide applications have been reported are limited, this review suggests the need for monitoring programme to inform farmers of the health risks that can result from poor pesticide application practices, policy makers and regulators for action such as organizing intervention program and reinforcement of regulations. To demonstrate the foregoing, Mhauka (2014) reported pesticide residues in raw vegetables and the mean residues are presented in Table 2.

Table 2: Occurrence of pesticide residues in vegetables of Tanzania

Vegetable	Area	Pesticide group	Pesticide residue	Range of pesticide residues (mg/kg)	Mean concentration (mg/kg)	Prevalence (%)	Prevalence >MRL	MRL (mg/kg)	Reference
Amaranthus	Dar es Salaam	Organochlorine	g-HCH	-	0.000 08	6.01	0	0.01	(Ndengerio-Ndossi and Cram, 2005)
Amaranthus	Dar es Salaam	Organochlorine	pp-DDE	-	0.000 74	30.03	0	0.01	(Ndengerio-Ndossi and Cram, 2005)
Amaranthus	Dar es Salaam	Organophosphate	Chlorpyrifos	-	0.000 02	96.97	0	1	(Ndengerio-Ndossi and Cram, 2005)
Amaranthus	Karatu	Pyrethroid	λ-cyhalothrin	-	0.21	6.25	0	0.5	(Mhauka, 2014)
Amaranthus	Karatu	Organophosphate	Dimethoate	-	0.012	6.25	0	0.02	(Mhauka, 2014)
Amaranthus	Karatu	Organophosphate	Profenofos	-	0.6	18.75	33.3	0.01	(Mhauka, 2014)
Amaranthus	Karatu		Tebuconazole	-	0.42	6.25	16.7	0.01	(Mhauka, 2014)
Amaranthus	Karatu	Organophosphate	Chlorpyrifos	-	0.74	12.5	16.7	0.02	(Mhauka, 2014)
Amaranthus	Karatu	Pyrethroid	Cypermethrin	-	0.22	12.5	16.7	0.02	(Mhauka, 2014)
Spinach	Dar es Salaam	Organochlorine	p,p'-DDD	0.001-0.64	0.64	75	8.3	0.2	(Mahugija *et al.*, 2017)
Spinach	Dar es Salaam	Organochlorine	o,p'-DDD	0.01-0.00		16.7	8.3	0.2	(Mahugija *et al.*, 2017)
Spinach	Dar es Salaam	Organochlorine	α-endosulfan	0.14-0.24	0.20	33.3	33.3	0.05	(Mahugija *et al.*, 2017)
Spinach	Dar es Salaam	Organochlorine	β-endosulfan	0.05-0.08	0.068	75	75	0.05	(Mahugija *et al.*, 2017)

Table 2: cont...

Vegetable	Area	Pesticide group	Pesticide residue	Range of pesticide residues (mg/kg)	Mean concentration (mg/kg)	Prevalence (%)	Prevalence >MRL	MRL (mg/kg)	Reference
Spinach	Dar es Salaam	Organophosphate	Chlorpyrifos	1.31-3	2.006	41.7	41.7	0.5	(Mahugija *et al.*, 2017)
Spinach	Dar es Salaam	Pyrethroid	Cypermethrin	0.01-0.04	0.021	33.3	0	0.02	(Mahugija *et al.*, 2017)
Spinach	Karatu	Organophosphate	Dimethoate	-	0.3	6.25	100	0.02	(Mhauka, 2014)
Spinach	Karatu	Triazole	Tebuconazol	-	1.6	-	100	0.05	(Mhauka, 2014)
Spinach	Karatu	Organochlorine	Endosulfan	--	0.14	-	100	0.05	(Mhauka, 2014)
Spinach	Karatu	Pyrethroid	λ-cyhalothrin	-	0.67	-	100	0.5	(Mhauka, 2014)
Cabbage	Dar es Salaam	Organochlorine	p,p'-DDD	0.001-0.01	0.005	-	-	-	(Mahugija *et al.*, 2017)
Cabbage	Dar es Salaam	Organochlorine	o,p'-DDD	-	0.001	83.3	0	0.02	(Mahugija *et al.*,2017)
Cabbage	Dar es Salaam	Organochlorine	total DDT	-	0.012	83.3	0	0.02	(Mahugija *et al.*, 2017)
Cabbage	Dar es Salaam	Organochlorine	α-endosulfan	0.1-0.6	0.365	33.3	8.3	0.5	(Mahugija *et al.*, 2017)
Cabbage	Dar es Salaam	Organochlorine	β-endosulfan	0.03-0.21	0.128	33.3	8.3	0.5	(Mahugija*et al.*, 2017)
Cabbage	Dar es Salaam	Organophosphate	Chlorpyrifos	0.04-2.40	2.275	33.3	33.3	1	(Mahugija *et al.*, 2017)
Cabbage	Dar es Salaam	Pyrethroid	Cypermethrin	0.03-0.04	0.023	25	0	1	(Mahugija *et al.*, 2017)
Kale	Karatu	Organophosphate	Profenofos	-	18.1	-	0	0.05	(Mhauka, 2014)

Table 2: cont..

Vegetable	Area	Pesticide group	Pesticide residue	Range of pesticide residues (mg/kg)	Mean concentration (mg/kg)	Prevalence (%)	Prevalence (%) >MRL	MRL	Reference
Tomato	Ngarenanyuki	Organophosphate	Chlorpyrifos	0.83-6.3.6	7.53	46.2	46.2	1	(Kariathi *et al.*, 2016)
Tomato	Ngarenanyuki	Pyrethroid	Permethrin	0.69-29.05	5.29	46.2	46.2	1	(Kariathi *et al.*, 2016)
Tomato	Karatu	Organophosphate	λ-cyhalothrin	-	0.079	6.25	0	0.1	(Mhauka, 2014)
Tomato	Karatu	Triazole	Tebuconazole	-	0.075	-	0	1	(Mhauka, 2014)
Tomato	Karatu	Organophosphate	Chlorpyrifos	-	0.16	12.5	0	0.2	(Mhauka, 2014)
Tomato	Karatu	Chloronitrile	Chlorothalonil	-	0.045	12.5	16.7	0.02	(Mhauka, 2014)
Tomato	Karatu	Organophosphate	Dimethoate	-	0.017	12.5	0	0.02	(Mhauka, 2014)
Tomato	Karatu	Organophosphate	Profenofos	-	0.031	12.5	0	10	(Mhauka, 2014)
Onion	Dar es Salaam	Organophosphate	Chlorpyrifos	0.1-2.12	1.86	25	25	0.2	(Mahugija *et al.*, 2017)
Onion	Dar es Salaam	Pyrethroid	Cypermethrin	0.014-0.04	0.01	16.7	8.3	0.01	(Mahugija *et al.*, 2017)
Onion	Dar es Salaam	Organochlorine	p,p'-DDD	0.01-0.001	0.0102	50	0	0.2	(Mahugija *et al.*, 2017)
Onion	Dar es Salaam	Organochlorine	α-endosulfan	0.02-0.22	0.19	16.7	16.7	0.05	(Mahugija *et al.*, 2017)
Onion	Dar es Salaam	Organochlorine	B-endosulfan	0.07-0.3	0.06	16.7	16.7	0.05	(Mahugija *et al.*, 2017)
Onion	Karatu	Organophosphate	Chlorpyrifos	-	0.022	6.25	0	0.02	(Mhauka, 2014)
Onion	Karatu	Organophosphate	Profenofos	-	0.59	12.5	100	0.05	(Mhauka, 2014)

Note: - = unavailable data

2.7 Dietary exposure of pesticide residues

Studies on dietary exposure of pesticide residues in Tanzania are limited. This is due to lack of monitoring data on pesticide residues in vegetables and other food crops in the country, contrary to developed countries where this data is regularly collected and made available.

Ndengerio-Ndossi and Cram (2005) assessed exposure of adult individuals to pesticide residues in Dar es Salaam. The study used average body weight of Tanzanian adult man of 60 kg and National food consumption data of 2004. The estimated daily intakes of pesticide residues through vegetable consumption were found below the ADI and therefore no significant risk was associated with the dietary exposure to pesticide residues. These results may be different from results obtained for vegetables from areas which are more potential for vegetable production and use a wider variety of pesticides in pest management. One of these areas is Arusha which is reported as the major pesticide trading and user region (Agenda, 2006).

Mhauka (2014) assessed risk of vegetable dietary exposure to pesticide residues in adults in nine households from Karatu district. Consumption data was obtained by weighing bundles of raw vegetable purchased from retail selling points equivalent to portion size consumed in the households. Then the average weight of the raw vegetable was used to compute the amount of vegetables consumed per day and used the processing factor of one. Household handling such as washing, peeling and cooking could alter the residues levels in the cooked vegetables. The processing factor of one implies that the effect of these processes in pesticide residues was not accounted for (Keikotlhaile *et al.*, 2010). Together with the consumption data, secondary retrieved data on pesticide residues concentrations in 16 vegetable samples and adult weight of 50 kg were used to compute exposure levels. The results found out that, individuals were at risk of exposure to organophosphates with EDI to ADI ratio [also referred to as hazard index (HI)] of 5.9 and pyrethroids with HI of 0.96. Although the study provided information on the exposure to these residues, the sample size of nine households would be difficult to make statistical inference on the risk levels to the general population (Hulley *et al.*, 2013). The weight of the adult person used in this study is lower than the average body weight estimated for African adult person of 60.7 kg (Walpole *et al.*, 2012). Also, estimation of the amount of vegetables consumed by an individual as the average of the weight of vegetable selling unit is considered relatively weak approach.

Kariathi *et al.* (2016) determined dietary exposure levels of permethrin and chlorpyrifos in vegetable farmers in Ngarenanyuki. The study estimated exposure levels by combining the estimated amount of raw tomato consumed per day and pesticide residues levels in the tomatoes assuming the adult weight of 60 kg. The study revealed that 5 (10%) of the farmers were at risk of exposure to permethrin and chlorpyrifos residues. The results of this study suggest that the vegetable farmers may be at a higher risk of exposure to pesticide residues than reported as they consume not only tomatoes but also other types of vegetables. Similarly, Mhauka (2014) estimated exposure levels from residues in raw tomatoes without considering the effect of processing for those consumers who would consume processed tomatoes.

Other developing countries have conducted similar studies on the pesticide residues exposure through vegetable consumption. For instance, Darko and Akoto (2008) estimated the risk of exposure to methyl- and ethyl- chlorpyrifos, omethoate, and monocrotophos in eggplant, tomato and pepper and found that the hazard indices (HI) of methyl-chlorpyrifos, ethyl-chlorpyrifos and omethoate in tomato and eggplant were above one indicating pesticide-health risks associated with consumption of eggplant and tomato, whereas there were no health effects associated with consumption of pepper as its HI was below one. Another study in Cairo assessed pesticide exposure to adults through vegetable consumption and found highest exposure in ethion and chlorpyrifos, having HQ of 15.04% and 2.45% of their respective ADI, respectively, indicating negligible risk (Gad-Alla *et al.,* 2015). For vegetable farmers the risk is not only associated with dietary exposure but also to the occupational exposures as most of the reports show that vegetable farmers do not wear appropriate protective gears (Lekei *et al.,* 2014a; Ngowi *et al.,* 2007).

Regular risk assessment studies are important in order to facilitate management of the risk of exposure to pesticide residues in the community. Exposure studies are useful to policy makers and managers to make decisions based on scientific evidence and therefore appropriate management options. Exposure information is much more important in high vegetable production areas. This is particularly vital where there is a high potential of exposure to vulnerable groups including women and children. Vegetable consumption data in Tanzania is not only limited but also out-dated (Weinberger and Swai, 2006) and therefore exposure studies will require a fresh collection of information on vegetable consumption. The in-country available information on exposure to pesticides was from the earlier reported

studies by Ndengerio-Ndossi and Cram (2005), Mhauka (2014) and Kariathi *et al*. (2016). The results on estimated exposure levels from these studies are presented in Table 3.

Table 3: Estimated dietary pesticide daily intakes and hazard indices

Pesticide group	Pesticide	EDI (mg/kg bwt/day)	ADI (mg/kg bwt/day)	EDI/ADI	Vegetable	Reference
Organophosphates	Dimethoate	1.584×10^{-4}	0.001	0.158 4	Amaranthus	(Mhauka, 2014)
	Dimethoate	2.14×10^{-4}	0.001	0.214 2	Tomato	(Mhauka, 2014)
	Dimethoate	4.14×10^{-5}	0.001	0.041 4	Spinach	(Mhauka, 2014)
	Chlorpyrifos	9.78×10^{-3}	0.01	0.976	Amaranthus	(Mhauka, 2014)
	Chlorpyrifos	2.016×10^{-3}	0.01	0.201 6	Tomato	(Mhauka, 2014)
	Chlorpyrifos	2.93×10^{-2}	0.01	2.929 3	Tomato	(Kariathi *et al.,* 2016)
	Chlorpyrifos	6.6×10^{-9}	0.01	6.6×10^{-6}	Amaranthus	(Ndengerio-Ndossi and Cram, 2005)
	Profenofos	1.32×10^{-3}	0.03	0.044	Amaranthus	(Mhauka, 2014)
	Profenofos	0.014 5	0.03	0.119 6	Onion	(Mhauka, 2014)
	Profenofos	3.906×10^{-4}	0.03	0.153 4	Onion	(Mhauka, 2014)
	Profenofos	0.104 98	0.03	3.499 3	Kale	(Mhauka, 2014)
Organochlorine	g-HCH	$2.66 \text{ X } 10^{-3}$	0.001	$2.66 \text{ X } 10^{-5}$	Amaranthus	(Ndengerio-Ndossi and Cram, 2005)
	DDT	$9.6 \text{ X } 10^{-7}$	0.01	$9.6 \text{ X } 10^{-4}$	Amaranthus	(Ndengerio-Ndossi and Cram, 2005)
	Endosulfan	1.932×10^{-5}	0.006	3.22×10^{-3}	Spinach	(Mhauka, 2014)
Chloronitrile	Chlorothalonil	5.67×10^{-4}	0.015	0.037 8	Tomato	(Mhauka, 2014)
Triazole	Tebuconazole	5.544×10^{-3}	0.05	0.184 8	Amaranthus	(Mhauka, 2014)
	Tebuconazole	9.45×10^{-4}	0.05	0.031 5	Tomato	(Mhauka, 2014)
	Tebuconazole	2.205×10^{-4}	0.05	7.36×10^{-3}	Spinach	(Mhauka, 2014)
Pyrethroids	Permethrin	2.06×10^{-2}	0.005	0.4117	Tomato	(Kariathi *et al.,* 2016)
	Cypermethrin	2.90×10^{-3}	0.015	0.1936	Amaranthus	(Mhauka, 2014)
	λ-cyhalothrin	2.772×10^{-3}	0.005	0.5544	Amaranthus	(Mhauka, 2014)
	λ-cyhalothrin	9.954×10^{-4}	0.005	0.19908	Tomato	(Mhauka, 2014)
	λ-cyhalothrin	9.246×10^{-5}	0.005	0.01849	Spinach	(Mhauka, 2014)

2.8 Pesticide health effects

Pesticides are toxic and are expected to exhibit toxicity effect to the target pests. However when mishandled, the toxicity can spill over to non-target organism such as beneficial insects, human and animals as well as the environment. Symptoms associated with acute exposure to pesticide residues in human include coughing, nausea, vomiting, abdominal pain, headache, diarrhoea and loss of vision (Lekei *et al.,* 2014a). Chronic exposure to pesticide residues is associated with endocrine disruption, neurotoxicity, cytogenetic damage and effects in the reproductive and immunological system (Nasreddine *et al.,* 2016). Dietary pesticide residues exposure is the major source of pesticide exposure followed by inhalation and through skin (Lemos *et al.,* 2016; Lu *et al.,* 2008).

Health effects resulting from exposure to pesticide residues vary with the nature of pesticides and the mode of action. Organophosphate pesticides are associated with inhibition of cholinesterase and affect neurologic and cognitive development in children (Lu *et al.,* 2008). A birth cohort study examined the association between pre-natal and post-natal exposure to organophosphate pesticides and cognitive abilities in school-age children and found a positive association in pre-natal but not in post-natal exposure to organophosphate pesticides and cognitive development (Bouchard *et al.,* 2011). Carbamates are also cholinesterase inhibitors though its activity is reversible (Lemos *et al.,* 2016) whereas that of organophosphate is not (Wong *et al.,* 2014). Carbamates are also associated with endocrine disruption and it is evident that they affect cellular metabolic mechanism and mitochondrial function. They also cause reproduction disorders and are cytotoxic and genotoxic (Nicolopoulou-Stamati and Kotampasi, 2016). Organochlorine pesticides disrupt the endocrine system and alter the haematological and hepatic function (Nicolopoulou-Stamati and Kotampasi, 2016) in addition to being suspected carcinogenic. Studies have found a high association between the high levels of DDE in blood samples from women with breast cancer. Also, a significant association was found between male farmers exposed to DDT and prostate cancer although the association is not yet ascertained due to other confounding factors such as diet and exposure to other chemicals such as tobacco (Mnif *et al.,* 2011).

Pyrethroid pesticides which include cyhalothrin, permethrin and deltamethrin are associated with the endocrine disruption and they are linked to DNA damage in human sperm thus affecting human reproductive system (Nicolopoulou-Stamati and Kotampasi, 2016). In Tanzania studies on the health effects of exposure to pesticide residues have been directed to

occupational acute exposures and these studies suggest the need of performing long-term exposures (Ngowi *et al.,* 2016; Nicolopoulou-Stamati and Kotampasi, 2016). Based on the indiscriminate pesticide application to vegetables reported in literature (Lekei *et al*., 2014a; Ngowi *et al.,* 2007; Nonga *et al.,* 2011) the farmers and other vegetable consumers may be exposed to pesticide residues through diet. Therefore there is a need to estimate dietary pesticide exposure to vegetable consumers in Tanzania. This will inform risk managers and policy makers on the health risks associated with exposure to the residues so that necessary steps can be taken in case a risk is revealed.

2.9 Household vegetable preparation practices and fate of pesticide residues

In Tanzanian context, most of vegetables are usually prepared and heat-processed before consumption. Among processes reported to have considerable effect on pesticide residues in vegetables include washing, peeling and cooking (Mnif *et al.,* 2011; Ngowi, 2002). Most of these processes results in the level reduction of pesticide in the vegetables thus reducing the risk of human exposure to these residues (FAO/WHO, 1997b). On the other hand, processes that tend to concentrate product may lead to increase of the pesticide residues in the final product (Keikotlhaile *et al.,* 2010). The physical and chemical properties of pesticide residues in the vegetable, such as volatility, hydrolytic rate, solubility and physical structure of the vegetables influences the removal of these residues (Keikotlhaile *et al.,* 2010). These practices have been tested based on best practices in other countries and at experimental levels which may not be applicable in Tanzania as the practices differ from one ethnic group to another, and from diverse geographical locations (Shackleton *et al.,* 2009). It is therefore important to assess these practices at local level to find out if they could help in reducing the pesticide residues in the vegetables.

2.9.1 Effect of washing

Washing of vegetables with tap water has been reported as one of the common practice applied at household level when preparing vegetables for family meals. Selim *et al.* (2011) studied the effect of household processing of vegetables on pesticide residues and found out that washing of vegetables with tap water could reduce the concentration of methomyl, dimethoate, pirimiphos-methyl, metalaxyl, endosulfan, dicofol and cypermethrin by 59%, 15%, 10%, 30%, 49%, 67%, and 65%, respectively, in sweet pepper. Addition of acetic acid in the washing water increased the percentage reduction of residues for methomyl (99.7%),

dimethoate (34%), pirimiphos-methyl (89%), metalaxyl (61%), endosulfan (90%), dicofol (100%), and cypermethrin (100%) (El-Saeid and Selim, 2016). Similarly, other studies reported reduction of pesticide residues in vegetables due to washing. Bonnechère *et al.* (2012) found reduction of up to 90% of boscalid, chlorpyrifos, tebuconazole, dimethoate, difenoconazole and linuron in carrot (Bonnechere *et al.,* 2012) whereas Randhawa (2007) who studied the influence of household processes on the removal of endosulfan revealed that endosulfan was reduced by 30% in okra, 25% in tomato, 22.2% in spinach and 10% in brinjal. In addition, Sheikh *et al.* (2013) found endosulfan to be reduced by 36.42% in okra. Moreover, lambda-cyhalothrin residues could be reduced by 37-40% in tomatoes (Chauhan *et al.,* 2012). Another study found that washing olives in water reduces chlorpyrifos by 26-36%, lambda-cyhalothrin by 26-39%, cypermethrin by 48%, profenofos by 66%, and diazinon by 67%. However, a study by Chavarri *et al.* (2004) reported different results on washing of asparagus in which the washing process did not alter the levels of chlorpyrifos residues significantly. These studies suggest that solubility has no significant influence on pesticide removal rather, the removal is more influenced by the mechanical action of washing, nature of the surface of the vegetable and contact duration of the pesticide (Randhawa *et al.,* 2007; Thanki *et al.,* 2012; Yang *et al.,* 2012). Washing is reported as the most effective preparatory step for pesticide removal in vegetables (Yang *et al.,* 2012). The reported effects of washing were based on experimental scale results which call for a need to study the effects at community level.

2.9.2 Effect of peeling

It is a common practice to peel bulb, root and tuber vegetables before they are consumed. Pesticide residues are usually applied on the surface of vegetables, so they can be removed with the peel in the peeling process (Tomer and Sangha, 2013). It is reported that peeling is effective in reduction of lindane, profenofos, dimethoate, and pirimiphos-methyl from tomatoes by 80.6-89.2% (Djordjevic and Djurovic-Pejcev, 2016), endosulfan residues from potatoes by 76% and eggplant by 60% (Randhawa *et al.,* 2007) and chlorpyrifos from asparagus by 60% (Chavarri *et al.,* 2004). Further, peeling removes up to 65% of malathion residues, 66% of methomyl, 80% of dicofol and 83% of abamectin. Diazinon and carbaryl in cucumber are reported to be reduced by 67.3% and 40%, respectively (Djordjevic and Djurovic-Pejcev, 2016). Also peeling was found to reduce carbaryl residues by 40% in cucumber (Hassanzadeh *et al.,* 2010). To the contrary, Bonnechère *et al.* (2012) could not

find any considerable reduction of pesticide residues by peeling. For instance, there was no decrease in the levels of dimethoate and omethoate residues in carrot. Similar to the studies on the effect of washing, peeling effects were also derived from studies at laboratory scale which may not reflect what is happening at the community level and therefore emphasize the need of studying their effects at community level.

2.9.3 Effect of cooking

Cooking processes including blanching, boiling, frying and roasting enhance the hydrolysis and volatilization of chemicals, thus altering their level in the food. Studies show that cooking reduces deltamethrin residues in vegetables by 19-40% (Tomer and Sangha, 2013). Reduction of pesticide residues in vegetables by cooking is influenced by the physical-chemical structure of the pesticide. For instance, Bonnechère *et al.* (2012) found that the effect of blanching on reduction of difenoconazole which have low water solubility, with a log-octanol-water partitioning coefficient of 4.2 and the linuron and tebuconazole with similar properties were relatively lower as compared to dimethoate and omethoate which has lower coefficient and high water solubility. Blanching is reported to reduce up to 72% of fat-soluble and up to 79% of water-soluble pesticide residues in cauliflower (Sheikh *et al.*, 2013). This study reports further that blanching reduces residues of endosulfan by 58.95%, bifenthrin by 72.18% and profenofos by 67.34%. Boiling process was reported to reduce organophosphate pesticide residues by 32-100% (Kumari, 2008). The 100% reduction was observed in brinjal, followed by cauliflower (92%) and okra (75%). Another study found that boiling reduced the organophosphate residues in tomato, bean, okra, eggplant, cauliflower and capsicum by 52-100% (Satpathy *et al.*, 2012). Frying is reported to reduce endosulfan, bifenthrin and profenofos which are fat-soluble pesticides by 94.32%, 98.71%, and 96.75%, respectively. On the other hand, processes like pre-heating, pulping, evaporation and half-pasteurization was found to increase deltamethrin levels by 2.33% while decreasing endosulfan residues by 66.5% (Tomer and Sangha, 2013).

Most of the studies on the influence of the household processes on pesticide residues are carried at laboratory level which can not reflect the variations in the processes occurring at community level. Types of vegetables and household handling of these vegetables differs between household preferences, tribes and geographical location (Keding *et al.*, 2007). This

necessitates the need for performing studies on the actual household vegetable handling practices in order to ascertain their practical effect on pesticide residues.

2.10 Conclusion and Recommendations

This review work shows that vegetables have high potential to the economy, food and nutrition security of the people in Tanzania, but their quality and safety has not been critically monitored. As in other developing countries, the current status shows that vegetables are intensively treated with pesticide during production. However, there is very limited information on the occurrence of pesticide residues in these vegetables. Moreover, the association of these practices with pesticide residues in the vegetables is not well studied. Based on the existing information, Tanzania should establish pesticide application practices that are more associated with occurrence of pesticide residues in the vegetables. This will allow a more focused allocation of resources in controlling pesticide residues in the food thus minimizing pesticide exposure among vegetable consumers in Tanzania. As vegetable consumption levels influence the extent of dietary pesticide exposures, consumption studies should also be updated as the existing data are largely outdated. This implies further that once new data on pesticides contamination in vegetables and updated data on consumption of vegetables are available, the current status of pesticide exposure in Tanzania will be assessed. From the review, it is acknowledged that the findings of the influence of vegetable processing at experimental settings on reducing pesticide residues are a foundation for formulation of pesticide control interventions. However, it calls for further research to be carried out on household-based studies in order to validate the actual impact of vegetable processing on pesticide reduction at household level. The following chapters attempt to determine the association of pesticide application practices to the risk of exposure and results are presented in chapter three. The level of pesticide residues in the vegetables and estimation of the risk of exposure to these residues in vegetable consumers are also assessed and results presented in chapter three. Household-based studies on the influence of household vegetable handling practices on reduction of pesticide residues are also studied and results presented in chapter four.

CHAPTER THREE

THE RISK OF DIETARY EXPOSURE OF PESTICIDE RESIDUES AND ITS ASSOCIATION WITH PESTICIDE APPLICATION PRACTICES AMONG VEGETABLE FARMERS IN ARUSHA, TANZANIA[2]

Abstract

This study was done to assess the risk of dietary exposure to pesticide residues and associated pesticide application practices among vegetable farmers in Arusha, Tanzania. Face-to-face interviews using semi-structured questionnaires (including 24 hour recall and food frequency questionnaire) were conducted to collect information on pesticide application practices and vegetable consumption from 76 farmers. A sample of ready-to-eat vegetables was collected from each farmer's household for pesticide residues determination. Pesticide residues were analyzed using Gas Chromatography-Mass spectroscopy. A deterministic approach was used to assess dietary exposure to pesticide residues. Among the analyzed samples, 31.4% contained detectable levels of organophosphate residues. The detected organophosphates were dimethoate (mean, 8.56 mg kg^{-1}), acephate (mean, 2.9 mg kg^{-1}), profenofos (mean, 8.44 mg kg^{-1}), dichlorvos (mean, 20.8 mg kg^{-1}) and malathion (mean, 5.47 mg kg^{-1}). The mean exposures for dimethoate (0.0021 mg kg^{-1} body weight (bwt) day^{-1} was higher than its corresponding acceptable daily intakes of 0.002 mg $kg^{-1}bwtd^{-1}$ resulting in hazard quotient of 1.044 with a consequent hazard index of 1.19 for organophosphates. Pyrethroid pesticides (permethrin, cypermethrin and lambda-cyhalothrin) were also detected but at a relatively lower frequency (17.1%) and hazard index (0.029). The exposure to pesticide residues was significantly associated with limited access to expert advice on pesticide application (P = 0.031, adjusted odds ratio = 6 56) and over-dosage (P = 0.038, adjusted odds ratio = 3.751). The risk may be minimized by increasing access to extension service advice and application of appropriate doses for pesticides.

[2] This chapter is based on a paper published in the 'Journal of Food Research' 7(2), 2018

3.1 Introduction

Malpractices in pesticides application result in pesticide residues in foods and consequently increase the risk of dietary pesticide exposures in human. Dietary exposure to unacceptable levels of pesticide residues has been associated with risks of cancer development, genetic and immune system defects and neurological system disorders (Hashmi *et al.,* 2004; Keifer, 2008; Thatheyus and Selvam, 2013). Parkinson's and Alzheimer's diseases are the most common neurodegenerative disorders which are associated with exposure to pesticides (Campdelacreu, 2012; Sanchez-Santed, 2015). Pesticides possess estrogenic activity and therefore are associated with breast cancers in women and low sperm count in male human (Laffin *et al.,* 2010; Toft *et al.,* 2004). To ensure the pesticide safety of vegetables and other foods, Codex Alimentarius Commission in collaboration with Environmental Protection Agency (EPA) has set maximum tolerable residual levels (MRLs) for particular pesticides in food including vegetables (EFSA, 2012b; FAO/WHO, 1997b).

Vegetables which form an important part of human diet are among food crops with very high likelihood of containing pesticides. Surveys in developing countries indicate that there is an indiscriminate pesticides use in vegetables to control pests and diseases combined with non adherence to pesticides' pre-harvest intervals and lack of knowledge on pesticide use which could result in excessive pesticide residues in vegetables (Amera and Abate, 2008; Banjo *et al.,* 2010; Lozowicka *et al.,* 2015; Zyoud *et al.,* 2010). A study done in Chile revealed that 27% of 118 leafy vegetable samples analyzed were contaminated with pesticide residues above MRLs and 65% of them had multiple pesticide residues (Elgueta *et al.,* 2017). In Pakistan, Sheikh *et al.* (2013) analyzed pesticide residues in vegetable samples from markets found that okra, bitter gourd, brinjal, tomato, onion, cauliflower,and chilies were highly contaminated with chlorpyrifos, profenofos, endosulfan, imidacloprid, benzoate, lufenuron, bifenthrin, diafenthiuron, and cypermethrin. Another study analyzed dichlorvos residues levels in vegetables sold in Lusaka, Zambia and found that the average dichlorvos residue levels were significantly higher than the country's set maximum limits (1 mg kg^{-1}) (Sinyangwe *et al.,* 2016). High pesticide residue levels in vegetables imply that vegetable consumers might be at risk of exposure to unacceptable levels of pesticides. In order to ensure that dietary exposures to pesticide residues are within safe limits, the FAO/WHO Joint Meeting of Pesticide Residues (JMPR) establishes acceptable daily intakes (ADI) of pesticides (FAO/WHO, 1997b). For instance, the ADI for dimethoate is 0.002 mg kg^{-1} body

weight and that of dichlorvos is 0.004 mg kg^{-1} body weight. Malathion which is relatively less toxic has ADI of 0.3 mg kg^{-1} body weight.

Tanzania being one of the developing countries is affected by the problem of malpractices in pesticide application. This is evidenced in surveys conducted in Southern highlands (Iringa), Central (Morogoro) and Northern zones (Arumeru and Karatu) (Lekei *et al.,* 2014a; Manyilizu and Mdegela, 2015; Ngowi *et al.,* 2007; Nonga *et al.,* 2011). These studies suggest that vegetables from these areas may be highly contaminated with pesticide residues, posing a risk of exposure to pesticide residues. However, only limited studies have been done in Tanzania to estimate pesticide residues or exposure in vegetables. A study by Ndengerio-Ndossi and Cram (2005) which analysed 33 samples of spinach found that 72.7% of the samples were contaminated with gamma-hexachlorocyclohexane (g-HCH) (0.08 µg kg^{-1}), 1,1-dichloro-2,2-bis (p-chlorophenyl) ethylene (pp-DDE) (0.74 µg kg^{-1}), dichlorodiphenyltrichloroethane (pp-DDT) (2.15 µg kg^{-1}) and chlorpyrifos (0.02µg kg^{-1}). Mahugija *et al.* (2017) analyzed 72 samples of cabbage, onion and spinach for pesticide residues in which 72.2% of the vegetables were found contaminated with DDT and its metabolites, endosulfan and cypermethrin. These two studies were done in Dar es Salaam which is located in lowlands and is not among major producers of vegetables in Tanzania. In Tanzania, vegetables are mainly produced in highlands of Morogoro, Iringa, and Arusha (Putter and Koesveld, 2007; SCF, 2008) whereby Arusha leads in pesticide trading and use (Agenda, 2006). The reported levels of pesticide residues in the vegetables sampled in Dar es Salaam indicate that farmers in major vegetable producers and pesticide users in Arusha might be exposed to high levels of pesticide residues. A study in Arumeru district in Arusha analyzed 50 tomato samples for pesticide residues and 12% of the samples contained permethrin and chlorpyrifos at a mean concentration of 5.2899 mg kg^{-1} and 7.5281 mg kg^{-1}, respectively (Kariathi *et al.,* 2016). However, the results from this work are not adequate for drawing a conclusion on the dietary exposures through consumption of vegetables in Arusha as there are more varieties of vegetables consumed in the region. Furthermore, in Tanzania and other parts of developing countries, there is no documented information on specific pesticide application practices that can be attributed to pesticide residues. The current study assessed pesticide residue exposures through vegetable consumption among vegetable farmers in Arusha and determined pesticide application practices attributable to the exposures.

3.2 Materials and Methods

3.2.1 Study area

The study was conducted in Arusha district within Arusha region. Arusha district was selected due to its high production of vegetables and known pesticide use (Agenda, 2006). The district covers an area of 1446.692 km^2 with a population of 290 041. It is characterized by two agricultural zones (green and lowland belt zones). The main vegetable producing areas of the Arusha district are in the green belt (highlands), which covers the wards of Ilkiding'a, Kimnyaki, Kiranyi, Sambasha and Olmotonyi. The main vegetable crop cultivated in Arusha is cabbage. Due to its high vulnerability to pests infestation, the crop requires frequent application of pesticides (Ngowi *et al.*, 2007; URT, 2012).

3.2.2 Study design and sample size

A cross-sectional study design was adopted to survey pesticide residues, exposure and application in 76 farmers selected by simple random technique from 7 villages in 4 wards of the green belt zone of the Arusha district. At ward level, village(s) leading in vegetable farming were purposively selected as follows: Ilkiding'a (Ilkiding'a), Olimring'aring'a and Olevolous (Kimnyaki), Siwandeti (Kiranyi), Timbolo and Shiboro (Sambasha) and Emaoi (Olmotonyi). The wards were purposively identified, with the assistance of district agricultural extension officers based on their potential for vegetable production.

The sample size was estimated at 90% confidence level, following the formula for calculating sample size for cross sectional studies (Charan and Biswas, 2013). Farmers who formed the sample were selected using a given criteria. One of the criteria used was the willingness of a farmer to participate in the research during the field survey and his/her availability during first and second vegetable consumption surveys. Farmers were pre-informed of the objectives of the research and those who consented to participate in the study were recruited.

3.2.3 Data collection

Data collection was done from June to November 2015 (a period that covers dry and rainy seasons) through face to face interviews. Semi-structured questionnaires were used in the interviews to obtain information on socio-demographic characteristics of the participants, vegetable cropping system, pesticide application practices and vegetable consumption. Detailed information on vegetable consumption was further collected using two-time point

24-hour dietary recall and food frequency questionnaires. Prior to actual data collection, the questionnaires were pre-tested in Seela village of Sing'isi ward which is in a similar geographical location and of the same socio-cultural characteristics to that of the study area.

3.2.4 Sampling and quantification of ready-to-eat vegetables

A repeated 24 hours dietary recall and food frequency techniques were employed to estimate amount of vegetables consumed by the farmers (Kimanya, 2008). Two home visits were done to the respondents' residence, on non-consecutive days. The respondent farmer was requested to recall what she/he ate during the past 24 hours. If vegetables were among what she/he consumed she/he was requested to mention the type of vegetables consumed. The respondent was also requested to mention the source of the consumed vegetables, whether from own farm, neighbour's farm or market. The respondent was further asked to mention number of days in the previous week that she/he ate the same type of vegetables.

The respondent was requested to explain how the vegetable was prepared and mention all ingredients in the vegetable recipe. He/she was also requested to estimate the amount of ready-to eat-vegetable consumed in the previous day, by using a bowl or any other utensil that is usually used for serving vegetables. Grains or pulses were used to aid in estimating the vegetable volumes on the bowl by filling into the bowl up to the usual level of the share per single serving. Left-over, shared amount was deducted from the volume served per single serving and the actual estimate obtained and noted. The respondent was requested to prepare vegetables and provide a duplicate portion (per serving) of the ready-to-eat vegetables as reported in the interview. Arrangements were made for those who had no vegetables in their home at the time of survey so that the samples were collected on the next day. The sample of the ready-to-eat vegetables was then collected in a glass container and kept in a cool box with ice blocks and transported to the Tropical Pesticide Research Institute (TPRI) laboratory where its weight was measured using electronic kitchen scale (CAMRY, model EK3131) and recorded before was stored at -20^{o}C in a freezer until analysed for pesticide residues. The average weight of vegetable consumed by each respondent as collected during the two home visits was calculated and recorded.

Respondents, who reported that they had not consumed vegetables on the previous day, were requested to estimate the amount that they usually consume whereby the duplicate sample was measured based on this amount. In order to be able to estimate per capita vegetable

consumption per kg body weight per day, the weight of the respondent was taken using a weighing scale (Ashton Meyers' model 7757; maximum scale 130 kg) and recorded.

3.2.5 Analysis of pesticide residues in ready-to-eat vegetables

(i) Chemicals and reagents

All chemicals and reagents were of analytical grade. Pesticide standards (96% or more purity) were obtained from different suppliers, namely Siba Geigy Limited for profenofos and Cypermethrin, Calliope Rural Traders, Australia for lambda-cyhalothrin, Sapa chemicals Industries Limited Tanzania for malathion, Dow AgroSciences France for dimethoate, Baytrade Tanzania Limited for acephate, Norvatis S.A for dichlorvos, Zeneca Agrochemicals for permethrin and Twiga Chemicals Industries Limited Tanzania for heptachlor. Solvents (acetonitrile, acetic acid and acetone), salts (sodium acetate, magnesium sulphate and sodium sulphate) Primary Secondary Amine (PSA), glassware, centrifuge tubes and GC-MS vials were obtained from a local dealer Smacco–Flo General Supplies, Arusha. All glassware was washed with a detergent in running water and rinsed with distilled water followed by acetone, before and after each use. Centrifuge tubes and GC-MS vials were non-recyclable.

(ii) Pesticide residues extraction and analysis

Pesticide extraction and clean-up were done following QuEChERS Protocol (AOAC, 2007). Briefly, samples were removed from the freezer and allowed to acquire room temperature before homogenization. Afterwards they were homogenized using a motor and pestle, 15 g of a sample was weighed into 50 ml polypropylene centrifuge tube and extracted using acetonitrile with 1% acetic acid (1:10 v/v ml) whereby 15 ml of the solvent followed by 100 µl or 200 µl of 1 mg ml^{-1} or 0.1 mg ml^{-1} heptachlor as an internal standard, were added to the sample followed by 6g of anhydrous Magnesium sulphate and 1.5 g sodium acetate. The mixture was then centrifuged in a Universal 320 centrifuge from Andreas Hettick GmbH Co KG, Tuttlingen Germany at 536.64 x *g* for 5 minutes. A volume of 3 ml of the supernatant was transferred to a 15 ml polypropylene centrifuge tube added with 900 mg anhydrous magnesium sulphate, 150 mg primary secondary amine (PSA) and 150 mg graphitized carbon and homogenized on a vortex mixer (Vortex Genie-2 from Bohemia, USA). The mixture was centrifuged at 536.64 x *g* for 5 minutes. Then, 2 ml of the supernatant was transferred to the GC-MS vial for analysis of pesticide residues.

Pesticide residues were analyzed using GC-MS (Agilent 7890A equipped with 7693 auto-sampler coupled to 7000B triple quadruple MS system). The column was fused with silica DB35 capillary column of 30 mm long with 0.25 mm internal diameter and 0.25 µm film thick capable of operating at a range of 50 ^{o}C to 360 ^{o}C. The temperature was set at 50 ^{o}C for 1 minute, then ramped to 150 ^{o}C at a rate of 50 ^{o}C per minute for 1 minute, followed by 280 ^{o}C at a heating rate of 5 ^{o}C per minute and held for four minutes. The injector temperature was 250 ^{o}C. The carrier gas was helium at a flow rate of 1.2 ml min^{-1} splitless injection. The injection volume was 1µl at a pressure of 43.193 Psi. The MS ion source temperature was 250 ^{o}C operated in full scan mode at a scan range of 50-550 ^{o}C atomic mass unit.

3.2.6 Method performance and quality assurance

The method performance was validated according to the European Commission guidelines (SANCO, 2014) by performing analyses to determine recovery, limit of detection (LOD), limit of quantification (LOQ), precision and linearity. Recovery was performed by analyzing, in triplicate, a mixture of standard pesticides in blank vegetable samples at levels of 0.0050, 0.0100 and 0.0200 mg kg^{-1}. These levels are below or above the MRLs of most of the pesticides approved for use in horticultural crops in Tanzania, therefore could provide information on performance of the method at a range of the concentrations below, at, and above the MRLs of the pesticide residue in the vegetables. LOD was determined as the lowest concentration of the pesticide that could be detected but not quantifiable. LOQ was determined as the lowest concentration that could be quantified at acceptable accuracy and linearity. LOD and LOQ were determined as 1:3 and 1:10 signal to noise ratio, respectively. Precision was determined by calculating relative standard deviation (rsd) of the lowest concentration that could show linearity (n = 5) in blank vegetable sample, whereas linearity was assessed by analyzing a mixture of pesticide standards at 0.005, 0.0075, 0.01, 0.0125, 0.0150, 0.0175 and 0.0200 mg kg^{-1}. The routine quality control was done by adding heptachlor as an internal standard in each analytical sample and calculated percentage recovery. Blank reagents were analyzed at the beginning and end of each batch to check for interference from chemicals and equipment. The concentration of pesticides analyzed was quantified from their corresponding calibration curves.

3.2.7 Estimating dietary pesticide residues exposure

Dietary exposure [mg kg^{-1} body weight (bwt) per day] of a pesticide residue in an adult vegetable farmer was determined following the deterministic approach as guided by WHO and FAO (FAO/WHO, 2009b) whereby for situations where the exposure study is being done for the first time, it is more appropriate to use the deterministic approach in order to find out whether or not there is any safety concern associated with exposure to pesticide residues. If heath risk is determined, then more refined methods are suggested to incorporate more data that cover the entire population and more types of food consumed which implies more resources. This approach involves multiplying concentration of the pesticide residue (mg kg^{-1}) in the vegetable sample (from the farmer's household) with the estimated amount of vegetable consumed by the individual (kg day^{-1}) and dividing by bw (kg) of the individual as shown in equation 1 to obtain estimated daily intakes of the particular pesticide residue.

$$EDI = \frac{Q(kg/day)xC(mg/kg)}{bw(kg)} \qquad (1)$$

Where; EDI is the estimated daily dietary intake of the pesticide residue in milligram per kilogram body weight of the consumer, Q is the quantity of vegetable consumed per day (kg per day) and C is the concentration of the residue in the vegetable in mg kg^{-1}.

3.2.8 Estimating the risk of unacceptable exposures

Risk of unacceptable exposure to a particular pesticide residue was determined by calculating the hazard quotient of such particular pesticide using the equation as described by EFSA, (2008) and USEPA, (2005) (equation 2).

$$HQ = \frac{EDI}{ADI} \qquad (2)$$

Where: HQ is the hazard quotient, EDI is the estimated daily intake (mg kg^{-1} bw day^{-1}) of a particular pesticide and ADI is the corresponding acceptable daily intake (mg kg^{-1} bw day^{-1}) for the pesticide

For multiple exposures to pesticide residues falling under the same chemical group (same mechanism of toxicity) such as organophosphates or pyrethroids, the risk of exposure was

calculated by adding the HQs of pesticide residues of the same chemical group to obtain Hazard index, using equation 3 (EFSA, 2008; FAO/WHO, 2005; USEPA, 2005).

$$HI = \frac{EDIa}{ADIa} + \frac{EDIb}{ADIb} + ... \frac{EDIn}{ADIn} \qquad (3)$$

Where: HI is the hazard index, *a, b…n* represent different pesticides of the same mechanism of toxicity, EDI is the estimated daily intake of each pesticide and ADI is the corresponding acceptable daily intake.

HQ or HI $\leq$ 1 indicates that adverse health effect(s) are not likely to occur and thus the amount of pesticide residue consumed can be considered to have a tolerable effect. When HQ or HI > 1, the exposure is greater than ADI. This implies that there might be a risk from the residue consumed and calls for risk management action to be taken (FAO/WHO, 2005; USEPA, 2005). Exposure in farmers who consumed vegetables with undetectable pesticide residues was performed by assigning a default value of half the limit of detection for each pesticide (middle bound scenario), according to the USEPA's Office of Pesticide Programs (USEPA, 2000). Assigning half the limit of detection as concentration values for non-quantified samples is important to control underestimation or overestimation of the exposure levels as it is recommended jointly by the WHO and FAO in the International Programme of Chemical safety (IPCS) (FAO/WHO, 2009b).

3.2.9 Data analysis

Data entry and clean-up for pesticide application practices were done using epidata version 3.1, a free downloadable software owned by WHO which was obtained from The Tanzania National Institute for Medical Research (NIMR). The data were then exported to Microsoft Excel 2007 and SPSS version 21 for analysis. Data for pesticide residues content, vegetable consumption and body weights were used to calculate and estimate daily intakes and risk of exposure using equations *'1'* to *'3'* (sections 3.2.7 and 3.2.8). Descriptive statistics (frequency and percentage) were used to interpret information captured from questionnaires. Logistic regression was used to analyze the association between level of education, the source of vegetables (between home-grown and market sourced), or pesticide application practices and exposures of pesticide residues to farmers. The significance level of association was set at $P \leq 0.05$.

3.3 Results and Discussion

3.3.1 Method performance and quality assurance

Average recoveries of all pesticide standards in sample matrix ranged from 79% to 112% indicating that the results obtained are reproducible (Table 4). Limits of detection ranged from 0.001 to 0.004 mg kg^{-1} whereas limits of quantification ranged from 0.002 to 0.015 mg kg^{-1} which shows that the sensitivity of the method is good enough for detection and quantification of pesticide residues in the vegetable samples below the set MRLs for most of the pesticides. The percent rsd ranged from 1.02% to 18.6 % and coefficient of correlation was between 0.955 and 0.999 (Table 4) showing good repeatability of the method. Recovery for heptachlor (added to each analytical sample to check for the on-going performance of the method) ranged from 70% to 132% with an average of 95% (Table 4). No corrections made to the concentration of residues in samples as the recoveries were within recommended range. It is recommended that for the on-going method performance verification, recovery should range from 60%-140% (SANCO, 2014). No pesticide residues detected in the blank chemical reagents which indicate that there was good control of interferences from chemicals and instrument. These results indicate that the method was reliable for analysis of the pesticide residues of interest in the ready-to-eat-leafy vegetables. For a method to be reliable, initial method validation recovery should be between 70 and 120%, percent rsd not higher than 20% and coefficient of correlation equal to or higher than 0.95 (Kofi *et al.*, 2016; SANCO, 2014).

Table 4: Results of QuEChERS multi-residues method validation in leafy vegetables

Analyte	LOD (mg kg^{-1})	LOQ (mg kg^{-1})	r^2	Mean recovery (%)	rsd % (n = 5)
Permethrin	0.001	0.005	0.997	88.01	13.9
Cypermethrin	0.002	0.006	0.999	92.52	9.60
Cyhalothrin	0.001	0.005	0.992	112.3	13.6
Dimethoate	0.004	0.015	0.955	89.98	9.93
Acephate	0.003	0.009	0.960	78.86	18.6
Profenofos	0.004	0.010	0.992	91.12	1.02
Malathion	0.001	0.002	0.995	83.15	12.2
Dichlorvos	0.004	0.010	0.995	100.2	1.70
Heptachlor	0.001	0.030	0.999	102.0	9.80

3.3.2 Socio-demographic characteristics of the participants

The results on socio-demographic characteristics of the surveyed vegetable farmers in Arusha district are as indicated in Table 5. The socio-demographic characteristics recorded were gender, age and level of education.

Most 52 (74.3%) of the respondents in this study were male within the age range from 25 to 65 years and mean age of 42.3±13.6 years (Table 5). It was reported that pesticide application in Arusha is done by men. In cases where farmers are women, they hired men to apply pesticides for them. As a consequence and considering exposure through inhalation or skin, the risks of exposure to pesticides for men can be higher than in women. The gender distribution is congruent to that made previously in Manyara basin Tanzania by Nonga *et al.* (2011), who reported 75% of farmers being males with mean age of 47±14 years. In a similar work done in Muheza, Arumeru, Singida and Kongwa, it was found that 85% of all farmers (Table 5) involved in vegetable cultivation were men (Weinberger and Msuya, 2004). Studies done in other developing countries also report similar results (Amera and Abate, 2008; Banjo *et al.*, 2010).

Most (52.9%) of the vegetable farmers in Arusha district had the formal education of up to primary level (Table 5). About one-fourth of the respondents had no formal education whereas less than a quarter had secondary and college education. Illiteracy of farmers has been linked to poor pesticide application practices by farmers in previous surveys (Mengistie *et al.*, 2015; Nonga *et al.*, 2011).

Table 5: Socio-demographic characteristics of vegetable farmers (n = 70)

Variable	Category	Percentage (%)
Sex	Male	74.3
	Female	25.7
Age	15-35	37.1
	36-45	21.4
	46 and above	41.5
Level of education	No formal education	25.7
	Primary school	52.9
	Secondary and higher level	21.4

3.3.3 Pesticide residue contents in ready-to-eat vegetables

Ready-to-eat vegetable samples were available in 70 out of the 76 farmers as six farmers were not willing to provide samples. The seventy (70) ready-to-eat vegetable samples were analyzed for pesticide residues. They included 31 African nightshade *(Solanun nigrum)* (44.3%), 15 kale *(Brassica oleracea var. sabellica)* (21.4%), 10 cabbage *(Brassica oleracea)* (14.3%), three spinach (4.3%), two Ethiopian mustard *(Brassica carinata)* (2.9%), one Chinese cabbage *(Brassica rapa subsp pekinensis)* (1.4%), two *Amaranthus spp*. (2.9%) and six vegetables prepared with combinations of nightshade with kale (4.3%), nightshade with kale and spinach *(Spinacia oleracea)* (1.4%), nightshade with Ethiopian mustard (1.4%), or kale with spinach (1.4%). Overall, 40% of all the 70 samples contained detected levels of pesticide residues. Individually, 60.0% of cabbage, 53.3% of kale, 35.5% of nightshade, 33.3% of spinach and 33.3% of the mixed vegetables contained pesticide residues. No pesticide was detected in *Amaranthus spp*, Chinese cabbage, and Ethiopian mustard (Table 7).

Among the 70 samples, 58 (83%) were obtained from respondents' own grown vegetables whereas the rest 12 (17%) samples were from vegetables purchased from outside homes (Table 7). The sources of samples were as follows: three and two nightshade samples, from neighbours and market, respectively, two kale samples (one from market and the other from a neighbour), two *Amaranthus spp.* samples (both from neighbours), kale and nightshade and kale and spinach for the two mixed vegetable samples from the market and a neighbour, respectively. All the cabbage samples were obtained from respondents' own grown vegetables. Of the 12 samples from market or neighbours only two (17%) were contaminated with pesticide residues whereas among the 58 samples from farmers own farm vegetables, 26 (45%) contained detectable levels of residues (Table 7). The farmers who obtained their vegetables from their neighbours disclosed that they preferred neighbours' vegetables because they were grown without pesticides. This might be the reason why pesticide residues were not detectable in vegetables obtained from neighbours, except one nightshade sample which was detected with permethrin. It is also possible that the market vegetables had taken longer time, from harvest to consumption, as compared to home-grown vegetables. The longer time could allow reduction of pesticide residues to undetectable levels. This is concurrent with the statement of European Food Safety Authority that depending on the point

along the distribution chain where vegetables are obtained, pesticide residues may have declined to levels not detectable at the time of consumption (EFSA, 2012b).

There are published reports of higher prevalence of pesticide residues in vegetables than found in the current study. For instance, in Chile, pesticide analysis was done in 118 leafy vegetable samples and found out that 72% of spinach samples were contaminated with pesticide residues (Elgueta *et al.*, 2017). In Algeria, 120 vegetable samples were analyzed and pesticide residues, detected in 57.5% of the samples (Mebdoua *et al.*, 2017). Another study which analyzed pesticide residues in parsley, lettuce and spinach in Turkey found that all of the samples contained detectable levels for two or more pesticide residues, including dichlorvos which was quantified in every vegetable at a prevalence of 100% (Esturk *et al.*, 2011). High prevalence of pesticide residues in ready-to-eat vegetables reflects the indiscriminate use and misuse of pesticides as reported in the literature (Ngowi *et al.*, 2007; Nonga *et al.*, 2011) and observed in the current study.

On the other hand, two studies in India found lower prevalence of pesticide residues compared to the levels found in the current study. In Indian studies, 20% of 50 vegetable samples from Karnataka and 34% of 250 vegetable samples from the Andaman Islands were found to be contaminated with pesticide residues (Pujeri *et al.*, 2015; Swarman and Velmurugan, 2012).

The detected pesticide residues were insecticides in the groups of organophosphates and pyrethroids which were, in 31.4% and 17.1% of the analysed vegetable samples, respectively. Organophosphate pesticides detected (with their prevalence in brackets) were dimethoate (14.3%), acephate (12.9%), profenofos (8.57%), malathion (2.86%) and dichlorvos (2.86%) and the pyrethroid pesticides were permethrin (17.1%), cypermethrin (1.43%) and lambda-cyhalothrin (1.43%). Representative chromatograms of the detected pesticides are presented in Fig. 2 and 3. Range and mean concentration of pesticide residues in the ready-to-eat vegetables are presented in Table 6.

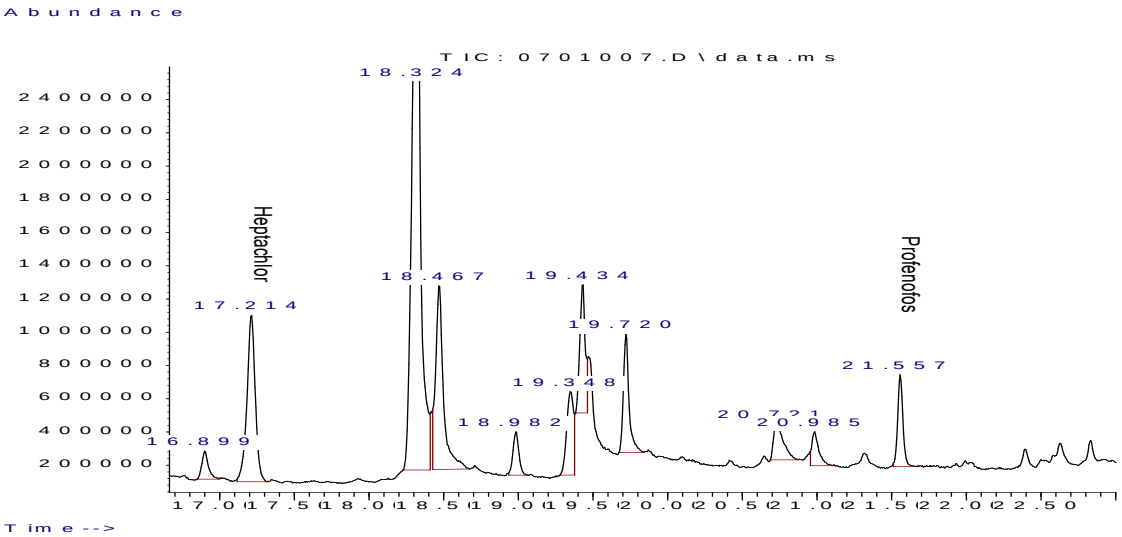

Figure 2: A chromatogram of Profenofos in kale

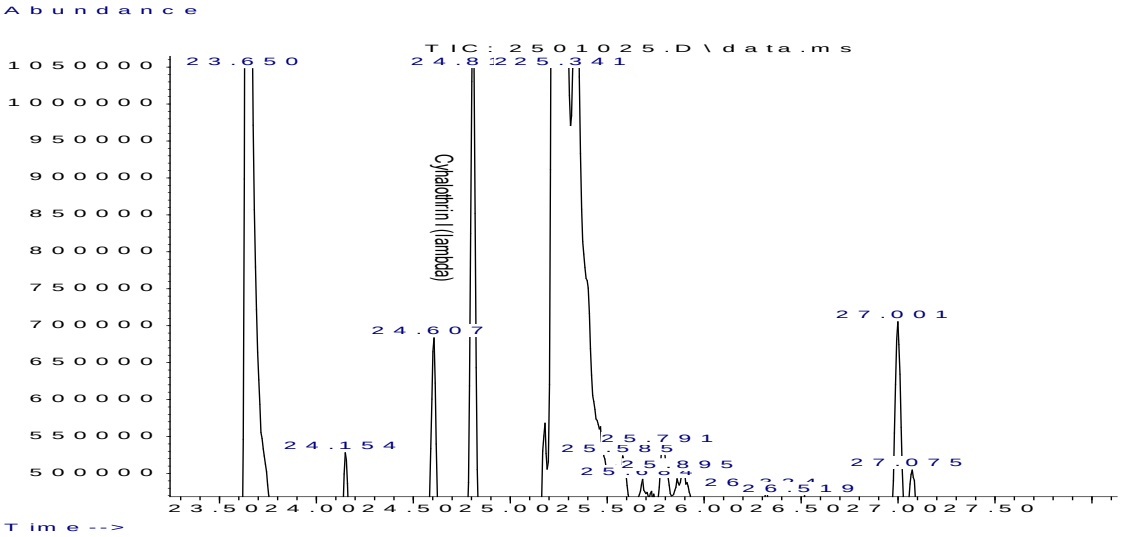

Figure 3: A chromatogram of Lambda cyhalothrin in kale

During field survey in the current study, 18.6% of the visited farmers reported to apply endosulfan in the vegetables to control pests. However, this pesticide and other organochlorine pesticides were not detected in the current study which is a good indication that there is a shift from the use of organochlorine pesticides to pyrethroid and organophosphorus pesticides and therefore a reduced risk of exposure to health effects associated with exposure to organochlorines. Endosulfan had provisional registration of two years from 2011 for use in agriculture in various crops implying that its registration ceased in 2013. Its availability for use during the current survey indicates that it was still in market.

This calls for improving pesticide distribution and use strategies so as to curb use of banned pesticides in Agriculture. Organochlorines were detected in the studies done in Dar es Salaam (Mahugija *et al.*, 2017; Ndengerio-Ndossi and Cram, 2005). The organochlorine pesticides were found in foods as reported in 2005 despite the fact that they had been banned from use in agriculture in Tanzania since 1997 due to their long persistence in the environment and bioaccumulation properties (URT, 2005).

Table 6: Occurrence of pesticide residue in ready-to-eat vegetables (n = 70)

Pesticide group (prevalence, (%))	Pesticide	Prevalence (%)	Range (mg kg^{-1})	Mean±SD[1] (mg kg^{-1})
Organophosphates (31.4)	Dimethoate	14.3	2.88-15.4	8.56±4.52
	Acephate	12.9	0.33-12.4	2.90±3.81
	Profenofos	8.57	6.53-16.6	8.44±3.98
	Dichlorvos	2.86	8.60-33.0	20.8±17.3
	Malathion	2.86	4.63-6.31	5.47±1.19
Pyrethroids (17.1)	Permethrin	17.1	1.23-8.18	2.95±1.92
	Lambda cyhalothrin	1.43	<0.05-16.2	16.2±0.05
	Cypermethrin	1.43	<0.06-2.34	2.34±0.06

[1]Standard deviation

Distribution, range and mean concentration of pesticides in individual vegetables are presented in Table 7. The highest mean concentration for permethrin, dimethoate, and lambda-cyhalothrin (3.44±0.93 kg mg^{-1}, 10.8±6.90 mg kg^{-1}, and 16.2±0.05 mg kg^{-1}, respectively) were found in kale samples whereas that of cypermethrin, acephate, malathion, and dichlorvos (2.34±0.06 mg kg^{-1}, 4.19±5.55mg kg^{-1}, 5.47±1.19 mg kg^{-1} and 33.0±0.01mg kg^{-1}, respectively) were found in nightshade. The highest mean concentration for profenofos (16.4±0.01 mg kg^{-1}) was found in mixed vegetables.

The lowest mean concentrations of permethrin, cypermethrin and malathion (1.7±0.05 mg kg^{-1}, 2.34±0.06 mg kg^{-1}, 5.47±1.19 mg kg^{-1}) were found in nightshade (Table 7). The lowest concentration for dimethoate (6.48±2.68 mg kg^{-1}) was estimated in cabbage whereas that of acephate (0.36 mg kg^{-1}), was found in mixed vegetables (Table 7). The lowest mean concentration for dichlorvos and profenofos were quantified in kale (8.60±0.01 mg kg^{-1}) and nightshade (6.64±0.01 mg kg^{-1}), respectively. It should be noted that lambda cyhalothrin and cypermethrin were detected in one sample only. For the samples in which pesticide residues were detected, the concentrations were above respective EU MRLs (Table 7). Quantification

of pesticide residues in ready-to-eat-vegetables at levels higher than MRLs indicates poor adherence to good agricultural practices by vegetable farmers.

Table 7: Variation of pesticide residues in individual types of ready-to-eat vegetables

Vegetable (n)	Source (n)	Group	Prevalence (%)	Pesticide	MRL-(EU)	Range (mg kg^{-1})	Mean±SD[1] (mg kg^{-1})	f^2>LoD (%)	f^3>MRL (%)
Cabbage (10)	own farm (10)	Organophosphate	6(60)	Dimethoate	0.05	4.58-8.37	6.48±2.68	(2)20.0	(2)20.0
				Profenofos	0.01	<0.01-7.07	7.07±0.01	(1)10.0	(1)10.0
				Acephate	0.01	<0.01-1.97	1.97±0.01	(1)10.0	(1)10.0
		Pyrethroids		Permethrin	0.05	1.44-3.91	2.37±1.34	(3)30.0	(3)30.0
Kale (15)	own farm (13)	Organophosphate	8(53)	Dimethoate	0.02	2.88-15.4	10.8±6.90	(3)20.0	(3)20.0
				Acephate	0.01	2.04-4.60	3.32±1.81	(2)13.3	(2)13.3
				Profenofos	0.01	<0.01-7.24	7.24±0.01	(1)6.70	(1)6.67
				Dichlorvos	0.01	<0.01-8.60	8.60±0.01	(1)6.67	(1)6.67
		Pyrethroids		Permethrin	0.05	2.62-4.45	3.44±0.93	(3)20.0	(3)20.0
				Cyhalothrin	0.05	<0.05-16.2	16.2±0.05	(1)6.67	(1)6.67
	purchased (2)	Organophosphate		Profenofos	0.01	<0.01-6.53	6.53±0.04	(1)6.67	(1)6.67
Nightshade (31)	own farm (26)	Organophosphate	11(35.5)	Dimethoate	0.02	4.25-12.0	8.05±3.74	(5)16.1	(5)16.1
				Acephate	0.01	0.33-12.4	4.19±5.55	(4)12.9	(4)12.9
				Malathion	0.02	4.63-6.31	5.47±1.19	(2)6.45	(2)6.45
				Profenofos	0.01	<0.01-6.64	6.64±0.01	(1)3.22	(1)3.22
				Dichlorvos	0.01	<0.01-33.0	33.0±0.01	(1)3.22	(1)3.22
		Pyrethroid		Permethrin	0.05	1.23-8.18	3.40±3.20	(4)12.9	(4)12.9
	purchased (5)	Pyrethroid		cypermethrin	0.05	<0.06-2.34	2.34±0.06	(1)3.22	(1)3.2
				Permethrin	0.05	<0.05-1.70	1.70±0.05	(1)3.22	(1)3.2
Mixed (6)	own farm (4)	Organophosphate	2(33.3)	Profenofos	0.01	<0.01-16.4	16.4±0.01	(1)16.7	(1)16.7
				Acephate	0.01	0.30-0.42	0.36±0.01	(2)33.3	(2)33.3
		Pyrethroid		Permethrin	0.05	<0.05-2.60	2.60±0.05	(1)16.7	(1)16.7
Spinach (3)	own farm (3)	Organophosphate	1(33.3)	Profenofos	0.01	<0.01-6.63	6.67±0.01	(1)33.3	(1)33.3

[1]Standard deviation; [2]detection frequency of the pesticide in the particular vegetable; [3]Frequency of detected pesticides that were above MRL; Source (MRLs): (European Comission, 2017)

Multiple pesticide residues were detected in 14.9% of the 70 samples (Table 8). This prevalence is equivalent to 35.7% of the 28 samples which were positive for pesticide residues. Among the 31 nightshade and six mixed vegetable samples analyzed, 16.13% and 16.67%, respectively, had multiple residues whereas among 15 kale samples 20% had multiple residues. Cabbage had the least samples with multiple residues (one out of six (10%)) (Table 8). Multiple occurrences of pesticide residues in vegetables have also been reported in literature. In Khazastan 82 samples of tomato and cucumber were analyzed and found that 30% of the samples contained two to nine multiple pesticide residues in one sample (Lozowicka *et al.,* 2015). Presence of multiple pesticide residues in one sample indicates that consumers are at higher risk of exposure and synergistic health effects of pesticides.

Table 8: Co-occurrence of multiple pesticide residues in ready-to-eat vegetables

Vegetable	Pesticide residues combination	Prevalence (%)
Kale	Acephate, permethrin	
	Dimethoate, permethrin, cyhalothrin	
	Profenofos, dichlorvos,	
Overall prevalence		20.00
Nightshade	Dimethoate, dichlorvos, malathion	
	Acephate, dimethoate, permethrin	
	Acephate, dimethoate	
	Dimethoate, malathion	
	Permethrin, cypermethrin	
Overall prevalence		16.13
Nightshade with kale and spinach mix	Acephate, profenofos, permethrin	16.67
Cabbage	Dimethoate, permethrin	10.00

The quantified concentrations of most pesticide residues in the current study were higher than those found in other studies. Elgueta *et al.* (2017) quantified low pesticide residues concentration in vegetables whereby lambda-cyhalothrin, cypermethrin and permethrin were quantified at a range of 0.029-1 mg kg^{-1}, 0-1.61 mg $kg^{-1}$and 0-1.45 mg kg^{-1}, respectively in chard, lettuce, and spinach. However, they quantified methamidophos (29.47 mg kg^{-1}) and chlorpyrifos (6.86 mg kg^{-1}) at higher concentrations than quantified in the current study. Also, a study in the Andaman Islands in India quantified profenofos, dimethoate and acephate in vegetables at a lower concentration than that found in the current study whereby profenofos concentrations in the study done in the Andaman Islands ranged from 0.023-1.696 mg kg^{-1}, acephate 0.083-0.509 mg kg^{-1} and dimethoate at 0.345 mg kg^{-1} (Swarman and

Velmurugan , 2012). However, a study in Egypt found a concentration of profenofos in green parsley (7.2 mg kg^{-1}) (Gad-Alla *et al.*, 2015) similar to that of the current study (8.44 mg kg^{-1}). In Ghana, lower concentrations of 0.12-0.143 mg kg^{-1} as compared to 4.6-6.3 mg kg^{-1} in the current study were found in vegetables. However, the prevalence of contaminated samples was higher in the Ghanian study (Darko and Akoto, 2008) than in this one. In Turkey, analysis of pesticide residues in 120 samples of parsley, lettuce and spinach found dichlorvos at concentrations ranging from 0.002-0.071 mg kg^{-1}, levels that are lower than the 8.6-33 mg kg^{-1} levels found in this study. In Zambia, Sinyangwe *et al.* (2016) analysed dichlorvos residues in 14 lettuce, 15 cabbage and 9 rape samples and, by summing up the prevalence of the residues detected below and above MRL, found that 71%, 93% and 100% of lettuce, cabbage and rape samples, respectively, contained mean dichlorvos concentrations of 5.23 mg kg^{-1}, 6.35 $mgkg^{-1}$ and 398.28 mg kg^{-1}. The reported overall prevalence (89%) is much higher than that obtained in the current study (2.86%) for dichlorvos. Also, the concentration of dichlorvos residues in the rape reported in the same study is considerably higher than that found in the current study (33 mg kg^{-1}).

WHO recommends classifying pesticides by hazard toxicology whereby class Ia refers to pesticides that are extremely hazardous, class Ib are highly hazardous, class II are moderately hazardous, class III are slightly hazardous and class U are unlikely to cause acute health hazard (IPCS, 2010). The pesticides residues found in the ready-to-eat vegetables are in class Ib, II and III. Most pesticides were found under Class II insecticides with exception of dichlorvos which is classified as class Ib and malathion classified as class III insecticides. These results indicate that vegetable farmers are shifting from using more to less hazardous pesticides and therefore exposed to reduced health effects. The class Ib pesticides are registered under restriction conditions and therefore less accessible to vegetable farmers.

3.3.4 Presence of unauthorized pesticide in ready to eat vegetables

In Tanzania, Dichlorvos is restricted to control of larger grain borer in maize grain storage facilities. Pesticides registered for restricted use are those that are highly hazardous and intended for specific use or are technical materials for formulation purposes and must be used by specifically trained personnel or under the close supervision of specifically trained personnel (URT, 2011). Dichlorvos, although less frequently detected (2.86%) as compared to other organophosphate pesticides, it had the highest mean concentration of 20.8 mg kg^{-1}

with a range of 8.6-33.01 mg kg^{-1}. Detection of dichlorvos in the ready to eat vegetables indicates misuse of pesticides. It is recommended to provide continuous training to vegetable farmers on pesticide application and undertake regular monitoring of pesticide residues in vegetables to ensure that restricted pesticides such as dichlorvos are not inappropriately used and to control pesticide residues (in general) to acceptable levels in vegetables.

3.3.5 Risk of exposures above acceptable daily intakes

(i) Type, frequency and quantity of consumed vegetables

The vegetable consumers in Arusha district take vegetables as side dishes to main dishes that include stiff porridge, rice or banana. Among the mainly consumed leafy vegetables, African nightshade was the most consumed. It was consumed by 43% of the respondents. For the vegetables used as a minor ingredient in the recipe, onions and tomatoes were consumed by most respondents (76.3 and 70.4, respectively). The average daily vegetable consumption at the time of the survey was 119 g per person. The consumption rates ranged from 14 - 302 g per person. In Sub Saharan Africa less per capita daily vegetable consumptions ranging from 13 g (Malawi), through 70 g (Ethiopia) to 84 g (Guinea) and higher quantities ranging from 126 g (Rwanda) through 137 g (Ghana) and 142 g (Uganda) to 242 g (in Kenya) are reported (Ruel *et al.,* 2004). The values in the review work were reported as consumption per year but were converted into consumption per day in the current work to enable comparison. With the exemption of Kenya, average consumption of vegetables in developing countries is a half way the recommended amount of 200 g per person per day (Smith and Eyzaguirre, 2007). It is recommended to consume at least 400 g of fruits and vegetables per day and it is assumed that 200 g of this is from vegetables (Agudo and FAO, 2005; Keding *et al.,* 2007). Based on this study, only 18.6% of vegetable farmers in Arusha district met the required daily vegetable consumption. If the farmers in Arusha consumed vegetables at the recommended intake of 200 g per person per day the risk of unacceptable pesticide intakes would increase considerably. Assuming a vegetable farmer with a body weight of 67 kg (the average body weight of farmers in Arusha district), consumes 200 g of vegetables every day containing pesticides at the mean concentrations determined in this study, mean exposures in mg kg^{-1} bwd^{-1} for this farmer, with the pesticide in bracket, would be 0.0036 (dimethoate), 0.0018 (dichlorvos), 0.0022 (profenofos), 0.0011 (acephate), 0.0005 (malathion) for organophosphate pesticides. For pyrethroids, the mean exposures would be 0.0011 (permethrin), 0.0001 (cypermethrin) and 0.007 for lambda-cyhalothrin. These would lead to

unacceptable hazard quotients of 1.829 for dimethoate, and a hazard index of 2.385 for organophosphates. The hazard index for organophosphates is more than two-fold the hazard index of 1.19 determined in this study with the normal vegetable consumption pattern. This indicates that promotion for increased vegetable consumption should go hand in hand with training and awareness creation to vegetable farmers on the appropriate use of pesticides and continuous monitoring and control of pesticide residues in vegetables.

(ii) Risk of pesticide exposure

Overall assessment of chronic exposure to pesticide residues through vegetable consumption indicates potential health risks to vegetable farmers. Among the 70 farmers, 18.6% were at potential health risks of unacceptable exposure to pesticide residues. Exposure levels and hazard indices of organophosphate and pyrethroid pesticides to vegetable farmers in Arusha district are presented in Tables 9, 10, 11 and 12, respectively.

The vegetable farmers were at higher health risk of unacceptable exposure of organophosphate pesticides. The hazard quotient of 7.5 was determined for dimethoate when considering positive detects only (Table 9), and was still above one (1.044) even after including non-detects assigned with the respective half limit of detection (0.5 LOD) in the mean exposure estimation (Table 10). The mean exposure level for this chemical was 0.015 mg kg^{-1} bwd^{-1} when considering positive detects only, and 0.0021 when 0.5 LOD of this residue was included in the exposure estimation. Both values were above the ADI of dimethoate (0.002 mg kg^{-1} bwd^{-1}). The HQ of dimethoate was above one for kale (2.57 and 12.8 with and without 0.5 LOD included in the exposure estimation, respectively) whereas in cabbage it was 0.928 and 4.75 with and without the 0.5 LOD included in the estimation, respectively. Mean exposure for dichlorvos was 0.011 mg kg^{-1} bwd^{-1}which was also above its corresponding ADI (0.004 mg $kg^{-1}bwd^{-1}$) yielding HQ of 2.75. After including 0.5 LOD in the exposure estimation for this residue, the mean exposure was reduced to 0.0003 and HQ of 0.075 indicating minimum potential health risk.

Mean exposure for other organophosphate (acephate, profenofos, and malathion) and pyrethroid (permethrin, cypermethrin, and lambda cyhalothrin) pesticide residues quantified in this study were below one in both scenarios indicating minimum health risk. These results indicate that vegetable farmers in Arusha district are at risk of intolerable health effects associated with exposure to organophosphate pesticides and that the risk is mainly

contributed by intake of dimethoate through consumption of kale. Risk of cumulative exposures to the organophosphate pesticide residues is above one even after including the 0.5 LOD of the non-detects in the exposure estimation as shown by the Hazard index (HI) of 11 for positives only (Table 10) and 1.19 after including the 0.5 LOD of the respective residues in the exposure mostly contributed by dimethoate (88%) (Table 13). The HI for pyrethroid pesticide residues was found below one in both scenarios (0.029 and 0.9 with and without the 0.5 LOD, included in the estimation, respectively) (Table 11 and 12). These results show that the risk of exposure to the pesticide residues is exaggerated when values for non-detects are not included in estimation of the risk. However, even after including these values it shows that there is still a risk of intolerable health effects and the risk is aggravated through multiple exposures to the organophosphate pesticide residues.

A study in Egypt reports cumulative hazard indices for organophosphates higher than those of pyrethroids but both of them below one (Gad-Alla *et al.,* 2015; Thabet *et al.,* 2016). Usually, in Arusha district, vegetables are prepared for consumption for the entire family including children and pregnant women who are reported to be vulnerable to health risks associated with exposure to pesticide residues than other groups of the population (FAO/WHO, 2009a). Exposure to organophosphate pesticides during pregnancy has been linked with autism spectrum disorders (ASD) characterized by problems in socio-communication and restricted repetitive behaviours and pregnancy miscarriage. Children are more adversely exposed to the pesticide residues due to their small body size and therefore might be at a higher risk than estimated in this study for adults (Arbuckle and Lin, 2001; Eskenazi *et al.,* 2004; Bouchard *et al.,* 2011). Furthermore, dietary exposure to pesticides is not limited to vegetables. The farmers may also be exposed to pesticides from other food, water and air.

Table 9: Risk of dietary pesticides exposures above ADIs for organophosphate (positives only)

Pesticide (Prevalence (%))	Code	Vegetable	Concentration (mg kg^{-1})	EDI (mg kg $bw^{-1}d^{-1}$)	ADI (mg kg^{-1} bw)	HQ/HI
Dimethoate (14.3)	B26	Nightshade	4.25	0.011	0.002	5.500
	B41	Nightshade	12.0	0.013	0.002	6.500
	B1	Nightshade	11.7	0.005	0.002	2.500
	B74	Nightshade	7.75	0.016	0.002	8.000
	B4	Nightshade	4.54	0.005	0.002	2.500
		Nightshade (average)		0.010		5
	B71	Kale	15.4	0.052	0.002	26.00
	B36	Kale	14.1	0.023	0.002	11.50
	B5	Kale	2.88	0.002	0.002	1.000
		Kale (average)		0.026		12.80
	B62	Cabbage	4.58	0.003	0.002	1.500
	B6	Cabbage	8.37	0.016	0.002	8.000
		Cabbage (average)		0.010		4.75
				0.015		**7.5**
Dichlorvos (2.86)	B73	Kale	8.60	0.007	0.004	1.750
	B1	Nightshade	33.0	0.014	0.004	3.500
				0.011		**2.75**
Acephate (12.9)	B15	Spinach, nightshade	0.30	0.001	0.030	0.033
	B33	Kale, nightshade	0.42	0.001	0.030	0.033
	B54	Nightshade	12.4	0.012	0.030	0.400
	B34	Nightshade	2.03	0.002	0.030	0.067
	B41	Nightshade	1.97	0.002	0.030	0.067
	B74	Nightshade	0.33	0.001	0.030	0.033
		Nightshade (average)		0.004		0.140
	B39	Kale	4.6	0.003	0.030	0.100
	B44	Kale	2.04	0.005	0.030	0.167
		Kale (average)		0.004		0.130
	B49	Cabbage	1.97	0.005	0.030	0.167
				0.004		**0.130**
Malathion (2.8)	B1	Nightshade	6.31	0.000	0.300	0.001
	B4	Nightshade	4.63	0.005	0.300	0.017
		Nightshade (average)		0.003		**0.009**

Table 9: cont.

Pesticide (Prevalence (%))	Code	Vegetable	Concentration (mg kg^{-1})	EDI (mg kg $bw^{-1}d^{-1}$)	ADI (mg kg $bw^{-1}d^{-1}$)	HQ/ HI
Profenofos (8.6)	B15	Spinach, nightshade	16.6	0.069	0.03	2.300
	B51	Nightshade	6.64	0.011	0.03	0.367
	B46	Kale	6.53	0.015	0.03	0.500
	B73	Kale	7.24	0.004	0.03	0.133
		Kale (average)		0.010		0.320
	B61	Cabbage	7.07	0.001	0.03	0.033
	100	Spinach	6.63	0.015	0.03	0.500
				0.019		**0.630**
						11

Note: [1] mg $kgbw^{-1}d^{-1}$ is mg per kg body weight per day; Source (ADI): (FAO/WHO, 2015)

Table 10: Risk of dietary pesticides exposures above ADIs for organophosphate (including non-detects assigned with 0.5 LOD); EDIs in (mg kg $bw^{-1}d^{-1}$)

n	Vegetable	Acephate		Dimethoate		Profenofos	
		Mean EDI	HQ	Mean EDI	HQ	Mean EDI	HQ
31	African nightshade	0.001	0.018	0.002	0.813	0.000	0.011
15	Kale	0.001	0.018	0.005	2.570	0.001	0.046
10	Cabbage	0.000	0.012	0.002	0.928	0.000	0.005
3	Spinach	0.000	0.000	0.000	0.002	0.005	0.166
2	Ethiopian mustard	0.000	0.000	0.000	0.003	0.000	0.000
2	Amaranthus spp	0.000	0.000	0.000	0.001	0.000	0.000
1	Chinese	0.000	0.000	0.000	0.005	0.000	0.000
6	Mixed vegetables	0.000	0.011	0.000	0.002	0.011	0.382

Table 10: cont…

n	Vegetable	Dichlorvos		Malathion	
		Mean EDI	HQ	Mean EDI	HQ
31	African nightshade	0.000	0.112	0.000	0.001
15	Kale	0.001	0.116	0.000	0.000
10	Cabbage	0.000	0.001	0.000	0.000
3	Spinach	0.000	0.001	0.000	0.000
2	Ethiopian mustard	0.000	0.001	0.000	0.000
2	Amaranthus spp	0.000	0.001	0.000	0.000
1	Chinese	0.000	0.002	0.000	0.000
6	Mixed vegetables	0.000	0.001	0.000	0.000

Table 11: Risk of dietary pyrethroid pesticide exposures below ADIs (positives only)

Pesticide (Prevalence(%))	Code	Vegetable	Concentration mg kg^{-1}	EDI mg $kgbw^{-1}d^{-1}$	ADI mg $kgbw^{-1}d^{-1}$	HQ/HI
Lambda cyhalothrin (1.4)	B5	Kale	16.2	0.012	0.02	**0.600**
Cypermethrin (1.4)	B10	Nightshade	2.34	0.003	0.02	**0.150**
Permethrin (17.1)	B15	Spinach, nightshade	2.60	0.011	0.05	0.220
	B4	Nightshade	2.10	0.002	0.05	0.040
	B10	Nightshade	1.70	0.002	0.05	0.040
	B29	Nightshade	2.17	0.002	0.05	0.040
	B28	Nightshade	1.23	0.002	0.05	0.040
	B41	Nightshade	8.18	0.009	0.05	0.180
		Nightshade (average)		0.003		0.068
	B11	Cabbage	3.91	0.013	0.05	0.260
	B62	Cabbage	1.76	0.001	0.05	0.020
	B3	Cabbage	1.45	0.002	0.05	0.040
		Cabbage (average)		0.005		0.11
	B45	Kale	4.45	0.010	0.05	0.200
	B5	Kale	3.27	0.002	0.05	0.040
	B44	Kale	2.62	0.007	0.05	0.140
		Kale (average)		0.006		0.13
				0.005		**0.1**
						0.9

Note: [1]mg $kgbw^{-1}d^{-1}$ is mg per kg body weight per day; Source (ADI): (FAO/WHO, 2015)

Table 12: Risk of dietary pesticides exposures below ADIs for pyrethroids (including non-detects assigned with 0.5 LOD), EDIs in mg kg bw^{-1} d^{-1}

n	Vegetable	Permethrin		Cypermethrin		Cyhalothrin	
		Mean EDI	HQ	Mean EDI	HQ	Mean EDI	HQ
31	African nightshade	0.001	0.011	0.000	0.005	0.000	0.000
15	Kale	0.001	0.026	0.000	0.000	0.001	0.041
10	Cabbage	0.002	0.031	0.000	0.000	0.000	0.000
3	Spinach	0.000	0.000	0.000	0.000	0.000	0.000
2	Ethiopian mustard	0.000	0.000	0.000	0.000	0.000	0.000
2	Amaranthus spp	0.000	0.000	0.000	0.000	0.000	0.000
1	Chinese	0.000	0.000	0.000	0.000	0.000	0.000
6	Mixed vegetables	0.000	0.036	0.000	0.000	0.000	0.000

Table 13: Average estimated daily intakes and hazard quotients of pesticide residues in vegetables, EDIs in mg kg $bw^{-1}d^{-1}$

Pesticide group	Pesticide residue	EDIs	HQ	% contr	HI
Organophosphates	Dimethoate	0.002	1.044	88	1.19
	Acephate	0.000	0.014	1.2	
	Profenofos	0.002	0.055	4.6	
	Dichlorvos	0.000	0.075	6.3	
	Malathion	0.000	0.000	0.0	
Pyrethroids	Permethrin	0.001	0.018	62	0.029
	Cypermethrin	0.000	0.002	6.9	
	Cyhalothrin	0.000	0.009	31	

Note: contr = contribution of a particular pesticide residue to the hazard index (HI)

3.3.6 Association of pesticide exposure and application practices

The source of vegetables for household consumption, knowledge and awareness on pesticide use, vegetable cropping system and lack of advice from agricultural extension officers, pesticide application rates and adherence to pre-harvest interval were assessed in this study in order to establish their association with exposures to pesticide residues through vegetable consumption.

(i) Sources of vegetables

Among the 70 vegetable farmers interviewed only 12 (17%) reported to obtain their vegetable samples from market or neighbors as discussed in the previous section. This

finding indicates that most of the vegetable farmers consume what they produce. The farmers who outsourced vegetables reported that they usually do so while waiting for the pre-harvest interval to elapse after they have shortly sprayed their own vegetables or prefer a different type of vegetable than what they have on their farm. It was revealed in this study that the odds of exposure to pesticide residues were 4.062 higher for farmers who obtain own grown vegetable for consumption than for those who outsourced vegetable. However, the association was not statistically significant.

Results of exposure to pesticide residues to vegetable farmers who reported to obtain the vegetable samples from their own farms (n = 58) were used in the logistic regression analysis in order to clearly associate the practices and exposure. Results showing the association between exposure to pesticide residues and knowledge or application practices for pesticides are presented in Table 14.

(ii) Knowledge and awareness on pesticide application

Knowledge and awareness of pesticide application practices are important for appropriate pesticide application and handling. Most of the vegetable farmers 38 (n = 58) had not received professional training on safe pesticide use at the time of this survey. Among the 58 vegetable farmers interviewed, only 20 (34.5%) had attended some form of training on pesticide application. Among those who had no training, 52.6% were exposed to pesticide residues. Linear regression analysis shows that there is a significant association (P=0.043) between lack of training on pesticide application and exposure to pesticide residues. The adjusted odds of exposure to pesticide residues are 3.73 times higher for the vegetable farmers who had no training than for those who had undertaken training on pesticide application (Table 14).

It was reported that 81% (47) of the farmers had a low level of education of up to primary level and the others (19%) had a higher level of education (secondary to university). A similar level of literacy is reported in other developing countries. In Nigeria, 96.2% of farmers had a low level of education of up to primary level. The odds of exposure to pesticide residues for the farmers with a low level of education were 1.745 higher than for those who had a higher level of education but the results were not statistically significant (P = 0.634). These results suggest that continuous training and awareness creation among vegetable farmers on pesticide application regardless of their level of education can significantly reduce

dietary exposure to the pesticide. The training would impart knowledge on health and environmental effects associated with indiscriminate use of pesticides. It will also provide other options for pest and disease control so that farmers can willingly shift from relying on the indiscriminate use of synthetic pesticides to safer pest management methods such as the integrated pest management (IPM) approach. This approach combines various means of pest and disease control including the use of cultural and mechanical means, biological control such as introduction of beneficial insects and mites and minimum use of IPM compatible pesticides (Dijkxhoorn *et al.,* 2013; Lahr *et al.,* 2016). This approach is currently operating in Europe and in East Africa particularly Kenya for farmers who grow vegetable for export to meet the stringent regulations which requires that vegetables should contain pesticide residues below MRLs (Maredia *et al.,* 2003).

Table 14: Association between dietary exposure to pesticide residues with knowledge and pesticide application practices

Variable	Farmers exposed (%)	p-value	OR[1]	CI[2] (95%)	AOR[3]	*P*-value	CI (95%)
Primary or lower level of education (n = 47)	23	0.634	1.745	0.176-17.261			
Source of vegetables (own grown n = 58)	44.8	0.087	4.062	0.817-20.201			
Lack of a formal training on pesticide application (n = 20)	34.5	**0.133**	**2.317**	**0.822-8.179**	**3.73***	**0.043**	**1.04-13.363**
Vegetables intercropped with cabbage (n = 33)	51.5	0.961	1.889	0.652-5.476			
Lack of advice from extension officer (n = 13)	15.4	**0.031**	**6.768**	**1.188-38.57**	**6.56****	**0.031**	**1.187-36.291**
Prepare pesticide at over-dosage (n = 24)	58.3	**0.032**	**4.12**	**1.127-15.06**	**3.751**	**0.038**	**1.078-13.06**
Non-adherence to PHI[4] (n = 31)	32.3	**0.038**	**3.83**	**1.166-11.659**	**3.223**	**0.057**	**0.964-10.768**

[1]odd ratio, [2]confidence interval; [3]adjusted odd ratio; [4]the time that lags between last pesticide spraying and harvest of the vegetables; * odds ratio of exposure to the residues for lack of training after being adjusted from influence of low level of education and lack of advice from extension officer; ** adjusted odds ratio of exposure to the residues for lack of advice from extension officers after being adjusted for confounding influence of lack of adherence to PHI and over-dosage

(iii) Vegetable cropping system

During field survey, it was observed that vegetables were grown in small farms mostly ≤0.5 acre located close to the residential area of the respondents. Vegetables, either intercropped or in separate plots. Most of the farmers who grew cabbage and another type of vegetables claimed that they separated cabbage from other crops because the crop is more frequently sprayed with pesticides than the other vegetables. Thus they separated cabbage from the other vegetable in order to control pesticide cross-contamination. Among the 58 respondents who consumed vegetables from their own farm, 55.2% (32) reported growing cabbage, of which 75% planted cabbage in a separate farm. Among those who intercropped cabbage with other vegetables, 62.5% were exposed to pesticide residues. However, there was no significant association between intercropping cabbage with other vegetables and exposure to pesticide residues (P = 0.961, odds ratio = 3.769).

Results of pesticide residue analysis in the vegetable samples show that pesticide residues were more frequently detected in cabbage samples than other vegetables whereby 60% of cabbage samples analyzed contained pesticide residues as compared to 53.3% of kale and 35.5% of nightshade (Table 7). However, the occurrence of multiple pesticide residues was high in nightshade 18.75% and kale 10.5% as compared to cabbage (10%) samples, indicating that the farmers' claim is not validated. Literature reports that intercropping of cabbage with right vegetables (referred to as companion crop) is potential in controlling pests in vegetables and thus minimising pesticide use. For instance, intercropping cabbage with alliums and tomato were found to minimise pests in the field significantly (Baidoo, 2012; Debra and Misheck, 2014; Luchen, 2001).

(iv) Lack of advice from agricultural extension officers

The role of agricultural extension officers is to provide farmers with knowledge, information, experience, and technology that are important for improved productivity. In the current study, most of the vegetable farmers (84.6%; n=58) reported that they did not seek for agricultural officers' advice on pesticide application issues. Of those who did not rely on the officers' advice, 53.3% were exposed to pesticide residues. The result from regression analysis indicates that there is a significant association between exposure to pesticide residues and lack of advice from Agricultural extension officers (P = 0.031). The adjusted odds for exposure to pesticide residues are 6.56 higher in the farmers who did not rely on extension

officers' advice than for their counterparts.

It has been reported that farmers based on their own decision rather than extension officers' advice in pesticide application issues (Issa and Atala, 2012; Lekei *et al.,* 2014c; Ngowi *et al.,* 2007). Each ward and two villages (Shiboro and Siwandeti) visited in the current study had Agricultural extension officers. Therefore, if well equipped and utilized by farmers, the risk of exposure to pesticide residues would be minimized.

(v) Over-dosage of pesticides in vegetables

Appropriate pesticide preparation is vital for controlling pesticide residues in the vegetables. By comparing application rates for pesticides as indicated on labels to the rates applied to vegetables, it was realized that 41.1% of the interviewed farmers prepared pesticides at over-dosage. Among those who over-dosed, 58.3% were exposed to pesticide residues. The adjusted odds ratio of exposure to the residues was found to be 3.751 higher in the farmers who overdosed than for those who prepared pesticides, accurately. The association was statistically significant at $P = 0.038$. Pesticide dosage has been a great challenge in developing countries whereby most farmers measure inaccurate dosage which results to excessive pesticide residues in vegetables (Adjrah *et al.,* 2013; Banjo *et al.,* 2010; S A Sheikh *et al.,* 2013).

During field survey, farmers reported measuring liquid pesticides by using calibrated caps, most of them accompanying the pesticide package. However, in the case of powdery pesticides such as Linkmil 72WP, Ebony 72WP, and Ivory 72WP, tablespoons were used as measurement tools. This is a challenge because powdery pesticides are indicated on the package to be weighed in grams. Unpublished information from Horticultural Research and Training Institute Tengeru, Arusha reported that the lack of appropriate measures such as weighing balances for powdery pesticides is a common challenge. It further reported that the extension officers have attempted to calibrate commonly used equivalent tools at the farm level, such as spoons, but it is still a challenge because new pesticides which are lighter or heavier than the previously used for the calibration, are entering the market. The officers calibrated and set one tablespoonful equivalent to 10g of pesticide. A similar challenge is reported in Ethiopia where farmers use non-calibrated measuring tools (Mengistie *et al.,* 2015). Pesticide formulators and extension officers should find means for farmers to be able

to measure an accurate quantity of pesticides. This will minimize the risk of exposure to pesticide residues associated with inappropriate measurement of pesticides.

(vi) Adherence to pre-harvest interval (PHI)

The time that lags between last pesticide spraying and harvest of the vegetables is important to allow withdraw of the applied pesticides to at least recommended maximum residual levels. Field survey revealed that all vegetable farmers interviewed were aware of PHI. Among the 58 respondents, 31 (53.4%) reported waiting for the recommended PHI whereas 27 (46.6%) harvest earlier than the recommended intervals. Adherence to PHI was in concurrence with the effectiveness of pesticides whereby (87.1%) of the farmers who reported that the pesticides they applied were effective, could adhere to PHI. Among the farmers who reported to harvest vegetables before the recommended interval (n = 27), 59.3% were exposed to pesticide residues through vegetable consumption. The odds ratio of exposure to the residues were 3.83 times higher for the farmers who did not adhere to PHI than their counterparts and the result was statistically significant at $P = 0.026$. However, after adjusting for confounding influences of lack of advice from extension officers, the results showed no significant association ($P = 0.057$) suggesting that the lack of advice from extension officers was the cause for non-adherence to PHI. It is therefore suggested that farmers should be advised on the importance of adherence to PHI so that safe vegetables are produced for their own consumption and for other consumers.

3.4 Conclusion and recommendations

The findings of the present study indicate that 18.6% of vegetable farmers in Arusha district are at potential risk of exposure to organophosphate pesticide residues through vegetable consumption. The risk is contributed by high levels (above MRLs) of organophosphate pesticide residues that were detected in almost one-third of vegetable samples. Dimethoate was the main contributor for the exposure to high levels of organophosphates with the hazard index above one. Other organophosphate pesticides detected were dichlorvos, acephate, profenofos, and malathion whose HQs were below one. Pyrethroids including permethrin, cypermethrin, and lambda-cyhalothrin were also detected having HQ and combined HI below one indicating minimum potential health risks. Our findings showed that lack of formal training, non-reliance to agricultural extension officers' advice and over-dosage of pesticides to vegetables are the main factors for the observed potential risk of exposure to pesticide

residues. Since vegetable farms were closer to the residential houses, there are possibilities that individuals especially pregnant women and children are at higher risk of exposure through other routes such as inhalation and skin contact. For that reason, we recommend that risk of exposure to the general population be carried out using a more robust approach that includes other potential routes including consumption, inhalation and skin contact. The risk may be minimized by observing extension service advice, specifically by observing pre-harvest intervals for these pesticides and applying pesticides at an appropriate dose. Since the vegetables are usually processed before consumption, the processes can influence the levels of pesticide residues in the vegetables. In the next chapter, study on the influence of household processes on pesticide residues in the ready-to-eat vegetables is presented.

CHAPTER FOUR

HOUSEHOLD VEGETABLE HANDLING PRACTICES INFLUENCING OCCURRENCE OF PESTICIDE RESIDUES IN READY-TO-EAT VEGETABLES

Abstract

Influence of vegetable processing on the pesticide residues in ready-to-eat vegetables has been studied at experimental level which does not necessarily reflect the actual situation at household level. This paper presents findings of a cross-sectional study that assessed the influence of household vegetable handling practices on the pesticide residues in ready-to-eat vegetables at household level in Arusha city, Northern Tanzania. Data on vegetable preparation practices was collected through observations and physical interviews in 70 households. Samples of raw and ready-to-eat vegetables were collected for pesticide residues analysis, from each household. Pesticides were analysed using Gas Chromatography-mass spectroscopy.

Of the surveyed households, 3% wash vegetables in running tap water, before cooking, and 90% of them cooked their vegetables before consumption. Detectable pesticide levels were found in 32 (46%) of the raw and 10 (14%) of the ready-to-eat vegetable samples. Washing of vegetables twice or more and changing the washing water after one use ($\chi^2(1) = 6.56$; P = 0.01) or peeling ($\chi^2(1) = 6.949$; P = 0.008) was significantly associated with reduction of pesticide residues in them. Among the 70 households, 9% do not always pay attention to minor ingredients (tomato, carrot, sweet pepper and onions) during washing. There was a significant association between the occurrence of pesticide residues in the ready-to-eat vegetables and washing of the minor ingredients with water used to wash the major ingredients (including mainly african nightshade and *Amaranthus spp*) (χ^2 (1) = 25.55; P = 0.001). Raw vegetables from Arusha city contain pesticide residues and that the household practices of washing of vegetables with portable water followed with peeling (where appropriate) can reduce the residue levels significantly.

Keywords: Pesticide residues, household processing, organophosphates, pyrethroids, organochlorines

4.1 Introduction

Application of pesticides to control pests and diseases in vegetable production may result in unacceptable levels of the chemicals in the vegetables. This is specifically the case when

good pesticide application practices are not observed. Ingestion of pesticide residues in vegetables increases the risk of health effects associated with exposure to the toxins. Nonetheless, it is not practical to eliminate the possibility of having pesticide residues in food. The practical option is minimizing the residues to tolerable levels. In order to ensure that efforts are taken to minimize content of pesticide residues in food to tolerable levels, Codex Alimentarius Commission has set maximum residue levels for the various pesticides used in food production (MRLs) (FAO/WHO, 1997a). It is reported that estimation of the MRLs is based on the toxicity properties of the pesticide and residues in the harvested crop/animal from pesticide use according to good agricultural practices.

To ensure that pesticides residues in foods comply with the set maximum limits, actors along the food chain, have to observe good food agricultural and preparation practices. It is reported that in Tanzania most of vegetable farmers do not follow good agricultural practices (Kiwango *et al.,* 2018a). For example, studies conducted in Arusha and Meru districts of Tanzania (Kariathi *et al.,* 2016; Kiwango *et al.,* 2018a; Lekei *et al.,* 2014c) reported that farmers in Arusha apply pesticide indiscriminately or do not observe the pre-harvest interval; a period between pesticide application and harvest, resulting in pesticide residue levels above MRLs.

Keikotlhaile (2010) reported that processing of agricultural raw products can alter levels of pesticide residues at rates dependent on properties of the pesticide and the processes applied. Processes such as washing and peeling of vegetables reduce pesticide residues significantly. However, for systemic pesticides, the reduction is insignificant as these pesticides are capable of penetrating into the flesh of the vegetable tissues (Keikotlhaile, 2010). Combined effects of washing and cooking can effectively decrease pesticide residues in vegetables (Bajwa and Sandhu, 2014; Krol *et al.,* 2000). For instance, a study on the effect of household processes on pirimiphos-methyl residues in green beans and potato showed that, washing and cooking of green beans could reduce residue levels by 53.6% and 70.3%, respectively, in green beans and by 63.8% and 100%, respectively, in potatoes (Mohamed *et al.,* 2010).

In the cooking step, holding time, the degree of moisture loss and whether the process takes place in open or closed vessel affect pesticide residues retention (Ahmed *et al.,* 2011; González-Rodríguez *et al.,* 2011; Uysal-pala and Bilisli, 2006). For instance, cooking under open conditions resulted in 85 to 98% reduction of chlorothalonil residues (Ahmed *et al.,* 2011). However, in some cases, heating and evaporation have shown to concentrate

endosulfan and deltamethrin concentrations in tomato paste (Uysal-pala and Bilisli, 2006). Extraction of oil from oil seeds may also concentrate pesticide residues in the oil fraction (FAO/WHO, 1997b) particularly for fat soluble pesticides (European Union Oil and Proteinmeal Industry, 2018).

The literature on effects of household food processing on pesticide residues at community level in Tanzania is not available. Most of the available studies carried in other countries (Selim *et al.*, 2011; Tomer and Sangha, 2013) were conducted at the laboratory level, failing to depict the real household practices. Additionally, household food preparation practices vary with ethnicity and geographical location (Shackleton *et al.,* 2009). This paper presents findings of a study focusing on the influence of household vegetable preparation practices on pesticide content in ready-to-eat vegetables in Arusha city.

4.2 Materials and methods

4.2.1 Study area

The study was carried out in Arusha city, Northern Tanzania, from May to September 2016. Northern Tanzania is one of the famous areas for vegetable production in the country, where farmers apply pesticides intensively (Lekei *et al.*, 2014c). Vegetables produced in Arusha include cabbages, spinach, pumpkin leaves, Ethiopian mustard, *Amaranthus spp* and nightshade (Kiwango *et al.,* 2018a). Arusha city is one of the major markets for vegetables produced in Northern Tanzania. The city is located in the North East of Tanzania, at the slopes of Mount Meru, 03°22’21”S 36°41’40”E, with 416,442 inhabitants.

4.2.2 Study design and sample size

A cross-sectional study was carried out in households with individuals suffering from non-communicable diseases (NCDs). This segment of the population was selected because health practitioners advise them to consume more vegetables in their diet as compared to their counterparts.

Individuals with NCDs were recruited from relevant clinics of the Lutheran Medical Centre Arusha (LMCA), Arusha International Conference Centre (AICC) hospital, Kaloleni health centre and Mount Meru hospital. Permission to recruit the patients was sought from Medical officer in-charge of each hospital and each client was informed of the purpose of the research.

Individuals residing in Arusha city and willing to participate in the study were recruited as prospective respondents. A sample size of 65 was calculated to give a statistical power of 0.8 following equation (4), where N is sample size, Z is the number of standard deviations above or below the population mean, *p* is prevalence of pesticide residues in vegetables (in this case, 40% prevalent obtained from the study in Arusha district (chapter 3) was used) and δ is confidence interval (source: https://www.surveysystem.com/sample-size-formula.htm).

$$N = \frac{(Z\alpha)^2 P(1-P)}{\delta^2} \qquad (4)$$

4.2.3 Data collection

On recruitment, participants were interviewed on the type of vegetables commonly consumed and preparation procedures employed, to guide selection of vegetables and practices for the study. A checklist of various vegetable handling practices at household was prepared. Arrangement to visit each subject's home was done at least a day before the visit. The participants were requested to obtain some commonly consumed vegetables and ingredients (from their usual source which could be mobile or stationery local vendors, market, home or neighbour garden).

A sample of the raw vegetable constituting the largest portion (at least 75% of the total volume of the ingredients) was taken for residue analysis. In case of mixed vegetables with similar proportions, a mixed vegetable sample was taken after thorough mixing to make a composite. The raw vegetable sample was wrapped in an Aluminum foil and kept in a polyethene bag. In each family, the household cook was requested to prepare the remaining portion of the sampled vegetable stock as habitually done to obtain ready-to-eat vegetables, from which a sample was also taken.

Preparation practices including mixing, sorting, washing, peeling, chopping, type of cooking, holding time and whether cooked closed or open, were observed and recorded on a check list (Appendix 3). Salad preparation was observed only in households of participants who reported to consume salad at least four times a week.

A sample of the ready- to- eat vegetables was taken in a glass bottle wrapped with an aluminum foil to prevent reduction of pesticide levels during handling as some of these chemicals are sensitive to ultra violet (UV) light. Both samples were coded uniquely and

stored in a cool box with ice blocks and transported to a laboratory at the Tropical Pesticide Research Institute (TPRI) in Arusha. The samples were kept at -20°C until analysis.

4.2.4 Analysis of pesticide residues

Analysis of pesticide residues in vegetables was performed by gas chromatography mass spectroscopy (GC-MS) as described by AOAC, 2005, Method number 2007.01.

4.2.5 Ethical Approval

Consent to participate in the study was sought from all the participants. A pre-prepared consent letter was read-out to all the participants and those who consented to its contents signed on it to express their informed consent to participate in the study. For those who could not write, the consent letter was approved by the medical officer in-charge, on their behalf.

4.2.6 Data analysis

Data were entered in Microsoft Excel 2007 for calculation of the concentration of the residues in vegetables. Information on vegetable processing practices were analysed by SPSS version 21. Descriptive statistics were used to interpret the observed information. Chi-square was used to analyse the association between the household processes and pesticide residue in vegetables. Result on association of the practice and pesticide residues in vegetables was considered significant at $P \leq 0.05$.

4.3 Results and discussion

4.3.1 Participants' compliance

A total of 87 respondents with NCDs were recruited and consented to participate in the study. In the course of home visits for data collection, 17 respondents dropped out due to various reasons including changing of residence (3), serious sickness (1), busy schedule in business (7), travelled for a long period (2), and non-reachability of provided telephones (4). Therefore, a total of 70 individuals completed the study. The dropouts did not affect the statistical outcome of the study as the minimum number of participants required for this study at a statistical power of 0.8 is 65.

4.3.2 Demographic information

Individuals who participated in the current study were mainly women (64%) with a mean age of 55 years ranging from 35 to 75 years. Similar age groups on NCDs are reported by WHO (http://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases). Most of the individuals were literate with primary education (57.1%) or secondary or higher level education (32.9%). Some of them were occupied in farming (24.3%), business (21.4%) or both farming and business (5.7%). Others were retired (5.7%) or involved in household activities (21.4%). Fifteen (21.4%) had formal employment (teaching, driving, technicians, and accountancy) indicating that most of the individuals were informally employed (Table 15).

Table 15: Socio-demographic characteristics of respondents (n = 70)

Variable	Category	Percentage (%)
Sex	Male	35.7
	Female	64.3
Age	Less than 35	1.4
	36-45	15.7
	46-60	50
	61and above	32.9
Level of education	No formal education	1.4
	Primary school	57.1
	Secondary and higher level	32.9
Occupation	Farming	24.3
	Business	21.4
	Farming and business	5.7
	Formal employment	21.4
	Household activities	21.4
	Retired	5.7

4.3.3 Recipes of vegetables

In each household, generally, vegetable recipes contained a combination of more than one type of vegetables. Principal ingredient(s) in the vegetable meals were African nightshade, *Amaranthus spp.*, kale, Ethiopian mustard, sweet potato leaves, headed cabbage, chinese cabbage, okra, african eggplant, cucumber, pumpkin and bean leaves. Minor ingredients were onion, carrot, tomato and sweet pepper. In two recipes (3%) for salad, tomato and carrot were used as principal ingredients. Forty five recipes had one principal ingredient whereas 25 had two or more principal ingredients. The principal ingredients, either mixed or single, are as presented in Table 16. As minor ingredients, 65 (93%) of recipes contained onions; 47 (67%),

tomato; 50 (71%), carrot and 20 (29%), sweet pepper. Of the 70 samples, the most reported/observed vegetables were African nightshade (19%) and *Amaranthus spp* (10%) or a mix of the two (10%). The recipes in Arusha city comprise of exotic vegetables like carrots, tomatoes and sweet pepper that are not commonly added in recipes reported in Meatu-Shinyanga, Tanzania by Ang (2012). Availability of exotic vegetables in Arusha could be contributed to the fact that, Arusha is a tourist city, thus the tourists would demand for such varieties. This encourages farmers to grow such vegetables. Meatu is characterized with long period of dry season, therefore, relying more on dried than fresh vegetables which include dried wild cucumber leaves, cowpea leaves, jute mallow, pumpkin leaves and spider leaves (Ang, 2012).

Table 16: Diversity of vegetable recipes in Arusha city

Vegetable name	Number of samples, *f* (%)
Potato leaves	3(4.3)
African nightshade	13(18.6)
Cabbage	4(5.71)
Ethiopian mustard	4(5.71)
Chinese cabbage	5(7.10)
Cucumber	3(4.29)
Eggplant	1(1.43)
Kale	3(4.29)
Carrot	1(1.43)
Tomato	1(1.43)
Amaranthus spp	7(10.0)
Amaranthus spp and african nightshade	7(10.0)
Ethiopian mustard, sweet potato leaves, bean leaves, african nightshade and chinese cabbage	1(1.43)
Ethiopian mustard, kale and chinese cabbage	1(1.43)
Sweet potato leaves and kale	1(1.43)
Amaranthus spp, ethiopian mustard, chinese cabbage and kale	1(1.43)
Amaranthus spp, bitter lettuce, pumpkin leaves	1(1.43)
Amaranthus spp and ethiopian mustard	1(1.43)
Nightshade and pumpkin leaves	2(2.86)
Amaranthuss pp and african eggplant	1(1.43)
Potato and pumpkin leaves	1(1.43)
Amaranthus spp and *Caylusea abyssinica*	1(1.43)
Ethiopian mustard and kale	1(1.43)
Cabbage, tomato, carrot, sweet pepper and cucumber	1(1.43)
Ethiopian mustard and chinese cabbage	1(1.43)
Okra, african eggplant	2(2.86)
Okra, african eggplant, eggplant	1(1.43)
Okra, african eggplant and carrot	1(1.43)
Total	**70**
Single principal ingredient recipes	**45(64.3)**
Mixed principal ingredients recipes	**25(35.7)**

4.3.4 Occurrence of pesticide residues in vegetables

Of the samples collected before and after household handling, 32 (45.7%) and 10 (14.3%), respectively, were detected with pesticide residues (Table 17). African nightshade and *Amaranthus spp* were the most contaminated vegetables, whereby 38.5% of the African nightshade and 71.4% of *Amaranthus spp.,* were found with detectable pesticide residues.

Some samples including eggplant, tomato and a mixture of *Amaranthus spp*, ethiopian mustard, chinese cabbage and kale, *Amaranthus spp.* and ethiopian mustard, *Amaranthus spp.* and *Caylusea abyssinica* and african eggplant and eggplant were not commonly consumed by most of respondents. As a result only one sample per each of these vegetables/mixtures was collected and found contaminated with pesticide residues. This calls for another study to validate such results.

After household handling, fewer vegetables recipes (14.3% of the ready-to-eat vegetables) were found contaminated with detectable pesticide residues indicating the benefits of household processing. Similar results were found in previous studies (Chauhan *et al.,* 2012; Satpathy *et al.,* 2012; Sheikh *et al.,* 2012).

Table 17: Occurrence of pesticide residues in raw and ready-to-eat vegetables

Vegetable	Percent positive samples	
	Raw	Ready-to-eat
Sweet potato leaves	1(33.3)	0.00
African nightshade	5(38.5)	2(15.4)
Cabbage	1(25.0)	1(25.0)
Ethiopian mustard	1(25.0)	1(25.0)
Chinese cabbage	1(20.0)	0(0.00)
Cucumber	0(0.00)	0(0.00)
Eggplant	1(100)	0(0.00)
Kale	0(0.00)	0(0.00)
Carrot	0(0.00)	0(0.00)
Tomato	1(100)	0(0.00)
Amaranthus spp	5(71.4)	0(0.00)
Amaranthus spp and african nightshade	3(42.9)	1(14.3)
Ethiopian mustard, sweet potato leaves, bean leaves, nightshade and chinese cabbage	0(0.00)	0(0.00)
Ethiopian mustard, kale and chinese cabbage	1(100)	0(0.00)
Sweet potato leaves and kale	0(0.00)	0(0.00)
Amaranthus spp, ethiopian mustard, chinese cabbage and kale	1(100)	0(0.00)
Amaranthus spp, bitter lettuce, pumpkin leaves	0(0.00)	0(0.00)
Amaranthus spp and ethiopian mustard	1(100)	1(100)
African nightshade and pumpkin leaves	2(100)	1(50)
Amaranthus spp and african eggplant	0(0.00)	0(0.00)
Potato and pumpkin leaves	0(0.00)	0(0.00)
**Amaranthus spp* and *Caylusea abyssinica*	1(100)	1(100)
Ethiopian mustard and kale	0(0.00)	0(0.00)
Cabbage, tomato, carrot, sweet pepper and cucumber	0(0.00)	1(100)
Ethiopian mustard and chinese cabbage	0(0.00)	0(0.00)
*Okra, african eggplant	1(50)	1(50)
*Okra, african eggplant, **carrot	1(100)	0(0.00)
*Okra, african eggplant, eggplant	1(100)	0(0.00)
Overall	**32(45.7%)**	**10(14.3)**
Single ingredient recipes	**23(32.8%)**	**4(5.71)**
Multiple ingredient recipes	**9(12.8%)**	**6(8.57)**

Note: *samples were analysed for pesticide residues individually in their raw form **not detected with residues

In the raw vegetables, organophosphates were more prevalent (22.8%) followed by pyrethroids (14.3%) (Table 18). Similar results were observed in Ghana (Asiedu, 2013). Among the organophosphates quantified, dichlorvos (7.1%) and profenofos (1.4%) were the most and the least frequently detected pesticides, respectively. Other organophosphate pesticides detected in the vegetable samples were chlorpyrifos, pirimiphos-methyl,

dimethoate, and malathion. Dichlorvos is class Ib insecticide approved for restricted use in storage of grains in Tanzania (URT, 2011). Its detection in vegetables could indicate misuse or cross-contamination of the pesticide. Quantification of pesticides which are not approved for use in vegetables has also been reported in other studies (Elgueta *et al.,* 2017; Esturk *et al.,* 2011).

Table 18: Prevalence of pesticide residues in raw vegetables

Pesticide group (prevalence, (%))	Pesticide	Prevalence (%)	Range (mg kg^{-1})	Median ±SD[1] (mg kg^{-1})
Organophosphates (22.8)	Dimethoate	5.7	2.76-14.4	13.1±10.1
	Profenofos	1.4	0.005-6.12	6.12±0.005
	Dichlorvos	7.1	28.0-91.2	61.5±25.7
	Malathion	2.8	2.03-10.6	6.3±6.04
	Chlorpyrifos	5.7	7.47-16.8	13.8±4.47
	Pirimiphos-methyl	5.7	0.11-0.51	0.32±0.32
Pyrethroids (14.3)	Permethrin	8.6	0.16-1.12	0.59±0.41
	Cyhalothrin	2.8	0.51-18.8	9.63±12.9
	Cypermethrin	2.8	28.3-56.6	42.4±20.0
	Tetramethrin	5.7	1.77-63.0	33.3±26.1
Organochlorines (7.14)	Endosulfan	2.8	0.35-1.23	0.79±0.62
	Dieldrin	4.3	1.74-2.53	2.12±0.40
Benzoic acid (7.14)	Dicamba methyl ester	7.1	2.25-34.3	13.9±9.43
Carbamates (5.71)	Bendiocarb	5.7	8.10-22.9	15.6±7.68

[1]Standard deviation

Among the pyrethroids, permethrin was the most frequently detected pesticide at prevalence of 8.6% whereas cyhalothrin and cypermethrin were the least quantified at a prevalence of 2.8% each (Table 18). These pesticides are approved for management of pests in horticultural crops in Tanzania (URT, 2011).

Tetramethrin was another pyrethroid pesticide quantified in the vegetable samples at a prevalence of 5.7%. In Tanzania, tetramethrin is not approved for use in vegetables but for management of domestic insects (URT, 2011). Therefore its occurrence in vegetables could result from cross-contamination during storage of vegetables or misuse of the product.

The use of insecticides for household pests to control pest in vegetables is reported in Morogoro whereby Sumithrin piperonylbutoxide approved for control of mosquitoes was found to be applied in tomatoes (Mdegela *et al.,* 2013). This result suggests a need for awareness creation to farmers on the side effects associated with inappropriate use of

pesticides and promotion of attitude change from misuse to proper use of pesticides and adherence to label directives when spraying around household settings to avoid contamination of food and domestic utensils.

Residues of two organochlorine pesticides namely endosulfan (2.6%) and dieldrin (3.9%) were detected (Table 18). Endosulfan is reported as a commonly used insecticide in management of insects in vegetables in Tanzania and in other developing countries. Dieldrin is a metabolic product of aldrin and it is more stable and persistent in environment than its parent compound (Deck *et al.,* 2015). Detection of dieldrin in the vegetables indicates that its residues are still persisting in the environment and thus contaminate the crops (Lekei *et al.,* 2014a; Manyilizu and Mdegela, 2015; Nonga *et al.,* 2011; Swarman and Velmurugan, 2012).

Organochlorine pesticides have been banned for use in Tanzania since 1997 due to their persistent and bioaccumulation properties with exception of endosulfan which was lastly registered under restricted use in 2011 for a provision of three years (Agenda, 2006; URT, 2011). Given a provision of three years from 2011 implies that, endosulfan should have been stopped from use by 2014. However, a survey done in Arusha district in 2015 revealed that farmers were still applying this pesticide in vegetables (Kiwango *et al.*, 2018a), indicating a need for improved reinforcement of pesticide use management regulations.

Furthermore, one carbamate (bendiocarb) and one benzoic acid (dicamba methyl ester) pesticides were detected in the raw samples. Bendiocarb, which was found in 5.7% of the samples (Table 18), is not approved for use in crops but for control of mosquitoes in Tanzania. Therefore its detection in the vegetables could indicate cross-contamination or misuse of the product (tetramethrin) as it was described earlier in this section. Dicamba methyl ester which was found in 7.1% of the samples is approved in Tanzania for control of weeds in maize (URT, 2011). Therefore, farmers might have been inappropriately using this herbicide to control weeds in vegetables. This implies that, trials for safe use of this pesticide in vegetables are yet to be done in Tanzania, therefore, difficult to control its residues at safe levels. Chronic exposure to unsafe levels of dicamba may cause adverse health effects to the reproductive system of the consumer (https://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+311).

Among the 32 raw vegetable samples with residues, 13 (40.6%) contained two to four different types of pesticides (Table 19). Tomatoes contained the four types of pesticides

followed by a mixed vegetable prepared from *Amaranthus spp* and nightshade, which contained three types of pesticides, each. Among the 13 samples with multiple residues, 10 (76.9%) had multiple residues from different pesticide groups whereas the remaining (23.1%) samples contained residues from one pesticide group. Multiple occurrences of pesticide residues in the vegetables confirm previous reports (Mhauka, 2014; Ngowi *et al.*, 2007) that, due to high infestation of pests and diseases of vegetables, farmers apply different types of pesticides onto the vegetable. Also, due to ignorance, farmers mix pesticides with different trade names but containing similar active ingredient. Multiple occurrences of pesticide residues in vegetables lead to health risks associated with human exposure to all such pesticides.

Co-occurrences of pesticide residues have been reported in various studies. A study in India found more than one pesticide residues in 10.8% of analysed vegetable samples (Swarman and Velmurugan, 2012). Also, a study conducted in Chile found that 64% of lettuce, 65% of chard and 72% of spinach samples were contaminated with multiple residues (Elgueta *et al.*, 2017). These results call for a continuous monitoring of pesticide residues in vegetables and reinforcement of regulations to control their use and ensure safe vegetables supply chain. It also calls for improved extension services and education on implementation of good pest management practices.

Table 19: Occurrence of multiple pesticide residues in raw vegetables

Vegetable	Pesticide residues combination	Prevalence (%)
Nightshade	Dichlorvos and bendiocarb	1(7.7)
Chinese cabbage	Dicamba methyl ester and chlorpyrifos	1(20)
Ethiopian mustard	Dicamba methyl ester and dieldrin	1(20)
Eggplant	Pirimiphos-methyl and chlorpyrifos	2(100)
	Chlorpyrifos and permethrin	
Okra	Dimethoate and pirimiphos-methyl	2(50)
	Tetramethrin and permethrin	
African eggplant	Dichlorvos and tetramethrin	1(25)
Sweet potato leaves	Pirimiphos-methyl and cypermethrin	1(33.3)
African egg plant	Endosulfan and bendiocarb	1(25)
Amaranthusspp	Bendiocarb and dimethoate	1(12.5)
Tomato	Pirimifos-methyl, chlorpyrifos, permethrin and cypermethrin	1(100)
Amaranthus and nightshade	Malathion, dichlorvos, and permethrin	1(5)

All detectable pesticide residues were quantified at levels exceeding the EU maximum residue limits (Table 20). This indicates that farmers did not observe the pre-harvest interval

after pesticide application. Kiwango *et al.* (2018a) and Mhauka, (2014) report that most of vegetable farmers do not adhere to pre-harvest interval. Quantifying pesticide residues in vegetables at levels above MRL can expose the vegetable consumer at health risks associated with pesticides.

Table 20: Prevalence of vegetables exceeding maximum residue levels (MRL)

Vegetable (n)	Pesticide name	MRL[a] (mg kg^{-1})	Mean±SD[b] (mg kg^{-1})	Percent positive samples	Percent mean exceeding MRL
African nightshade (13)	Malathion	0.02	2.03±0.006	7.7	7.7
	Dichlorvos	0.01	43.3±0.009	7.7	7.7
	Dieldrin	0.05*	1.74±0.001	7.7	7.7
	Bendiocarb	0.01	15.8±8.21	15.4	15.4
	Dicamba methyl ester	0.05	2.25±0.006	7.7	7.7
Amaranthus (8)	Dichlorvos	0.01	72.4±8.23	25	25
	Dimethoate	0.02	6.60±0.001	12.5	12.5
	Permethrin	0.05	0.37±0.006	12.5	12.5
	Cyhalothrin	0.05	0.51±0.003	12.5	12.5
	Tetramethrin	0.01	24.3±0.003	12.5	12.5
Chinese cabbage (5)	Permethrin	3.00*	0.45±0.006	20	20
Ethiopian mustard(4)	Dieldrin	0.05*	2.53±0.001	25	25
	Dicamba methyl ester	0.05	3.40±0.006	25	25
Cabbage (4)	Chlorpyrifos	1.0	16.8±0.003	25	25
Sweet potato leaves(3)	Pirimiphos	0.01	0.50±0.006	33.3	33.3
	Cypermethrin	0.7*	28.3±0.004	33.3	33.3
Eggplant (1)	Pirimiphos	0.01	0.12±0.006	100	100
	Chlorpyrifos	0.05	13.7±0.003	100	100
Tomato (1)	Pirimiphos	0.01	0.51±0.006	100	100
	Chlorpyrifos	1.0*	7.47±0.003	100	100
	Permethrin	1.0*	0.16±0.006	100	100
	Cypermethrin	0.2*	56.6±0.004	100	100
Mixed vegetables (25)	Profenofos	0.05*	6.12±0.005	4	4
	Malathion	0.02	10.6±0.006	4	4
	Dimethoate	0.02	6.68±6.66	12	12
	Dichlorvos	0.01	59.6±44.7	8	8
	Pirimiphos	0.01	0.15±0.006	4	4
	Chlorpyrifos	0.01	17.1±0.003	4	4
	Permethrin	0.05	0.86±0.42	12	12
	Cyhalothrin	0.05	18.8±0.003	4	4
	Tetramethrin	0.01	53.6±12.2	8	8
	Endosulfan	0.01	0.79±0.62	4	4
	Bendiocarb	0.01	8.10±0.004	4	4
	Dicamba	0.01	18.7±22.1	8	8

Note: [a]maximum residue level set by European Union except those with * MRLs set by CODEX alimentarius commission [b]standard deviation; for samples whose "n" is 1 the value for limit of quantification of the particular pesticide was used as the SD.

Of the 70 ready-to-eat vegetable samples analysed, a total of seven active ingredients of pesticides were detected in 10 (14.3%) samples (Tables 17 and 21). The most prevalent pesticide group was pyrethroid which was found in 11.4% of the samples, followed by organophosphates found in 8.6% and organochlorines in 5.7% of the vegetable sample (Table

21). Endosulfan which is an organochlorine pesticide (banned from use in agriculture) was quantified in 5.7% of the samples.

Organophosphate and pyrethroid pesticide residues quantified in the ready-to-eat vegetables with their prevalence included pirimiphos-methyl (7.1%), chlorpyrifos (4.3%), and dimethoate (1.4%) for organophosphates and permethrin (5.7%), tetramethrin (2.9%), and cyhalothrin (1.4%) for pyrethroids (Table 21). These pesticides are registered in Tanzania for control of pests in vegetables.

Table 21: Pesticide prevalence and content in ready-to-eat vegetables

Pesticide group (prevalence, %)	**Pesticide**	**Prevalence (%)**	**Range**	**Mean ±SD[1] (mg kg^{-1})**
Organophosphates (8.6)	Dimethoate	1.4	0.003-4.40	0.003-4.40
	Chlorpyrifos	4.3	8.98-19.8	14.7±5.44
	Pirimiphos-methyl	7.1	0.04-0.15	0.09±0.04
Pyrethroids (11.4)	Permethrin	5.7	0.41-2.55	1.24±0.78
	Cyhalothrin	1.4	0.003-0.27	0.003-0.27
	Tetramethrin	2.9	3.62-21.3	14.4±12.5
Organochlorines (7.1)	Endosulfan	5.7	0.71-24.4	6.98±11.6

[1]Standard deviation

All pesticide residues in the ready-to-eat vegetables were quantified at levels above their MRL set by European Union. The mean concentrations and prevalence of these pesticides in the ready-to-eat vegetables are presented in Table 22. The occurrence of the pesticide residue in the ready-to-eat vegetables at levels above their respective MRL calls for an immediate intervention to protect human health.

Table 22: Prevalence of vegetables exceeding maximum residue levels (MRL)

Vegetable (n)	Pesticide	Mean±SD[1] (mg kg-1)	MRL (EU)	% positive samples	% mean exceeding MRL
African nightshade (13)	Malathion	5.20±0.005	0.02	7.7	7.7
	Chlorpyrifos	15.3±0.003	0.01	7.7	7.7
	Dimethoate	4.40±0.003	0.02	7.7	7.7
	Pirimiphos methyl	0.09±0.01	0.01	14.4	14.4
	Permethrin	2.55±0.005	0.05	7.7	7.7
	Endosulfan	1.42±0.57	0.05	15.4	15.4
Ethiopian mustard(4)	Chlorpyrifos	19.8±0.003	0.01	25	25
	Permethrin	1.78±0.005	0.05	25	25
Cabbage (4)	Permethrin	0.41±0.005	0.05	25	25
Mixed vegetables (25)	Chlorpyrifos	8.98±0.003	0.01	4	4
	Pirimiphos methyl	0.12±0.05	0.01	8	28
	Permethrin	1.49±0.005	0.05	4	4
	Tetramethrin	14.4±9.45	0.01	8	8
	Cyhalothrin	0.27±0.003	0.05	4	4
	Endosulfan	12.5±16.7	0.05	16	16

Pesticide residues were more prevalent in mixed vegetables (60%) than those prepared from one major vegetable (40%). This is contrary to the so called 'dilution effect' as described in FAO/WHO guideline for assessment of dietary exposure of chemicals in food (FAO/WHO, 2005). Therefore this needs further research to validate the results.

The prevalence of pesticides in ready-to-eat vegetable sampled from selected households in Arusha city was much lower than previously reported for selected farms from Arusha district (Kiwango *et al.*, 2018a) where pesticides were detected in 28 (40%) out of 70 samples. Pesticides are normally dissipated during storage and transportation (FAO/WHO, 1997b). This could contribute to the low prevalence of the residues in vegetables in Arusha city.

Detection of organochlorine residues in vegetables has also been reported in various literature including studies done in Dar-es-Salaam, Tanzania (Mahugija *et al.*, 2017; Ndengerio-Ndossi and Cram 2005), Basque (Lemos *et al.*, 2016), and Cameroon (Gimou *et al.*, 2008). Pyrethroids and organophosphates are reported as the most frequently applied pesticides in vegetable farming (Ngowi *et al.*, 2007).

Among the 10 ready-to-eat vegetable samples containing pesticide residues, six (60%) equivalent to 8.6% of all analysed ready-to-eat vegetable samples were found with multiple pesticide residues. Up to five pesticide residues were quantified in a sample (Table 23). Also, these multiple pesticide residues were from different pesticide groups. For instance, two samples were quantified with pesticide residues from organochlorine, pyrethroid and organophosphate. The other five samples contained residues from organochlorine and pyrethroids (1), pyrethroids and organophosphates (3) or organochlorine and organophosphates (1). Co-occurrence of multiple pesticide residues in the same meal exposes consumer to multiple health risks associated with exposure to these residues (EFSA, 2008). Multiple occurrences of pesticide residues are also reported in other studies (Esturk *et al.*, 2011; Thabet *et al.*, 2016a).

Table 23: Co-occurrence of pesticide residues in ready-to-eat vegetables

Vegetable (n)	Pesticide residues combination	Prevalence (%)
Amaranthus and nightshade (7)	Tetramethrin, pirimiphos-methyl, and endosulfan	14.3
Cabbage, tomato, carrot and cucumber (1)	Chlorpyrifos, pirimiphos-methyl and permethrin	100
Cabbage (4)	Pirimiphos-methyl and permethrin	25.0
Nightshade (13)	Pirimiphos-methyl and endosulfan	15.4
	Endosulfan, dimethoate, pirimiphos-methyl chlorpyrifos and permethrin	
Ethiopian mustard (4)	Chlorpyrifos and permethrin	25.0

4.3.5 Impact of household processes on pesticide residues

The common household practices on vegetable preparation identified in Arusha city included sorting, trimming, washing, peeling, chopping and cooking.

(i) Sorting and trimming

In every household visited, sorting and/or trimming were done prior to further processes. These were done to remove dirt, over-matured stems, damaged and yellowish leaves. Also, the outer stem tissue for leafy vegetables was removed. The stalk for okra, African eggplant and tomato were trimmed off after washing. It is reported in literature (Bajwa and Sandhu, 2014) that, most of the non-systemic pesticide residues are more concentrated on the outer surfaces of leaves and at the fruit stalk and exocarp for fruiting vegetables. Therefore their

removal may reduce considerable amount of residues from the vegetable (FAO/WHO, 1997b).

(ii) Washing

The survey found that, all visited households practise washing of vegetables before further preparation. It was revealed that there is a wide variation on procedures of vegetable washing in the visited households. The variation was based on frequency of washing, mode of washing and treatment of minor ingredients (onions, carrot, tomato, sweet pepper). Most of the households 68 (97.1%) wash their vegetables in bowl whereas two (2.9%) wash in running water from tap. In the reported studies, vegetables were mostly washed under tap or distilled water, with addition of washing chemicals like brine solution, sodium bicarbonate, and acetic acid (Zhang *et al.*, 2006; Vemuri *et al.*, 2007; Tomer and Sangha, 2013). These practices were not common in the study area.

Frequency of washing vegetables in bowl

For those who wash vegetables in bowl, majority 41 (58.6%) wash twice whereas few of them wash once 14 (20%) or more than twice 13 (18.6%) before further preparation. The vegetables are washed by hand followed by streaming the water by removing the vegetables from the bowl. The dirty water is poured off and clean water added to the bowl to repeat the procedure, for those who wash the vegetables more than once.

In 14 households in which vegetables were washed once, five (35.7%) vegetables were found contaminated with residues. Among the 41 households in which vegetables were washed twice, three (7.3%) samples were found with residues whereas out of 13 households in which vegetables were washed three times or more, one (7.7%) was found with residues. The vegetable sample which was washed three times and detected with residues had its minor ingredients washed once with the water that had been used to rinse a principal ingredient. Chi-square analysis indicated that, there was a statistically significant association between frequency of washing and occurrence of pesticide residues in the ready-to-eat vegetables (χ^2 (1) = 6.563, P = 0.01) whereby, washing of vegetables in a bowl more than once was significantly more effective in reducing the pesticide residues than washing only once.

Experiments on washing vegetables in bowl are not reported. Therefore this information gives a background for further studies on optimizing frequency of washing of vegetables in

bowl for effective reduction of pesticide residues and other contaminants, while maintaining the nutrional quality of the vegetables.

Treatment of minor ingredients

In some of households 6 (8.6%), less attention is given to minor ingredients (onion, carrot, tomato, sweet pepper) during washing. Among the 41 households who washed vegetables twice, and 13 households who washed vegetables three times, three (7.3%) and one (7.7%) washed the minor ingredients only once, respectively. The water used to wash the minor ingredients had been used to rinse the major ingredients. In one of the households who washed vegetables under running tap water washed the principal ingredient (cabbage) for a longer period (average 17sec) than the time (average 5sec) used to wash the minor ingredients (carrot). In the other household, they washed african nightshade for an average of 2.26 minutes and one minute for onion, carrot and tomato.

Among the six samples whose minor ingredients were less treated during washing, five (83.3%) were detected with pesticide residues. When chi-square analysis was performed it revealed that, after controlling for confounding factors of frequency of washing there was a significant association between treatment given to minor ingredients during washing and occurrence of pesticide residues in the ready-to-eat vegetable ($\chi^2(1) = 25.551$, $P = 0.001$). Of the pesticide residues which occurred in ready-to-eat vegetable and previously not detected in their respective fresh major vegetable, dimethoate was quantified in one sample. Others were chlorpyrifos and pirimiphos-methyl residues which were quantified in three and five ready-to-eat vegetables, respectively. The minor ingredients in the contaminated samples were either not peeled (carrot, tomato, african eggplant) or washed once. These results indicate that, if not properly washed as the principal ingredients, minor ingredients may contribute to the contamination of the ready-to-eat vegetables with pesticide residues given that they contained these residues in their raw form.

Washing of vegetables has been reported as one of the effective household vegetable processes that can reduce pesticide residues from raw agricultural produce (Randhawa *et al.*, 2007). A study reported that, washing of green beans reduced pirimiphos-methyl by 53.6% whereas washing treated tomato with tap water reduced profenofos residues between 12.90% to 12.60% depending on time from pesticide application and harvest (Mohamed *et al.*, 2010).

Volume of washing water

It was revealed that there is a variation on the volume of water used to wash vegetable on a bowl with respect to the amount of vegetables among households. It was found that 52 (74.2%) of those who wash vegetables in a bowl, fill the bowl with water to the level of the vegetables whereas 16 (22.9%) of them who wash vegetables with plenty of water, far above the level of the vegetables in the bowl. Among the vegetables which were washed in plenty of water, eight (50%) contained pesticide residues in their raw form. After processing the vegetables, all of them had no detectable residues (100% reduction). For the vegetables which were washed with water at the same level as the vegetables, 20 (38.5%) had pesticide residues in their raw form and after household processes, 18 (90%) had no detectable residues. However, volume of washing water had no significant association ($\chi^2(1) = 0.432$, $P = 0.511$) with reduction of residues indicating that both levels of water were adequate in reducing pesticide residues in the vegetables

(iii) Peeling

Peeling of vegetables was a common practice in all the visited households. Onion is usually peeled to remove the outer dry cover. In all observations, the outer tissue of the stem were peeled out from leafy vegetables including *Amaranthus spp.*, african nightshade, ethiopian mustard, pumpkin leaves and chinese cabbage. In 34 (48.6%) households, tomato, african eggplant and/or carrot were peeled to remove the outer skin. Among the households who prepared salad, four of them included cucumber in the recipe. The whole skin of cucumber was peeled out in two, partially peeled in one and not peeled at all in one out of the four cucumbers.

Peeling influenced residue content in the ready-to-eat vegetables. Carrot, eggplant and/or tomato were peeled in 55% of the vegetables not detected with pesticide residues. Carrot and tomato were not peeled in 90% of the samples detected with residues. The chi-square test showed a significant association between the practice of not peeling vegetables and occurrence of pesticide residues in the ready-to-eat vegetables ($\chi^2(1) = 6.949$, $P = 0.008$), after adjusting for the effect of minor ingredients washing.

Removal of outer tissue of the vegetable could lead to reduction of pesticide residues concentrated on the peel. In a study by (Randhawa *et al.,* 2007), peeling removed 67% and 60% of endosulfan residues in potato and brinjal, respectively.

(iv) Cooking

Most of the visited households 63 (90%) cooked vegetables before consumption. Vegetable cooking included frying, steaming and boiling. Of the households who cooked vegetables 40 (63.5%) fried the minor ingredients. After frying, the major ingredients were added and steamed in 37 or steamed followed by boiling in 3 households. In 4 (5.7%) households, the vegetables were steamed followed with boiling without frying. In 19 households vegetables were steamed and in 5 households, boiled only.

The frying duration varied from one to 24 minutes with an average of 5.12 minutes. Steaming duration ranged from two to 34 minutes with an average of 11.22 minutes whereas boiling duration ranged from seven to 29 minutes with an average of 14.33 minutes. Total cooking duration ranged from four to 42 minutes with an average of 14.33 minutes.

The 10 ready-to-eat vegetable samples quantified with pesticide residues were prepared in less than 30 minutes with an average duration of 8.7 minutes. Reduction of residues was effective in vegetables cooked for 30 minutes or more. Reports show that cooking can increase volatilization, hydrolysis and decomposition of pesticide thus, reducing their concentration in ready-to-eat food (Shoeibi *et al.,* 2011). However, chi-square analysis showed that there was no association between the duration of cooking and reduction of pesticide residues ($\chi^2(1) = 0.273$, $P = 0.601$).

4.3.6 Cumulative influence of household handling processes

Cumulative effects of household vegetable handling from sorting to cooking altered pesticide residue content in the vegetables. For instance, Profenofos, malathion, dimethoate and dichlorvos were detected in one, two, four and five out of 70 raw vegetable samples, respectively. After household handling of these vegetables, the quantified residues were below their corresponding detection limits (Table 24).

Dichlorvos is unstable and volatile pesticide thus easily removed by heat treatment (Bajwa and Sandhu, 2014). A study by Mohamed *et al.* (2010) found that profenofos and malathion can be reduced to non-detectable levels by washing, peeling and cooking. Malathion is highly sensitive to hydrolysis which is one of the ways of pesticide degradation (Keikotlhaile *et al.,* 2010; Newhart, 2006; Tano, 2011). Therefore this could allow its complete degradation from the vegetables after household handling processes.

Chlorpyrifos and pirimiphos methyl were detected in three and four vegetable samples, respectively. After processing, chlorpyrifos concentration in the three samples was below the LoD (0.003 mg kg^{-1}). However, two ready-to-eat vegetable samples not detected with the residue in their raw form were found contaminated after processing. After processing, pirimiphos-methyl concentration was below its LoD (0.004 mg kg^{-1}), but two ready-to-eat vegetables not contaminated with the residue in their raw form were detected with the residue. Occurrence of residues in ready-to-eat vegetables that were previously not detected could be due to contamination from other ingredients (water, oil and the minor ingredients) which were not analysed for residues before use.

Table 24: Influence of household processing of vegetables on profenofos, dimethoate and dichlorvos residues (the values are the mean concentration for the respective vegetable)

	Profenofos (mg kg^{-1})		Dimethoate (mg kg^{-1})		Dichlorvos (mg kg^{-1})	
Vegetable	**Before processing**	**After processing**	**Before processing**	**After processing**	**Before processing**	**After processing**
Nightshade	<0.005[f]	<0.005	11.37	4.40	43.29	<0.006
Amaranthus spp	<0.005	<0.005	6.6	<0.003	72.43	<0.006
Chinese cabbage	<0.005	<0.005	<0.001	<0.003	<0.009	<0.006
Ethiopian mustard	<0.005	<0.005	<0.001	<0.003	<0.009	<0.006
African eggplant	<0.005	<0.005	<0.001	<0.003	28.02	<0.006
Okra	<0.005	<0.005	2.9	<0.003	<0.009	<0.006
Cabbage	<0.005	<0.005	<0.001	<0.003	<0.009	<0.006
Sweet potato leaves	<0.005	<0.005	<0.001	<0.003	<0.009	<0.006
Egg plant	<0.005	<0.005	<0.001	<0.003	<0.009	<0.006
Tomato	<0.005	<0.005	<0.001	<0.003	<0.009	<0.006
Carrot	<0.005	<0.005	<0.001	<0.003	<0.009	<0.006
Mixed vegetables	6.12	<0.005	8.56	<0.003	91.19	<0.006

[f]less than (<)' values are the limit of detection for the particular pesticide obtained during method validation. This note also applies to Table 25 and 26.

Table 24: cont...

Vegetable	Malathion (mg kg^{-1})		Chlorpyrifos (mg kg^{-1})		Pirimiphos methyl (mg kg^{-1})	
	Before processing	After processing	Before processing	After processing	Before processing	After processing
Nightshade	2.030	<0.005	<0.003	<0.003	0.090	0.080
Amaranthus spp	<0.006	<0.005	<0.003	<0.003	<0.006	<0.004
Ethiopian mustard	<0.006	<0.005	<0.003	19.82	<0.006	<0.004
African eggplant	<0.006	<0.005	<0.003	<0.003	<0.006	<0.004
Okra	<0.006	<0.005	<0.003	<0.003	0.015	<0.004
Cabbage	<0.006	<0.005	16.78	<0.003	<0.006	0.040
Sweet potato leaves	<0.006	<0.005	<0.003	<0.003	0.500	<0.004
Egg plant	<0.006	<0.005	17.12	<0.003	0.110	<0.004
Tomato	<0.006	<0.005	7.470	<0.003	0.510	<0.004
Carrot	<0.006	<0.005	<0.003	<0.003	<0.006	<0.004
Mixed vegetables	10.57	<0.005	<0.003	8.980	<0.006	0.090

Two raw vegetable samples contained cypermethrin which was reduced to non-detectable levels after processing (Table 25). In other studies, cypermethrin is reported to be reduced by less than 70% through washing, peeling and cooking (Mohamed *et al.,* 2010; Walia *et al.,* 2010). Permethrin was found in five raw vegetable samples whereby after processing the permethrin residues were all below limit of detection. However, three ready-to-eat vegetables not detected with residues in their raw form were found contaminated with pesticide residues after handling. Previous literature shows that permethrin is reduced by 25% by cooking (Thanki *et al.,* 2012). Four raw samples contained tetramethrin residues. After processing, three out of the four samples contained the residue whereas in one of the samples the residue decreased by 92%. One sample previously not detected with pesticide residues was detected with tetramethirn. One raw vegetable sample contained cyhalothrin which decreased by 45% (from 0.51 to 0.28 mg kg^{-1}) after processing. It is reported that washing followed by boiling of tomato reduces lambda-cyhalothrin residues by 74-84% which is higher to that obtained in the current study (Chauhan *et al.,* 2012). The samples in which cypermethrin, permethrin and tetramethrin were removed to less than detection limit levels, were initially, washed twice or thrice, and tomato and carrot peeled and mostly cooked for more than 20 minutes with exception of one sample which was washed three times but cooked for four minutes. The samples in which permethrin, tetramethrin and lambda-cyhalothrin residues occurred after handling or reduced only were characterized by the ingredients (all or part of them) washed once only and/or cooked for less than 12 minutes.

Table 25: Influence of household processing on pyrethroid pesticide residues

	Permethrin (mg kg^{-1})		Tetramethrin (mg kg^{-1})		Cypermethrin (mg kg^{-1})		Cyhalothrin (mg kg^{-1})	
Vegetable	**Before processing**	**After processing**	**Before processing**	**After processing**	**Before processing**	**After processing**	**Before processing**	**After processing**
Nightshade	<0.006	2.550	<0.003	<0.004	<0.004	<0.009	<0.003	<0.003
Amaranthus spp	0.050	<0.005	24.29	<0.004	<0.004	<0.009	0.510	0.280
Chinese cabbage	0.450	<0.005	<0.003	<0.004	<0.004	<0.009	<0.003	<0.003
Ethiopian mustard	<0.006	1.830	<0.003	<0.004	<0.004	<0.009	<0.003	<0.003
African eggplant	<0.006	<0.005	44.99	<0.004	<0.004	<0.009	<0.003	<0.003
Okra	1.082	<0.005	62.24	<0.004	<0.004	<0.009	<0.003	<0.003
Cabbage	<0.006	0.410	<0.003	<0.004	<0.004	<0.009	<0.003	<0.003
Potato leaves	<0.006	<0.005	1.770	<0.004	28.27	<0.009	<0.003	<0.003
Egg plant	<0.006	<0.005	<0.003	<0.004	<0.004	<0.009	<0.003	<0.003
Tomato	0.160	<0.005	<0.003	<0.004	56.55	<0.009	<0.003	<0.003
Carrot	<0.006	<0.005	<0.003	<0.004	<0.004	<0.009	<0.003	<0.003
Mixed vegetables	0.370	<0.005	<0.003	14.40	<0.004	<0.009	<0.003	<0.003

Dieldrin was detected in three raw vegetable samples and its levels reduced to less than the limit of detection after preparation (Table 26). Dieldrin is a systemic pesticide persistent in the environment hence it could be absorbed during growth of the vegetables (Jas, 2007). Endosulfan was detected in two raw samples whereby after preparation, one was non-detectable while the other increased in concentration. In the sample whose endosulfan concentration increased had the minor ingredients washed once and tomato, carrot, and eggplant were not peeled. If the minor ingredients were contaminated with endosulfan residues could contribute in the increase of the concentration. It is reported that endosulfan is not easily removed by washing due to its lipophilic nature and therefore might be adsorbed to the waxy surface of the product (González-Rodríguez *et al.*, 2011). Also, evaporation during cooking can result into increased concentration of pesticide residues (Amvrazi, 2011).

Bendiocarb and dicamba methyl ester was found in one and four raw vegetable samples, respectively but their concentration decreased to less than their detection limit after handling (Table 26). Bendiocarb and dicamba are reported to have a relatively high vapour pressure making them unstable under thermal exposure and therefore undergo degradation before boiling (Pesticide Properties Database, 2017a, 2017b; Sibanda *et al.*, 2011).

Table 26: Influence of household processing on organochlorines, carbamates and benzoic acid

	Organochlorines				Carbamates		Benzoic acid	
	Endosulfan (mg kg^{-1})		Dieldrin (mg kg^{-1})		Bendiocarb (mg kg^{-1})		Dicamba methyl ester (mg kg^{-1})	
Vegetable	**Before processing**	**After processing**	**Before processing**	**After processing**	**Before processing**	**After processing**	**Before processing**	**After processing**
Nightshade	<0.005	1.420	1.740	<0.008	15.80	<0.004	2.250	<0.006
Ethiopian mustard	<0.005	<0.004	2.530	<0.008	<0.004	<0.004	3.400	<0.006
African eggplant	1.230	<0.004	<0.001	<0.008	<0.004	<0.004	<0.006	<0.006
Okra	<0.005	<0.004	<0.001	<0.008	8.100	<0.004	<0.006	<0.006
Mixed vegetables	0.350	12.50	<0.001	<0.008	<0.004	<0.004	18.70	<0.006

Combined household operations in vegetable preparation are effective in eliminating pesticide residues. Previous studies (El-Saeid and Selim, 2016; Joshi *et al.*, 2015; Yang *et al.*, 2012) show that the household processing considerably reduces pesticide residues in food crops. However in actual household operations, poor practices can lead to contamination of food previously with pesticide residues below limit of detection. It is therefore recommended that, households should carefully adhere to best vegetable handling practices for effective reduction of pesticide residues to safe levels.

4.3.7 Other routes of pesticides

Household vegetable handling practice considerably reduced pesticide residues to less than their respective LOD. Of the 32 raw vegetables that contained pesticide residues, 29 cleared after processing. However, seven out of the ten ready-to-eat vegetables not detected with residues in their raw form were found contaminated after processing. The new residues might have originated from the added minor ingredients, water used for processing and/or cooking oil. It should be noted that the principal ingredients were the only one drawn for pesticide residue analysis, before processing. It is reported that domestic water and cooking oil may be contaminated with pesticide residues (Amvrazi, 2011; Hellar-Kihampa, 2011; Lema *et al.*, 2014; Van Duijn, 2008).

Information from Arusha urban water supply and sanitation authority shows that, domestic water supply in Arusha city is from two springs, 19 boreholes and rivers. One of the spring and 16 boreholes are located in Arumeru district where pesticides are intensively applied to crops (http://www.auwsa.or.tz/services/auwsa/category/water_services). Rivers flow from the foot of mount Meru, the area which is intensively cultivated with vegetables with intensive pesticides application (Lekei *et al.*, 2014c; Ngowi *et al.*, 2007). Water from these rivers is also used for irrigation of the crops (Komakech and Zaag, 2011). The water from these sources might be contaminated with pesticide residues due to drift from vegetable farms or contamination due to poor practices of the farmers. Consequently, the pesticide residues in water from these sources could take their way to the vegetables during washing and cooking. The current study could not find available data on pesticide contamination levels for the water from these sources. It is therefore suggested that the water quality from these sources is assessed for pesticide residues.

Literature shows that pesticides, particularly the oil soluble ones tend to concentrate during oil extraction. Refining process has shown ability to significantly reduce these pesticide residues in the final product (Van Duijn, 2008). In Tanzania, only few companies process and supply refined oil. Other companies which are small scale process and supply unrefined sunflower oil (RLDC 2008), which was mostly preferred by the respondents due to its health qualities. The unrefined oil could be contaminated with pesticide residues thus a source of pesticide residues contamination in the ready-to-eat vegetables. These results suggests further studies to assess the pesticide residues content in cooking oil and domestic water to ensure that they are safe for domestic use.

4.4 Conclusion and recommendations

The findings of this study show that raw vegetables from households are highly contaminated with pesticide residues. Organochlorines which are banned from use in Tanzania (endosulfan and dieldrin) and unregistered pesticides for use in vegetables (tetramethrin, dichlorvos, dicamba methyl ester and bendiocarb) were quantified in the raw and/or ready-to-eat vegetables at levels above MRLs. Household vegetable processing effectively reduces pesticide residues in the ready-to-eat vegetables. Proper washing of all ingredients with adequate potable water followed with peeling of fruiting (tomatoes, african eggplant) and root (carrot) vegetables significantly reduce the pesticide residues in the vegetables to levels below their respective MRLs. Washing vegetables in a bowl require a repeated washing and rinsing for the pesticide residues to be eliminated. The recipes with mixed principal ingredients were found to be more contaminated than the ones with single principal ingredient contrary to the current principles and guidelines thus a need of further research. The quantification of banned and unregistered pesticides in vegetables at levels above MRLs reflects malpractices of pesticide use in vegetables among vegetable farmers. The study suggests pesticide management regulation be reinforced and continuous monitoring of pesticide residues to be done in order to ensure safe vegetables are supplied to consumers. Further, consumers should be advised on proper household handling including proper washing, peeling and adequate cooking of vegetables to ensure effective removal of pesticides from vegetables before consumption.

The quantification of pesticide residues in levels above MRLs and occurrence of endosulfan which is a banned organochlorine in the ready to eat vegetables at levels above MRLs raised

the need of estimating the risk of exposure to these residues. Therefore, individuals with NCDs were selected as high consumers of vegetables in Arusha city for this study. Results for the risk assessment of pesticide residues in individuals with NCDs are presented in chapter five.

CHAPTER FIVE

THE RISK OF DIETARY EXPOSURE TO PESTICIDE RESIDUES IN INDIVIDUALS WITH NON-COMMUNICABLE DISORDERS

Abstract

As reported in chapter four, ready-to-eat vegetables from the households of individuals with non-communicable disorders (NCDs) in Arusha city are contaminated with organophosphate, pyrethroid and organochlorine pesticides in levels above their respective maximum residue levels (MRLs). The current study assessed the risk of exposure to pesticide residues among individuals with (NCDs) in Arusha city, Northern Tanzania. A 24-hour recall and food frequency questionnaire were administered to collect vegetable consumption information among 70 individuals with NCDs. Pesticide residues data obtained in 70 ready-to-eat vegetable samples from the same individuals' households, during assessment of the influence of household processing on pesticide residues in vegetables, was used in the risk assessment. The findings show that 8.6% of the individuals with NCDs are at risk of exposure to unacceptable levels of pesticide residues. The risk is mostly contributed by exposure to organophosphates, with hazard index of 1.12 and organochlorines, with hazard index of 1.08. The individual pesticides with highest contribution to the exposure were chlorpyrifos and endosulfan. The exposure was through consumption of Ethiopian mustard, African nightshade, and mixed vegetables. For pyrethroids (permethrin, cypermethrin, and lambda-cyhalothrin), carbamates (bendiocarb) and benzoic acid (dicamba methyl ester), the risk of exposure was minimum. These findings show the need for a bigger exposure assessment for organophosphates and organochlorine pesticide residues in the entire population and using a wider variety of the foods consumed in this community.

5.1 Introduction

Vegetables are highly infested with pests and pathogens and therefore they are intensively sprayed with pesticides to rescue the produce from loss and ensure high yield. Pesticides degrade with time after application but some amount of residues may still persist in the produce after harvest even when good agricultural practices (GAPs) are followed. When GAPs are not followed, the pesticide residues may remain in the produce at levels higher enough to cause health effects to consumer of the treated product either in a short-term (acute health effects) or long-term (chronic health effects). Various studies show that in developing countries, Tanzania included, most of the vegetable farmers apply pesticides without observing good agricultural practices, such as non-adherence to the appropriate application rates and pre-harvest intervals. As a consequence, some vegetables from these countries have been quantified with pesticides at levels above maximum residue limits (MRLs) established by the Codex Alimentarius Commission, a joint Food and Agriculture Organisation (FAO) and World Health Organisation (WHO) body. Studies in Nigeria (Njoku *et al.,* 2017), Ghana (Botwe *et al.,* 2011), India (Bankar *et al.,* 2012), Pakistan (Sheikh *et al.,* 2013), Chile (Elgueta *et al.,* 2017) and Zambia (Sinyangwe *et al.,* 2016) quantified different types of pesticides in vegetables. Among the pesticides quantified in the vegetables include profenofos, malathion, chlorpyrifos, dichlorvos, cypermethrin, lambda-cyhalothrin, permethrin, carbofuran, dieldrin, endosulfan and DDT and its metabolites. These residues are reported to occur in. Consumption of pesticidecontaminated vegetables exposes the consumer to risk of health effects associated with the pesticide residues. The most vulnerable are those who consistently consume high amounts of vegetables (EFSA, 2012a; FAO/WHO, 2009a). Currently, WHO promotes consumption of vegetables (and fruits) due to their nutritional content and functional properties, as they are good sources of vitamins and minerals and contain phytochemicals which are important in controlling and preventing development of health problems particularly the non-communicable disorders (NCDs) including cancer, cardiovascular disorders, diabetes mellitus and respiratory disorders, which are mostly associated with lifestyle of the person (Bempah *et al.,* 2011; Pronczuk *et al.,* 2002; WHO, 2003). The risk of exposure to pesticides in vegetables is more alarming in developing countries where there are limited monitoring programmes of pesticide residues in food. As previously reported in chapter two, in Tanzania, few studies have been done to analyse pesticide residues in vegetables. A study in Dar es Salaam quantified endosulfan, DDT, chlorpyrifos and cypermethrin in spinach, cabbage and onion samples obtained from four

major markets of the city. Chlorpyrifos was quantified at levels above MRL (Mahugija *et al.*, 2017). In Arusha, a region with high vegetable production in Tanzania, chlorpyrifos and permethrin were quantified in tomato samples obtained from farmers in Ngarenanyuki at levels above their MRLs. As it is reported in chapter three and four, the current study quantified pesticide residues at levels above European Union (EU)-MRLs in 40% and 14.3% of the samples, respectively, of ready-to-eat vegetables from Arusha district and Arusha city. This information indicates that, vegetable consumers might be at health risks associated with exposure to pesticide residues through vegetable consumption. A study on exposure to pesticide residues in Arusha district found that 18.6% of vegetable farmers were at risk of health effects of pesticide residue exposure (chapter three). Therefore, this study was undertaken to investigate the risk of exposure of pesticide residues to individuals with NCDs in Arusha city, through vegetable consumption.

5.2 Materials and Methods

5.2.1 Study area, design and recruitment of subjects

The study area, design and recruitment of individuals with NCDs were done as described in section 4.2 of chapter four.

5.2.2 Pesticide residue concentration

Pesticide residues levels in the ready-to-eat vegetables obtained in chapter four were used in the current study. A value of half the limit of detection was assigned to a pesticide which was quantified in the raw but not in the ready-to-eat vegetable. The limit of detection of that pesticide was obtained during method validation of pesticide residues analysis (chapter four).

5.2.3 Consumption data

Information of vegetable consumption among individuals with NCDs was collected as described in section 3.2.4 of chapter three.

5.2.4 Estimation of dietary exposure to pesticide residues

There are no exposure studies that have ever been reported in Arusha city before the current study. Therefore, the deterministic approach was used to assess the exposure of pesticide residues to individuals with NCDs in the city. The dietary exposure of a particular pesticide residue to the adult individual with NCD (mg kg^{-1} bwt day^{-1}) in each of the 70 households was calculated from the average per capita consumption data (kg day^{-1}), the average concentration of the residue (mg kg^{-1}) in the consumed vegetables and weight of the individual (kg). The equation for this estimation is presented as equation "1" in chapter three.

5.2.5 Determination of health risk for exposures

Hazard quotients (HQ) and hazard indices (HI) were determined to estimate the risk of unacceptable exposure to a particular pesticide residue. The hazard quotient of such particular pesticide was determined by using the equation "2" presented in chapter three.

Hazard indices (HI) were determined to estimate multiple exposures to pesticide residues of the same mechanism of toxicity. The HI was calculated by summation of HQs of pesticide

residues of the same chemical (EFSA, 2008; FAO/WHO, 2005; USEPA, 2005). As stated in chapeter three hazard quotients/indices less than one indicates that adverse health effect(s) are not likely to occur and thus the amount of pesticide residue consumed can be considered to have a tolerable effect. When hazard quotient/index is greater than one, the exposure is greater than ADI. This implies that there might be a risk from the residue consumed and calls for risk management action to be taken (FAO/WHO, 2005; USEPA, 2005).

5.2.6 Data analysis

Data entry was done in Microsoft Excel 2007. Data entered was for the amount of vegetable consumed and weight of each participant.The data was used to calculate the daily intakes and risk of exposure using equations *'1'* to *'3'* found in section 3.2.7 in chapter three. Descriptive statistics (frequency and percentage) were used to interpret information captured from questionnaires.

5.3 Results and discussion

5.3.1 Socio-demographic characteristics

Socio-demographic characteristics of the subjects were described in chapter four.

5.3.2 Consumption of vegetables

The individuals consumed an average of 166 g /person/day with a range of 49-534 g/person/day.Respondents consumed vegetables once to three times a day with an average of 1.6 times a day and 5.73 days a week. This is less than the 5 times a day recommended by the World Health Organization (WHO, 2003). As reported in chapter four, majority (35.7%) of the individuals with NCDs in Arusha city consume vegetable mixtures whereby two to four different vegetables are mixed and prepared in a single recipe. The main one includes a mixture of *Amaranthus spp.* and african nightshade 7 (10%) and african nightshade and pumpkin leaves 3 (4.3%). For those who consume a single variety of vegetable per meal (64.3%), the proportion is mostly distributed to nightshade (18.6%), *Amaranthus spp* (10%), chinese cabbage (7.14%) and ethiopian mustard (5.7%). Other vegetables consumed but in minor quantities per meal include onions, carrot, sweet pepper, african eggplant and tomato which are usually added as spices. The vegetables are usually cooked before consumption and only a few of them consume fresh salad (8.57%). The vegetables reported to be

consumed in Arusha city are also consumed in Arusha district at an average of 119 g ranging from 14 - 302 g/person/day (chapter three) and in Babati district at an average of 205.9 g/person/day (Jape, 2017). The amount of vegetables consumed is lower than the 400 g/person/day recommended by WHO for fruits and vegetables (WHO, 2003). Noting that, the amount reported in this study was only for vegetables and assuming that daily vegetable consumption per person is 200 g/person/day (leaving apart 200g for fruits), (Keding *et al.,* 2007), only 27% of respondents could manage to consume the recommended amount of the vegetables. Similar results are also reported in other developing countries including Malawi, Ethiopia, Ghana, Kenya and Uganda (Ruel and Minot, 2004) in which the quantity of 400 g/person/day is not mostly attained. However, consumption of large quantities of vegetables may increase the risk of exposure to the residues as it was revealed in the study in Arusha district (chapter three). This calls for a necessity of monitoring and control of pesticide residues in vegetables to ensure protection of consumer health.

5.3.3 Risk of exposures to pesticide residues

The risk of exposures to pesticide among individuals with NCDs was estimated based on pesticide residues data for ready-to-eat vegetable samples determined in chapter four. The mean concentrations of the pesticide residues are presented in Table 27. Tetramethrin residue was not included in the exposure estimations as its toxicological reference value is yet to be established. As discussed before in chapter four, tetramethrin is currently not registered for use in agricultural crops. It is registered for control of domestic pests. However, cross-contamination could occur if instructions for use were not adhered to (EPA, 2010). The occurrence of the pesticide residue in the ready-to-eat vegetables at levels above their respective MRLs calls for a need for continuous monitoring on their occurrence in food and actions for its control to be taken.

Estimation of exposure of pesticide residues shows that 8.6% of the individuals with NCDs in Arusha are at risk of exposure to adverse health effects of pesticdes. The risk is mainly contributed by the exposure to organophosphate and organochlorine pesticides. The total exposure estimates for the pesticide residues through vegetable consumption and corresponding hazard quotients and cumulative hazard indices are presented in Table 27.

Among the organophosphates, chlorpyrifos had the highest contribution (93%) to the exposure of organophosphate pesticides. Hazard quotient (HQ) for chlorpyrifos was 1.04

with a mean exposure of 0.010 4 mg kg^{-1}bwt $day^{-1.}$. Dimethoate, pirimiphos-methyl, profenofos, dichlorvos and malathion had a lower contribution to the total exposure of organophosphates. Their respective HQ were estimated to be 0.64, 0.008, 0.002, 0.027 and 0.000 24, respectively. There is a health risk associated with exposure to chlorpyrifos as its HQ is greater than one. Cumulative exposure to the organophosphates shows that there is a potential health concerns associated with exposure to these residues. The hazard index (HI) for this group of pesticides was found to be 1.12. The organophosphates are endocrine system desruptors thus adversely affects functioning of consumer body systems. This result suggests that the risks be managed. The management consideration needs to focus on the control of exposure to chlorpyrifos in the vegetables. A study by Chowdhury and Alam (2015) and Gad-Alla *et al.* (2015) recorded similar results of exposure to chlorpyrifos and malathion but with higher HQ of 1.97 and 2.45 for chlorpyrifos and 0.5 and 0.02 for malathion, respectively, compared to those obtained in the current work of 1.04 and 0.000 2, respectively.

Among the organochlorine pesticides, total exposure estimates show that individuals with NCDs were more exposed to endosulfan with HQ of 0.96 and mean exposure of 0.005 8 mg kg^{-1}bwt day^{-1} as compared to dieldrin which had HQ 0.12 and mean exposure of $1x10^{-5}$ mg kg^{-1}bwt day^{-1}. A cumulative exposure to endosulfan and dieldrin shows to have a significant risk to the health of consumer as it has HI of 1.08. Endosulfan contributed 89% of the total risk. Therefore a concern on the control of these residues in the vegetables should be considered focusing on endosulfan. These residues are banned from use in crops due to their ability to accumulate in the human tissues resulting to adverse health effects to the consumer. Therefore it is suggested that immediate action should be taken to control its occurrence in vegetables to ensure that the consumer will not fall into the risks. Hazard quotient for dieldrin was obtained at half its LOD of the method set at 0.001 mg kg^{-1} as the residue was not quantified in the ready-to-eat vegetable samples. Due to the health risks of dieldrin, FAO/WHO has set very low ADI value of 0.000 1 mg kg^{-1} to ensure consumer health is protected. Detection of dieldrin in the raw vegetables (Table 16; chapter four) indicates that the residue still persists in the environment, thus vegetables (and other food crops) might be contaminated. Monitoring and control of these residues is important because with the current results where a concentration of 0.000 5 (half of the LOD) could result into HQ of 12%, implies that a minimum quantification of the residue in vegetables (and in other foods) can result into a great health risk.

Exposure to cypermethrin, lambda-cyhalothrin and permethrin (pyrethroids), bendiocarb (carbamate) and dicamba methyl ester (benzoic acid) pesticide residues through vegetable consumption are unlikely to show adverse health effects to individuals with NCDs as their HQ values are below one. Determination of the risk of cumulative exposure for pyrethroids resulted in HI of 0.039 as well indicating that cumulative exposures to the pyrethroids is unlikely to cause harm to the consumer.

Table 27: Total exposure to pesticide residues for individuals with NCDs

Pesticide group (HI)	Pesticide residue	[1]Mean concentration (mg kg^{-1})	[2]EDI (mg kg^{-1}bwt d^{-1})	[3]ADI	HQ	% [4]contr
Organophosphates (1.12)	Dimethoate	0.663	0.000 9	0.002	0.450	4.0
	Profenofos	0.002	0.000 1	0.030	0.002	0.2
	Chlorpyrifos	0.632	0.010 4	0.010	1.041	93
	Pirimiphos-methyl	0.009	0.000 2	0.030	0.008	0.7
	Dichlorvos	0.004	0.000 1	0.004	0.027	2.4
	Malathion	0.003	0.000 7	0.300	0.000 2	0.0
Organochlorines (1.08)	Endosulfan	0.400	0.005 8	0.006	0.960	89
	Dieldrin	0.001	0.000 01	0.000 1	0.118	11
Pyrethroids (0.04)	Permethrin	0.092	0.001 7	0.050	0.034	57
	Cypermethrin	0.002	0.000 5	0.020	0.002	3.3
	Lambda cyhalothin	0.005	0.000 2	0.050	0.003	5.0
Carbamates	Bendiocarb	0.002	0.000 1	0.004	0.012	100
Benzoic acid	Dicamba methyl ester	0.003	0.000 1	0.300	0.0002	100

Note: [1]Mean concentration for non-detects was set at half limit of detection for the particular pesticide; EDI = [2]Estimated daily intakes; ADI = [3]Acceptable daily intakes; [4]contribution of each residues to the cumulative risk of exposure (HI)

The exposure to these residues was mainly associated with the consumption of african nightshade, *Amaranthus spp.*, cabbage, cucumber, kale, sweet potato leaves, chinese cabbage, ethiopian mustard, tomato, carrot, sweet pepper, and cucumber which are commonly consumed vegetables among individuals with NCDs in Arusha city. As it was reported earlier in section 4.3.3 and Table 16 of chapter four, the individuals with NCDs consume mixed vegetables prepared in the same recipe. In the exposure assessment, the mixed vegetables were treated as one group of vegetables.

Results in Table 28 show exposure estimates of organophosphate pesticide residues in individual with NCDs against the types of vegetable consumed. The exposure to chlorpyrifos was mainly contributed by consumption of ethiopian mustard, nightshade and a mixed vegetable. The recipe of the mixed vegetable was a salad of cabbage, cucumber, tomato and sweet pepper. The HQ for chlorpyrifos is highest through consumption of ethiopian mustard (HQ = 5.63) followed by nightshade (HQ = 1.63) and mixed vegetables (HQ = 1.16) which results in HQ values greater than one. However, in the estimation of total exposure to this residue by including the 0.5 LOD for non-detects, the HQs are reduced to 1.04 for chlorpyrifos and to less than one for nightshade and mixed vegetables. This result shows that consuming varied types of the vegetables rather than being a high consumer of a single type of vegetable particularly ethiopian mustard, nightshade or the mixed vegetable helps to reduce the risk of exposure to chlorpyrifos health effects. Consumption of the common vegetables was unlikely to result in health risks associated with exposure to pirimiphos-methyl, dimethoate, profenofos, dichlorvos and malathion. This is indicated by the low HQs of the residues in all reported vegetables commonly consumed by the individuals with NCDs. The highest exposure risks for pirimiphos-methyl and dimethoate were associated with consumption of nightshade with HQ of 0.017 and 0.234, respectively. Profenofos, dichlorvos and malathion exposure risks were mostly associated with consumption of tomato salad with HQ of 0.004 1, 0.055 6 and 0.000 5, respectively.

Table 28: Average concentration (mg kg^{-1}), EDI (mg kg^{-1} bwt day^{-1}) and HQ for organophosphate pesticides in individual vegetables

n	Vegetable	Chlorpyrifos			Pirimiphos-methyl		
		Conc	EDI	HQ	Conc	EDI	HQ
13	Nightshade	1.179 4	0.016 32	1.631 5	0.015 9	0.000 51	0.017 0
7	Amaranthus	0.001 5	0.000 04	0.003 8	0.003 0	0.000 08	0.002 5
4	Cabbage	0.001 5	0.000 03	0.002 8	0.013 1	0.000 32	0.010 5
3	Cucumber	0.001 5	0.000 04	0.003 9	0.003 0	0.000 08	0.002 6
3	Kale	0.001 5	0.000 04	0.003 6	0.003 0	0.000 07	0.002 4
3	Potato leaves	0.001 5	0.000 03	0.003 0	0.003 0	0.000 06	0.002 0
5	Chinese cabbage	0.001 5	0.000 03	0.003 3	0.003 0	0.000 07	0.002 2
4	Ethiopian mustard	4.955 0	0.056 33	5.632 6	0.003 0	0.000 09	0.002 9
1	Carrot	0.001 5	0.000 02	0.001 8	0.003 0	0.000 04	0.001 2
1	Eggplant	0.001 5	0.000 03	0.003 4	0.003 0	0.000 07	0.002 3
1	Tomato	0.001 5	0.000 07	0.007 4	0.003 0	0.000 15	0.004 9
25	Mixed vegetables	0.360 8	0.011 62	1.161 9	0.011 3	0.000 30	0.009 9

Table 28: cont...

n	Vegetable	Dimethoate			Profenofos		
		Conc	EDI	HQ	Conc	EDI	HQ
13	Nightshade	0.339 0	0.004 69	0.234 45	0.002 5	0.000 04	0.001 3
7	Amaranthus	0.000 5	0.000 01	0.000 63	0.002 5	0.000 06	0.002 1
4	Cabbage	0.000 5	0.000 01	0.000 47	0.002 5	0.000 05	0.001 6
3	Cucumber	0.000 5	0.000 01	0.000 65	0.002 5	0.000 07	0.002 2
3	Kale	0.000 5	0.000 01	0.000 59	0.002 5	0.000 06	0.002 0
3	Potato leaves	0.000 5	0.000 01	0.000 49	0.002 5	0.000 05	0.001 5
5	Chinese cabbage	0.000 5	0.000 01	0.000 55	0.002 5	0.000 06	0.001 8
4	Ethiopian mustard	0.000 5	0.000 01	0.000 72	0.002 5	0.000 07	0.002 4
1	Carrot	0.000 5	0.000 01	0.000 31	0.002 5	0.000 03	0.001 0
1	Eggplant	0.000 5	0.000 01	0.000 57	0.002 5	0.000 06	0.001 9
1	Tomato	0.000 5	0.000 02	0.001 24	0.002 5	0.000 12	0.004 1
25	Mixed vegetables	0.000 5	0.000 01	0.000 67	0.002 5	0.000 07	0.002 2

Table 28: cont...

n	Vegetable	Dichlorvos			Malathion		
		Conc	EDI	HQ	Conc	EDI	HQ
13	Nightshade	0.004 5	0.000 08	0.019 8	0.003	0.000 05	0.000 2
7	Amaranthus	0.004 5	0.000 11	0.028 4	0.003	0.000 08	0.000 2
4	Cabbage	0.004 5	0.000 08	0.021 1	0.003	0.000 06	0.000 2
3	Cucumber	0.004 5	0.000 12	0.029 5	0.003	0.000 08	0.000 3
3	Kale	0.004 5	0.000 11	0.026 8	0.003	0.000 07	0.000 2
3	Potato leaves	0.004 5	0.000 09	0.022 2	0.003	0.000 06	0.000 2
5	Chinese cabbage	0.004 5	0.000 10	0.024 8	0.003	0.000 07	0.000 2
4	Ethiopian mustard	0.004 5	0.000 13	0.032 4	0.003	0.000 09	0.000 3
1	Carrot	0.004 5	0.000 06	0.013 8	0.003	0.000 04	0.000 1
1	Eggplant	0.004 5	0.000 10	0.025 8	0.003	0.000 07	0.000 2
1	Tomato	0.004 5	0.000 22	0.055 6	0.003	0.000 15	0.000 5
25	Mixed vegetables	0.004 5	0.000 13	0.032 0	0.003	0.000 08	0.000 3

Exposure estimates for organochlorine pesticides (endosulfan and dieldrin) in association with type of vegetables consumed are presented in Table 29. It shows that risk of exposure to endosulfan is mainly from consumption of mixed vegetables and African nightshade which results into HQ of 1.92 and 1.46, respectively. These results show that individuals with NCDs are likely to be exposed to the health risks associated with endosulfan exposure through consumption of african nightshade and mixed vegetables. The mixed vegetable was composed of *Amaranthus spp.* and african nightshade vegetables as major ingredients. Survey on pesticide application practices among vegetable farmers shows that farmers apply endosulfan to vegetables intensively (Manyilizu and Mdegela, 2015; Nonga *et al.,* 2011), which could be the reason of high concentration of the residues in the vegetables and consequently exposure levels above ADI.

Table 29: Concentration (mg kg^{-1}), EDI (mg kg^{-1} bwt day^{-1}) and HQ for organochlorine pesticides in individual vegetables

		Endosulfan			Dieldrin		
n	**Vegetable**	**Conc**	**EDI**	**HQ**	**Conc**	**EDI**	**HQ**
13	Nightshade	0.220 7	0.008 74	1.456 8	0.000 5	0.000 01	0.079 7
7	Amaranthus	0.002 5	0.000 06	0.010 5	0.000 5	0.000 01	0.126 4
4	cabbage	0.002 5	0.000 05	0.007 8	0.000 5	0.000 01	0.093 7
3	Cucumber	0.002 5	0.000 07	0.010 9	0.000 5	0.000 01	0.131 0
3	kale	0.002 5	0.000 06	0.009 9	0.000 5	0.000 01	0.118 9
3	Potato leaves	0.002 5	0.000 05	0.008 2	0.000 5	0.000 01	0.098 8
5	Chinese cabbage	0.002 5	0.000 06	0.009 2	0.000 5	0.000 01	0.110 2
4	Ethiopean mustard	0.002 5	0.000 07	0.012 0	0.000 5	0.000 01	0.144 2
1	Carrot	0.002 5	0.000 03	0.005 1	0.000 5	0.000 01	0.061 4
1	Eggplant	0.002 5	0.000 06	0.009 6	0.000 5	0.000 01	0.114 6
1	Tomato	0.002 5	0.000 12	0.020 6	0.000 5	0.000 02	0.247 1
25	Mixed vegetables	1.000 2	0.011 50	1.917 4	0.000 5	0.000 01	0.134 93

Pyrethroid exposure estimates per consumption of individual vegetables are presented in Table 30. The results indicate that it is unlikely to be exposed to the health risk of pyrethroid pesticides through commonly consumed vegetables among individuals with NCDs in Arusha. Permethrin had the highest HQ of 0.102 from consumption of ethiopian mustard, followed with african nightshade 0.055 and cabbage 0.053. Lambda-cyhalothrin and cypermethrin had HQ values less than 0.001 respectively, in all vegetables. The study in Arusha district which assessed exposure to pesticide residues among vegetable farmers obtained similar results whereby the risk of exposure to the pyrethroid pesticide residues was mainly contributed by permethrin. Permethrin, cypermethrin, and lambda-cyhalothrin are among the approved pesticides for use in horticultural crops in Tanzania (URT, 2011). This is because pyrethroid pesticides are unstable under light and are highly biodegrable. A study on exposure of several Belgian consumer groups to pesticide residues through fresh fruit and vegetable consumption (Claeys *et al.,* 2011) reported similar results on cypermethrin and lambda-cyhalothrin with HQ values of 0.1 and 0.4, respectively. Pyrethroid pesticides are also reported to be intensively applied in vegetables in Tanzania (Lema *et al.,* 2014; Ngowi *et al.,* 2007).

Table 30: Concentration (mg kg^{-1}), EDI (mg kg^{-1} bwt day^{-1}) and HQ for pyrethroid pesticides in individual vegetables

		Permethrin			Cypermethrin			Cyhalothrin		
n	**Vegetable**	**Conc**	**EDI**	**HQ**	**Conc**	**EDI**	**HQ**	**Conc**	**EDI**	**HQ**
13	Nightshade	0.199	0.002 75	0.055	0.002	0.000 03	0.002	0.001 5	0.000 02	0.000 5
7	Amaranthus	0.003	0.000 08	0.001	0.002	0.000 05	0.001	0.001 5	0.000 04	0.000 8
4	Cabbage	0.104	0.002 66	0.053	0.002	0.000 04	0.002	0.001 5	0.000 03	0.000 6
3	Cucumber	0.003	0.000 08	0.002	0.002	0.000 05	0.003	0.001 5	0.000 04	0.000 8
3	Kale	0.003	0.000 07	0.001	0.002	0.000 05	0.002	0.001 5	0.000 04	0.000 7
3	Potato leaves	0.003	0.000 06	0.002	0.002	0.000 04	0.002	0.001 5	0.000 03	0.000 6
5	Chinese cabbage	0.003	0.000 07	0.001	0.002	0.000 04	0.002	0.001 5	0.000 03	0.000 7
4	Ethiopian mustard	0.447	0.005 13	0.102	0.002	0.000 06	0.003	0.001 5	0.000 04	0.000 9
1	Carrot	0.003	0.000 04	0.001	0.002	0.000 02	0.001	0.001 5	0.000 02	0.000 4
1	Eggplant	0.003	0.000 07	0.001	0.002	0.000 05	0.002	0.001 5	0.000 03	0.000 7
1	Tomato	0.003	0.000 15	0.003	0.002	0.000 10	0.005	0.001 5	0.000 07	0.001 5
25	Mixed vegetables	0.063	0.001 99	0.040	0.002	0.000 05	0.003	0.012 2	0.000 42	0.008 3

The HQ values for dicamba methyl ester and bendiocarb in association with consumption of the common vegetables to individuals with NCDs were all far below one, showing tolerable health risk (Table 30). The highest exposure to bendiocarb was due to consumption of tomatoes with HQ of 0.025 whereas minimal exposure was due to consumption of eggplant with HQ of 0.006. Dicamba methyl ester though approved for use as an herbicide in the country it is not commonly reported to be applied to vegetables in Tanzania. It is commonly applied to crops in developed countries in the management of weed. Bendiocarb is approved for use as an insecticide for management of public insects. Its occurrence in vegetables could be due to cross-contamination.

Table 31: Concentration (mg kg^{-1}), EDI (mg kg^{-1} bwt day^{-1}) and HQ for dicamba methyl and bendiocarb residues in individual vegetables

		Dicamba			Bendiocarb		
n	**Vegetable**	**Conc**	**EDI**	**HQ**	**Conc**	**EDI**	**HQ**
13	Nightshade	0.003	0.000 1	0.000 2	0.002	0.000 0	0.008
7	Amaranthus	0.003	0.000 1	0.000 3	0.002	0.000 0	0.013
4	Cabbage	0.003	0.000 1	0.000 2	0.002	0.000 0	0.009
3	Cucumber	0.003	0.000 1	0.000 3	0.002	0.000 1	0.013
3	Kale	0.003	0.000 1	0.000 2	0.002	0.000 1	0.012
3	Potato leaves	0.003	0.000 1	0.000 2	0.002	0.000 0	0.010
5	Chinese cabbage	0.003	0.000 1	0.000 2	0.002	0.000 0	0.011
4	Ethiopian mustard	0.003	0.000 1	0.000 3	0.002	0.000 1	0.014
1	Carrot	0.003	0.000 0	0.000 1	0.002	0.000 0	0.006
1	Eggplant	0.003	0.000 1	0.000 2	0.002	0.000 1	0.012
1	Tomato	0.003	0.000 2	0.000 5	0.002	0.000 1	0.025
25	Mixed vegetables	0.003	0.000 1	0.000 3	0.002	0.000 1	0.014

Note: Source of values for acceptable daily intake: FAO/WHO, 2015

It should be noted that the exposure estimates were based on vegetable consumption only. There are other sources of exposure to the residues including other types of food and water. Therefore the exposure and HQ values obtained in this study may underestimate the exposure levels.

5.4 Conclusion and recommendations

The findings of this study show that individuals with NCDs are at risk of exposure to organophosphates and organochlorine pesticide residues at a prevalence of 8.6%. The exposure to organophosphates is mainly contributed by exposure to chlorpyrifos and

dimethoate through consumption of ethiopian mustard, african nightshade, and a mixed salad whereas exposure to organochlorines is mainly contributed by endosulfan through consumption of african nightshade and mixed vegetables. Pyrethroid pesticides are unlikely to cause health effects. These results suggest a need to perform a refined risk assessment of organophosphates and organochlorines particularly chlorpyrifos, dimethoate and endosulfan for the entire population distribution to control for their occurrence and risk of exposure to the consumers. Although permethrin is unlikely to have health risks, it is also suggested that a close monitoring of the residue be done because its HQ was close to one which is the margin of safety.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General discussion

This study investigated the dietary exposure of pesticide residues to farmers and individuals with non communicable disorders in Arusha through vegetable consumption. It further determined the association of risk of dietary exposure to pesticide residues and pesticide application practices and found out how household vegetable handling practices could help in minimizing the pesticide residues in the vegetables.

It is reported in previous surveys that vegetable farmers indiscriminately apply pesticide to vegetables to control pests and diseases. The vegetables are produced for consumption by farmers' households and for commercialization implying that, if the vegetables contain unacceptable levels of pesticide residues a wide number of consumers may be at risks of exposure to the pesticide residues.

The association of dietary exposure and pesticide application practices was assessed and results presented in chapter three. Seventy vegetable farmers were interviewed on the pesticide application practices. Further they were interviewed on the vegetable consumption using a repeat 24 hour recall and food frequency questionnaire. A ready-to-eat vegetable samples was collected from each of interviewed farmers and analyzed for pesticide residues using GC-MS.

The results showed that vegetable farmers consume an average of 119 g of vegetables per day per person. The ready-to-eat vegetables are highly contaminated with pesticide residues whereby 40% of the vegetable samples were found contaminated with pesticide residues, and the residues concentrations were above MRLs set by European Commission. A total of eight pesticide residues were quantified in the vegetable samples from Arusha District. These residues were in the group of organophosphates (profenofos, acephate, dimethoate, malathion, and dichlorvos) and pyrethroids (permethrin, cypermethrin and lambda cyhalothrin). The study found that, the prevalence of pesticide residues in the vegetables from Arusha District were relatively higher when compared to that of pesticide residues in the ready-to-eat vegetables from Arusha City (results presented in chapter four), whereby in Arusha City prevalence was 14.3%. However, a wider variety of pesticide residues was

detected in samples from Arusha City. Whereas only two pesticide groups were found in Arusha District, five groups of pesticide residues were detected in Arusha City which included organophosphates (profenofos, pirimiphos methyl, dichlorvos, dimethoate, chlorpyrifos and malathion), organochlorines (endosulfan and dieldrin), benzoic acid (dicamba methyl ester) and carbamates (bendiocarb). The lower prevalence of pesticide residues in the samples from Arusha City could indicate that pesticide residues degraded during distribution of vegetables from farm–to-market-to-consumer as compared to the short distribution chain from the farm-to-consumer in the samples from Arusha District, as most (83%) of the vegetable samples in Arusha District were from their home grown garden vegetables. The wider variation in the types of pesticides detected in the samples from the two sites could result from the fact that vegetables from Arusha City are not only obtained from Arusha District but also from other districts/regions. Therefore, reflecting the variations in pesticides applied to vegetables among districts/regions. In both study areas, pesticide residues were above the set EU-MRLs. Also, multiple pesticide residues were observed in the ready-to-eat vegetables in both areas whereby 14.9% and 8.6% of the vegetables from Arusha District and Arusha City, respectively, were contaminated with multiple pesticide residues. Again, samples from Arusha City with multiple pesticide residues had higher number of residues co-occuring in the same sample than those from Arusha District whereby, in Arusha City, up to five residues were observed in the same sample as compared to Arusha District where three residues co-occurred in the same sample.

The risk of exposure to the pesticide residues was analyzed deterministically and found that 18.6% of vegetable farmers in Arusha District and 8.6% of individuals with NCDs in Arusha City were at risk of exposure to pesticide residues. In Arusha District vegetable farmers were mainly exposed to organophosphates mainly contributed by dimethoate whereas in Arusha City individuals with NCDs were mainly exposed to organophosphate and organochlorine pesticides mainly contributed by chlorpyrifos and endosulfan pesticide residues, respectively. In Arusha City, the hazard index (HI) for exposure to pesticide residues was 1.12 for organophosphates whereas that of organochlorines was 1.08. In Arusha District, the HI for organophosphates was 1.19 which was higher than that of Arusha City. These results indicate that both vegetable farmers and consumers who purchase vegetables from markets are at risk of exposure to pesticide residues. These results suggest that studies on monitoring of pesticide residues to be done regularly. Also, the study recommends more refined exposure

studies to ascertain the risk of exposure to the community and if any risk is confirmed action for risk management should be done.

A number of pesticide application practices are reported among vegetable farmers. The influence of each practice to the dietary exposure was analyzed and results presented in chapter three. Statistical analysis was performed to find out the association of the dietary exposure to the pesticide residues with the pesticide application practices and revealed that the risk of exposure to the pesticide residues was significantly associated with the lack of adherence to the advice from agricultural extension officers, lack of professional training on pesticide use and over-dosage of pesticide to vegetables. Farmers who lacked advice from agricultural officers were 6.56 times more likely exposed to pesticide residues than their counterparts ($P = 0.031$). It was also revealed that 46.6% of the farmers did not adhere to pre-harvest interval and they were more likely to be exposed to the pesticide residues. The lack of adherence to pre-harvest interval was due to lack of the officers' advice from the officers. This was realized after analysing for confounding effect of reliance on extension officer's advice to adhering to PHI. The farmers who lacked professional training were 3.73 more likely to be exposed to pesticide residues ($P = 0.043$) and those who over-dozed were 3.75 more likely to be exposed to pesticide residues ($P = 0.038$). There was no significant association between the level of education of the farmers and exposure to pesticide residues thus concluding that regardless of the level of education of farmers, there is need of training and awareness creation on the health effects associated with exposure to pesticide residues and emphasize on the need of reducing pesticide use, for instance by relying on integrated pest management approach.

The study went further to assess the influence of household handling practices on the pesticide residues in the vegetables to find out ways for reducing pesticide content in the vegetables. This was achieved by assessing various operations carried out during vegetable preparation in households in Arusha City and statistically identified the practices that had significant effect in the reduction of the residues by using Chi-Square analysis. Vegetable samples were collected before processing (raw vegetables) and after processing (ready-to-eat vegetables) and analyzed for pesticide residues. The findings for this objective were presented in chapter four. It was found that the most common practices involved in household vegetable preparation include sorting and trimming, washing, peeling, and cooking. Most of the vegetables are cooked rather than prepared as salad. This finding was also observed in

Arusha District whereby most of the farmers interviewed reported to consume cooked rather than raw vegetables in salad. It was found that 41.6% of the raw vegetables were contaminated with pesticide residues before processing. The prevalence was reduced to 14.3% of the ready-to-eat vegetable samples after processing. The washing process was done either in running water or bowl. Washing of vegetables in bowl twice or more while changing the washing water showed significant association with the reduction of pesticide residues ($\chi^2(1) = 6.563$; $P = 0.01$) than washing only once. Peeling of fruiting and root vegetables also had significant association with the reduction of pesticide residues ($\chi^2(1) = 6.949$; $P = 0.008$) whereas poor treatment of minor ingredients during washing had significant association with the occurence of pesticide residues in the vegetables. Profenofos, dichlorvos, malathion, cypermethrin, dieldrin, dicamba methyl and bendiocarb quantified in raw vegetables were non quantifiable in the ready-to-eat vegetables. On the other hand, some pesticide residues which were not quantified in raw vegetables were quantified in ready to eat vegetables. The study supposes that the residues could be introduced into the vegetables from the water used for washing, from cooking oil or from the minor ingredients which were not analyzed for pesticide residues in their raw form or could result from concentration of pesticide residues due to evaporation in the samples which were cooked while open. Overall, the results suggest that, vegetable farmers and vegetable processors have important role to play in controlling pesticide residues in the vegetables for consumer health protection. This is not only applicable to vegetables but also to other food crops.

6.2 Conclusion

The findings of the present study show that both vegetable farmers and individuals with NCDs in Arusha are at risk of exposure to pesticide residues through vegetable consumption. The risk is mostly associated with exposure to high levels of organophosphates in vegetable farmers and organophosphate and organochlorines among individuals with NCDs. The dietary exposure to pesticide residues is significantly associated with lack of advice from agricultural extension officers, over-dosage and lack of professional training on pesticide application.

The study found that the high levels of pesticide residues can be reduced by household processeses. Most of the households were found to wash their vegetables in bowl. Washing of vegetables more than once with changing of the washing water was associated with

significant reduction of the residues. Treatment of the minor ingredients during washing had a significant association to occurrence of pesticide residues in vegetables. In 8.6% of the households visited, minor ingredients were poorly washed for instance by washing them once while the major ingredients were washed twice or more. The vegetables whose minor ingredients were washed in this way were more likely to be quantified with pesticide residues as compared to those whose minor ingredients were equally treated as the major ingredients. Also peeling had significant association with the reduction of pesticide residues in the vegetables whereby the fruiting and root vegetables which were peeled were less likely to be quantified with pesticide residues.

6.3 Recommendations

It is recommended that vegetable farmers should be made aware of the health risks associated with exposure to pesticide residues and counselled to adhere to PHI and apply pesticides at appropriate rates. Safer pest management options should be established to provide a wider choice of pest management options among farmers. Households are adviced to wash their vegetables more than once with adequate water including the minor ingredients to minimize levels of pesticide residues. Peeling of outer tissues of fruiting and root vegetables is important in reducing the pesticide residues significantly. The agricultural extension officers if effectively utilized can help in reducing the risk of pesticide residues exposure through provision of advice and training to farmers on Good Agricultural Practices. Regulatory bodies should be more stringent in ensuring that regulations are followed by farmers and all stakeholders in pesticide management to ensure safe vegetables and other foods are supplied to consumers. The study recommends that further studies on the risk assessment of the pesticide residue exposure to be carried out to the general population using a more robust approach that includes a wider food types and other potential routes of exposure for risk management.

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APPENDICES

Appendix 1: Assessing pesticide application practices in Arusha district

Nelson Mandela African Institution of Science and Technology

School of life sciences

Department of Food biotechnology and Nutritional sciences

Research Title: Risk assessment for dietary exposure of pesticides among vegetable consumers in Arusha, Tanzania

Researcher: Purificator Andrew Kiwango, PhD candidate in Food and Nutritional Sciences

Questionnaire on assessing pesticide application practices in vegetable cultivated in Arusha district and their influence to dietary pesticide residues exposure to farmers

Part A: General Information

1. Names: First name…… Second name …… Code….....
2. Gender Male/female (please tick on appropriate gender)
3. Age …….. years

   OR on the list below please tick on the appropriate range of your age:

   (i) Less than 30 (ii) 31---40 (iii) 41---50 (iv) 51---60 (v) 61---70 (vi) 71 and above
4. Place of residence: Village……Ward……..District ……
5. Level of education: (Please tick on the appropriate answer)

   (i) not completed primary education (ii) primary education (iii) secondary education (iv) college/university education (v) never attended school

Part B: Aseessment of pesticide application knowledge and practices

6. Where is your farm located? …… village ……. province
7. How much hectare is for cabbage cultivation? ……hectare(s)
8. What are other types of vegetables do you grow? ……
9. Of the mentioned vegetables which one do you produce in the largest quantity? ……..

10. How are they grown? (i) intercropped with cabbage (ii) in separate plots close to cabbage

    iii) in separate plot away from cabbage

11. How many seasons do you cultivate cabbage and each other vegetable mentioned in question 8 above in a year? Write type of vegetable and its number of seasons in a bracket

    Cabbage (….....seasons) ……

12. Do you experience pests/diseases in cultivating cabbage and the other vegetables mentioned in question 8 above? **YES/NO** (Please tick on the appropriate answer)
13. If answer in question (12) is **YES**, how do you manage the diseases/pests ……

14. If the individual mentions that s/he uses pesticides then ask if s/he seeks advice before use of pesticide (also check for the source of advice**). YES/NO**

15. What reason drives you to apply pesticides (Please tick on the appropriate answer)
    (i) Pests and/or diseases observed in the crop
    (ii) Age of the growing cabbage
    (iii) Neighbor is spraying his/her crop
    (iv) Other reasons (please mention) ----------
16. Which kind of pesticides do you use to spray cabbage and other vegetables? Please mention (the interviewer will write the type of vegetable followed with name of pesticide in bracket) ……
17. Where do you buy pesticides that you apply to the vegetables that you apply? (Please tick on the appropriate answer)
    (i) From licensed vendor (ii) Non licensed vendor (iii) Neighbor Market (iv) Elsewhere (please mention) ……..
18. How do you prepare and use the pesticides you mentioned above? (check if he reads labels and able to understand and follow instructions on the label)

    ……

19. If in question 18 s/he mentions mixing of more than one pesticide in the same tank, ask to mention which ones does s/he mix in the same tank …..……
20. How many sprays of pesticides do you apply to each vegetable you mentioned in question 6 above per season? (please interviewer recall for the interviewee the

vegetables s/he mentioned in question 6 then write type of vegetable followed with number of sprays in bracket) ……..……

21. For how long do you wait from last spray and harvest? ……
22. Is the pesticide applied effective? **YES/NO** (Please tick on the appropriate answer)
23. If the answer in question 20 is NO, what other means do you use to deal with the problem?
    (i) Apply inorganic farming
    (ii) Mixing of more than one pesticide in same tank
    (iii) Increase the amount of dosage
    (iv) Seek for advice from Agricultural extension officer
    (v) Other means (Please explain) ……
24. Have you ever received training on pesticide issues in Agriculture? **YES/NO** (please tick on the appropriate answer)
25. If answer in question 23 is YES, in which area were you trained? (Please tick on appropriate answers)
    (i) On how to prepare pesticide solution
    (ii) On health and safety issues
    (iii) On disposal of used equipments
    (iv) On how to apply pesticide to crops
    (v) On dosage of pesticide
    (vi) Others (please mention) ……
26. Where do you store pesticides and pesticide application equipments? (Please tick on appropriate answers)
    (i) In the kitchen (ii) In the bedroom (iii) In seating room (iv) In a separate place (v) In the farm site (vi) In animal house (vii) Buy and use all of it immediately
27. What do you do with empty pesticide containers?
    (i) Wash and reuse them for other purposes such as storing food/water
    (ii) Burry them in the soil
    (iii) Sell them to other people for use
    (iv) Leave them in the farm site
28. Are you aware that pesticides do expire? **YES/NO** (please tick on appropriate answer)

29. If the answer in question 27 is YES, how do you know that the pesticide has expired?

    ……

    ……

30. When you realize that pesticide has expired what do you do with it? (please tick on the appropriate answer.

    (i) Burry it in the soil (ii) Continue using it (iii) Seek advice from Agricultural extension officer? (iv) Other (Please specify) ……..

Appendix 2. Assessing vegetable consumption pattern

Nelson Mandela African Institution of Science and Technology

School of Life sciences and Bioengineering

Department of Food and Nutritional sciences

Research Title: Investigating human exposure of pesticide residues through vegetable consumption in Arusha

Researcher: Purificator Andrew Kiwango, PhD candidate in Food and Nutritional Sciences

A. General information

1. Names: First name ----------second name ----------code-----
2. Gender: Female/Male (please tick on the appropriate answer)
3. Age ----------years
4. Level of education: (Please tick on the appropriate answer)
   (i) not completed primary education (ii) primary education (iii) secondary education (iv) college/university education (v) Never attended school (vi) Occupation ----------
5. Place of residence
   (i) Street ……(ii) Ward …….. (iii) District ……. (iv) Region ……

B. Assessment of consumption pattern

C. Section I: 24 h recall

6. Did you consume vegetables yesterday? **(Yes/No)**
7. If answer for question 7 is '**Yes'** which vegetables did you consume yesterday?

Please put a tick in the box in the column next to the vegetable that you consumed yesterday in the Table below. Please on the cell right to the consumed vegetable

Table A. Frequency of vegetable consumption

Vegetable	**Number of times consumed per day**		**Number of times consumed per day**
Cabbage		Sweet paper	
Tomato		Chinese	
Carrot		Pumpkin leaves	
Spinach		Broccoli	
Cucumber		Cabbage red	
Egg plant		Lettuce	
Amaranths		Okra	
African black night shade		Cauliflower	
Green beans		Sweet potato leaves	
Others: please mention			

8. How did you take the vegetables? As salads ☐ as cooked vegetables ☐ Please tick on the appropriate answer.

9. How much of vegetable did you eat yesterday? ------- Tablespoonful. Ask the interviewee to show you the container/equipment used to measure vegetable)
10. Did you leave some vegetables on plate? **Yes/No** (please tick on the appropriate answer)

If answer for question 11 is **'Yes'** answer question 12. Otherwise go to question 13.

11. How much of vegetable did you leave on plate?
12. Did you share vegetables with a second person? **Yes/No** (please tick on the appropriate answer)

If answer in question 13 is **'Yes'** answer question 14. Otherwise go to question 15.

13. How much of vegetable was consumed by the second person? ---------- tablespoonful
14. What is your usual place of getting your meals and vegetables?

(i) At home ☐
(ii) Elsewhere ☐

15. If answer in question 1 is **'Yes'**, how did you prepare your vegetables? ----------
---
16. What were the ingredients used to prepare the vegetable?----------
--
17. Where did you purchase the raw vegetables? ----------
At the end of vegetable preparation (observational using the check list), collect a duplicate ready-to-eat vegetable sample into clean glass bottle

Section II. Food consumption frequency

18. How many times in a day do you eat vegetables? ……times.
19. How much of vegetable do you usually eat per serving? ----------
20. Do you usually leave vegetables on the plate or share with another person? (Yes/No). (Please tick appropriate answer)
21. How many days in a week do you eat vegetables? ……. days
22. Ask to take weight of the individual on the weighing scale……kg
23. Where is your usual place of purchasing vegetables ----------
24. How many times in a previous week did you eat the following vegetables? (Please indicate number of times the vegetable is eaten in the second column and amount consumed in the third column)

Table B. Vegetables consumed

Vegetable	**Number of times eaten**	**Amount consumed**	**Vegetable**	**Number of times eaten**	**Amount consumed**
Cabbage			Sweet paper		
Tomato			Chinese		
Carrot			Pumkin leaves		
Spinach			Broccoli		
Cucumber			Cabbage red		
Egg plant			Lettuce		
Amaranths			Okra		
Black night shade			Cauliflower		
Green beans			Sweet potato leaves		
Others: please mention					

D. Assessing vegetable handling practices

The interviewer should visit the respondent to observe how vegetable is prepared at household level twice.

D. How do you usually prepare your vegetables?

25. Washing: How do you usually wash your vegetables?
26. No washing (ii) Washing once (iii) Washing twice (iv) Washing three times (v) washing more than three times
27. Washing is done on: (Please tick appropriate answer)
    (i) running water from tap (ii) In bowl
28. Peeling: (Please tick appropriate answer)
    (i) Done (ii) Not done
29. Chopping: (Please tick appropriate answer)
    (i) Done ii) Not done
30. Cooking: (Please tick appropriate answer)
    (i) Boiling (Yes/No)
    (ii) In closed/Open cooking pot
    (iii) Duration for boiling ----------minutes
    (iv) Frying (Yes/No) (Please tick appropriate answer)
31. Duration for frying ----------minutes
32. How do you prepare your salads? ----------
33. What are the ingredients added to your salad? ----------

Next appointment

34. Ask for appointment for next visit …….day/date
35. Ask for contacts:

i. Own phone number ----------
ii. Close relative phone number ----------

Thank you for your participation and cooperation in this study. I declare that the answers you have provided will remain confidential and used for the sole purpose of this study.

Appendix 3: A checklist for observations of household vegetable processing practices

Nelson Mandela African Institution of Science and Technology

School of Life sciences and Bioengineering

Department of Food Biotechnology and Nutritional sciences

Research Title: Investigating human exposure of pesticide residues through vegetable consumption in Arusha

Researcher: Purificator Andrew Kiwango, PhD candidate in the Department of Food Biotechnology and Nutritional Sciences

Thank the participant for agreeing to cooperate and declare that the answers they have provided will remain confidential and used for the sole purpose of this study.

E. General information

36. Full name: ---------- ----------Code----------

Assessing vegetable handling practices at household level

Check list

1. Note down the names and quantity/ number of pieces of the ingredients included in vegetable cooking ----------
2. Ask the respondent for the source of each vegetable/ingredient
   ----
3. Take fresh sample from the ingredient added in the largest quantity by observation (large proportion at least two third of the total vegetable ingredients). If the ingredients are all added at approximately equal amounts, collect composite sample.
   Some more observations ----------
4. Note down equipments to be used for vegetable cookin ----------
5. Note the source of cooking energy----------

Washing: Note down the amount of water added to wash vegetable if washed in bowl (please tick appropriate)

(i) Adequate (at the level of vegetables)

(ii) Too little (below the level of vegetables)

(iii) Plenty (high above the level of the vegetables)

More notes----------

6. Washing: note down how vegetables are washed

(i) No washing (ii) Washing once (iii) Washing twice (iv) Washing three times (v) washing more than three times. More notes----------

7. Washing is done on: (Please tick appropriate answer)

(i) running water from tap ii) In basin iii) basket iv) washing bowel

More notes----------

8. Peeling: (Please tick appropriate answer)

(i) Type of vegetables peeled (ii) Type of vegetables not peeled

More notes----------

9. Chopping: observe and note down

i. Type of vegetables chopped (ii) Type of vegetables not chopped

More notes----------

10. Cooking: request the household to cook as she does always. Observe and note down:

a. Type of cooking

(i) Frying (Yes/No), Duration --------minutes (ii) Steaming (Yes/No), Duration ------ minutes (iii) Boiling (Yes/No), Duration -------minutes

b. Cooked in:

(i) In closed cooking pot (ii) Open cooking pot

Note how salads is prepared if applicable? ----------

What are the ingredients added to the salad? ----------

More notes----------

11. Ask the cook to serve on the plate/bowel for respondent an exact amount of cooked vegetable/salad as that one she/he is used to serve for him/her and transfer it to the sampling bottle. Keep it in cool box with ice blocks to be taken to the lab for weighing and pesticide residue analysis.

Any more observations----------