Vegetable Pest Management and Pesticide use in Kigoma, Tanzania: Challenges and way Forward

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Abstract: *This study assessed farmers' knowledge and practices regarding pesticide use and pest management in vegetables and implications for human health and the environment. Participatory approaches including focus group discussions, individual farmer interviews and observations were held. The study revealed that most of the farmers are relatively new to vegetable production and use synthetic pesticides as the major strategy for controlling pests and diseases. The farmers lack access to information on proper management of pest and safe use of pesticides, and most often depend on informal advice, notably from pesticide retailers. Consequently, the majority of farmers apply pesticides haphazardly without correctly identifying diseases and pests on their crops. The anomaly is attributed to the lack of knowledge on pesticide use and related hazards, lack of alternatives to synthetic pesticides, stringent market requirements for unblemished crops, and the unwillingness of farmers to accept the risk of crop loss. The indiscriminate application of pesticides, if it remains unchecked, will have adverse effect on the environment, health of farmers and consumers of vegetables. The challenges faced by these farmers in their attempt to manage vegetable pests and possible strategies for intervention are discussed.*

Keywords: Pesticide use, Risk exposure, Farmer awareness, Tanzania

Introduction

Pesticides are the major components of the modern agricultural production because of their high capability and reliability for crop protection against pests and assurance of high crop yields (Schreinemachers *et al*., 2017). In this respect, high input intensive agricultural production systems which involve greater and widespread use of pesticides in managing pests have now become a dominant feature (Abhilash and Singh, 2009; Gautam *et al*., 2017; Jallow *et al*., 2017). Unfortunately, this trend has made farmers in low income countries to become overly reliant on synthetic pesticides in managing crop pests and diseases (Gautam *et al*., 2017). However, reliance on pesticides is difficult to sustain because of the risks, which are associated with misuse of pesticides, and which can cause harm to humans and to the environment. These risks include pesticide poisoning; acetylcholinesterase depression; increased health burden; and adverse effects on animals and fishes, birds, and honey bees (see Abhilash and Singh, 2009; Damalas and Koutroubas, 2016; Gangemi *et al*., 2016; Kiwango *et al*., 2018; Mahugija *et al*., 2018).

Human exposure to pesticides can occur indirectly from environmental contamination (dietary intake or atmospheric contamination) or directly from occupational, agricultural, and household use. In this regard, farm workers are more likely to be exposed both directly and indirectly, which puts them at higher risks of both acute intoxication and long-term adverse health effects (Gangemi *et al*., 2016; Lehmann, *et al*., 2017). Scholars (e.g. Gangemi *et al*., 2016; Mrema *et al*., 2017) provide comprehensive reviews of the impact of pesticides on human health, particularly as regards to the development of chronic diseases.

Many of the adverse effects of pesticides are a direct result of the overuse and misuse of pesticides. These include deviation from the recommended application procedures and dosages; the use of obsolete and banned pesticides; and improper storage, handling, and disposal of pesticides (Damalas *et al*., 2006; Ngowi and Semali, 2011; Damalas and Koutroubas, 2016; Jallow *et al*., 2017; Kiwango *et al*., 2018). Additionally, harvesting of treated fruits and vegetables without following the correct withholding period/pre-harvest interval leads to unacceptable levels of pesticide residues and poisoning to the consumers as observed by Kiwango *et al*. (2018).

Over the years, there has been a substantial increase of pesticide usage trend in agriculture and public health in Tanzania, making pesticide poisoning and contamination of consumer products a major public health concern (see Ngowi *et al*., 2007; Ngowi and Semali, 2011; Kiwango *et al*., 2018). This scenario was envisaged in the villages along the Eastern shores of Lake Tanganyika by the "Tuungane" project. The Tuungane project was introduced in year 2012 as a partnership of the District governments, Pathfinder International, and The Nature Conservancy, to protect the health and well-being of the natural environment and people living in the Greater Mahale Ecosystem (GME) in western Tanzania. The main occupation of the people in the GME is agriculture, followed by fishing and livestock (Hess *et al*. 2016). Owing to an increase in vegetable cultivation and pesticide usage in the villages along the shoreline of Lake Tanganyika, there was a strong need to assess farmers' pest management practices and pesticide use.

Several studies on knowledge, attitude, and behaviour among smallholders' farmers in their handling of pesticides have shown that unsafe use of pesticides is common in Tanzania and other developing countries (Ngowi and Semali, 2011; Kiwango *et al*., 2018), Ethiopia (Mengistie *et al*., 2017), Iran (Rezaei *et al*., 2018), Nepal (Bhandari *et al*., 2018b) and Bangladesh (Gautam *et al*., 2017; Akter *et al*., 2018). The anomaly is linked to the lack of education and training in pesticide use, lack of alternatives to pesticides, inadequate information on related hazards, stringent market requirements for crop aesthetic perfection, and unwillingness of farmers to accept the risk of crop loss (Damalas and Koutroubas, 2016; Jallow *et al*., 2017; Bhandari *et al*., 2018).

The lack of knowledge among farmers on safer pesticides handling (application, storage, and disposal) has also been reported in Tanzania (see Ngowi and Semali, 2011; Lekei *et al*., 2014; Elibariki and Maguta, 2017; Lekei *et al*., 2017; Ngowi *et al*., 2017; Kiwango *et al*., 2018). This calls for a critical consideration of agricultural technologies and identification of best practices of reducing the negative effects of pesticides on human health and the environment for promoting sustainability of agricultural production (Jallow *et al*., 2017; Mengistie *et al*., 2017). The identification of factors that contribute to unsafe behaviours and practices is a prerequisite for the development of appropriate preventive interventions in reducing occupational risks and health problems among vegetable farmers and consumers.

The current study was carried out to (i) assess pest management and pesticide use practices, among vegetable farmers with a special focus on tomato and cabbage, (ii) identify farmers' pesticide use practices that risk the environment and human health (iii) determine the challenges faced by these farmers in their attempt of managing vegetable pests, and (iv) recommend possible alternative strategies for managing pests that will reduce synthetics pesticide use and promote safer pesticide use.

Materials and Methods

Description of the study area

The research was carried out from August to September, 2016. The study area was confined to 16 villages located in Buhingu and Kalya zone along the eastern shores of Lake Tanganyika in Uvinza District of Kigoma region. The villages in Buhingu zone were; Mgambo, Buhingu, Katumbi, Nkokwa, Rukoma, Igalula, Kaparamsenga, Herembe, Kanyase, Mgambazi, Kabusemele, and the villages in Kalya zone were Sibwesa, Kalya, Tambusha, Kashagulu and Lufubu (Figure 1). The 16 villages were purposively included in this study as they were constituent villages of the Tuungane project.

The villages in the Kalya zone, in the southern part of the study area are not easily accessible by roads. Kigoma region has a tropical climate with a long wet rainy season running from October to May, with a short dry spell of 2-3 weeks in January or February followed by a prolonged dry season. The months of January to May receive more precipitation than the months of October to December. The average temperature in Kigoma is 23.2°C while the average rainfall is 1033 mm.

There is a marked difference in soil fertility in the villages. A study by Wickama (2016), revealed that the twelve villages in the Buhingu zone have clay loam soils of better fertility conditions compared to the sandy soils of the four villages in the Kalya zone. All the villages have serious limitations in zinc and all major plant nutrients except calcium. The common soil amendments in vegetables include application of farm yard manure and inorganic fertilizers such as Urea, CAN and a form of Minjingu Phosphate Rock called Minjingu Mazao. However, the manures and fertilizers are applied at less than a quarter of the recommended rates.

This study focused on tomato and cabbage as they are the most cultivated crops in the study area. The crops are susceptible to many arthropod pests and diseases, while consumers prefer unblemished pest-free vegetables. As such, pesticide use is particularly high for these two crops.

Figure 1. Map showing location of most of the villages included in the study. Adopted from Hess *et al.* (2017)

Sampling

For Participatory Rural Appraisal (PRA), the representative farmers were selected by the Tuungane project staff and local village leadership based on a simple random sampling method.

Farmers invited for Focus Group Discussions (FGDs) related to vegetables, were chosen by simple random sampling among the list of known vegetable farmers in each village. Respondents for key informant interviews were selected by both convenience sampling technique (Pesticide retailers and farmer leaders) and purposively by selecting all resident Extension Officers.

Data collection

Data collection methods

Desk/ literature review: A review of literature and various reports concerning vegetable growers and their farming practices in the study area, and important crops pests and diseases as well as methods of control was done. The risks associated with environmental hazards for each of the pesticides already in use was established based on Food and Agriculture Organisation of the United nations (FAO) classification of pesticide toxicity. The relative appropriateness of pesticides used was also assessed in respect to effectiveness, human health and environmental risks.

Focus group discussions: At the beginning of the study, FGDs were held in each of the 16 villages, to establish crop produced and major pest problems encountered. Thereafter, additional six FGDs were held in the villages where vegetable production was deemed important. Each FGD consisted of eight to fourteen representative individuals. Discussions were tape recorded.

Key informant interviews: The informants included; all four resident Agricultural Extension staff, all three Pesticide retailers at Mwanga market area in Kigoma town and the two retailers at Kalya. Additionally, Village leaders, selected vegetable Farmers' group leaders, Tuungane field staff and officials from Uvinza District Headquarters, were interviewed. A checklist of questions was used to guide discussions with key informants as described in section 2.3.2.

On the spot observations: Participatory observations were carried out to complement information obtained from interviews and FGDs. A checklist for different types of observations was used. Key pesticides and their application methods were identified based on the description given by farmers and photo documentation. In addition, the two Agrovet shops located in one village (Kalya) and the three shops at Mwanga area in Kigoma town were visited to identify and get more information about the pesticides currently in demand or commonly used by the vegetable growers. The interaction of customers and pesticide shop keepers as well as handling of pesticides was also observed in each shop. The focus here was to assess whether (i) Shop keepers have adequate knowledge about the different pesticides in their stores (ii) Shopkeepers adhere to safety precaution while handling pesticides and (iii) Farmers have adequate knowledge to allow them to choose a pesticide that is appropriate to their pest problem**.**

Checklist for interviews

The FGD with vegetable farmers used an interview guide that probed information on (i) the type of vegetables grown, (ii) the type of pests/diseases and methods of control, (iii) the type of pesticides used and their methods of application, (iv) farmers' knowledge about pesticide use (selecting, storing, and applying pesticides), (v) adherence to safety precaution when using pesticides, (vi) perceptions of the consequences of their behaviour, in other words, farmers' awareness on the effect of pesticides on health and environment (vii) the challenges vegetable growers face in managing pests and diseases. During interviews, self-perceived pesticide poisoning symptoms were also recorded. A similar checklist was used for Key informant interviews where the interviewees also helped to clarify issues that were not clear from the discussions with farmers.

Data analysis

Data analysis was done immediately after the field visit. Data from interviews and FGDs were transcribed from tape recordings and later typed using MS Microsoft Word immediately after fieldwork. Content and thematic analyses were done by first ordering the narratives in relation to the interview checklist topics and specific objectives of the study. The information gathered was then summarized as major qualitative results in separate sections of the findings, following the objectives that guided the collection of the particular data.

Limitation of the study

The study was carried out during off season. Usually, there are more pests and disease incidences and high disease severity during the rainy season. Vegetable crops observed in the field included tomato, cabbage, Chinese cabbage, collard, Amaranthus, watermelon and cucumber. Hence, the identification of some of the pests and diseases which could not be seen relied mostly on the descriptions obtained from farmers. However, despite these limitations, it is envisaged that the data collected and the results of the study are a true representation of the situation existing in the study area.

Results

Type of vegetables grown

A wide range of vegetable crops are cultivated mostly on small plots of less than 0.25Ha. Only watermelons (*Citrullus lanatus*) are grown on large plots of about 0.5Ha. The most cultivated vegetables in the order of importance, are tomato (*Lycopersicon esculentum*) and cabbage (*Brassica oleracea* var.

capitata). Other vegetables include Chinese cabbage (*Brassica rapa* subsp. *pekinensis*), watermelon, cucumber (*Cucumis sativus*), collard greens (*Brassica oleracea* var. *acephala*), Amaranthus (*Amaranthus* spp.), onion (*Allium cepa*) and the African eggplant (*Solanum aethiopicum*). The most important vegetable producing villages were Katumbi, Mgambo, Buhingu, Magambazi, Lagosa, Herembe and Kalya. The major field crops grown are rice, cassava, maize, common bean (*Phaseolus vulgaris*) and oil palm. Other field crops grown include banana, sweet potato, coconut and groundnut.

Major crop pests and Pest management strategies
The major pests and diseases for tomato and cabbage are listed in Tables 1 and 2.

Table 9. Important Pests and Diseases Of Tomato

SN	Tomato Pests	Tomato Diseases
1	Fruit borers (*Helicoverpa* spp., *Spodoptera* spp.)	Late blight (*Phytophthora infestans*)
2	Cutworm (*Agrotis* spp.)	Tomato yellow leaf curl virus
3	Leaf miner (*Liriomyza* spp.)	Fusarium wilt (*Fusarium oxysporum* f. sp *lycopersici*)
4	Root knot nematode (*Meloidogyne* spp.)	Blossom end rot of fruits (Physiological problem)
5	Aphids (*Aphis gossypii, Myzus persicae*)	Stem canker (*Didymella lycopersici*)
6	Loppers (*Trichoplusia* spp.)	
7	Spider mite (*Tetranychus* spp.)	

In tomato, fruit borers and leaf miners were reported as the most troublesome insects, whereas late blight was singled out as the major disease. In cabbage, the diamondback moth and black rot were the most important constraints. Farmers during FGDs reported that synthetic pesticides are by far the commonest crop protection technology used to control arthropod pests and diseases. However, other discussions and field observations revealed an increase in cultivation of disease resistant varieties. A very popular, but disease susceptible tomato variety Marglobe was largely being phased out by farmers in favour of a variety Tengeru 97, which is fairly resistant to a number of diseases, and has a long post-harvest shelf life. For cabbage, field observation showed several fields planted with variety Gloria F1 which is less susceptible to black rot as opposed to open pollinated varieties.

Table 10. Important Pests and Diseases of Cabbage

SN	Cabbage Pests	Cabbage Diseases
1	Diamondback moth (*Plutella xylostella*)	Black rot (*Xanthomonas campestris* pv. *campestris*)
2	Aphids (*Brevicoryne brassicae, Lipaphis erysimi, Myzus persicae*)	Bacterial soft rot (*Erwinia carotovora* var. *carotovora*)
3	Cutworms (*Agrotis* spp.)	
4	Cabbage looper (*Trichoplusia* spp)	
5	Green grasshoppers	

In Katumbi village, one farmer complemented insecticide spraying by hand picking and destroying tomato leaf miners. Some good agricultural practices such as field sanitation, tomato staking, and correct crop spacing were being implemented by farmers. Unfortunately, farmers do not bother with removing and destroying crop residues immediately after harvest.

Type and source of pesticides used

Type of pesticides used

Thirty-two different pesticides were reported by farmers or were observed during field visits (Tables 3 and 4). Their formulations were predominantly emulsifiable concentrates (EC) for insecticides or wettable powders (WP) for fungicides. Insecticides accounted for 56% of the pesticides followed by fungicides, while herbicides were not used in the study area (Tables 3 and 4). The commonly used insecticides included Organophosphates (50%), mostly comprising Chlorpyrifos 400EC and Profenofos 720EC, Pyrethroids with or without Neonicotinoids (39%), and Biopesticide Abamectin. It is worth noting that organochlorines, such as the banned Endosulfan, were neither stocked in the pesticide retailer shops nor used by farmers. The most popular fungicides were Mancozeb with or without Metalaxyl and Chlorothalonil. A few farmers reported of having tried or having heard about spraying with botanical concoctions prepared from chillies and tobacco.

Table 11. List of Crop Insecticides used by Farmers and Sold at Kalya/Kigoma Pesticide Retailer Shops

SN	Chemical group[11]	Common name (Active ingredient)	Trade name(s)[12]	WHO class[13]
1	BP	Abamectin	Bimectin 3.6 EC; Dudu-Acelamectin	II
2	NC	Imidacloprid 20%	Metro 200 SC*	II
3	NC, PY	Acetamiprid 3% + Lambda-cyhalothrin 3.0%	Blasto 60 EC	II, II
4	NC, PY	Imidacloprid 20% + Cypermethrin 14.4%	Attakan C344 SE	II, II
5	OP	Chlorpyrifos 400 EC	Ascoris 48 EC*; DASBA 40 EC; Farmrifos 48 EC; Twigaphos 48EC*	II
6	OP	Fenitrothion	Sumithion	II
7	OP	Profenofos 720 g/l	Mocron 720 EC; Profit 720 EC*; Selecron 720 EC*; Wilcron 720 EC	II
8	PY	Cypermethrin 10% EC	FA Supa*	II
9	PY	Lambda-cyhalothrin	CS-Calates 5EC*; Su Karatii 5EC	II
10	PY, NC	Lambda-cyhalothrin + Imidacloprid	Perfecto	II, II

[11] Chemical group: BP = Biopesticide, NC=Neonicotinoids, OP Organophosphate and PY=Pyrethroids

[12] Trade names with an asterisk had labels with instructions in Kiswahili

[13] WHO class: Ia=Extremely hazardous, Ib = Highly hazardous, II=Moderately hazardous, III = Slightly hazardous, and U = Unlikely to present acute hazard

Table 12: List of Crop Fungicides used by Farmers and Sold at Kalya/Kigoma Pesticide Retailer Shops

SN	Common name (Active ingredient)	Trade name[14]	Target/Use	WHO class[15]
1	Chlorothalonil 500 SC	Banko 500 SC*; Linkonil; Twigathalonil 500*	Contact broad spectrum	U
2	Chlorothalonil 720 SC	Asconil 720 EC; Odeon 720 SC	Contact broad spectrum	U
3	Fosetyl-al 20% + Mancozeb 30%	SuperKinga*	Contact Broad spectrum	U
4	Hexaconazole 5 EC	Xantho*	Powdery mildew, Rusts	III
5	Mancozeb 640 + Metalaxyl 80	Eureka 72 WP*; Supalaxyl 72 WP*	Broad spectrum Systemic & Contact	U, II
6	Mancozeb 800	Farmerzeb 80WP; Supazeb 80 WP	Broad spectrum, contact & preventive	U
7	Mancozeb	Dithane M45	Broad spectrum, contact & preventive	U
8	Metalaxyl 80g+Mancozeb 640g	Ivory M 72 WP; Linkmil 72 WP	Protective and curative broad spectrum	II, U

Source of pesticides used

Pesticides were mainly obtained from pesticide shops located in Kigoma town. There were no pesticide retailer shops in all the villages except in Kalya. In some villages, notably Mgambo, Buhingu, and Rukoma, some

[14] Trade names with an asterisk had labels with instructions in Kiswahili
[15] Who class: Ia=Extremely hazardous, Ib = Highly hazardous, II=Moderately hazardous, III = Slightly hazardous, and U = Unlikely to present acute hazard

individuals sell a few pesticides in shops not meant for agricultural inputs. Farmers also buy pesticides from crop buyers and other individuals who re-pack pesticides and sell them in smaller quantities in unlabelled containers. A few banned substances and products that are not registered in the country were reported by farmers. These include a banned Endosulfan insecticide called "Teretere", which used to be imported in yesteryears from Burundi, and an Abamectin insecticide named "Dudu-Acelamectin", which is apparently illegally imported with label/language suggesting that Uganda was the country of origin.

Risky practices associated with pesticides use
Farmers' perception of pesticide toxicity
Farmers and retailers are aware that pesticides are toxic but they seem to be less worried by fungicides as compared to insecticides. As such, fungicides are facetiously referred to, in the local Kiswahili language, as "dawa" (medicine) while insecticides are called "sumu" (toxin/poison) basing on their perceived curative and lethal effects on diseases and insects, respectively.

Farmers' knowledge of pesticides: choice and application rates
Farmers in the study area most often depend on informal advice for information on pesticide selection, dosage, and application. The advice is sought mostly from pesticide retailers, neighbouring farmers, and very occasionally from extension staff. Many farmers are relatively new to vegetable production; and despite the fact that resident Extension Officers are available in the four villages, farmers do not usually consult them. In Kalya village, the Extension Officer, who also serves as a Village Administrative Officer, reported to have been frequently consulted by farmers. Furthermore, observations and discussions with pesticide retailers revealed that retailers are not familiar with the use of most of the products stoked in their stores.

The majority of the vegetable farmers were noted to apply pesticides haphazardly and sometimes routinely, without correctly identifying the diseases and pests on their crops. Hence, often farmers use pesticides which are not appropriate in addressing the problem in the field. Fungicides are routinely and frequently applied for up to two times a week as a protective measure against late blight in tomato fields. Whereas, insecticides are applied weekly once leaf miners and Diamondback moth damage are sighted in tomato and cabbage fields, respectively. When a pesticide is not effective, it is often replaced by a more toxic and potent alternative or higher dose or a combination of pesticides is applied, and sometimes the frequency of application is increased. Cases of crop injury due to excessive use of pesticides were noted in tomato fields at Mgambazi and Katumbi villages. Studies elsewhere have shown that higher than the recommended dosage of pesticides are applied under the misconception that a higher dose means better eradication of pests (Mengistie *et al*., 2017).

Pesticide packaging and labelling

The pesticides were commonly sold in containers ranging from 0.25 to 5 L or in packets ranging from 0.25 to 25 Kg. Most of the pesticide retailers stocked small package size (<0.75 L) because they are affordable to most farmers. However, small packages have little room for adequate display of instructions, requiring a magnifying glass to read some of the instructions in the containers of less than 250mL. Surprisingly, most of the pesticides (59%) lacked instructions in Kiswahili (Tables 3 and 4). On the contrary, a few pesticides, notably Selecron 720 EC (Profenofos), included an easy to read, detachable folded leaflets with detailed information.

In the remote area of Kalya, one of the pesticide retailers was re-packing and selling fungicides, particularly Mancozeb (Dithane M45), that were originally packed by manufacturers in large packages (>5Kg), into small (<1Kg) unlabelled packages. Incidentally, the practice is commonly used for pesticides used against store pests such as Pirimiphos-methyl (Actellic EC), originally packed in one litre bottles, and Aluminium phosphide (Quickphos/Phostoxin) tablets.

Several pesticides of the same common name, such as Mancozeb 80 % WP and Insecticides Profenofos 720 g/L and Chlorpyrifos 400 EC are sold by different manufactures using different trade names (Tables 3 and 4), and hence add more confusion to farmers during the selection of pesticide for purchasing or applying them in the field. Furthermore, some insecticides such as Blasto 60EC, Attakan C344 SE and Perfecto are blends of two different active ingredients (Table 3).

Many farmers in the study area neither understand nor rely on the information on pesticide packages. The communication barrier is attributable to having labels in English language, having some users who are illiterate or labels being illegible due to font type and small font size used or the use of signs and symbols in the labels which are not comprehensible to farmers. Similar observations were previously made in Tanzania and elsewhere by other scholars (e.g. Ngowi *et al*., 2007; Damalas and khan, 2016; Mengistie *et al*., 2017).

Pesticides application technique

The majority of farmers in the study area apply pesticides using 15-20L Lever Operated Knapsack (LOK) sprayers and occasionally using small hand-held sprayers of <2.0L. Pesticides are applied while diluted with water as high-volume sprays. The LOKs sprayers are fitted with hollow cone spray nozzles, which as correctly noted by Sibanda *et al*. (2000), are in principle quite appropriate for vegetable spraying. They produce a relatively fine spray at low pressures and disperse the spray droplets quite effectively. However, most of the LOKs used by farmers were of poor design/construct, and did not have the desired safety, durability, comfort, or efficiency, which is considered essential for smooth functioning of the equipment. Accordingly, many of the LOKs were either leaking or having problems with their nozzles as a result of wear, damage, and poor maintenance. Similar observations were made by Sibanda *et al*. (2000) in Zimbabwe.

Most of the farmers spray their crops in the morning or late in the afternoon and avoid the hot hours of the day. Incidences of spray drift were occasionally observed in the fields because sometimes farmers directed the spray into the wind or advancing through the crop in a downwind direction thus moving into contaminated vegetation. This was partly due to limitations posed by crop rows as is the case with staked tomato.

The tank mixing of pesticides

Mixing of different types of pesticides in one spray tank was a very common practice in the study area. Up to four different types of pesticides may be mixed in one spray tank as a strategy of controlling multiple pests or diseases. Sometimes the same chemical ingredient from different products is mixed and sprayed leading to overdose and plant injury.

Use of personal protective equipment

Farmers in all villages and all pesticide retailers visited did not comply with the use of personal protective equipment (PPE). As a result, contact with pesticides is a common feature during handling or spraying of pesticides. Besides, after field sprays, contaminated work clothes are not washed daily. The PPEs were not used by farmers because they were deemed (i) expensive (ii) uncomfortable during application and (iii) unavailable. Additionally, some farmers reported to have not been aware of the adverse effects of handling pesticides without PPEs. Consequently, several pesticides, notably fungicide Chlorothalonil 720 SCR have commonly been reported to have caused discomfort during and after spraying. This fungicide irritates the eyes, the nose and the throat. Pesticide contamination of the ground may lead to contamination of water points.

Pesticide poisoning and safety harvest period

Farmers do not stick to the recommended safety harvest period before the sale or consumption of the produce. For instance, it is a common practice for fungicides to be sprayed on ripe harvested tomatoes, which are destined for the markets, because farmers and even crop buyers believe that spraying the tomatoes prior to harvesting helps to prolong the shelf life of the fruits.

Most farmers reported to have experienced a range of pesticide poisoning symptoms after spraying. Commonly self-reported toxicity symptoms were headache, dizziness, itching/skin irritation, and general body weakness. Pesticide poisoning symptoms were more common with insecticides than was the case with fungicides.

All farmers declared to have been washing their hands with soap immediately after handling pesticides. Body washing is done at the homesteads or at the edge of the fields or right in the water streams. The equipment used in the fields is washed at the edges of the fields or along the stream banks but reportedly not in the stream. These practices obviously lead to contamination of water sources.

Pesticides storage and disposal of used containers

Pesticide packages were reportedly to have been stored in areas beyond easy reach of children. The practices mentioned include hanging on walls, hiding under the bed, placement in designated storage room as well as hiding pesticide containers in the concealed places outside the house or in the field. Farmers seemed to have been aware that used containers need to be properly disposed of. They reportedly dispose the containers in the waste (dump) areas, pit latrines, or burn, or bury them in the soil or throw them in their fields. Incidentally, large (ca. One litre) plastic containers are occasionally used for keeping kerosene or collecting water from the streams for spot irrigation or for filling the sprayers. However, observation in some of the vegetable fields revealed that used plastic pesticide containers are placed on top of staking sticks in the tomato fields or are just thrown haphazardly.

Discussion

Challenges faced by farmers

The following are some of the challenges which farmers face in managing pests in vegetables.

Farmer reliance on synthetic pesticides

The high dependence on pesticides by vegetable farmers noted in this study has earlier been observed in other parts of Tanzania (see Ngowi *et al*., 2007), Ethiopia (see Mengistie *et al*., 2017), Zimbabwe (see Sibanda *et al*., 2000) and elsewhere (see Abhilash and Singh, 2009). Synthetic pesticides are advantageous because they are reasonably acting fast and have a relatively broad spectrum of activity, hence they can deal with a range of pests or diseases at the same time. Heavy dependence on pesticides is catalysed by the fear among farmers of economic loss resulting from crop damage by pests. The dependence is also catalysed by the requirement of high-quality standards demanded by the market (Damalas and Koutroubas, 2016; Jallow *et al*., 2017). Additionally, low knowledge on beneficial and harmful insects was also associated with more pesticide use (Schreinemachers *et al*., 2017). However, this reliance implies that farmers may not be aware of other pest management strategies that are effective, inexpensive, and friendly to the environment (Ngowi *et al*., 2007; Mengistie *et al*., 2017).

Risky practices associated with the use of pesticides
Farmers' perception of pesticide toxicity

Farmers' knowledge and perceptions about pesticide risks play an important role in determining the extent of their exposure to pesticides. Despite the fact that farmers have limited control over the toxicity of a pesticide, significant control over risks that are associated with the use of this pesticide can be expected (Damalas and Koutroubas, 2016). The misconception noted in this study about pesticide toxicity, has also been reported in other countries (see Mengistie *et al*., 2017; Bhandari *et al*., 2018) and seem to influence the way farmer handle pesticides. Nevertheless, Ngowi *et al*. (2007) cautioned that serious and acute damage to farmer's health may occur following long-term exposure to fungicides.

Farmers' knowledge of pesticides: choice and application rates

The majority of the vegetable farmers were noted to apply pesticides haphazardly and sometimes routinely without proper identification of the pest problem. Similar observations were also reported in other parts of Tanzania (see Ngowi *et al*., 2007; Victoria *et al*., 2017; Kiwango *et al*., 2018) and elsewhere (see Sibanda *et al*., 2000; Abhilash and Singh, 2009; Mengistie *et al*., 2017; Akter *et al*., 2018; Bhandari *et al*., 2018). In most cases, the noted anomalies were attributed to farmers' inadequate knowledge of pesticides and safe pesticide handling practices (Damalas and Koutroubas, 2016; Sharma and Peshin, 2016; Mrema *et al*., 2017; Bhandari *et al*., 2018).

This study noted that pesticide retailers play an important role in the pesticide supply chain in Tanzania. The overt farmers'reliance on advice from pesticide retailers noted in this study is common in Tanzania and in several other developing countries (Sibanda *et al*., 2000; Ngowi *et al*., 2007; Ngowi and Semali, 2011; Jallow *et al*., 2017; Sharma and Peshin, 2016; Mengistie *et al*., 2017; Ngowi *et al*., 2017; Schreinemachers *et al*., 2017). According to Jallow *et al*. (2017), this tendency may be driven by the desire among the retailers of making super profit from the sales of more pesticides, which in turn promote aggressive use of the pesticides. Unfortunately, as Jallow *et al*. (2017) and Ngowi *et al*. (2017) correctly put it, the retailers are also known to practice unsafe behaviours; such as selling unregistered, prohibited, or expired pesticides; mixing, reweighing and repacking pesticides; and trading on the open market.

It was also noted that farmers are vulnerable to pesticides which are brought to local retailers in Tanzania from unauthorised, sometimes illicit, sources and illegal trading. Informal cross border movement of pesticides is a problem that has been reported in other countries such as Ethiopia (see Mengistie *et al*., 2017) and Nepal (see Bhandari *et al*., 2018).

Pesticide packaging and labelling

Farmers in the study area face a lot of difficulties in understanding information on pesticide containers. The problem seems to be aggravated by packaging pesticides in small packages, which were incidentally very popular among farmers. Consequently, most farmers do not read labels instead they rely on advice from pesticide dealers, extension workers, and neighbours. Inadequate or illegible information provided on the labels and package leaflets was considered to be the main barriers against good safety behaviour practices in Pakistan (Damalas and Khan, 2016) and Nepal (Bhandari *et al*., 2018). According to Stadlinger *et al*. (2011), this is a challenge which pesticide manufacturers need to overcome by producing smaller packages that meet the needs of the end-users. Additionally, the selling of pesticides belonging to the same common name using different trade names confuses farmers (Mengistie *et al*. 2017).

Pesticides application technique

Pesticides are typically applied by using the Lever Operated Knapsack (LOK) sprayers. However, most of the LOKs had some problems related to their design/manufacturing and poor maintenance but farmers obstinately continued to use them. In Ethiopia, Mengistie *et al*. (2017) noted that about 50% of the sprayers examined during their study were leaking. The leaks either came from the trigger valve or from the pipe union with the tank. Incidentally, farmers in Sri Lanka continued to use faulty sprayers even when they were trained to avoid using leaking LOK sprayers. Furthermore, Abhilash and Singh (2009) correctly observed that despite the use of modern pesticides in India, the technology used for their application has not been upgraded resulting in a waste of pesticides and unnecessary environmental contamination. According to the authors, a change of the design of the nozzles of LOK sprayers could have saved up to 70% of pesticides as opposed to the farmers' previous practice.

Spray drift due to a change in wind speed or direction was another challenge observed in this study. Spray drift should be a major concern because it diverts the pesticides from the intended target, reduces efficacy, and deposits pesticide where it is not needed or wanted causing environmental and health hazards (Abhilash and Singh, 2009; Delcour *et al*., 2015). Experience in Ghana has shown that pesticide applied to a watermelon farm can drift and accumulate in significant levels in the neighbouring non-target okra crop (Elibariki and Maguta, 2017).

The tank mixing of pesticides

The mixing of more than one pesticide in a spray tank was common in the study area and in other parts of Tanzania and elsewhere (see Ngowi *et al*., 2007; Ngowi and Semali, 2011; Mengistie *et al*., 2015; Damalas and Khan, 2016; Bhandari *et al*., 2018). For example, Ngowi and Semali (2011) noted that onion farmers in Northern Tanzania sprayed a cocktail of up to five insecticides that incidentally included three Prefenofos insecticides. Whereas, in Cambodia applicators mixed an average of 3.7 pesticides together in a single spray (Schreinemachers *et al*., 2017).

The practice of tank-mixing pesticides is carried out to save time, labour cost, and with the anticipation of high efficacy in pests and diseases control (Ngowi *et al*., 2007; Mengistie *et al*., 2017). Nevertheless, label instructions do not cover mixtures of three or more pesticides and give no information on the compatibility of inert ingredients such as emulsifiers and wetting agents (Mengistie *et al*., 2017). An interaction between fungicides, insecticides, and water mineral content that influences the efficacy of individual pesticide against fungal pathogens and insect mortality has been reported elsewhere (see Smit *et al*., 2002; Ngowi *et al*., 2007). In the study of Ngowi *et al.* (2007), some of the tank mixtures induced phytotoxicity on tomato. Similarly, this study observed several tomato plots, which were abandoned due to pesticide phytotoxicity associated with failed attempts of controlling leaf miners and or late blight. Furthermore, it is on record that mixtures of insecticides generally result in the simultaneous development of insect resistance (Ngowi *et al*., 2007).

The tank mixing malpractice is generally attributed to lack of basic knowledge of pesticides application among farmers. However, studies in Kuwait and Sri Lanka show that the practice of mixing pesticide may continue even after farmers are trained on pesticide application (Jayasooriya and Aheeyar, 2016; Jallow *et al*., 2017).

Use of personal protective equipment

Vegetable farmers in the study area are at a high risk of pesticide exposure because they hardly use any Personal Protective Equipment (PPEs). Similar observations have been noted in other parts of the country (see Ngowi *et al*., 2001, 2007; Victoria *et al*., 2017). A study by Lekei *et al*. (2014) in Tanzania noted that over 60% of PPEs used by farmers were damaged or extremely contaminated by pesticides. The correct use of personal protective equipment has always been considered fundamental for the safety of workers (Gangemi *et al*., 2016). Usually, the risks (hazards) from a specific pesticide depend on the toxicity of the specific product used and the amount and form of exposure (Damalas and Koutroubas, 2016). Often, occupational exposure to pesticides is associated with the mixing of these substances, transportation, application on crops, and cleaning of the equipment. When PPEs are not used, the dermal and inhalation routes of entry are the most common routes of farmers' exposure to pesticides (Damalas and Abdollahzadeh, 2016; Damalas and Koutroubas, 2016).

Dermal exposure can be limited by wearing the most common types of PPEs such as gloves, boots, hats, long sleeve shirts, and chemical-resistant coveralls (Damalas and Koutroubas, 2016). In their excellent review on farmers' exposure to pesticides, Damalas and Koutroubas (2016) cautioned that personal protection can be low because the PPE is unsuitable, incorrectly fitted, and improperly maintained and used. Additionally, experience elsewhere has shown that farmers may not use PPEs due to unavailability of the equipment or lack of awareness and economic burden or time limitation resulting from performing the work or discomfort resulting from heat stress and dampness experienced in the field (Ngowi *et al*., 2001, 2007; Mengistie *et al*., 2017; Akter *et al*., 2018; Bhandari *et al*., 2018). Similar observations were reported by Sharma and Peshin (2016) in India, Yassin *et al*. (2002) in Gaza strip, and by Schreinemachers *et al*. (2017) in Cambodia and Laos.

The protection offered by common protective clothing against exposure to pesticides vary according to the fabric type, including thickness and weight. For instance, a greater protection in terms of decreasing dermal exposure occurs when waterproof polypropylene fabrics are worn as opposed to cotton garments (Damalas and Koutroubas, 2016). It is further cautioned that the safety behaviour depends on the perceived susceptibility, the severity of the risks and the benefits as well as the current inhibiting factors to adopting good safety behaviours (Akter *et al*., 2018; Bhandari *et al*., 2018; Bondori *et al*., 2018).

Safety harvest period and pesticide poisoning

The non-adherence to safety harvest period noted in the study area implies that, the consumption of vegetables with pesticide residues cannot be ruled out. This anomaly cuts across the food chain as almost each household regularly consumes tomato and other vegetables. In other parts of Tanzania, tomato farmers were reportedly applying Lambda cyhalothrin (Karate EC) every seven days instead of fourteen days and one day instead of seven days before harvesting (Victoria *et al*., 2017). Similarly, in Nepal, researchers discovered that farmers apply pesticides to vegetable crops at rates nearly four times higher than the recommended (Bhandari *et al*., 2018). Regrettably, this indiscriminate use of pesticides does not translate into increasing crop yields for the farmers, but rather increasing the potential of adversely affecting human health and the environment. Incidences of pesticide residues, above the maximum residual limits, have been reported in various vegetables grown in Tanzania (see Victoria *et al*., 2017; Kiwango *et al*., 2018).

Unfortunately, the monitoring of pesticide residues in vegetables is not a common practice in Tanzania (Kiwango *et al*., 2018). In Kuwait, the presence of chlorinated pesticides in the breast milk of lactating women has raised even greater concerns over the possible health risks of breastfed infants (Jallow *et al*., 2017). The common incidences of pesticide poisoning symptoms reported by farmers imply that pesticides are not correctly handled and farmers are at a great risk of pesticide poisoning.

Pesticides storage and disposal of used containers

Throwing of empty pesticide containers was a common practice in the study area despite the fact that farmers seemed to be aware of the malpractice. This anomaly has previously been noted in other parts of the country (see Lekei *et al*., 2014; Nonga *et al*., 2017). In other studies, empty pesticide containers have been reused mostly by women, for domestic purposes such as storing food items and kerosene (see Remoundou *et al*., 2014; Ngowi *et al*., 2017). Empty containers always have residues and are a source of exposure that can cause harmful effects to users (Ngowi *et al*., 2017). Incidentally, even the recommended practices of burning or burying these empty packages are also potentially hazardous to human health and the environment (Mengistie *et al*., 2017). Recently, Bolivia successfully implemented a responsible management plan for empty plastic pesticide containers (Skovgaard *et al*., 2017). The programme entailed training of farmers to practice triple rinsing and puncturing of the containers, followed by disposal of containers in designated collection points for further processing and recycling by plastic manufacturing companies.

Lack of access to alternative pest management technologies

Host plant resistance: Host plant resistance remains the most feasible strategy for managing important diseases in Tanzania and other developing countries where vegetables are largely produced by smallholder farmers. Promising varieties with resistance to major diseases of cabbage and tomato are shown in Table 5. However, most of the varieties are not available to farmers.

Safer pesticides and biological control: Viable alternative to synthetic methods of pest control include biopesticides, biological control and pheromone-based pest management (Jallow *et al*., 2017). Isman (2017) underscored the existence of a very large "inventory" of plant extracts or compounds therefrom arising from scholarly researches in contrast to the very few investigations on (i) methods of extraction on an industrial scale, (ii) formulation of plant extracts or oils into consistent, concentrated products, and (iii) best practices for the use of such products. Thus, the author called for more emphasis on technology transfer end in order to push the products to farmers.

These observations are reflected in a recent review of Moshi and Matoju (2017), that indicated the status of application of biopesticides in Tanzania and challenges that need to be addressed in order to exploit their inherent potential. Up to now, a few bio pesticides have provisional or full registration in the country. The few commercially available bio-pesticides are mainly used for mosquito control e.g. *Bacillus bassiana* strain GHA (Bio-bassiana), *B. thurugiensis* var. (BN3WP), *B. sphaericus* (Griselesf) and Neemray super (Azadirachtin) for control of cotton bollworms (Moshi and Matoju, 2017). Examples of interventions that can help the farmers to manage pests are shown in Table 5. Regrettably, botanical pesticides, such as neem products, have not been very popular because of variability between batches of formulation leading to variable efficacy, short shelf life and the difficulty of preparing sufficient quantities for medium scale cropping systems. Possible mammalian toxicity is an issue which has been largely neglected. Furthermore, some of these botanical products are not officially registered and have, therefore, not usually undergone systematic toxicological testing (Sibanda *et al*., 2000).

Pesticide registration and monitoring system: According to Moshi and Matoju (2017), the legal framework in Tanzania is seen as one of the limiting factors against registration and commercialization of biopesticides. The authors cautioned that pesticide registration procedures are unnecessarily costly and bureaucratic, and are four times higher than those in Kenya. This could be one of the reasons for increased illegal trading of pesticides in the country.

Lack of information on pest management and proper use of pesticides

The incorrect pesticide uses and heavy reliance on pesticides noted in the study area are attributable to farmers' social and farming characteristics, increased pest incidences, lack of access to extension support, lack of access to non-synthetic methods of pest control, and farmers' perception of yield loss due to pests. As Jallow *et al*. (2017) observed, farmers who had access to extension support were more knowledgeable about pesticides and alternative methods of pest control, and thus were less receptive to using pesticides. Recently, Bondori *et al*. (2018) noted that farmers' knowledge of pesticide hazards, attitudes towards pesticides, past experience of pesticide poisoning, and the use of information sources are important variables that can shape farmers' behavior towards safety. However, in the absence of effective extension services and training in the country (Ngowi *et al*., 2007), other intuitive training approaches need to be developed and tailored to the needs of smallholder farmers. In India, Sharma and Peshin (2016) emphasised the need for refocusing extension services to traders/retailers dealing with pesticides, with training on safe handling, storage, and correct pesticide usage. In another study done in Southeast Asia, Schreinemachers *et al*. (2017) observed that raising awareness about pesticide health risks was not enough to reduce the actual use, although higher awareness was associated with fewer self-reported poisoning symptoms as it may induce farmers to protect themselves better. Similarly, Remoundou *et al*. (2014) attributed the risk-related behaviours to other factors such as economic and employment pressures and peer group related influences.

Conclusion

This study sought to reveal pest management strategies and pesticide use among vegetable farmers in a remote district of Uvinza, Tanzania and the challenges faced by these farmers in managing vegetable pests. The study has shown the plight of farmers who embark on small scale vegetable production, whilst they have limited knowledge on pest management and on correct use of pesticides. This scenario has long been observed in Tanzania and other developing countries where an increase of the demand for vegetables encourages farmers to venture into vegetable production (Massomo *et al*., 2005). There are so many risks posed to humans and the environment from indiscriminate use of pesticide in vegetable farming. The adverse effects are more acute in Tanzania and other developing countries where farmers lack training and access to awareness programs on proper management of pest and safe use of pesticides.

The heavy dependence on pesticide as well as pesticide poisoning may be reduced through better farmers' education, training in Integrated Pest

Management (IPM) and improved safe use and handling practices on pesticides, and improved access to extension support. Efforts should be

made to develop and promote alternative methods of pest control such as host plant resistance to common diseases and non-synthetic pesticides in the context of IPM. It is envisaged that with climate change, increase in temperatures and changes in precipitation patterns will be the main determinants of pests and pathogen infection. This may lead to an increased pesticide use in terms of high amounts, doses, frequencies, and differences in varieties or types of products applied if the situation is not addressed. Excessive and haphazard use of pesticides is detrimental because it leads into contamination of our ecological systems including soil, sediments, and waterways (that adversely impact the wildlife) and through transfer of residues across the food chain.

Way forward

This study therefore recommends three strategies for reducing synthetic pesticide use, improving pesticide use and handling practices among smallholder farmers in developing countries. These strategies are; (i) Enhancement of farmers' awareness (ii) Development and use of alternative pest management methods, and (iii) Enforcement of laws and regulations on pesticides use and handling.

Enhancement of farmers awareness

(i) It is important to raise awareness among farmers about good safety behaviours and long-term consequences of pesticide use. This may be achieved through development of more educational programs, such as documentaries and talk shows as well as information dissemination through radio, television, and any other possible means.

(ii) Mobile software applications should be developed by researchers in order to assist farmers in the identification of pest problems and the potential strategies for control. This is encouraged by good cell phone coverage and increased affordability and possession of cell phones by farmers in developing countries and in the study area as well.

(iii) Stakeholders, notably pesticide manufacturers, should be encouraged to facilitate the development of simple informative crop specific posters/flyers/booklets with coloured images of pests/diseases for ultimate sale to farmers. These would assist farmers to choose appropriate types of intervention(s) according to the problem in question. An example of excellent and concise poster on tomato pests and diseases was developed by ICIPE and Biovision and appears at http://www.biovision.ch/fileadmin/pdf/e/projects/tomato_6-02-08.pdf (Last visited in February, 2019).

(iv) The available crop specific technical guidelines, such as the one by Massawe *et al*. (2010) on integrated tomato production in northern Tanzania, should be translated in the local language (i.e. Kiswahili) and sold to farmers.

(v) Local government authorities should strive to re-train, motivate, and guide resident extension workers so as to improve farmers'

(vi) knowledge, especially on IPM. This can be done in villages that have resident extension workers including; Mgambo, Mgambazi, Rukoma and Kalya. This is crucial because many government extension programmes in African countries have been encouraging the use of pesticides (Abate *et al*., 2000), but they seem to have been insensitive to the impact of pesticides on health and the environment (Ngowi and Semali, 2011).

(vii) Pesticide retailers should be trained on pesticide use/misuse, its storage, safe handling and application, so that they can effectively disseminate accurate and reliable information on these aspects to farmers (Jallow *et al*., 2017; Mengistie *et al*., 2017). For instance, they could promote low-cost improvements to spraying equipment, such as the use of smaller nozzles and adaptations such as the V-lance and training on their use in order to reduce dosage and frequency of pesticide application (Sibanda *et al*., 2000; Schreinemachers *et al*., 2017).

(viii) Interventions such as farmer field schools and farmer exchange visits that allow for local knowledge sharing in pest management, need to be promoted. This would encourage farmers to seek advice from friends and neighbours instead of pesticide retailers who are known to encourage much more pesticides use for selfishness (Schreinemachers *et al*., 2017).

(ix) Empowering communities to monitor the impact of pesticides and making decisions that might reduce the risks to themselves and to their environment, as recommended by Ngowi and Semali (2011) need to be explored.

Use of alternative pest management methods

Farmers are understandably reluctant to adopt new pest management strategies which are not familiar to them, and will need to see convincing on-farm results before shifting from chemical-based pest control strategies to non-chemical alternatives (Jallow *et al*., 2017). However, the development and promotion of alternative pest control methods are important components of broader efforts of reducing pesticide risk and promoting a more sustainable form of vegetable production.

The alternative pest management strategies are usually packaged in the form of integrated pest management (IPM), which aim at a more rational deployment of a variety of pest control methods designed to complement, reduce, or replace the application of synthetic pesticides, as discussed below.

IPM training and IPM promotion

Several studies have indicated that training in vegetable IPM methods improve farmers' knowledge and attitudes in pest management, lead to safer use of pesticides, and reduce the number of pesticide sprays (see Ngowi and Semali, 2011; Musebe *et al*., 2014; Jayasooriya and Aheeyar, 2016; Sharma and Peshin, 2016; Gautam *et al*., 2017). The IPM methods typically involve regular scouting of plants for pests and action is taken only when an economic threshold is reached. The IPM includes such measures as; healthy seeds, the use of non-chemical preventive methods, biopesticides, biocontrol agents, and resistant varieties as well as judicious use of synthetic pesticides. Furthermore, several cultural practices can be promoted to make the environment less attractive and less favourable for the survival, dispersal, growth and reproduction, of pests and disease-causing organisms, and hence reduce the prevalence of unwanted pests and diseases. These practices include the use of proper crop rotation, good agricultural practices (GAP) including optimization of other inputs and field sanitation. Incidentally, some interventions such as crop rotation can be limited by shortage of irrigable land. The reduction of pesticide use was reported in Burkina Faso when tomato plants were planted in combination with onions (Diakalia, 2018).

However, it should be cautioned that IPM is not a straight forward concept for application, and it requires farmers training and a supportive environment that make knowledge and inputs available to farmers (Williamson *et al*., 2008; Ngowi and Semali, 2011; Gautam *et al*., 2017). For instance, a study in India on IPM training in cauliflower, cabbage and okra, did not find a significant adoption of non-chemical practices other than pheromone traps which are used by okra growers (Sharma and Peshin, 2016). Whereas, in Sri Lanka Jayasooriya and Aheeyar (2016) identified several major constraints in promoting IPM among vegetable farmers. These included weaknesses in the national level policies for IPM promotion, poor attitudes among farmers and Extension Officers, insufficient human resource in the extension system, lack of capacity on IPM among Extension Officers, and lack of resources and institutional support for IPM promotion. Thus, for a widespread adoption of IPM components, it is important for researchers to focus on the development of IPM methods that reduce costs and increase profits (Sharma and Peshin, 2016). The IPM training also needs to be gender-sensitive to be more effective (Remoundou *et al*., 2014; Jallow *et al*., 2017; Schreinemachers *et al*., 2017).

Host plant resistance

Improved levels of resistance could increase yields by reducing crop losses and expenditure on pesticides. Several tomato varieties with tolerance to major diseases are available in Tanzania (Table 5). Whereas in cabbage, management of black rot can be achieved by introduction and growing of esistant hybrid cultivars (Massomo *et al*., 2004; Jensen *et al*., 2005). Effort should be made to avail and promote these varieties to farmers.

Safer pesticides and biological control

Effort should be made to develop and promote non-synthetic products that can be used by farmers. Application of alternative strains of *B. thuringiensis* (BT), have successfully been used in Arusha-Tanzania to control the Diamondback moth in cabbage. The BT pesticides can also control a number of lepidopteran pests such as *Helicoverpa* spp. in other vegetables. Different plant extracts can significantly reduce pest populations in various vegetable crops (see Table 5), especially if used in combination with other biopesticides as recently shown by Jallow *et al.* (2018). In their study, the efficacy of biopesticides against the leaf miner (*T. absoluta*), was enhanced when a combination of *Azadirachtin* + *B. thuringiensis* or *Azadirachtin* + *Beauveria bassiana* were applied as compared to individual treatments. Pheromone insecticide baited traps, also need to be explored and promoted to vegetable farmers. Such traps have widely been adopted by watermelon and cucumber farmers in Tanzania for use against the melon fly (*Bactrocera* spp.).

Table 13. Potential Strategies for Managing Pests and Diseases of Cabbage and Tomato without using Synthetic Pesticides

Crop [16]	Intervention	Target pest	Reference
	Resistant varieties		
1	Several resistant varieties	Black rot	Massomo *et al*., 2004 ; Jensen *et al*., 2005
2	Tengeru 97	Late blight, Fusarium Wilt (FW), Tomato Mosaic Virus (TMV), Tomato Yellow Leaf Curl Virus and Root-knot nematodes (RKN)	Musebe *et al*., 2014
2	Meru	Late blight, TMV and RKN	ICIPE & Biovision (undated)
2	Roma VF	FW and verticillium wilt	Musebe *et al*., 2014
2	Kentom variety	Bacterial wilt, RKN and TMV	Musebe *et al*., 2014
2	Roma VFN	FW and verticillium wilt, RKN and red spider mites	Musebe *et al*., 2014
2	Rio Grande	FW, Early and Late blight	Musebe *et al*., 2014
	Botanicals		
1,2	Neem seed (*Azadirachta indica*)	Tomato leaf miner (*Tuta absoluta*) *and* other insects	Jallow *et al*., 2018 ; Musebe *et al*., 2014 ; Moshi & Matoju, 2017
1,2	*Tephrosia* leaf extract	Leafhopper, Thrips, Fruit borers, Cabbage Aphid and others	Musebe *et al*., 2014 ; Kerebba *et al*., 2019
	Biological		
1	*Bacillus subtilis*	Black rot	Massomo *et al*, 2004
1	*Diadegma semiclausum*	Diamondback moth	Nyambo and Löhr., 2005; Macharia *et al*., 2005
1,2	*B. thuringiensis*	Diamondback moth	Massomo *et al*., 2005
1,2	Nuclear Polyhedrosis Virus	Diamondback moth Other lepidopteran insects	Sibanda *et al*., 2000 ; Grzywacz *et al*., 2008
2	Spinosad (*Saccharopolyspora spinose*)	Thrips, leaf miners (including *T. absoluta*), spider mites, mosquitoes, ants, fruit flies and others	El-Aassar et al., 2015
2	*Beauveria bassiana*	*Tuta absoluta*	Jallow *et al*., 2018
2	*Aspergillus oryzae*	*Tuta absoluta*	Mbega *et al*., 2019

Enforcement of laws and regulations on pesticides

Despite the existence of several laws and regulations governing pesticide handling and management in Tanzania (see Ngowi *et al*., 2007; Moshi and

[16] Crop 1= Cabbage and 2= Tomato

Matoju, 2017; Kiwango *et al*., 2018), their enforcement is in most cases inadequate due to lack of capacity (human and equipment) among other reasons (see Ngowi and Semali, 2011; Moshi and Matoju, 2017; Kiwango *et al*., 2018). Nevertheless, efforts should be made to address the following aspects;

(i) There should be emphasis on improvement in pesticide labelling and packaging. A standard format of labelling pesticide containers should be adhered to. Manufacturers should be encouraged to include information in the local language (Kiswahili) and provide separate legible leaflets especially in cases of small packages. Pesticide manufacturers should be encouraged to visibly display the pesticide common names on the packages at the expense of their trade names.

(ii) The regulatory framework for pesticide evaluation and registration need to be reviewed to reduce the unnecessary bureaucratic processes and costs which are involved in the registration process. Furthermore, the registration phase for restricted use of pesticides need to be harmonised with those in other countries in the region as recommended by Moshi and Matoju (2017). Ease of regulation and active promotion of biopesticides and other IPM component technologies can drastically reduce chemical pesticide use (Schreinemachers *et al*., 2017).

(iii) Effort should be made to strengthen monitoring mechanisms to reduce illegal import and use of unregistered or banned pesticides as well as expired products. Where possible local communities should be empowered and involved to assist in this task.

(iv) Deliberate efforts should be made to promote and make protective safety devices more accessible and modify them to reflect local needs. As a compromise, farmers in the warm climate areas, such as Tanzania, ought to be encouraged to wear at least long sleeve dust coats and use gloves and boots. The last two are considered to be the minimum PPEs for most pesticide products (Damalas and Koutroubas, 2016).

(v) Efforts should be made to encourage the use of new pesticides such as Spinosad that have novel modes of action and improved safety profiles (see El-Aassar *et al*., 2015). Moreover, manufacturers need to be encouraged to improve the existing pesticide formulations towards safer formulations (e.g., microcapsule suspensions) that could reduce the adverse effects of farming and particularly the toxic effects of pesticides.

(vi) There is a need to explore the potential uses of nano-technology in integrated pest management as recently outlined by Kumar *et al*. (2018). The nano-technology offer controlled delivery of Active

Ingredients with enhanced activity at low drug concentration and efficient monitoring of pesticide interactions with the environment.

(vii) Regular monitoring of environmental pollution and pesticide residues in vegetables should be done in order to analyse the risk of exposure among consumers.

Disclosure of interest

The author reports no conflict of interest in this study.

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References

Abate, T., van Huis, A., and Ampofo, J. K. O. (2000). Pest Management Strategies in Traditional Agriculture: An African Perspective. Annual Review of Entomology, 45(1), 631–659. http://doi.org/10.1146/annurev.ento.45.1.631

Abhilash, P. C., and Singh, N. (2009). Pesticide use and application: An Indian scenario. Journal of Hazardous Materials, 165(1–3), 1–12. http://doi.org/10.1016/j.jhazmat.2008.10.061.

Akter, M., Fan, L., Rahman, M. M., Geissen, V., and Ritsema, C. J. (2018). Vegetable farmers' behaviour and knowledge related to pesticide use and related health problems: A case study from Bangladesh. Journal of Cleaner Production, 200, 122–133. http://doi.org/10.1016/j.jclepro.2018.07.130.

Bhandari, G., Atreya, K., Yang, X., Fan, L., and Geissen, V. (2018). Factors affecting pesticide safety behaviour: The perceptions of Nepalese farmers and retailers. Science of the Total Environment, 631–632, 1560–1571. http://doi.org/10.1016/j.scitotenv.2018.03.144.

Bondori, A., Bagheri, A., Damalas, C. A., and Allahyari, M. S. (2018). Use of personal protective equipment towards pesticide exposure : Farmers ' attitudes and determinants of behavior. Science of the Total Environment, 639, 1156–1163. http://doi.org/10.1016/j.scitotenv.2018.05.203

Damalas, C. A., and Abdollahzadeh, G. (2016). Farmers' use of personal protective equipment during handling of plant protection products:

Determinants of implementation. Science of the Total Environment, 571, 730–736. http://doi.org/10.1016/j.scitotenv.2016.07.042.

Damalas, C. A., and Khan, M. (2016). Farmers' attitudes towards pesticide labels: implications for personal and environmental safety. International Journal of Pest Management, 62(4), 319–325. http://doi.org/10.1080/09670874.2016.1195027.

Damalas, C., and Koutroubas, S. (2016). Farmers' Exposure to Pesticides: Toxicity Types and Ways of Prevention. Toxics, 4(1), 1. http://doi.org/10.3390/toxics4010001.

Delcour, I., Spanoghe, P., and Uyttendaele, M. (2015). Literature review: Impact of climate change on pesticide use. Food Research International, 68, 7–15. http://doi.org/10.1016/j.foodres.2014.09.030.

Diakalia, S. (2018). Effect of plant diversification on pest abundance and tomato yields in two cropping systems in Burkina Faso: farmer practices and integrated pest management. International Journal of Biological and Chemical Sciences. 12(1): 101-119. http://doi.org/10.4314/ijbcs.v12i1.8.

El-Aassar, M. R., Soliman, M. H. A., and Abd Elaal, A. A. (2015). Efficiency of sex pheromone traps and some bio and chemical insecticides against tomato borer larvae, *Tuta absoluta* (Meyrick) and estimate the damages of leaves and fruit tomato plant. Annals of Agricultural Sciences, 60(1), 153–156. http://doi.org/10.1016/j.aoas.2015.05.003

Elibariki, R., and Maguta, M. M. (2017). Status of pesticides pollution in Tanzania – A review. Chemosphere, 178, 154–164. http://doi.org/10.1016/j.chemosphere.2017.03.036.

Gangemi, S., Miozzi, E., Teodoro, M., Briguglio, G., De Luca, A., Alibrando, C., and Libra, M. (2016). Occupational exposure to pesticides as a possible risk factor for the development of chronic diseases in humans (Review). Molecular Medicine Reports, 14(5), 4475–4488. http://doi.org/10.3892/mmr.2016.5817

Gautam, S., Schreinemachers, P., Uddin, M. N., and Srinivasan, R. (2017). Impact of training vegetable farmers in Bangladesh in integrated pest management (IPM). Crop Protection, 102, 161–169. http://doi.org/10.1016/j.cropro.2017.08.022

Grzywacz, D., Mushobozi, W.L., Parnell, M., Jolliffe, F., and Wilson, K. (2008). Evaluation of *Spodoptera exempta* nucleo polyhedro virus (SpexNPV) for the field control of African armyworm (*Spodoptera exempta*) in Tanzania. Crop Protection 27, 17-24.

Hess, Sebastiaan; Leisher, Craig; Limbu, Peter; Magige, Hellen and Kahwa, A. (2017). Changes in household well-being and resilience 2011-2016. Kigoma. Retrieved from http://evidenceproject.popcouncil.org/wp-content/uploads/2017/10/Tuungane_outcome_analysis_2011-2016_FINAL.pdf.

ICIPE and Biovision (undated). Major Insect Pests and diseases of tomato in East Africa and their management. http://www.biovision.ch/fileadmin/pdf/e/projects/tomato_6-02-08.pdf Last visited in March, 2019

Isman, M. B. (2017). Industrial Crops and Products Bridging the gap : Moving botanical insecticides from the laboratory to the farm. Industrial Crops and Products, 110(April), 10–14. http://doi.org/10.1016/j.indcrop.2017.07.012

Jallow, M. F. A., Awadh, D. G., Albaho, M. S., Devi, V. Y., and Thomas, B. M. (2017). Pesticide risk behaviors and factors influencing pesticide use among farmers in Kuwait. Science of the Total Environment, 574, 490–498. http://doi.org/10.1016/j.scitotenv.2016.09.085.

Jayasooriya, H. J. C., and Aheeyar, M. M. M. (2016). Adoption and factors affecting on adoption of integrated pest management among vegetable farmers in Sri Lanka. Italian Oral Surgery, 6 (ICSUSL 2015), 208–212. http://doi.org/10.1016/j.profoo.2016.02.052.

Jensen, B. D., Massomo, S. M. S., Swai, I. S., Hockenhull, J., and Andersen, S. B. (2005). Field evaluation for resistance to the black rot pathogen *Xanthomonas campestris* pv. *campestris* in cabbage (Brassica oleracea). European Journal of Plant Pathology, 113(3). http://doi.org/10.1007/s 10658-005-2799-y.

Kerebba, N., Oyedeji, A. O., Byamukama, R., and Kuria, S. K. (2019). Pesticidal activity of *Tithonia diversifolia* (Hemsl.) A. Gray and *Tephrosia vogelii* (Hook f.); phytochemical isolation and characterization: A review. South African Journal of Botany. South African Association of Botanists. http://doi.org/10.1016/j.sajb.2018.11.024

Kiwango, P., Kassim, N., and Kimanya, M. (2018). Pesticide Residues in Vegetables: Practical Interventions to Minimize the Risk of Human Exposure in Tanzania. Current Journal of Applied Science and Technology, 26(1), 1–18. http://doi.org/10.9734/CJAST/2018/38976.

Kumar, S., Nehra, M., Dilbaghi, N., Marrazza, G., Hassan, A. A., and Kim, K.H. (2018). Nano-based smart pesticide formulations: Emerging opportunities for agriculture. Journal of Controlled Release, 294, 131–153. http://doi.org/https://doi.org/10.1016/j.jconrel.2018.12.012

Lehmann, E., Oltramare, C., Dibié, J. J., Konaté, Y., and de Alencastro, L. F. (2017). Assessment of human exposure to pesticides by hair analysis: The case of vegetable-producing areas in Burkina Faso. Environment International, 111, 317–331. http://doi.org/10.1016/j.envint.2017.10.025.

Lekei, E., Ngowi, A., London, L., and Mkalanga, H. (2017). Knowledge and Practices Relating to Acute Pesticide Poisoning Among Health Care Providers in Selected Regions of Tanzania. Environmental Health Insights, 11(0). http://doi.org/10.1177/1178630217691268.

Lekei, E.E., Ngowi, V.A., and London, L. (2014). Farmers' knowledge, practices and injuries associated with pesticide exposure in rural farming villages in Tanzania. BMC Public Health 14, 389. http://dx.doi.org/10.1186/1471-2458-14-389.

Macharia, I., Löhr, B., and De Groote, H. (2005). Assessing the potential impact of biological control of *Plutella xylostella* (diamondback moth) in cabbage production in Kenya. *Crop Protection*, 24(11), 981–989. http://doi.org/10.1016/j.cropro.2005.02.005.

Mahugija, J. A. M., Chibura, P. E., and Lugwisha, E. H. J. (2018). Residues of pesticides and metabolites in chicken kidney, liver and muscle samples from poultry farms in Dar es Salaam and Pwani, Tanzania. Chemosphere, 193, 869–874. http://doi.org/10.1016/j.chemosphere. 2017.11.094

Massawe, A., Mansuet, T., Kimani, M., Musebe, R., and Toepfer, S. (2010). Technical guideline for integrated production of outdoor tomatoes in northern Tanzania. Minds Investment Agencies Publisher. Nairobi, Kenya. P. 56.

Massomo, S. M. S., Mabagala, R. B., Mortensen, C. N., Hockenhull, J., and Swai, I. S. (2005). Cabbage production in Tanzania: Challenges faced by smallholder farmers in the management of black rot disease. Journal of Sustainable Agriculture, 26(4). http://doi.org/10.1300/ J064v26n04_08.

Massomo, S. M. S., Mortensen, C. N., Mabagala, R. B., Newman, M. A., and Hockenhull, J. (2004). Biological control of black rot (*Xanthomonas campestris* pv. *campestris*) of cabbage in Tanzania with Bacillus strains. Journal of Phytopathology, 152(2), 98–105.

Massomo, S. M. S., Mabagala, R. B., Swai, I. S., Hockenhull, J., and Mortensen, C. N. (2004). Evaluation of varietal resistance in cabbage against the black rot pathogen, *Xanthomonas campestris* pv. *campestris* in Tanzania. Crop Protection, 23(4). http://doi.org/10.1016/j.cropro. 2003.09.001

Mbega, E. R., Ndakidemi, P. A., Mtambo, M., Ramasamy, S., Chacha, M., and Zekeya, N. (2019). First record of an entomopathogenic fungus of tomato leaf miner, *Tuta absoluta* (Meyrick) in Tanzania. Biocontrol Science and Technology, 0(0), 1–12. http://doi.org/10.1080/ 09583157.2019.1573972

Mengistie, B. T., Mol, A. P. J., and Oosterveer, P. (2017). Pesticide use practices among smallholder vegetable farmers in Ethiopian Central Rift Valley. Environment, Development and Sustainability, 19: 301–324 DOI 10.1007/s10668-015-9728-9.

Moshi, A. P., and Matoju, I. (2017). The status of research on and application of biopesticides in Tanzania. Review. Crop Protection, 92: 16–28. http://doi.org/10.1016/j.cropro.2016.10.008

Mrema, E. J., Ngowi, A. V., Kishinhi, S. S., and Mamuya, S. H. (2017). Pesticide Exposure and Health Problems Among Female Horticulture Workers in Tanzania. Environmental Health Insights, 11: 1–13.

Musebe, R., Massawe, A., Mansuet, T., Kimani, M., Kuhlmann, U., and Toepfer, S. (2014). Achieving rational pesticide use in outdoor tomato production through farmer training and implementation of a technical guideline, 6(74), 367–381. http://doi.org/10.5897/JAERD14.0569

Ngowi, A. V. F., andSemali, I. (2011). Controlling pesticide poisoning at community level in Lake Eyasi Basin, Karatu district, Tanzania. European Journal of Oncology, 16(3), 139–148.

Ngowi, A. V. F., Mbise, T. J., Ijani, A. S. M., London, L., and Ajayi, O. C. (2007). Smallholder vegetable farmers in Northern Tanzania: Pesticides use practices, perceptions, cost and health effects. Crop Protection, 26(11), 1617–1624. http://doi.org/10.1016/j.cropro. 2007.01.008.

Ngowi, A., Mrema, E., Ngowi, A., Kishinhi, S., and Mamuya, S. (2017). Pesticide Exposure and Health Problems Among Female Horticulture Workers in Tanzania. Environmental Health Insights, 11(0). http://doi.org/10.1007/BF02176519.

Nonga, H.E., Victoria, K., Neema, K., Martin, K., Elibariki, R., Maguta, M. M., and Exposure, H. (2017). Assessment of farming practices and uses of agrochemicals in Lake Manyara basin, Tanzania. African Journal of Food Science, 11(8), 255–262. http://doi.org/10.5897/AJFS2016.1527.

Nyambo, B., and Löhr, B. (2005). The role and significance of farmer participation in biocontrol-based IPM for brassica crops in East Africa. In: Hoddle, M.S. (Ed.), Proceedings of the Second International Symposium on Biological Control of Arthropods, vol. I, pp. 290-301, 12-16 September 2005, Davos, Switzerland.

Remoundou, K., Brennan, M., Hart, A., and Frewer, L. J. (2014). Pesticide Risk Perceptions, Knowledge, and Attitudes of Operators, Workers, and Residents: A Review of the Literature. Human and Ecological Risk Assessment, 20(4), 1113–1138. http://doi.org/10.1080/ 10807039.2013.799405

Rezaei, R., Damalas, C. A., and Abdollahzadeh, G. (2018). Understanding farmers' safety behaviour towards pesticide exposure and other occupational risks: The case of Zanjan, Iran. Science of the Total Environment, 616–617, 1190–1198. http://doi.org/10.1016/j. scitotenv.2017.10.201

Schreinemachers, P., Chen, H. pu, Nguyen, T. T. L., Buntong, B., Bouapao, L., Gautam, S., and Srinivasan, R. (2017). Too much to handle? Pesticide dependence of smallholder vegetable farmers in Southeast Asia. Science of the Total Environment, 593–594: 470–477. http://doi.org/10.1016/j.scitotenv.2017.03.181

Sibanda, T., Dobson, H. M., Cooper, J. F., Manyangarirwa, W., and Chiimba, W. (2000). Pest management challenges for smallholder vegetable farmers in Zimbabwe. Crop Protection, 19(8–10), 807–815. http://doi.org/10.1016/S0261-2194(00)00108-3.

Skovgaard, M., Condarco, G., Jensen, O. C., Jørs, E., and Huici, O. (2017). Management of Empty Pesticide Containers—A Study of Practices in Santa Cruz, Bolivia. Environmental Health Insights, 11, 117863021771691. http://doi.org/10.1177/1178630217716917

Smit, Z.K., Indjic, D., Belic, S., and Miloradov, M., (2002). Effect of water quality on physical properties and biological activity of tank mix insecticide-fungicide spray, In: Paroussi, G., Voyiatzis, D., Paroussis, E. (Eds.), Proceedings of the Second Balkan Symposium on Vegetables and Potatoes (579), International Society Horticultural Science, Leuven, Belgium, pp., 551–556.

Stadlinger, N., Mmochi, A. J., Dobo, S., Gyllbäck, E., and Kumblad, L. (2011). Pesticide use among smallholder rice farmers in Tanzania. Environment, Development and Sustainability, 13(3), 641–656. http://doi.org/10.1007/s10668-010-9281-5

Victoria, K., Neema, K., and Martin, K. (2017). Risk of exposures of pesticide residues from tomato in Tanzania. African Journal of Food Science, 11(8), 255–262. http://doi.org/10.5897/AJFS2016.1527

Wickama, J. (2016). Assessment of soil fertility levels for integrated soil fertility management (ISFM) in selected villages in Uvinza District, Kigoma. A report on Individual consultancy undertaken with WEMA Consult (T) Ltd for The Nature Conservancy (TNC) in Kigoma.

Williamson, S., Ball, A., and Pretty, J. (2008). Trends in pesticide use and drivers for safer pest management in four African countries. Crop Protection, 27(10), 1327–1334. http://doi.org/10.1016/j.cropro.2008.04.006

Yassin, M. M., Abu Mourad, T. A., and Safi, J. M. (2002). Knowledge, attitude, practice, and toxicity symptoms associated with pesticide use among farm workers in the Gaza Strip. Occupational and Environmental Medicine, 59(6), 387–393. http://doi.org/10.1136/oem.59.6.387.