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Ecological limits and management practices of major arthropod pests of tomato in Kenya

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ABSTRACT: In Kenya, tomato is cultivated for home consumption, as a cash crop, and a source of vitamins. In recent years, the growth rate of tomato production in the country has increased. Yields, however, continue to remain low due to a myriad of constraints, including incidences of arthropod pests. This paper catalogues arthropod pests of tomato in Kenya, establishes the pests' distribution patterns in relation to spatial and temporal dimensions and documents practices employed by farmers for their management. The study relies on plant health clinics as primary providers of data. Relationship between variables is proved using multinomial logistic regression. A diverse range of arthropod pests was found to hamper tomato production in Kenya. Tomato leaf miner, whiteflies, and spider mites emerged as the major threats to the sustainability of tomato production. Most of the arthropod pests reported were associated with upper and lower midland agro-ecological zones. The reverse, however, was true for upper highland zones. For the management of arthropod pests, essentially, the use of synthetic pesticides was the preferred practice by farmers. The study underscores the need to consider variations in arthropod pests' risk, both spatially and temporally when designing their management strategies. Also, alternative management procedures to the use of highly hazardous pesticides and better assessments of potential profit-loss to a smallholder for application and non-application of highly hazardous pesticides are required.

Keywords: Arthropod pests, pest management, smallholder farmers, spatio-temporal, tomato distribution.

INTRODUCTION

Tomato (*Lycopersicum esculentum* Mill.) is a popular food crop cultivated and consumed worldwide (FAOSTAT, 2018; Gogo et al., 2012). In Kenya, the crop, cultivated in almost every homestead for home consumption, serves as an important cash crop for both small and medium scale commercial farmers, and as an important source of vitamins (Gogo et al., 2012). In addition to vitamins, tomato is also rich in antioxidants, including lycopene, carotenoids, phenolics and ascorbic acid, which can play an important role in averting cardiovascular diseases and cancer (Kirsh et al., 2006; Oduor, 2016; Toor and Savage, 2005).

Tomato thrives under warm conditions (Oduor, 2016). The ideal soil temperature for seed germination is 20^0C or above; below 16^0C germination is extremely slow. The optimal daily maximum air temperature for vegetative growth, fruit set and development is between 25^0 and 35^0C

(Hartz et al., 2008). With sufficient soil moisture, tomato plants can withstand temperatures well in excess of 38^{0}C, though the fruit set can be severely reduced. Fruit development and quality are adversely affected when night and day temperatures fall below 10^0 and 20^{0}C, respectively (Hartz et al., 2008). Also, the crop thrives under a variety of soil textures (Hartz et al., 2008; Oduor, 2016). Suitable soil textures range from sandy to fine-textured clay soil, provided it is well aerated, has a good structure, and is properly drained (Diver et al., 1999; Hartz et al., 2008).

In recent years, the growth rate of tomato production in Kenya has increased (FAOSTAT, 2018). Yields, however, continue to remain low due to a myriad of constraints. The main constraints hindering tomato production can be categorized into three, namely agronomic, institutional and market constraints (Asgedom et al., 2011). Lack of access to markets, coupled with fluctuating commodity prices, has been identified as a major constraint to smallholder tomato production (Asgedom et al., 2011; Clottey et al., 2009). Moreover, small - and medium – scale commercial farmers also contend with a number of institutional challenges which include; limited access to inputs, lack of improved varieties, lack of transportation and lack of storage facilities (Asgedom et al., 2011). On the other hand, key agronomic challenges faced in tomato production, include incidences of arthropod pests (insects and mites), diseases (fungi, bacteria and viruses) and physiological disorders (caused by non-pathological conditions such as drought, cold, heat and salinity) (Anastacia et al., 2011; Asgedom et al., 2011; Oduor, 2016; Toroitich et al., 2014; Umeh et al., 2002).

There are several arthropod pests in the tropics that are directly associated with tomato damage and yield losses while others are vectors of diseases (Boubou et al., 2011; Jones et al., 2014; Olabiyi, 2008; Umeh et al., 2002). Relating to their mode of feeding, two main types of crop damage can be associated with arthropod pests. The first is damage attributable to sucking of the plant sap from general tissues of fruits, roots or foliage or from the phloem (or xylem) system. The second is damage due to biting and chewing of plant material (Imam et al., 2010; Royalty and Perring, 1989). The effects of arthropod pests on tomato include reduction in yield, transmission of diseases, reduction in marketable yield and increase in farm inputs (Imam et al., 2010).

Among the factors that favour build-up of these pests include the existence of complex agroecosystems in the tropics and intra-continental dispersal by arthropod pests'. Accordingly, there is need to regularly update pest records and to document practices employed in their management (Gornall et al., 2010; Hill, 1983). This paper thus seeks to establish ecological limits and management practices of major arthropod pests of tomato in smallholder agriculture subsector of Kenya by (1) cataloguing major arthropod pests of tomato in Kenya, (2) determining the distribution patterns in relation to time and agro-ecological zonation of major arthropod pests of tomato in Kenya and (3) documenting pest management practices employed by tomato farmers including reviewing farmers' pesticide use pattern.

MATERIALS AND METHODS

Study area

This paper aggregates the survey results from 121 locations over a four-year period (June 2013 to May 2017). The range of these locations represented 18 different production potentials (Agro-ecological zones) (Table 1) and fell within 14 counties of Kenya (Table 2).

Study overview

From each location, smallholder farmers visiting plant clinics (managed by Plantwise Kenya) were sampled. Plantwise is a global program led by Centre for Agriculture and Bioscience International (CABI). The program seeks to assist farmers minimize their losses resulting from crop pests. Owing to a collaboration involving, among others, the national advisory services, the program oversees the setting up of networks of community-based plant clinics. It is here at the plant clinics where challenges relating to plant health problems are diagnosed and farmers benefit from practical plant health advice.

Plant clinics function as a demand-driven extension running one day weekly or twice monthly in locations readily reachable by smallholder farmers. A farmer brings a sample of an affected crop to the plant clinic where he/she deliberates with a knowledgeable agricultural extension agent (also referred to as a "plant doctor") regarding the plant health problem. In the course of the discussion, the farmer obtains a diagnosis of the problem attacking his or her crop. Moreover, the farmer is furnished with a written and verbal recommendation for the management of the problem. Ordinarily, farmers who frequent these facilities are mostly adult female and adult male smallholders producing either as individuals or collectively in groups and are dependent on rainfall for cultivation. Production is both for income and subsistence.

Plant doctors are taken through a four-part training course. The training is geared towards enabling them to correctly diagnose plant health problems and to prescribe appropriate management practices.

During the period under review a total 37,051 smallholder farmers visited plant clinics in 121 locations. Of these, 4,907 were farmers cultivating tomatoes. And of the farmers cultivating tomatoes, 2,189 of them had problems relating to arthropod pests. To avoid bias, records of repeat visits by farmers were omitted from the data that was considered in this study, meaning 'one farmer one record'.

Table 1. Agro-ecological zones in the study area.

Agro-Ecological Zone	**Average Altitude in m**	**Annual average mean temperature in ^{0}c**	**Annual average Rainfall in mm**	**No. of locations**
Upper Highland Zones (humid) – UH1	2,250 – 2,755	14.9 – 11.7	1,245 – 1,788	2
Upper Highland Zones (sub humid) – UH2	2,290 – 2,670	14.9 – 12.9	1,413 – 1,904	2
Lower Highland Zones (humid) – LH1	1,904 – 2,226	17.2 – 15.1	1,364 – 1,669	4
Lower Highland Zones (sub humid) – LH2	1,908 – 2,256	17.5 – 15.2	1,082 – 1,329	13
Lower Highland Zones (semi-humid) – LH3	1,942 – 2,196	17.1 – 15.4	885 – 1,105	17
Lower Highland Zones (transitional) – LH4	1,783 – 1,977	17.8 – 16.6	823 - 953	4
Lower Highland Zones (semi-arid) – LH5	1,980 – 2,040	16.2 – 15.7	650 - 850	3
Upper Midland Zones (humid) – UM1	1,578 – 1,802	19.3 – 18.0	1,355 – 1,675	3
Upper Midland Zones (sub humid) – UM2	1,523 – 1,755	19.7 – 18.3	1,140 – 1,410	4
Upper Midland Zones (semi-humid) – UM3	1,425 – 1,675	20.2 – 18.7	990 – 833	26
Upper Midland Zones (transitional) – UM4	1,477 – 1,704	20.0 – 18.7	983 – 1,173	11
Upper Midland Zones (semi-arid) – UM5	1,446 – 1,677	20.3 – 18.7	608 – 760	1
Upper Midland Zones (arid) – UM6	1,500 – 1,770	19.9 – 17.7	500 – 650	2
Lower Midland Zones (sub humid) – LM2	1,337 – 1,457	21.4 – 20.7	1,419 – 1,594	3
Lower Midland (semi-humid) – LM3	1,158 – 1,312	22.1 – 21.1	970 – 1,158	8
Lower Midland Zones (transitional) – LM4	1,114 – 1,297	22.3 – 21.2	786 – 904	11
Lower Midland Zones (semi-arid) – LM5	939 – 1,238	23.4 – 21.7	692 – 803	5
Lower Midland Zones (arid) – LM6	1,200 – 1,300	21.5 – 20.9	400 - 500	2

Table 2. Study area and tomato production performance.

County	**2014**			**2015**			**2016**		
	Size (Ha)	**Quantity (MT)**	**Value (Mi) Ksh**	**Size (Ha)**	**Quantity (MT)**	**Value (Mi) Ksh**	**Size (Ha)**	**Quantity (MT)**	**Value (Mi) Ksh**
Bungoma	1,700	50,399	1,611	1,055	25,429	1,211	811	21,305	951
Kajiado	1,680	47,368	1,624	1,360	27,440	1,388	1,452	32,789	1,612
Kiambu	964	18,029	812	986	16,545	692	965	9,132	327
Kirinyaga	1,648	48,560	1,156	2,015	42,780	2,100	3,128	54,185	2,323
Machakos	447	6,189	356	795	9,500	245	689	12,765	381
Nakuru	633	17,511	347	851	14,158	294	946	15,179	492
Narok	-	-	-	784	14,920	529	1,561	20,744	596
Trans Nzoia	628	14,848	416	659	14,690	617	733	16,660	638
Elgeyo Marakwet									
Embu									
Nyeri									
Siaya	17,002	197,300	5,481	9,873	165,217	5,846	9,826	158,267	6,367
Tharaka Nithi									
West Pokot									
Others									
Total	24,074	400,204	11,803	18,378	330,679	12,922	20,111	341,026	13,687

Source: Horticulture validated report 2014/2015 – 2016; Mi – million, MT – metric tons, Ha – hectare.

Data management system

For this study, data management workflow, which included data collection, was broken down into stages. Table 3 shows the data management stages and those responsible.

Data collection

In data collection, the Plantwise prescription form was used by plant doctors to capture particulars of farmers' queries. Besides the farmers and the plant clinic details, the plant doctors recorded information regarding the crop,

Table 3. Stages in the data management system process and actors involved.

Data management system category	Data management system step	Actors involved
Data collection	1. Recording	Plant doctors
	2. Transfer	Plant doctors, via data entry hubs
	3. Data entry	Data clerks
Data processing	4. Harmonization	Researcher
	5. Validation	Researcher.
Data use	6. Analysis	Researcher

symptoms and diagnoses, and pest management practices. Upon completion, the prescription forms were collated and couriered to the data hub located in Nairobi. The process of entering data was undertaken using an Excel-based tool mimicking the layout of the Plantwise prescription form. For storage, the data was entered into the restricted section within the Plantwise knowledge bank called Plantwise Online Management System (POMS). POMS serve as a focal resource for the management of plant clinic data.

Data processing

Harmonization of plant clinic data involved the cleaning of data (location details, plant doctor names, crop names and diagnoses). This was done by the researchers.

Data validation

At a plant clinic, a field diagnosis is based on signs and symptoms observed on the plant sample, combined with information gained from farmer. Plant doctors have access to hand lens to observe some of the smaller features. Additionally, plant doctors have access to diagnostic photosheets which offer pictorial guidance for diagnosing pests on crops. Symptom descriptions on the photosheets help the 'plant doctors' distinguish between similar problems.

At data validation stage, the researchers reviewed all the 2,189 plant clinic records to check the accuracy of the diagnoses. Validating diagnoses was done following the protocol developed by Plantwise program. This entailed checking that: (1) an actual diagnosis was provided in the prescription form; (2) the diagnosis was specific to at least sub-group level (e.g. thrips, mites, mealybugs etc.); (3) the diagnosis was plausible (i.e. has been reported in the country and is known to affect the host crop); (4) key symptoms of the diagnosed pest were recorded and; (5) it was definitive (symptoms were not easily confused with other causes); and (6) the picture of the sample accompanying the record confirmed the diagnosis.

Data analysis

Analysis of the data was carried out by means of a statistical program, SPSS, version 16 (SPSS, Released 2007). The analyses ran include trends over time, and recommendations from prescription forms. To gauge the comparative frequency of variables, cross tabulation was used and tested for significance by the Pearson Chi-square test. Associations between nominal dependent variables (seed variety, pest type and pest management intervention) and many independent variables were examined using multinomial logistic regression, and Goodness-of-fit test used to examine how well the model fits the data. Student's t-test and ANOVA were used to compare group means. Significance was defined as a p value ≤ 0.05.

RESULTS

Arthropod pests of tomato in Kenya

A diverse range of arthropod pests hamper tomato production in Kenya. A total of 9 species belonging to 7 orders were reported as major arthropod pests of tomato in Kenya (Figure 1). The primary arthropod pests attacking tomato seedlings were cutworms (*Agrotis* spp.) (CW), general foliage and fruit feeders were tomato leaf miner (*T. absoluta*) (TA), whiteflies (*Bemisia tabaci*) (WF), spider mites (*Tetranychus* spp.) (SM), African bollworm (*Helicoverpa armigera*) (ABW), leaf miners (*Liriomyza* spp.) (LM), thrips (*Frankliniella* spp.) (TH), aphids (*Aphis gossypii, Myzus persicae*) (AP), and mealybugs (*Planococcus* spp.) (MB). It is more likely that the incidence of these pests was influenced by the time, agro-ecological zonation and tomato variety (Table 4). Frequencies of arthropod pests showed considerable inter-year differences (Figure 2) with more cases of spider mites and whiteflies being recorded in first year of the study (June 2013 to May 2014) than any other arthropod pest. For *T. absoluta*, after the first year of the study (June 2013 to May 2014), there were more recorded cases of the

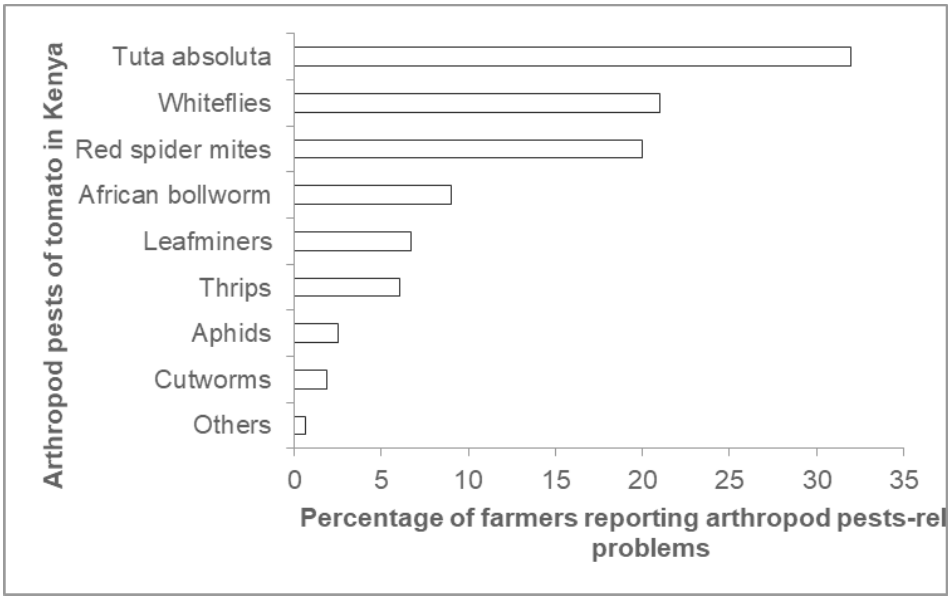

Figure 1. Diversity of arthropod pests of tomato in Kenya.

Table 4. Summary of results of Multinomial Logistic Regression for relationship between test variables (study period, AEZs, tomato variety, and plant growth type) and incidences of pests.

Test variables	Chi-Square	df	Sig.
Study period	241.220	27	<0.001
Agro-ecological zones	451.420	153	<0.001
Tomato variety	172.966	108	<0.001
Tomato growth type	27.567	18	0.069
Goodness-of-Fit (analysis)	3131.252	3294	0.979

pest than any other arthropod pest. Just like in time, differences in the incidences of arthropod pests were also observed among the different tomato varieties (Table 5). Cal J, Kilele F1 and Riogrande recorded the highest diversity of arthropod pests, with each recording presence of all the 9 main arthropod pests of tomato in Kenya. On the other hand, Rambo F1, Prostar F1 and Elgon (Napoli F1) had the lowest diversity, each recording 7 of 9 main arthropod pests of tomato in Kenya. Presence of four of the arthropod pests, namely, whiteflies, *T. absoluta*, and red spider mites were recorded in all the varieties.

Distribution of arthropod pests of tomato in relation to agro-ecological zonation

There was considerable variation in composition and frequency of arthropod pests in different agro-ecological zones (AEZs). Most of the arthropod pests reported were associated with upper and lower midland zones while only a few were reported in upper highland zones. AEZs that reported the highest diversity of arthropod pests were LH2, LH3, LM4 and UM3 while UH2 recorded the least diversity (Table 6). Among the arthropod pests, whiteflies, spider mites, leaf miners and *T. absoluta* were cosmopolitan in distribution, registering a presence in all or nearly-all of the study's AEZs. In terms of frequency (Table 7), there were more cases of spider mites, cutworms and thrips that were reported in lower highland AEZs than in the other AEZs. Also, compared to the other AEZs, there were more cases of African bollworm, aphids, leaf miners, and whiteflies that were reported in upper midland AEZs than in the other AEZs. On the other hand, cases of *Tuta absoluta* and mealybugs were mostly pronounced in the lower midland zones.

Farmers' practices on management of arthropod pests of tomato

At the point of consulting the agricultural extension officer at the plant clinic, 57% of the farmers had not initiated any

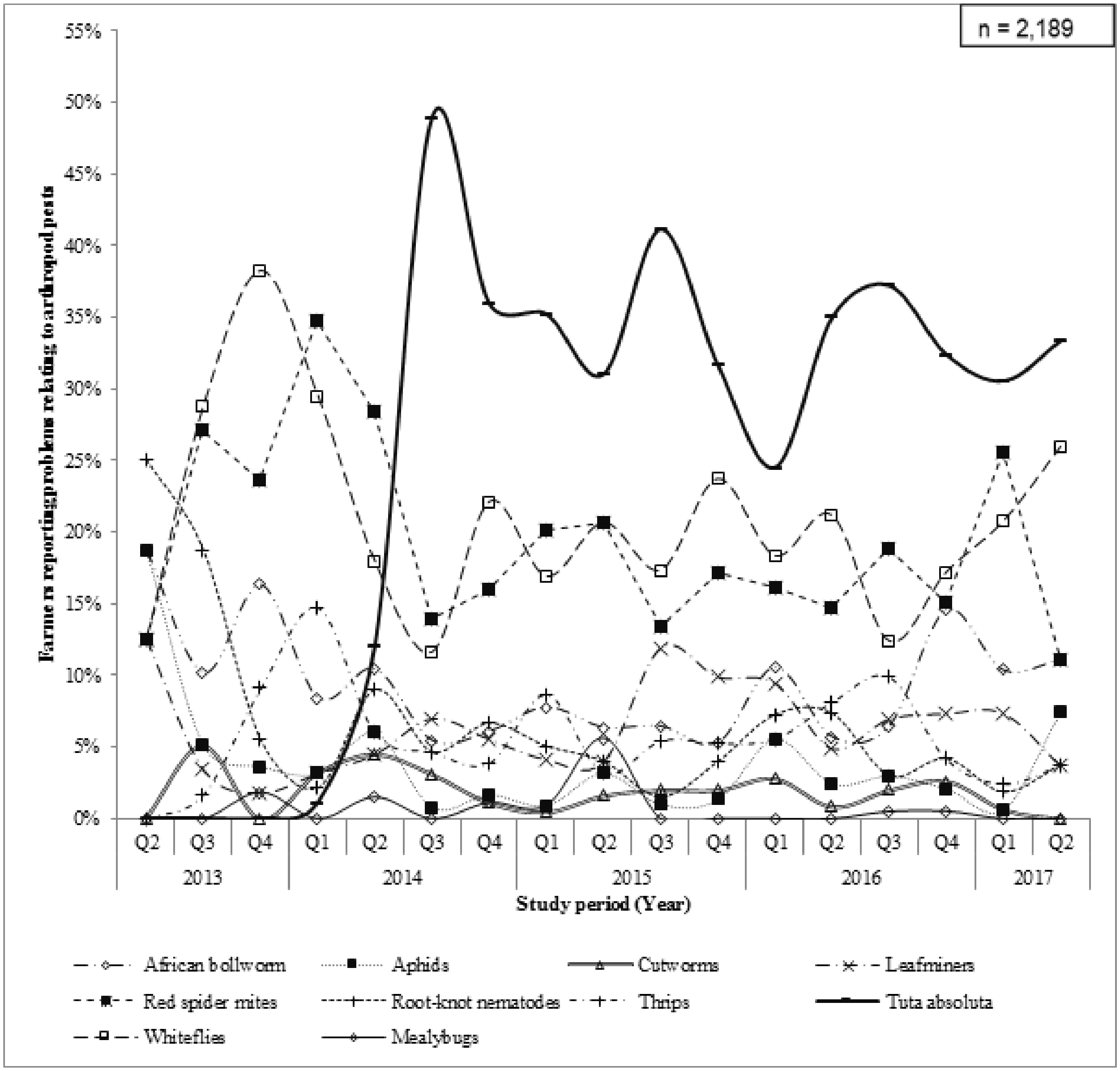

Figure 2. Distribution of arthropod pests of tomato in time.

intervention measures for control of arthropod pests. On the other hand, 42% applied pesticides (mostly synthetic pesticides) while a paltry 1% employed cultural practices.

A total of 43 active ingredients (AIs) were identified to be used by smallholder tomato farmers for the management of arthropod pests (Table 8). The identified AIs differed in terms of their overall hazard level: 8 of the AIs met one or more of the highly hazardous pesticides (HHP) criteria; 18 AIs were classified as "Danger" (at least one of the related human health hazard statements specified that AI is "fatal if inhaled" or "toxic"); 13 AIs were classified as "Warning"; and 2 AIs were classified as "Low hazard" (there were no known human health hazard statements related with AI).

The AIs identified to be HHPs are listed in Table 9. Of the HHPs identified, 5 out of 8 were carcinogens, 5 were known/presumed/suspected human reproductive toxicants and none causes heritable mutations in the germ cells of humans. Additionally, none of the AIs is persistent organic pollutant (POP) listed in the Stockholm Convention and none is currently listed in the Rotterdam database of notifications of final regulatory action. Seven (7) of 8 AIs are included in the PAN HHP list (2015). On an AI basis, all the 8 AIs are allowed for use in the EU (Approved = 8).

Of the farmers applying synthetic pesticides for the management of arthropod pests, slightly over 60% used a pesticide product that is highly toxic by at least one route

Table 5. Incidences of arthropod pests (presence-absence) reported among various tomato varieties in Kenya.

Variety	ABW	AP	CW	LM	SM	TH	TAb	WF	MB
Anna F1	+	+	+	+	+	+	+	+	0
Cal J	+	+	+	+	+	+	+	+	+
Eden F1	+	+	0	+	+	+	+	+	0
Napoli F1	0	0	+	+	+	+	+	+	0
Kilele F1	+	+	+	+	+	+	+	+	+
Local	+	+	0	0	+	0	+	+	0
Onyx F1	+	+	0	+	+	+	+	+	+
Others	+	+	+	+	+	+	+	+	+
Prostar F1	+	0	0	+	+	+	+	+	0
Rambo F1	+	0	0	+	+	+	+	+	0
Rio grande	+	+	+	+	+	+	+	+	+
Tylka F1	+	+	0	+	+	+	+	+	+
Unknown	+	+	+	+	+	+	+	+	+
n	184	55	41	147	412	132	667	427	15

Key: + = Present; 0 = Absent; ABW = African bollworm; AP = Aphids; CW = Cutworms; LM = Leaf miners; SM = Spider mites; ; TH = Thrips; TAb = *Tuta absoluta*; WF = Whiteflies; and MB = Mealybugs.

Table 6. Incidences of arthropod pests (presence-absence) reported in the different agro-ecological zones of Kenya.

AEZs	ABW	AP	CW	LM	SM	TH	TAb	WF	MB
UH1	+	0	0	+	0	+	0	+	0
UH2	0	0	0	+	+	0	0	+	0
LH1	0	0	0	+	+	0	+	+	0
LH2	+	+	+	+	+	+	+	+	+
LH3	+	+	+	+	+	+	+	+	+
LH4	0	+	0	+	+	0	+	+	+
LH5	0	0	0	0	+	0	+	+	0
LM2	+	0	0	0	+	+	+	+	0
LM3	+	+	0	+	+	+	+	+	0
LM4	+	+	+	+	+	+	+	+	+
LM5	+	+	+	+	+	0	+	+	+
LM6	+	+	0	+	+	+	+	+	+
UM1	+	+	+	+	+	+	+	+	0
UM2	+	+	0	+	+	+	+	+	0
UM3	+	+	+	+	+	+	+	+	+
UM4	+	+	+	+	+	+	+	+	0
UM5	+	+	+	+	+	0	+	+	+
UM6	+	+	0	+	+	0	+	+	0
n	184	55	41	147	412	132	667	427	15

Key: + = Present; 0 = Absent; ABW = African bollworm; AP = Aphids; CW = Cutworms; LM = Leaf miners; SM = Spider mites; TH = Thrips; TAb = *Tuta absoluta*; WF = Whiteflies; and MB = Mealybugs.

of exposure (Figure 3). It is more likely that the choice to intervene (including on application of pesticides or use of cultural practices) or not to intervene was influenced by the type of arthropod pest, time and the location of the farmer (Table 10). Over time, the number of farmers opting to consult extension agents before attempting to manage arthropod pests increased from 47% (2013) to 65% (2017). Farmers reporting challenges associated with whiteflies, *T. absoluta* and spider mites were, for their management, more likely to institute intervention

Table 7. Cross tabulation showing frequencies and percentages (represented in brackets) of arthropod pests in the various AEZs.

AEZs	ABW	AP	CW	LM	SM	TH	TAb	WF	MB
LH1	0 (0)	0 (0)	0 (0)	1 (1)	3 (1)	0 (0)	4 (1)	3 (1)	0 (0)
LH2	24 (13)	2 (4)	1 (2)	3 (2)	63 (15)	13 (10)	29 (4)	16 (4)	2 (13)
LH3	13 (7)	9 (16)	19 (46)	21 (14)	89 (22)	45 (34)	132 (20)	97 (23)	1 (7)
LH4	0 (0)	1 (2)	0 (0)	1 (1)	8 (2)	0 (0)	7 (1)	8 (2)	1 (7)
LH5	0 (0)	0 (0)	0 (0)	0 (0)	10 (2)	0 (0)	5 (1)	5 (1)	0 (0)
LM2	1 (1)	0 (0)	0 (0)	0 (0)	3 (1)	4 (3)	4 (1)	3 (1)	0 (0)
LM3	4 (2)	6 (11)	0 (0)	3 (2)	15 (4)	4 (3)	89 (13)	11 (3)	0 (0)
LM4	15 (8)	5 (9)	3 (7)	27 (18)	55 (13)	14 (11)	96 (14)	56 (13)	3 (20)
LM5	13 (7)	2 (4)	6 (15)	9 (6)	10 (2)	0 (0)	39 (6)	5 (1)	2 (13)
LM6	2 (1)	3 (5)	0 (0)	3 (2)	14 (3)	12 (9)	28 (4)	8 (2)	3 (20)
UH1	1 (1)	0 (0)	0 (0)	1 (1)	0 (0)	1 (1)	0 (0)	3 (1)	0 (0)
UH2	0 (0)	0 (0)	0 (0)	1 (1)	2 (0)	0 (0)	0 (0)	1 (0)	0 (0)
UM1	6 (3)	1 (2)	1 (2)	1 (1)	5 (1)	1 (1)	14 (2)	9 (2)	0 (0)
UM2	12 (7)	2 (4)	0 (0)	7 (5)	20 (5)	7 (5)	21 (3)	14 (3)	0 (0)
UM3	39 (21)	13 (24)	5 (12)	28 (19)	43 (10)	12 (9)	95 (14)	99 (23)	2 (13)
UM4	43 (23)	7 (13)	4 (10)	17 (12)	44 (11)	19 (14)	54 (8)	56 (13)	0 (0)
UM5	5 (3)	2 (4)	2 (5)	10 (7)	12 (3)	0 (0)	29 (4)	10 (2)	1 (7)
UM6	6 (3)	2 (4)	0 (0)	14 (10)	16 (4)	0 (0)	21 (3)	23 (5)	0 (0)
n	184 (100)	55 (100)	41 (100)	147 (100)	412 (100)	132 (100)	667 (100)	427 (100)	15 (100)

Key: ABW = African bollworm; AP = Aphids; CW = Cutworms; LM = Leaf miners; SM = Spider mites; TH = Thrips; TAb = *Tuta absoluta*; WF = Whiteflies; and MB = Mealybugs.

Table 8. List of active ingredients used by smallholder farmers for the management of arthropod pests in Kenya.

Pesticide Active Ingredients	Chemical class	Use type	Hazard summary
Abamectin	Fumigant	Nematicide	HHP
Acephate	Macrocyclic Lactone - avermectin		Danger
Acetamiprid	Neonicotinoid	Insecticide	Danger
Alpha-cypermethrin	Pyrethroid	Insecticide	Danger
Azadirachtin			Warning
Azoxystrobin	Strobilurin	Fungicide	Warning
Beta-cyfluthrin	Pyrethroid	Insecticide	HHP
Bifenthrin	Pyrethroid	Insecticide	Danger
Carbaryl	Carbamate	Insecticide	HHP
Carbosulfan	Carbamate	Insecticide	Danger
Chlorantraniliprole	Pyrazole/ diamide	Insecticide	Low hazard
Chlorpyrifos	Organophosphorous	Insecticide, Acaricide	Danger
Cyhalothrin	Pyrethroid	Insecticide	Danger
Cymoxanil	Cyanoacetamide oxime	Fungicide	Danger
Cypermethrin	Pyrethroid	Insecticide, Acaricide	Danger
Deltamethrin	Pyrethroid	Insecticide	Danger
Diafenthiuron	Thiourea	Insecticide, Acaricide	Danger
Diazinon	Organophosphorous	Insecticide	HHP
Dimethoate	Organophosphorous	Insecticide	Danger
Dimethomorph	Morpholine	Fungicide	Low hazard
Emamectin Benzoate			Danger
Fenpyroximate	Pyrazolium	Acaricide, Insecticide	Danger
Flubendiamide	Benzene-dicarboxamide	Insecticide	Warning
Fluopicolide	Benzamide	Fungicide	Warning

Table 8. Contd.

Homemade botanical pesticide	Unclassified	Insecticide	Warning
Homemade non-botanical pesticide	Unclassified	Insecticide	Warning
Imidacloprid	Neonicotinoid	Insecticide	Warning
Lambda-cyhalothrin	Pyrethroid	Insecticide	Danger
Lufenuron	Biochemical biopesticides - insect growth regulators	Insecticide	Warning
Malathion	Organophosphorous	Insecticide, Acaricide	HHP
Mancozeb	Dithiocarbamate	Fungicide, Oomycide	HHP
Metalaxyl	Phenylamide	Fungicide	Danger
Methomyl	Metabolite`	Insecticide, Acaricide,	HHP
Profenofos	Organophosphorous	Insecticide	Danger
Propamocarb hydrochloride	Carbamate	Fungicide	Warning
Propineb	Carbamate	Fungicide	HHP
Spiromesifenw	Tetronic acid	Insecticide	Warning
Spirotetramat	Tetramic acid	Insecticide	Warning
Sulphur	Inorganic compound	Fungicide, Acaricide,	Warning
Thiamethoxam	Neonicotinoid	Insecticide	Warning
Thiocyclam	Unclassified	Insecticide	Danger

Table 9. Characteristics of highly hazardous pesticides' active ingredients used by smallholder farmers for the management of arthropod pests in Kenya.

Pesticide Active Ingredients	Chemical class	Use type	HHP1 Acute toxicity	HHP2 Carcinogenicity	HHP3 Mutagenicity	HHP4 Reproductive toxin	HHP5 POP	HHP6 PIC	HHP7 ODS
Abamectin	Fumigant	Nematicide	1	N	N	2	N	N	N
Beta-cyfluthrin			1B	N	N	2	N	N	N
Carbaryl	Carbamate	Insecticide	2	1B	N	N	N	N	N
Diazinon	Organophosphorous	Insecticide	2	1B	N	1B	N	N	N
Malathion	Organophosphorous	Insecticide, Acaricide	N	1B	N	N	N	N	N
Mancozeb	Dithiocarbamate	Fungicide, Oomycide	U	1B		2	N	N	N
Methomyl			1B	N	N	N	N	N	N
Propineb			U	1B	N	2	N	N	N

Key: 1 = extremely hazardous; 1B = highly hazardous; 2 = moderately hazardous; U = unlikely to present acute hazard; N = no.

Table 10. Summary of results of Multinomial Logistic Regression for relationship between test variables and choice to intervene or not to intervene when it comes to management of arthropod pests.

Test variables	Chi-Square	df	Sig.
Farmer region	16.905	6	0.010
Farmer gender	0.251	2	0.882
Type of arthropod pest	230.981	18	<.001
Study year	47.669	6	<.001
Goodness-of-fit (analysis)	339.492	460	1.000

measures (prior to consulting an extension agent) than their counterparts experiencing challenges associated with cutworms and African bollworm. Finally, farmers in certain regions were more likely to institute intervention measures

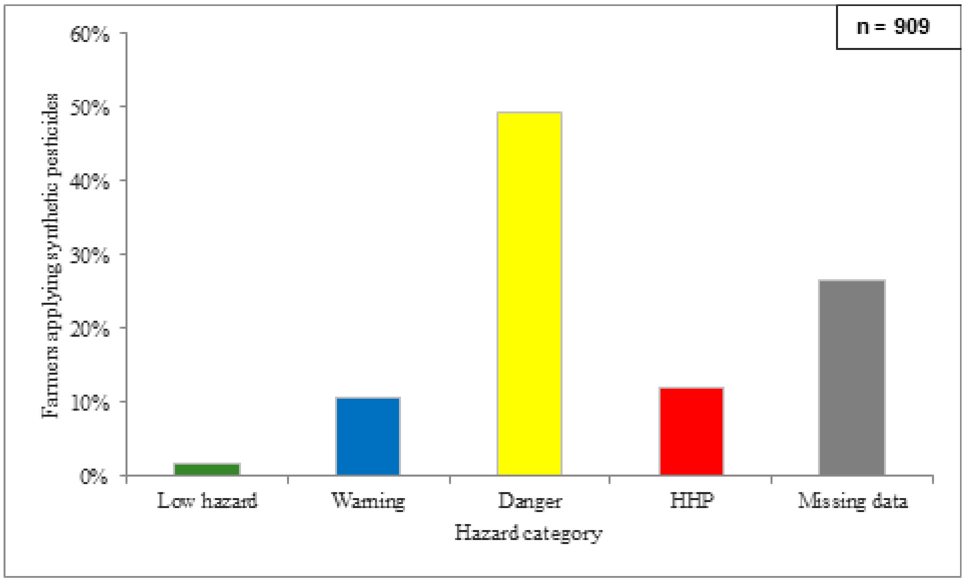

Figure 3. Farmers applying synthetic pesticides of different hazard categories.

(prior to consulting an extension agent) for the management of arthropod pests than their peers in other regions.

DISCUSSION

Arthropod pests of tomato in Kenya

Consistent with previous studies, a diverse range of arthropod pests were found to hamper tomato production in Kenya. Despite variations in arthropod pests' frequency, *T. absoluta*, whiteflies and spider mites were the most dominant pest species, confirming their major pest status on tomatoes as earlier reported by Oduor (2016) and Zeketa et al. (2016).

T. absoluta is an invasive pest of tomato native to South America (Tropea Garzia et al., 2012). According to Tonnang et al. (2015), surveys carried out in various places in Africa have demonstrated that *T. absoluta* is rapidly spreading across the continent. This meteoric spread could be credited to the widespread cultivation and movement of tomato fruits across the border through trade. Additionally, the climatic and ecological conditions of the continent mirror those of South America countries (Tonnang et al., 2015). *T. absoluta* was first reported in Kenya in 2014 (Gebremariamd, 2015). This report tallies with the research findings where the pest appeared for the first time in the study area in the second year of study (2014). Subsequently, higher incidences of *T. absoluta* are recorded, possibly, due to the pest's high biotic potential (Zekeya et al., 2016). The pest is a multivoltine species, exhibiting a high reproductive potential that allows its population to increase rapidly (Tropea Garzia et al., 2012). In addition, *T. absoluta* has a wide host range that allows it, when tomato is scarce, to switch to other available host in order to sustain its population and recover when tomato is in plenty (Zekeya et al., 2016). Another advantage *T. absoluta* possesses is its ability to tolerate and adapt harsh conditions such as dry conditions, extreme cold and hot environments (Zekeya et al., 2016). Like *T. absoluta*, whitefly also has high reproductive potential (Salas and Mendoza, 1995). Coupled with this, the pest has unique life habits that enable it to transmit viral diseases and cause severe damage through plant feeding (Salas and Mendoza, 1995). Spider mites, like *T. absoluta*, are invasive pests, native to South America (Migeon et al., 2009). Over the years, spider mites have become one of the most severe pests of tomato in Africa, resulting in significant losses in south-east Africa and west Africa (Migeon et al., 2009).

The findings of this study are in agreement with other studies on the effects of host plants on pest infestation (Akköprü et al., 2015; Kamara et al., 2007). According to Akköprü et al. (2015), plants influence host choice and the acceptance by arthropod pests with their biochemical, nutritional and morphological features. The differences in the frequencies of arthropod pests among various tomato varieties may be credited to differences in plant sap quality and the proportions of vital nutrients (Akköprü et al., 2015). Consequently, analysis of the sap composition of the tomato varieties will provide clarity on the factors affecting the incidences of arthropod pests on different tomato varieties.

Distribution of arthropod pests of tomato in relation to agro-ecological zonation

There was considerable variation in composition and frequency of infestation of arthropod pests in the different AEZs. This finding is in agreement with previous studies that have reported altered weather patterns increase or decrease crop vulnerability to pest infestations (Rosenzweig et al., 2001). According to Rosenzweig et al. (2001), the spatio-temporal distribution and proliferation of arthropod pests is controlled by climate.

In light of the foregoing, it is not surprising that most of the arthropod pests were reported in upper and lower midland zones, as opposed to the upper highland zones. Upper and lower midland zones are characterized by high temperatures and moderate precipitation. On the other hand, highland zones are characterized by low temperatures and excessive precipitation. Precipitation – whether insufficient, excessive, or optimal – is perhaps the most crucial variable affecting pest-crop interactions (Rosenzweig et al., 2001). The effects of moisture stress on crops predispose them to damage by pests, particularly in the early stages of plant development. In addition, moisture influences fecundity and speed of development of most arthropod pests (Rosenzweig et al., 2001). The predisposition to excessive moisture, however, can prove harmful to arthropod pests' population through encouraging pathogens such as fungi, mycoplasma and bacteria, thus causing mortality among arthropod pests. Also, excessive moisture may adversely affect the normal feeding and development activities of arthropod pests (Alto and Juliano, 2001; Atwal, 2014). When it comes to temperature, arthropod pests are sensitive to it due to the fact they are cold-blooded (Rosenzweig et al., 2001). Increases in temperature, for instance, may lead to changes in arthropod pests' population growth rates, changes in the pests' geographical distribution, changes in crop-pest synchrony, proliferations in pests' generations, and increased invasion of migrant pests (Porter et al., 1991). Extremely high temperature, however, reduce arthropod pests longevity (Rosenzweig et al., 2001).

In the study, whiteflies, spider mites, leaf miners and *T. absoluta* exhibited cosmopolitanism, registering a presence in all or nearly-all of the study's AEZs. This finding indicates that the aforementioned pests are widely spread in their distribution in Kenya, aided by their capacity to endure and adapt in severe conditions such as hot environments, dry conditions and extreme cold (Kang et al., 2009; Migeon et al., 2010; Skaljac et al., 2010; Zekeya et al., 2016).

Farmers' practices on management of arthropod pests of tomato

When it comes to the management of arthropod pests, a majority of the farmers opted not to intervene prior to consulting an agricultural extension officer. Perhaps, this was necessitated by the fact; farmers often have limited or incomplete information about pest problems and possible management practices (Hashemi et al., 2009). Additionally, the findings may indicate that farmers in the study area place a great degree of trust in the agricultural extension system (Ochilo et al., 2018). This finding, however, contradicts previous studies that have questioned the technical competence of agricultural extension agents. According to Roberts (1989), the technical competence of agricultural extension agents is limited and in most instances is inferior to that of farmers who are technologically more advanced. The author further postulates that agricultural extension agents are recruited from "school failures" and are provided only with a superficial kind of technical training (Roberts, 1989). More recently, Krishnan and Patnam (2013) reported that extension as a model for promoting modern input adoption may not be very effective. Instead, the duo advocated for social learning as a preferred mechanism for the same on the account of its persistence nature (Krishnan and Patnam, 2013).

For farmers who attempted to control arthropod pests prior to consulting an agricultural extension agent, essentially, the use of synthetic pesticides was the preferred practice. According to De Bon et al. (2014), the desire for quick results obtained immediately following pesticide application is at the heart of farmers' preference for synthetic pesticides over other pest control methods. Coupled with this is the lack of proven alternatives and the sustained availability of moderately cheap pesticides which has ensured pesticides remain the focal pest management tactic (Ngowi et al., 2007; Talekar and Shelton, 1993). Another factor appearing to drive synthetic pesticide use is smallholder farmers' quest to increase yield or quality and deficiency of knowledge in how to attain this without reliance on synthetic pesticides (De Bon et al., 2014; Williamson, 2003). According to Ngowi et al. (2007), when it comes to the choice of pesticide to use, smallholders are highly influenced by vendors dealing in pesticides and who operate in their farming communities. Over time, however, trends in pesticides use by smallholder farmers is influenced by farmers' knowledge on pesticide application with respect to pests, weather conditions, price, farm size and efficacy of pest control products (Ngowi et al., 2007).

With 60% of the farmers applying synthetic pesticides using pest control products that are highly toxic, the risk of long-term effects of pesticides, if not properly handled, is high. The risk is especially pronounced where exposure to carcinogens and endocrine disruptors is involved (Ngowi et al., 2007). Endocrine disruptors manifest their deleterious effect through antagonizing or mimicking natural hormones in the body. The consequence of which, in the long-term, leads to human health effects including reproductive abnormalities, hormone disruption, cancer, diminished intelligence, and immunosuppression (Kesavachandran et al., 2009). According to Pedlowski et al. (2012), pesticide contamination can occur through direct and indirect means, and farmers and farm workers are perhaps the group at most risk by means of occupational exposure. High levels of occupational exposure to pesticides by this group could be explained by the group's supposedly low education impeding their ability to heed the hazard warnings provided by regulatory agencies. Other factors cited include lack of awareness regarding the dangers of pesticide misuse, the challenge of extrapolating the dosage from a large dimension-basis to very small areas, the absence of instructions in the pesticide label, the inability of applicators to understand the color code system to enlighten them on the pesticide toxicity level, and lack of knowledge of pests (De Bon et al., 2014; Pedlowski et al., 2012). Furthermore, applicators who are conscious of the possible health hazards related to pesticides, and the advantages of personal protective equipment (PPE), do not always implement such measures. The main reasons provided for lack of use of PPE include discomfort of wearing PPE, cost, availability and general lethargy (Kesavachandran et al., 2009)

Conclusion

From this study, the key arthropod pests of tomato can be categorized into fruit borers, leaf feeders, leaf miners, cut worms, phloem feeders and gall producers. Among the arthropod pests, *Tuta absoluta*, whiteflies and spider mites are emerging as major threats to sustainability of tomato production. Changes in frequency and spatial patterns of arthropod pests are related to agro-ecological zonation. With climate change in perspective, future consequences for the performance of arthropod pests will certainly depend on the degree and character of climate change in the various AEZs and the quality of specific natural communities. AEZs representing upper distribution limits, such as the upper highlands, will possibly be impacted most by rise in temperature and enhanced developmental conditions of, for instance, aphids, cutworms, *T. absoluta* and mealybugs. On the other hand, the increase in temperature and drought will possibly result in shifts and range contractions of arthropod pests that are less tolerant to heat. In view of these future challenges and probable risks, crop protection practitioners are in need of effective measures developed on account of comprehensive planning and decision-making. Towards this end, monitoring tools and the incorporation into comprehensive pest management planning systems of essential pest risk assessment or simulation models become important.

For the management of arthropod pests, this study provides insights into practices used in the management of arthropod pests in tomato production in Kenya. High risk pesticides continue to be used by smallholder farmers in tomato production. In light of the foregoing, there is growing consensus on the need for reduction in agricultural pesticide use or risk, and integrated pest management (IPM) has been identified as a means to achieve this end. However, viable as IPM is as a concept, appealing to a cross-section of interest groups, it is unlikely that IPM will result in pesticide reduction among smallholder farmers. This is because, providing smallholder farmers with economical, non-risky pest management alternatives requires greater sustained institutional support than is presently available. Alternative management procedures to the use of HHPs and better assessments of potential profit-loss to a smallholder for application and non-application of HHPs are required. Crops bred for resistance could potentially reduce over-reliance in HHPs. However, for long-term effectiveness, development of resistance varieties must be developed within the confines of sustainable agriculture.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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REFERENCES

Akköprü, E. P., Atlıhan, R., Okut, H., & Chi, H. (2015). Demographic assessment of plant cultivar resistance to insect pests: A case study of the dusky-veined walnut aphid (hemiptera: Callaphididae) on five walnut cultivars. *Journal of Economic Entomology,* 108(2), 378-387.

Alto, B. W., & Juliano, S. A. (2001). Precipitation and temperature effects on populations of aedes albopictus (diptera: Culicidae): Implications for range expansion. *Journal of medical entomology,* 38(5), 646-656.

Anastacia, M. A., Thomas, K. K., & Hilda, W. N. (2011). Evaluation of tomato (lycopersicon esculentum l.) variety tolerance to foliar diseases at Kenya Agricultural Research

Institute Centre-Kitale in North West Kenya. *African Journal of Plant Science,* 5(11), 676-681.

Asgedom, S., Struik, P. C., Heuvelink, E., & Araia, W. (2011). Opportunities and constraints of tomato production in Eritrea. *African Journal of Agricultural Research,* 6(4), 956-967.

Atwal, A. (2014). *Pest population and assessment of crop losses.* Indian Council of Agricultural Research Krishi Anusandhan Bhavan Pusa; New Delhi.

Boubou, A., Migeon, A., Roderick, G. K., & Navajas, M. (2011). Recent emergence and worldwide spread of the red tomato spider mite, tetranychus evansi: Genetic variation and multiple cryptic invasions. *Biological Invasions,* 13(1), 81-92.

Clottey, V., Karbo, N., & Gyasi, K. (2009). The tomato industry in northern ghana: Production constraints and strategies to improve competitiveness. *African Journal of Food, Agriculture, Nutrition and Development,* 9(6), 1436-1451.

De Bon, H., Huat, J., Parrot, L., Sinzogan, A., Martin, T., Malézieux, E., & Vayssières, J. F. (2014) Pesticide risks from fruit and vegetable pest management by small farmers in sub-saharan africa. A review. *Agronomy for Sustainable Development,* 34(4), 723-736.

Diver, S., Kuepper, G., & Born, H. (1999). *Organic tomato production*: ATTRA.

FAOSTAT (2018). Faostat dataAvailable at http://www.fao.org/faostat/en/#data/QC. Accessed 17th April, 2018.

Gebremariamd, G. (2015). Tuta absoluta: A global looming challenge in tomato production, review paper. *Journal of Biology, Agriculture and Healthcare*, 5(14), 57-62.

Gogo, E. O., Saidi, M., Itulya, F. M., Martin, T., & Ngouajio, M. (2012). Microclimate modification using eco-friendly nets for high-quality tomato transplant production by small-scale farmers in East Africa. *HortTechnology*, 22(3), 292-298.

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K., & Wiltshire, A. (2010). Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 365(1554), 2973-2989.

Hartz, T., Miyao, G., Mickler, J., Lestrange, M., Stoddard, S., Nunez, J., & Aegerter, B. (2008). Processing tomato production in California. UC Agriculture & Natural Resources Farm. Publication 7228. 5p.

Hashemi, S. M., Hosseini, S. M., & Damalas, C. A. (2009). Farmers' competence and training needs on pest management practices: Participation in extension workshops. *Crop protection,* 28(11), 934-939.

Hill, D. S. (1983). *Agricultural insect pests of the tropics and their control*. CUP Archive.

Imam, T., Yusuf, A., & Mukhtar, M. (2010). A survey of some insect pests of cultivated vegetables in three selected irrigation areas along Jakara river, Kano, Nigeria. *International Journal of Biological and Chemical Sciences*, 4(2), 400-406.

Jones, J. B., Zitter, T. A., Momol, T. M., & Miller, S. A. (Eds.). (2014). *Compendium of tomato diseases and pests*. Saint Paul, MN: American Phytopathological Society. Pp. 58-60.

Kamara, Y., Chikoye, D., Omoigui, L., & Dugje, I. (2007). Influence of insecticide spraying regimes and cultivar on insect pests and yield of cowpea in the dry savannas of north-eastern Nigeria *Journal of Food Agriculture and Environment,* 5(1), 154.

Kang, L., Chen, B., Wei, J. N., & Liu, T. X. (2009). Roles of thermal adaptation and chemical ecology in Liriomyza distribution and control. *Annual Review of Entomology*, 54, 127-145.

Kesavachandran, C. N., Fareed, M., Pathak, M. K., Bihari, V., Mathur, N., & Srivastava, A. K. (2009). Adverse health effects of pesticides in agrarian populations of developing countries. In *Reviews of Environmental Contamination and Toxicology,* Volume 200 (pp. 33-52): Springer.

Kirsh, V. A., Mayne, S. T., Peters, U., Chatterjee, N., Leitzmann, M. F., Dixon, L. B., Urban, D. A., Crawford, E. D., & Hayes, R. B. (2006). A prospective study of lycopene and tomato product intake and risk of prostate cancer *Cancer Epidemiology and Prevention Biomarkers,* 15(1), 92-98.

Krishnan, P., & Patnam, M. (2013). Neighbors and extension agents in ethiopia: Who matters more for technology adoption? *American Journal of Agricultural Economics*, 96(1), 308-327.

Migeon, A., Ferragut, F., Escudero-Colomar, L. A., Fiaboe, K., Knapp, M., de Moraes, G. J., Ueckermann, E., & Navajas, M. (2009). Modelling the potential distribution of the invasive tomato red spider mite, tetranychus evansi (acari: Tetranychidae). *Experimental and Applied Acarology*, 48(3), 199-212.

Migeon, A., Nouguier, E., & Dorkeld, F. (2010). Spider mites web: A comprehensive database for the tetranychidae. In *Trends in acarology* (pp. 557-560): Springer.

Ngowi, A. V. F., Mbise, T. J., Ijani, A. S. M., London, L., & Ajayi, O. C. (2007). Pesticides use by smallholder farmers in vegetable production in Northern Tanzania. *Crop Protection (Guildford, Surrey)*, 26(11), 1617.

Ochilo, W. N., Otipa, M., Oronje, M., Chege, F., Lingeera, E. K., Lusenaka, E. & Okonjo, E. O. (2018). Pest management practices prescribed by frontline extension workers in the smallholder agricultural subsector of Kenya. *Journal of Integrated Pest Management*, 9(1), 15.

Oduor, K T. (2016). *Agro-morphological and nutritional characterization of tomato landraces (lycopersicon species) in africa.* University of Nairobi.

Olabiyi, T (2008). Pathogenicity study and nematoxic properties of some plant extracts on the root-knot nematode pest of tomato, *Lycopersicon esculentum* (l.) mill. *Plant Pathology Journal*, 7(1), 45-49.

Pedlowski, M. A., Canela, M. C., da Costa Terra, M. A., & de Faria, R. M. R. (2012). Modes of pesticides utilization by brazilian smallholders and their implications for human health and the environment. *Crop protection*, 31(1), 113-118.

Porter, J., Parry, M., & Carter, T. (1991). The potential effects of climatic change on agricultural insect pests. *Agricultural and Forest Meteorology,* 57(1-3), 221-240.

Roberts, N. (1989). *Agricultural Extension in Africa. A World Bank Symposium.* ERIC,

Rosenzweig, C., Iglesias, A., Yang, X., Epstein, P. R., & Chivian, E. (2001) Climate change and extreme weather events; implications for food production, plant diseases, and pests. *Global Change and Human Health,* 2(2), 90-104.

Royalty, R. N., & Perring, T. M. (1989). Reduction in photosynthesis of tomato leaflets caused by tomato russet mite (acari: Eriophyidae). *Environmental Entomology,* 18(2), 256-260.

Salas, J., & Mendoza, O. (1995). Biology of the sweetpotato whitefly (Homoptera: Aleyrodidae) on tomato. *Florida Entomologist*, 78(1), 154-160.

Skaljac, M, Zanic, K, Ban, S G, Kontsedalov, S and Ghanim, M (2010). Co-infection and localization of secondary symbionts in two whitefly species. *BMC microbiology*, 10(1), 142.

SPSS (Released 2007). Spss for windows, version 16.0. Chicago: SPSS Inc.

Talekar, N., & Shelton, A. (1993) Biology, ecology, and management of the diamondback moth *Annual Review of Entomology,* 38(1), 275-301.

Tonnang, H. E., Mohamed, S. F., Khamis, F., & Ekesi, S. (2015). Identification and risk assessment for worldwide invasion and spread of tuta absoluta with a focus on sub-saharan africa: Implications for phytosanitary measures and management. *PloS one,* 10(8), e0135283.

Toor, R. K., & Savage, G. P. (2005). Antioxidant activity in different fractions of tomatoes. *Food research international*, 38(5), 487-494.

Toroitich, F., Knapp, M., Nderitu, J., Olubayo, F., & Obonyo, M. (2014) Susceptibility of geographically isolated populations of the tomato red spider mite (tetranychus evansi baker & pritchard) to commonly used acaricides on tomato crops in Kenya. *Journal of Entomological and Acarological Research,* 46(1), 18-25.

Tropea Garzia, G., Siscaro, G., Biondi, A., & Zappalà, L. (2012). Tuta absoluta, a south american pest of tomato now in the eppo region: Biology, distribution and damage. *EPPO Bulletin,* 42(2), 205-210.

Umeh, V. C., Kuku, F. O., Nwanguma, E. I., Adebayo, O. S., & Manga, A. A. (2002). A survey of the insect pests and farmers' practices in the cropping of tomato in Nigeria. *Tropicultura*, 20(4), 181-186.

Williamson, S. (2003). *Pesticide provision in liberalised Africa: out of control?* (p. 15). Agricultural Research and Extension Network.

Zekeya, N., Chacha, M., Ndakidemi, P. A., Materu, C., Chidege, M., & Mbega, E. R. (2016). Tomato leaf miner (tuta absoluta meyrick 1917): A threat to tomato production in africa. *Journal of Agriculture and Ecology Research International,* 10(1), 1-10.