

Review Paper**Pesticide residues in vegetables: Practical interventions to minimize the risk of human exposure in Tanzania****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 work, we reviewed 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. The review has realized 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. The review suggests a broader research on the pesticide application practices to establish the important practices that have significant association to 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.

24 Keywords; pesticide residues, application practices, household vegetables processing, exposure
25 assessment

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29 **1. Introduction**

30 The occurrence of pesticide residues in horticultural produce has been a growing public health concern
31 worldwide. High pest infestation forces farmers to apply pesticides intensively to rescue crop loss. It is
32 reported that the crop loss due pest infestation can be as high as 100%, if they are not controlled [1].
33 However, good pesticide application practices have to be observed to protect and promote public health.
34 If not well controlled, pesticide use may result in pesticide residues in agricultural produce which in turn
35 results in pesticide exposure in human and animals. Consumption of pesticide containing food is the
36 major route of chronic exposure to pesticides. It is estimated that dietary pesticide exposure is five times
37 higher than exposure through other routes which include inhalation and contact [2, 3]. Health risks
38 associated with exposure to pesticide residues range from acute characterized with coughing, headache,
39 nausea, stomachache, diarrhoea and vomiting to chronic in the form of endocrine disruption,
40 reproduction and immune systems malfunctioning and development of some cancers [45].

41 Several initiatives have been taken to ensure pesticide safety of vegetables and other foods. Some of
42 these include the establishment and enforcement of maximum residue levels (MRLs). Countries or the
43 Codex Alimentarius Commission set MRLs based on reference limits such as acceptable daily intakes
44 (ADI) and acute reference dose (ARfD) prescribed by The Joint Meeting of Food and Agriculture
45 Organization (FAO) and World Health Organization (WHO) on Pesticide Residues (JMPR). MRLs are
46 established based on data obtained from field supervised trials following good agricultural practices
47 (GAPs) whereas ADI and ARfD are established based on international dietary risk assessment data [6].
48 The MRLs are set much higher above the ADI to ensure that, if the food produced under GAPs is
49 consumed in the entire lifetime of the consumer, the adverse health risks associated with the particular
50 pesticide will not be manifested [7].

51 Furthermore, international treaties and codes on pesticides trade encourages governments to establish
52 and/or review regulations and policies related to chemical trading, use and disposal to ensure protection
53 of human, animal and environment. Of these, are the FAO code of conduct on the distribution and use of
54 pesticides adopted in 2002 [8], The Rotterdam Convention on the Prior Informed Consent Procedure for
55 Certain Hazardous Chemicals and Pesticides in International Trade adopted in 1998 in Rotterdam,



Netherlands and The Stockholm Convention on Persistent Organic Pollutants (POPs) adopted in 2001 in Stockholm Sweden [9]. 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 effective use of pesticides for the public health protection in Tanzania [10].

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 [11,12], Ghana [13,14], Zimbabwe [15], Palestine [16] and Tanzania [17, 18] 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. As afore stated, 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 [19]. 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 minimize 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 of Tanzania.

2. Vegetable production in Tanzania

In Tanzania vegetables are produced at small, medium and large scale mainly for commercial purposes. It is reported that, of the vegetables produced in the country, 10% is for household consumption [20]. Vegetable production subsector contributes about 7% of the GDP [21]. Major vegetables cultivated in the country include tomato, cabbage, carrot, onions, kale, spinach, amaranth, nightshade and pumpkin leaves [20]. 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 [20–22].

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, 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 [23], 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 [24]. Since the risk of pesticide exposure is higher in heavy compared to the moderate consumers of vegetables, there is an urgent need to ensure the pesticide safety of vegetables.

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 [25]. Removal of subsidies in agricultural inputs resulted in decreased returns from cash crops due to increased production costs [26].

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 [25]. Also, trade liberalization has increased pesticide availability locally and in retail shops and therefore increased accessibility and rate of use [17, 18]. This has been realized in the increased volume of pesticides importation from 500 MT in 2000 to 2500 MT in 2003 [22] and then from 2500 MT in 2003 to 11,482 MT in 2014 [28, 29]. A number of active ingredients registered for use in Tanzania also increased from 450 [28] in 2012 to 1,182 in 2014 [27]. The later author reports that, of the 1,182 active ingredients 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 registered pesticides for use in Tanzania are mostly pyrethroids 230 (27.2%) and organophosphates 135 (15.9%) as reported by Lekei, *et al* [27], 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 in environment, mammalian and other non-target organisms body tissues [10], 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 [27], Table 1.

Table 1. Categories and respective uses of pesticides registered 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: [27,29,30]

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* [17] reported

that 59% of farmers interviewed applied insecticides; 29%, fungicide and 2%, herbicides. It was also documented by Nonga *et al* [18] in 2011 that, 50% of vegetable farmers applied insecticides; 37.5%, fungicides and 12.5%, herbicides [27]. 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 hazardous, Ib - highly hazardous , II - moderately hazardous and III - slightly hazardous and U - unclassified [31]. 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 [18]. 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 [32]. Most of these pesticides are cholinesterase inhibitors (16%) and classified as WHO class I and II (50%) [27]. 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. These 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 [17, 18, 22, 31], of which majority are in the groups of organophosphates (profenofos, dimethoate, chlorpyrifos, pirimiphos-methyl and fenitrothion), pyrethroids (cypermethrin, lambda-cyhalothrin, permethrin, and deltamethrin) and (organochlorines (endosulfan), mancozeb and metalaxyl. Endosulfan which is an endocrine disruptor is also reported as the most frequently applied pesticides to vegetables [18,34], whereas Carbamate (carbofuran) are reported at lower extent. Bio-pesticides which are regarded as safer and biodegradable are limited in use [35]. 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. 

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 [17, 18, 32, 33].

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 [37]. 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 environmental and human health protection in Tanzania done in Mtwara and Lindi regions in 2012 revealed 39.4% of pesticide shops selling unregistered pesticides [28]. Also, a survey by Ngowi *et al* [17] 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 [38] 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 [34]. 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 [17, 18]. 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* [17] reported that, 33.3 % of the farmers do mix two or more pesticides in the same spray tank whereby 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 [34]. 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 [17, 37] 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 [35, 38]. Farmers mix pesticides in the same sprayer to save money and reconstitution water [42]. Other farmers think that by mixing pesticides they become more effective. Since the manufacturers include inert material 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 to establish demo 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 store remained pesticides in kitchen or general stores with food [17, 18, 32, 36] 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 [39]. 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 [43]. 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 [17, 18, 32, 33, 40]. 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 for control of the poor practices



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* [39] evaluated pesticide residues in raw cabbage, onions and spinach where as Ndossi and Cram [45] analyzed pesticide residues in ready-to-eat amaranths (spinach) from markets in Dar es Salaam. Kariathi *et al* [46] analyzed pesticide residues in raw tomatoes from farmers in Ngarenanyuki -Arumeru district. Also, Mhauka [47] reported pesticide residues in raw vegetables and the mean residues are presented in Table 2. With exception of the residues detected in the study by Ndossi and Cram [45], one or more types of pesticide residues reported in these studies were above MRLs.



The study by Ndossi and Cram [45] 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 0.01mg kg⁻¹ g-HCH, pp-DDE and (pp-DDT), and 1 mg kg⁻¹ for chlorpyrifos. The study by Mahugija *et al* [39] 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. The study by Kariathi *et al* [46] analyzed 50 samples of tomato from farmers in Ngarenanyuki and quantified chlorpyrifos and permethrin in 46.15% of the samples. The study also reported to quantify 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 [32]. All quantified pesticide residues in this study were above their respective MRLs. However, none of these analyses were done as part of the routine monitoring system to ensure consumer protection, rather scholarly or research project related works which are location and time specific and targeting fewer vegetables. There is therefore a need of continuous monitoring of pesticide residues in vegetables and other foods 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 [48] 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 by Esturk [49] 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. 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 [50] 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,

263 policy makers and regulators for action such as organizing intervention program and reinforcement of
264 regulations.

265 **Table 2. Occurrence of pesticide residues in vegetables in Tanzania**

Vegetable	Area	Pesticide group	Pesticide residue	Range of pesticide residues	Mean concentration (mg/kg)	Prevalence (%)	Prevalence >MRL	MRL	Reference
Amaranthus	Dar es Salaam	Organochlorine	g-HCH	-	0.00008	6.01	0	0.01	[45]
Amaranthus	Dar es Salaam	Organochlorine	pp-DDE	-	0.00074	30.03	0	0.01	[45]
Amaranthus	Dar es Salaam	Organophosphate	Chlorpyrifos	-	0.00002	96.97	0	1	[45]
Amaranthus	Karatu	Pyrethroid	λ -cyhalothrin	-	0.21	6.25	0	0.5	[34]
Amaranthus	Karatu	Organophosphate	Dimethoate	-	0.012	6.25	0	0.02	[34]
Amaranthus	Karatu	Organophosphate	Profenofos	-	0.6	18.75	33.3	0.01	[34]
Amaranthus	Karatu		Tebuconazole	-	0.42	6.25	16.7	0.01	[34]
Amaranthus	Karatu	Organophosphate	Chlorpyrifos	-	0.74	12.5	16.7	0.02	[34]
Amaranthus	Karatu	Pyrethroid	Cypermethrin	-	0.22	12.5	16.7	0.02	[34]
Spinach	Dar es Salaam	Organochlorine	p,p'-DDD	0.001-0.64	0.64	75	8.3	0.2	[39]
Spinach	Dar es Salaam	Organochlorine	o,p'-DDD	0.01-0.000		16.7	8.3	0.2	[39]
Spinach	Dar es Salaam	Organochlorine	α -endosulfan	0.14-0.24	0.20	33.3	33.3	0.05	[39]
Spinach	Dar es Salaam	Organochlorine	β -endosulfan	0.05-0.08	0.068	75	75	0.05	[39]
Spinach	Dar es Salaam	Organophosphate	Chlorpyrifos	1.31-3.0	2.006	41.7	41.7	0.5	[39]
Spinach	Dar es Salaam	Pyrethroid	Cypermethrin	0.01-0.04	0.021	33.3	0	0.02	[39]
Spinach	Karatu	Organophosphate	Dimethoate	-	0.3	6.25	100	0.02	[34]
Spinach	Karatu	Triazole	Tebuconazol	-	1.6	-	100	0.05	[34]
Spinach	Karatu	Organochlorine	Endosulfan	--	0.14	-	100	0.05	[34]
Spinach	Karatu	Pyrethroid	λ -cyhalothrin	-	0.67	-	100	0.5	[34]
Cabbage	Dar es Salaam	Organochlorine	p,p'-DDD	0.001-0.01	0.005	-	-	-	[39]

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Vegetable	Area	Pesticide group	Pesticide residue	Range of pesticide residues	Mean concentration (mg/kg)	Prevalence (%)	Prevalence (%) >MRL	MRL	Reference
Cabbage	Dar es Salaam	Organochlorine	o,p'-DDD	-	0.001	83.3	0	0.02	[39]
Cabbage	Dar es Salaam	Organochlorine	total DDT	-	0.012	83.3	0	0.02	[39]
Cabbage	Dar es Salaam	Organochlorine	α -endosulfan	0.1-0.6	0.365	33.3	8.3	0.5	[39]
Cabbage	Dar es Salaam	Organochlorine	β -endosulfan	0.03-0.21	0.128	33.3	8.3	0.5	[39]
Cabbage	Dar es Salaam	Organophosphate	Chlorpyrifos	0.04-2.40	2.275	33.3	33.3	1	[39]
Cabbage	Dar es Salaam	Pyrethroid	Cypermethrin	0.03-0.04	0.023	25	0	1	[39]
Kale	Karatu	Organophosphate	Profenofos	-	18.1	-	0	0.05	[34]
Tomato	Ngarenanyuki	Organophosphate	Chlorpyrifos	0.83-6.3.6	7.53	46.2	46.2	1	[46]
Tomato	Ngarenanyuki	Pyrethroid	Permethrin	0.69-29.05	5.29	46.2	46.2	1	[46]
Tomato	Karatu	Organophosphate	λ -cyhalothrin	-	0.079	6.25	0	0.1	[34]
Tomato	Karatu	Triazole	Tebuconazole	-	0.075	-	0	1	[34]
Tomato	Karatu	Organophosphate	Chlorpyrifos	-	0.16	12.5	0	0.2	[34]
Tomato	Karatu	chloronitrile	Chlorothalonil	-	0.045	12.5	16.7	0.02	[34]
Tomato	Karatu	Organophosphate	Dimethoate	-	0.017	12.5	0	0.02	[34]
Tomato	Karatu	Organophosphate	Profenofos	-	0.031	12.5	0	10	[34]
Onion	Dar es Salaam	Organophosphate	Chlorpyrifos	0.1-2.12	1.86	25	25	0.2	[39]
Onion	Dar es Salaam	Pyrethroid	Cypermethrin	0.014-0.04	0.01	16.7	8.3	0.01	[39]
Onion	Dar es Salaam	Organochlorine	p,p'-DDD	0.01-0.001	0.0102	50	0	0.2	[39]
Onion	Dar es Salaam	Organochlorine	α -endosulfan	0.02-0.22	0.19	16.7	16.7	0.05	[39]
Onion	Dar es Salaam	Organochlorine	B-endosulfan	0.07-0.3	0.06	16.7	16.7	0.05	[39]
Onion	Karatu	Organophosphate	Chlorpyrifos	-	0.022	6.25	0	0.02	[34]
Onion	Karatu	Organophosphate	Profenofos	-	0.59	12.5	100	0.05	[34]

Note: - = unavailable data; Source: [39,45–47]

7. Dietary exposure to pesticide residues and possible health effects

Studies on dietary exposure to 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 these data are regularly collected and made available. The in-country available information on exposure to pesticides was from the earlier reported studies by Ndossi and Cram [45], Mhauka [47] and Kariathi *et al* [46]. The results on estimated exposure levels from these studies are presented in Table 3. Similarly, the coverage of these studies were limited to scholarly or research project capacity.

Ndossi and Cram [45] 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. Of such areas is Arusha which is reported as the major pesticide trader and user [10].

Study by Mhauka [47] assessed risk of vegetable dietary exposure to pesticide residues in adults in nine households from Karatu district. Consumption data were 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 [51]. 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 of 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 kg [41, 53]. 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* [46] 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.

Other developing countries have performed studies on the pesticide residues exposure through vegetable consumption. For instance, the study by Darko and Akoto 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 [54]. 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 [17,36].

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 are much more important to high vegetable production area and particularly where there is a high potential of exposure to vulnerable groups including women and children. Vegetable consumption

326 data in Tanzania are also limited or out-dated [55] and therefore exposure studies will require a fresh
327 collection of information on vegetable consumption.



328 **Table 3. Estimated daily intakes and hazard indices of pesticide residues through vegetables consumption**

Pesticide group	Pesticide	EDI	ADI	EDI/ADI	Vegetable	Reference
Organophosphates	Dimethoate	1.584×10^{-4}	0.001	0.1584	Amaranthus	[34]
	Dimethoate	2.14×10^{-4}	0.001	0.2142	Tomato	[34]
	Dimethoate	4.14×10^{-5}	0.001	0.0414	Spinach	[34]
	Chlorpyrifos	9.78×10^{-3}	0.01	0.976	Amaranthus	[34]
	Chlorpyrifos	2.016×10^{-3}	0.01	0.2016	Tomato	[34]
	Chlorpyrifos	0.0293	0.01	2.9293	Tomato	[46]
	Chlorpyrifos	6.6×10^{-9}	0.01	6.6×10^{-6}	Amaranthus	[45]
	Profenofos	1.32×10^{-3}	0.03	0.044	Amaranthus	[34]
	Profenofos	0.0145	0.03	0.1196	Onion	[34]
	Profenofos	3.906×10^{-4}	0.03	0.1534	Onion	[34]
	Profenofos	0.10498	0.03	3.4993	Kale	[34]
Organochlorine	g-HCH	2.66×10^{-3}	0.001	2.66×10^{-5}	Amaranthus	[45]
	DDT	9.6×10^{-7}	0.01	9.6×10^{-4}	Amaranthus	[45]
	Endosulfan	1.932×10^{-5}	0.006	3.22×10^{-3}	Spinach	[34]
Chloronitrile	Chlorothalonil	5.67×10^{-4}	0.015	0.0378	Tomato	[34]
Triazole	Tebuconazole	5.544×10^{-3}	0.05	0.1848	Amaranthus	[34]
	Tebuconazole	9.45×10^{-4}	0.05	0.0315	Tomato	[34]
	Tebuconazole	2.205×10^{-4}	0.05	7.36×10^{-3}	Spinach	[34]
Pyrethroids	Permethrin	0.0206	0.005	0.4117	Tomato	[46]
	Cypermethrin	2.90×10^{-3}	0.015	0.1936	Amaranthus	[34]
	λ -cyhalothrin	2.772×10^{-3}	0.005	0.5544	Amaranthus	[34]
	λ -cyhalothrin	9.954×10^{-4}	0.005	0.19908	Tomato	[34]
	λ -cyhalothrin	9.246×10^{-5}	0.005	0.01849	Spinach	[34]

329 Source: [45–47]

8. Pesticide exposure and 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 [36]. Chronic exposure to pesticide residues is associated with endocrine disruption, neurotoxicity, cytogenetic damage and effects in the reproductive and immunological system [56]. Dietary pesticide residues exposure is the major source of pesticide exposure followed by inhalation and through skin [57,58].

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 [57]. A birth cohort study examined the association between prenatal and post-natal exposure to organophosphate pesticides and cognitive abilities in school-age children and found a positive association in prenatal but not in postnatal exposure to organophosphate pesticides and cognitive development [59]. Carbamates are also cholinesterase inhibitors though its activity is reversible [58] where as that of organophosphate is not. [60]. They 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 [61]. Organochlorine pesticides disrupt the endocrine system and alter the haematological and hepatic function [61] 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 not yet ascertained due to other confounding factors such as diet and exposure to other chemicals such as tobacco [62].

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 [61]. 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 [33, 61]. Based on the indiscriminate pesticide application to vegetables reported in

literature [17,18,36] 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.

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 [62, 63]. Most of these processes results in reduction of the pesticide in the vegetables thus reducing the risk of human exposure to these residues [66]. On the other hand, processes that tend to concentrate product may lead to increase of the pesticide residues in the final product [51]. 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 [51]. These practices have been tested based on 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 different geographical locations [67]. It is therefore important to assess these practices at local level to find out if could help in reducing the pesticide residues in the vegetables.

9.1 Effect of washing

Washing of vegetables with tap water has been reported as one of the common procedures applied at household levels when preparing vegetables for family meals. Saeid and Selim [65] 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%). Similarly, other studies reported reduction of pesticide residues in vegetables due to washing. Bonnechère *et al* [68] found reduction of up to 90% of boscalid,

chlorpyrifos, tebuconazole, dimethoate, difenoconazole and linuron in carrot whereas Randhawa [69] 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. Sheikh [70] also found endosulfan to be reduced by 36.42% in okra. Moreover, lambda-cyhalothrin residues could be reduced by 37-40% in tomatoes [71]. 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 Chavarria [72] reported different results on washing of asparagus in which the washing process did not alter the levels of chlorpyrifos residues significantly. The 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 [62, 65, 69]. Washing is reported as the most effective preparatory step pesticide removal in vegetables [64]. The reported effects of washing were based on experimental scale results which call for a need to study the effects at community level.

9.2 Effect of peeling

It is a common practice to peel bulb, root and tuber vegetables before are consumed. Pesticide residues are usually applied on the surface of vegetables, so they can be removed with the peel in the peeling processing [74]. It is reported that peeling is effective in reduction of lindane, profenofos, dimethoate, and pirimiphos-methyl from tomatoes by 80.6-89.2% [75], endosulfan residues from potatoes by 76% and eggplant by 60% [69] and chlorpyrifos from asparagus by 60% [72]. 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 [75]. Also peeling was found to reduce carbaryl residues by 40% in cucumber [76]. Contrarily, in the study by Bonnechère et al [68] could not find any considerable reduction of pesticide residues by peeling. For instance, in this study, 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.

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% [74]. Reduction of pesticide residues in vegetables by cooking is influenced by the physical-chemical structure of the pesticide. For instance, the study by Bonnechère *et al* [68] 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 [77]. 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% [78]. The 100% reduction was observed in brinjal, followed by cauliflower (92%) and okra (75%). Another study by Satpathy [79] found that boiling reduced the organophosphate residues in tomato, bean, okra, eggplant, cauliflower and capsicum by 52-100%. 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% [74].

However these studies have shown that, 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 [80]. This necessitates the need of performing studies on the actual household vegetable handling practices in order to ascertain their practical effect on pesticide residues.

10 Conclusions 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 carry out household-based studies in order to validate the actual impact of vegetable processing on pesticide reduction at that level.

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