



Characteristics and production constraints of smallholder tomato production in Kenya

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ABSTRACT

Tomato is among the promising commodities in horticultural production in Kenya. Over the years, tomato production in Kenya has intensified. Yields, however, continue to remain low due to a myriad of constraints. This paper describes production practices and identifies challenges and opportunities for increased tomato productivity in smallholder production in Kenya. The study uses plant health clinics as primary providers of data. Association between variables is tested using multinomial logistic regression, and Goodness-of-fit test used to examine how well the model fits the data. In addition, ANOVA and Student's *t*-test were used to compare group means. Smallholder tomato production in Kenya is characterised by a decline in the area under tomato cultivation. Furthermore, production is dominated by male farmers while participation by youth is minimal. Coupled with these, a diverse range of biotic constraints impede tomato production, and for their management, use of conventional synthetic pesticides is the preferred practice by farmers. The findings of this study underscore the need to increase women and youth participation in tomato production. In addition, there is a need to explore initiatives that enable farmers to access available technologies such as improved seed. For the management of biotic constraints, smallholder farmers should be encouraged to consider alternatives other than an overreliance in the use of synthetic pesticides.

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Introduction

Agriculture is central to Kenya's economy accounting for 24 percent of the country's gross domestic product (GDP). In addition, it is estimated that 75% of the population, either directly or indirectly, depend on the sector [29]. In particular,

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Table 1

Agro-ecological zones in the study area.

Agro-ecological zone	Average altitude in m	Annual average mean temperature in °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

the horticulture sub-sector of agriculture has grown to be a vital source of income for smallholder farmers, government revenue, and foreign exchange earnings. Furthermore, the sub-sector contributes immensely to food security, as well as being a crucial source of raw materials for the manufacturing sector [15]. Smallholder production accounts for 80 percent of all growers and produces 60 percent of horticultural exports [18]. The main horticultural crops produced include vegetables, fruits, herbs, root crops (Irish and sweet potatoes), spices and cut flowers [23].

Tomato (*Lycopersicon esculentum* L), a popular and extensively cultivated vegetable, is among the promising commodities in horticultural production in Kenya. The crop is eaten by nearly all of the households as a source of vitamins A and C and lycopene [3]. In terms of production, Kenya is amongst the leaders in sub-Saharan Africa producing 410,033 tonnes of the produce [9]. Additionally, the crop constitutes 7% of the total horticultural produce in Kenya and 14% of the entire vegetable produce [13].

Over the years, tomato production in Kenya has intensified [9]. Yields, however, have remained low due to a myriad of impediments, key among them being abiotic (high temperature, erratic rainfall, poor soils, etc.) and biotic factors. Biotic factors of notable economic value in tomato production in Kenya comprise arthropod pests, fungal, bacterial and viral diseases [2,34,36]. For the management of biotic constraints, overreliance and indiscriminate use of chemical products among smallholder farmers has been reported [3]. This dependency on pesticides potentially poses a health hazard to growers and consumers besides associated environmental effects [3]. Another constraint leading to low tomato yields is the failure of smallholder farmers to take advantage of available technologies such as use of improved seeds [13]. The use of improved seeds could potentially aid farmers attain the utmost achievable yield level [3]. In appreciation of this, efforts have gone towards improving tomato production by means of developing improved varieties that are high yielding, resistant to pests amongst other qualities.

A missing component in studies on tomato production in Africa is characterisation of smallholder tomato producing households and determination of their technical efficiency [3]. Besides describing tomato farmers, it is necessary to investigate the causes of technical efficiency and productivity among them. Knowing this will highlight the extent to which inputs such as improved varieties and other factors account for disparities in yield. This paper thus seeks to characterise tomato producing households in Kenya by (1) describing demographic characteristics of sampled farmers, (2) investigating production practices and (3) identifying challenges and opportunities for increased productivity on smallholder production.

Materials and methods

Study area

This paper aggregates 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: Nyeri, Kirinyaga, Embu, Tharaka Nithi, Machakos, Kiambu, Nakuru, Trans Nzoia, Bungoma, Elgeyo Marakwet, Kajiado, Siaya, Narok and West Pokot. In relation to their prominence, the 14 counties account for only 11 percent of total land in Kenya, but for 23 percent of arable land. In addition, the 14 counties are the major tomato growing areas in Kenya (Table 2).

Table 2

Production of tomato in Kenyan counties from 2012 to 2014.

County	2012			2013			2014		
	Area (Ha)	Volume (MT)	Value (Million KES)	Area (Ha)	Volume (MT)	Value (Million KES)	Area (Ha)	Volume (MT)	Value (Million KES)
Kirinyaga	1,903	59,464	1,159	1,796	30,774	750	1,648	48,560	1,156
Kajiado	1,603	35,937	921	1,668	50,884	962	1,680	47,368	1,624
Bungoma	1,344	39,232	1,221	1,474	41,568	1,228	1,700	50,399	1,611
Kisumu	822	12,219	347	1,537	14,307	444	1,477	16,720	328
Kisii	876	15,590	331	951	16,985	364	937	16,664	351
Kiambu	964	18,029	811	691	9,169	419	964	18,029	812
Trans Nzoia	480	9,270	129	623	17,395	302	628	14,848	416
Machakos	547	10,335	222	724	11,548	323	447	6,189	356
Nakuru	509	6,745	602	495	8,668	516	633	17,511	347
Makueni	431	17,582	651	486	22,560	991	558	21,096	857
Others	9,706	139,702	3,992	10,540	160,010	5,353	13,402	142,820	3,945
Total	19,185	364,105	10,386	20,985	383,868	11,652	24,074	400,204	11,803

Source: Horticultural Crops Directorate (HCD) validated report 2014; Mi- million, MT- metric tons, Ha- hectare.

Table 3

Stages in the plant clinic 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

Study overview

From each location smallholder farmers visiting plant clinics (coordinated by Plantwise Kenya) were sampled. Plantwise is a global programme that is led by Centre for Agriculture and Biosciences International (CABI). The programme supports farmers to mitigate their losses on account of crop pests. By collaborating with government agricultural advisory services, the programme promotes the establishing of networks of community-based plant clinics where farmers are able to benefit from plant health advice.

The community-based plant clinics operate as a demand-driven extension tool. Plant clinics operate one day in a week or after every two weeks in locations that are convenient to smallholder farmers. At the plant clinic, a farmer brings a sample of the affected crop. The farmer then deliberates with a knowledgeable agricultural extension agent regarding the problem. Upon making a diagnosis, the experienced agricultural extension agent recommends, verbally and in writing, an appropriate management strategy for the plant health problem.

Agricultural extension agents manning plant clinics (also known as “plant doctors”), undertake four areas of capacity building and training to enable them, among other things, collect plant health data.

During the period under review a total 37,051 smallholder farmers visited plant clinics in 121 locations. Of these, 4,907 were tomato farmers. 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’.

Data management system

The process of data collection and management was divided into stages. Table 3 displays the stages and actors involved.

Data collection

At the point of collecting data, ‘plant doctors’ utilised the Plantwise prescription form to capture information about farmers’ queries. Besides recording information about the farmer and the plant clinic, the ‘plant doctors’ recorded information about the crop, variety, symptoms and diagnosis and pest management practices. Upon completion, the filled prescription forms were collated and transported to the national data hub in Nairobi. Data entry was achieved by means of an Excel-based form resembling the prescription form.

Data processing

Harmonization of data involved cleaning of digitized data (diagnoses and crop names, plant doctor names and location details). At data validation stage, the researcher reviewed all the 4,907 plant clinic records to check the accuracy of the diagnoses. Validating diagnoses was done by checking that: (1) a diagnosis was recorded in the form; (2) it was specific to

Table 4
Demographic characteristics of farmers involved in smallholder tomato production in Kenya.

(a) Categorical variables			
	Number of farms (n = 4,907)	Percentage (excluding missing values)	
Farmer's gender			
Male	3,297	68.8	
Female	1,493	31.2	
Missing value	117	–	
Farmer's age			
Youth	303	22.9	
Adult	971	73.3	
Senior	50	3.8	
Missing value	3,583	–	
Farm location			
Rural	3,571	72.8	
Peri-urban	1,336	27.2	
(b) Continuous variable			
	Mean	Median	Range
Farm size (acres)	0.292	0.131	0.006 – 2.0

at least sub-group level (e.g. mites, mealybugs, thrips, etc.); (3) it was plausible (i.e. known to affect the host crop and has previously been reported in the country); (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 data was executed using a statistical programme, SPSS, version 16 [33]. The analyses included assessing trends over time, and reviewing recommendations from prescription forms. To gauge the comparative frequency of variables, cross tabulation was employed and assessed for significance using the Pearson Chi-square test. Associations between nominal dependent variables (seed variety, pest type and pest management intervention) and many independent variables (seed variety – cost of seeds, growth habit of tomato plant, and tomato use; pest type – time, location and tomato variety; and pest management intervention – time, location and causative agent) were examined using multinomial logistic regression, and Goodness-of-fit test used to examine how well the model fits the data. ANOVA and Student's *t*-test were deployed to compare group means. Significance was defined as a *p* value ≤ 0.05 .

Results

Farm demographics

Farm demographic data is summarised in Table 4. The study indicated male dominance in tomato production in Kenya. A majority of the smallholder tomato farmers were male (69%). Of the smallholder farmers who provided their age, 23% were between the ages 20 – 35 years. On the other hand, 73% of the farmers were between 36 and 60 years while the rest (4%) were above 60 years. The area under tomato production ranged from 0.006 acres – 2 acres with a majority of the farmers planting tomatoes in an eighth of an acre or less (Fig. 1). There were significant ($p \leq .05$) differences between areas under tomato cultivation by male farmers (0.32 acres) and those under cultivation by female farmers (0.24 acres), $t(4788) = 7.220$, $p < 0.001$ (Table 5). Also, over time, there was a statistically significant ($p \leq .05$) difference in the area under tomato cultivation as determined by one-way ANOVA ($F(3, 4903) = 13.542$, $p < 0.001$) (Table 5). Further analysis indicated that the areas under tomato cultivation significantly declined in the third and fourth years of the study (Table 5). Areas under tomato cultivation, however, was not significantly affected by the location of the farmer (rural/peri-urban) ($t(4905) = 0.983$, $p = 0.326$) as well as the age of the farmer (youth/adult/senior) ($F(2, 1321) = 1.625$, $p = 0.197$) (Table 5).

Access to high quality seeds

The three main tomato varieties grown in Kenya and their corresponding percentage of farmers involved in their cultivation are Rio grande (32%), Cal J (16%) and Kilele F1 (11%) (Fig. 2). It is more likely that the choice of tomato variety cultivated was influenced by the cost of the seeds, the growth habit of the tomato plant (determinate vs indeterminate), and tomato uses (processing vs fresh market types) (Table 6). Most of the smallholder farmers (64%) opted for cheaper tomato varieties (cost less than KES 1,000). Over time, however, the numbers progressively declined. This culminated in nearly half of the farmers, by fourth year of the study, going for varieties that were medium priced (cost KES 1,000 – 10,000). Conversely, the number of smallholder farmers (13%) opting for expensive varieties (cost greater than KES 10,000) remained the same throughout the duration of the study. There was an overwhelming (84%) preference for determinate varieties compared to

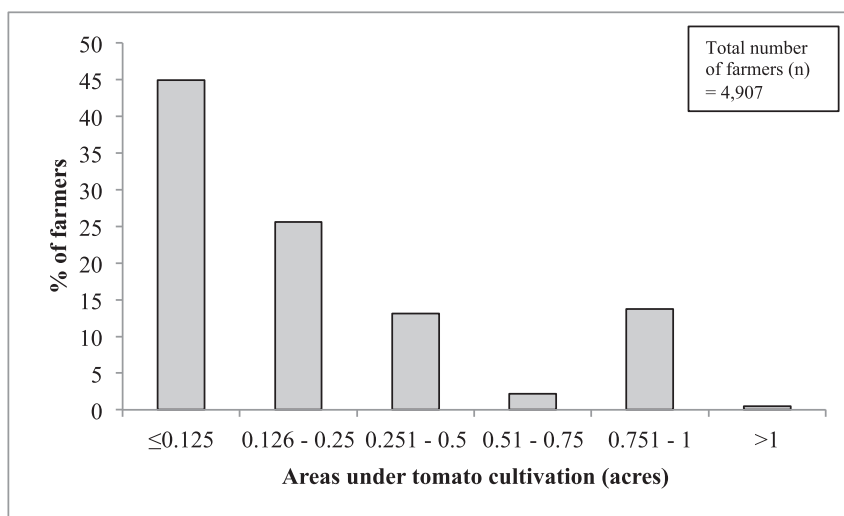


Fig. 1. Area under tomato cultivation in Kenya.

Table 5

Descriptive statistics for farm size in smallholder tomato production in Kenya.

	n	Average farm size (acre)	SD	Student's t-test
Farmers gender				
Male	3297	0.32	0.35	$t(4788) = 7.220, p < 0.001$
Female	1493	0.24	0.30	
Farm location				
Rural	3571	0.29	0.34	$t(4905) = 0.983, p = 0.326$
Peri-urban	1336	0.30	0.35	
Farmers age				
Youth	303	0.24	0.33	$(F(2, 1321) = 1.625, p = 0.197)$
Adult	971	0.26	0.33	
Senior	50	0.17	0.26	
Study period				
Year 1 (Jun 2013 – May 2014)	766	0.30ab	0.32	$(F(3, 4903) = 13.542, p < 0.001)$
Year 2 (Jun 2014 – May 2015)	1329	0.33a	0.36	
Year 3 (Jun 2015 – May 2016)	1439	0.30ab	0.34	
Year 4 (Jun 2016 – May 2017)	1373	0.25c	0.32	

*Means, within a column, followed by the same letter are not significantly different from each other at $p \leq 0.05$ (Fisher's Least Significant Difference Test).

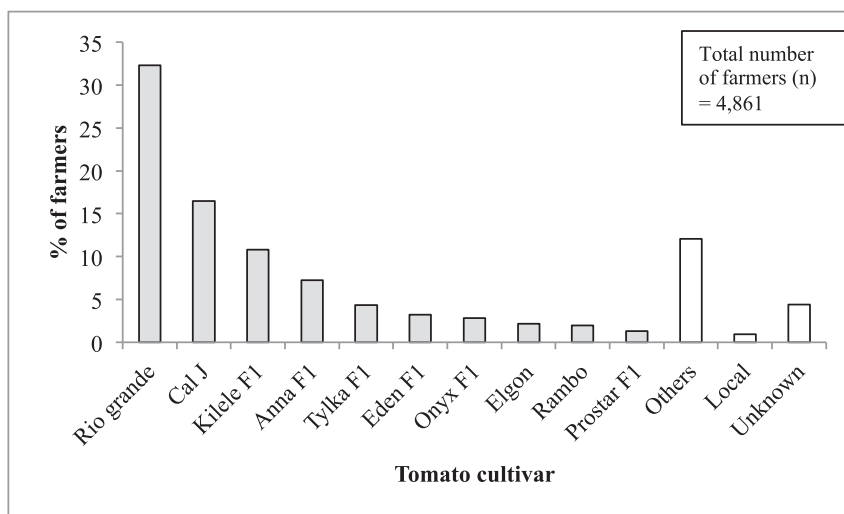


Fig. 2. Preferred tomato varieties by smallholder farmers in Kenya.

Table 6

Summary of results of Multinomial Logistic Regression for relationship between test variables (farmers' location and gender; cost of seeds; plant growth type; and plant use) and choice of tomato variety.

Test variables	Chi-Square	df	Sig.
Location	7.632	12	.813
Gender	14.106	12	.294
Cost of Seeds	574.514	12	<0.01
Growth habit	70.734	12	<0.01
Crop uses	736.134	12	<0.01
Goodness-of-Fit (analysis)	219.985	372	1.000

Table 7

Summary of results of Multinomial Logistic Regression for relationship between test variables (study period, farmers' location, tomato variety) and incidences of biotic and abiotic constraints.

Test variables	Chi-Square	df	Sig.
Study period	135.441	39	<.001
Location	32.908	13	.002
Variety	273.956	130	<.001
Goodness-of-Fit (analysis)	948.554	1105	1.000

Table 8

Cross tabulation showing frequencies and percentages (represented in brackets) of various biotic and abiotic constraints among an array of varieties in smallholder tomato production in Kenya.

	Bacteria	Fungi	Insects	Mites	Nematodes	Nutrient deficiency	Viruses	Water moulds	Others
Rio grande	177 (11%)	407 (26%)	523 (33%)	156 (10%)	45 (3%)	136 (9%)	61 (4%)	38 (2%)	16 (1%)
Cal J	106 (13%)	198 (25%)	220 (27%)	86 (11%)	19 (2%)	135 (17%)	19 (2%)	7 (1%)	8 (1%)
Kilele F1	62 (12%)	100 (19%)	213 (40%)	32 (6%)	7 (1%)	63 (12%)	19 (4%)	16 (3%)	11 (2%)
Anna F1	55 (16%)	69 (20%)	135 (38%)	14 (4%)	12 (3%)	48 (14%)	4 (1%)	8 (2%)	7 (2%)
Tylka F1	17 (8%)	42 (20%)	90 (43%)	13 (6%)	2 (1%)	31 (15%)	3 (1%)	1 (0%)	6 (3%)
Eden F1	31 (20%)	26 (17%)	55 (35%)	7 (4%)	2 (1%)	27 (17%)	1 (1%)	3 (2%)	6 (4%)
Onyx F1	17 (12%)	34 (25%)	46 (34%)	13 (9%)	2 (1%)	15 (11%)	4 (3%)	4 (3%)	3 (2%)
Elgon	2 (2%)	17 (16%)	60 (57%)	16 (15%)	4 (4%)	3 (3%)	1 (1%)	2 (2%)	1 (1%)
Rambo	15 (15%)	24 (25%)	31 (32%)	1 (1%)	2 (2%)	14 (14%)	5 (5%)	3 (3%)	2 (2%)
Prostar F1	9 (14%)	15 (23%)	20 (31%)	5 (8%)	1 (2%)	11 (17%)	2 (3%)	0 (0%)	1 (2%)
Others	95 (16%)	138 (24%)	188 (32%)	38 (7%)	6 (1%)	70 (12%)	20 (3%)	13 (2%)	18 (3%)
Local	5 (11%)	9 (20%)	13 (28%)	5 (11%)	3 (7%)	7 (15%)	2 (4%)	1 (2%)	1 (2%)
Unknown	28 (13%)	46 (22%)	82 (38%)	19 (9%)	4 (2%)	22 (10%)	7 (3%)	5 (2%)	0 (0%)

indeterminate varieties (16%), and this phenomenon was reflected throughout the duration of the study. A majority of the smallholder farmers (63%) selected varieties ideal for processing while the remaining 37% cultivated fresh market tomatoes.

Tomato production constraints and intervention

Constraints

A diverse range of constraints impede tomato production. These include pests and abiotic factors. The major groups of pests and abiotic factors impeding tomato production were insects (34%), fungi (23%), bacteria (13%), nutrient deficiencies (12%), mites (8%), viruses (3%), nematodes (2%), and water moulds (2%). It is highly likely that frequencies of biotic and abiotic constraints were influenced by time, tomato variety and location (Table 7). Incidences of pests showed considerable inter-year differences, particularly for insects, bacteria, fungi, nematodes and viruses. Over time, incidences of insect pests increased (from 26% [2013] to 36% [2017]) while incidences of bacteria (from 12% [2013] to 11% [2017]), fungi (from 27% [2013] to 22% [2017]), nematodes (from 3% [2013] to 1% [2017]) and viruses (from 5% [2013] to 2% [2017]) decreased. On the other hand, incidences of mites (10%), nutrient deficiencies (12%) and water moulds (2%) marginally varied over time. Certain tomato varieties were more susceptible to infestation by arthropod pests or diseases attack than other varieties (Table 8). For instance, while Elgon variety had the highest incidence of insect pests, it recorded the least incidence of fungal diseases. Pests damage was variable and site-specific. There were more reported cases of bacteria and insects in peri-urban locations (15% and 36%, respectively) than in rural locations (12% and 34%, respectively) while more cases of mites were recorded in rural locations (9%) than in peri-urban areas (7%).

Table 9

Summary of results of Multinomial Logistic Regression for relationship between test variables (time, farmers' location and gender, and problem type) and choice of pest management practice.

Test variables	Chi-Square	df	Sig.
Study period	576.373	15	<. .001
Location	23.916	5	<. .001
Gender	.	5	.
Variety	.	60	.
Problem type	1.607E3	65	<. .001

Table 10

Cross tabulation showing frequencies and percentages (represented in brackets) in of problem type among the various intervention measures employed in smallholder tomato production in Kenya.

	Cultural	Fertilizer application	Fungicides	Insecticides	Local knowledge	None
Bacteria	50 (8)	0 (0)	241 (39)	6 (1)	6 (1)	316 (51)
Fungi	11 (1)	0 (0)	743 (66)	11 (1)	0 (0)	349 (31)
Insects	17 (1)	9 (0)	34 (2)	1073 (64)	0 (0)	570 (34)
Mites	4 (1)	0 (0)	8 (2)	275 (68)	0 (0)	117 (29)
Nematodes	10 (9)	2 (2)	0 (0)	0 (0)	0 (0)	97 (89)
Nutrient deficiency	29 (5)	29 (5)	52 (9)	0 (0)	0 (0)	477 (82)
Viruses	1 (1)	1 (1)	38 (26)	13 (9)	0 (0)	93 (63)
Water moulds	1 (1)	1 (1)	24 (24)	1 (1)	0 (0)	74 (73)
Birds	1 (33)	0 (0)	1 (33)	0 (0)	0 (0)	1 (33)
Mammals	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (100)
Phytophthora	0 (0)	0 (0)	0 (0)	1 (17)	0 (0)	5 (83)
Weeds	2 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Others	1 (2)	0 (0)	0 (0)	0 (0)	0 (0)	56 (95)
Unknown	0 (0)	0 (0)	5 (22)	0 (0)	0 (0)	18 (78)

Interventions

There were varied interventions for biotic constraints. At the point of consulting the agricultural extension officer at the plant clinic, almost half of the farmers (45%) had not initiated any intervention measures for control of pests. Although farmers, who had attempted to control the problem prior to visiting a plant clinic, used some non-chemical control methods and occasionally applied homemade botanical (e.g. neem extract) and non-botanical (e.g. ash) pesticides (3%), pest management was mainly by the use of synthetic pesticides (insecticides and fungicides) (52%). The choice of intervention measure (including the option not to act) was most likely influenced by the time, location and problem type (Table 9). Over time, the number of farmers attempting to intervene in the management of crop pests increased leading to the heightened use of insecticides and fungicides. While only 49% of farmers failed to attempt to intervene in the management of crop pests in 2013, by 2017, the number had reduced to 21%. Also, more farmers in rural areas (58%), relative to their counterparts in peri-urban areas (47%), made an attempt to manage the pests prior to visiting a plant clinic. Finally, more farmers, before visiting a plant clinic, attempted to manage mite, fungal, and insect pests, than they did for the other pest categories (e.g. nematodes) (Table 10).

Discussion

Farm demographics

Male dominance in tomato production could be attributed to the fact that, tomato production requires a lot of capital investments and, in Kenya, men compared with women have higher levels of access to human and physical capital [19,27]. In addition, production of tomato is considered a risky undertaking and women tend to be risk averse [8]. Finally, this phenomenon could also be credited to variations in the quality of land cultivated by women and men, (including topography, soil quality, and nearness to access points such as housing, water sources and roads) and shadow prices of inputs and credits, leading women's production limit to lie below men's frontier [24].

Insufficient youth participation in tomato production could be the result of, among other things, scarcity of land (lack of land access). Land remains a challenge for most young people since a considerable number of them do not have land of their own to cultivate. Additionally, young people have limited access to improved farm inputs - aggravated by the fact that they are not targeted by government-sustained input programmes; and lack viable markets and targeted extension support. Impeding participation of youth in tomato production, also, is the widespread perception that agriculture is not rewarding and the resulting benefits are long term. Stemming from this, young people tend to choose urban salaried employment than farming [4,7,20].

The progressive decline in the area under tomato cultivation could be the result of more farmers adopting high-yielding varieties and other modern technologies which ensure increased production using less land [21]. Disaffection by farmers in the cultivation of tomato may be another possible reason explaining the decline in areas under tomato cultivation. This disaffection may be the result of institutional limitations such as poor post-harvest technologies; poorly organised urban and rural market infrastructures permitting volatile price fluctuations [13].

Access to high quality seeds

Given the array of high-yielding varieties available to smallholder farmers, and the association between adoption of improved seed and cost, limited adoption of high-yielding varieties could be the result of smallholder farmers' preference for traditional varieties, as an alternative to expensive varieties [14,17]. According to Kassie et al. [14], wealthier households are more likely and able to fund the procurement of expensive inputs, including improved seeds.

Preference for determinate tomato types could be premised on the fact that indeterminate types require staking, tying and hedging during the crop cycle. These cultural practices are costly, time consuming and require more labour. In addition, farmers prefer to grow determinate types in order to have concentrated fruiting, and relatively larger fruits [6,11,12,32]. Similarly, preference for processing tomatoes over fresh market tomatoes by smallholder farmers may have had cost considerations. Compared to processing tomatoes, fresh market tomatoes have larger production cost [5,31].

The maintenance of a wide genetic base, typified by farmers' cultivating a wide array of varieties, reduces the threat of crop loss occasioned by biotic and abiotic stressors specific to particular strains of the crop [1].

Tomato production constraints and intervention

Constraints

Consistent with previous studies, tomato production is highly limited by biotic and abiotic constraints, including diseases and insect pests [25,28]. Higher incidences of insect pests, particularly migrant pests, are recorded whenever there are increases in temperature occasioned by various inter-related processes, including amplified rates of population growth, development and migration. As a result of climate change, migrant pests are colonizing new habitats. This is because, the progressive, ongoing increase in atmospheric carbon dioxide impacts pests species directly (the carbon dioxide fertilization effect) and indirectly (through interactions with other environmental factors) [1].

Tomato production in the study was influenced by multiple biotic and abiotic factors whose incidences varied between years, location and variety. The spatio-temporal distribution of insects could be the result of numerous factors, including their high biotic potential, the artificial selection of insecticide-resistant populations, the enormous array of their host plants (intensifying their endurance in tilled areas), and intra-continental dispersion enablement due to their ability to drift and spread quickly into a new area, and due to human transport. Moreover, the lack of natural enemies that have co-evolved could explain why changes in pests populations, particularly for migratory insect pests (such as tomato leaf miner – *Tuta absoluta*) in the newly ravaged areas are faster than in the innate area, where natural enemies are more common [28,37]. During the study period, Africa was experiencing significant impacts from *T. absoluta* which threatened tomato production in the continent [26].

The influence of tomato variety on pests infestation could be tied to presence/absence of genes (within the cultivars) controlling the production of chemicals that kill or deter arthropod pests and pathogens [16,22]. In the natural environment, plants encounter numerous pests, and how they respond to attack by such organisms leads to tolerance or resistance mechanisms enabling the plant to survive. According to Lattanzio et al. [16], resistance mechanisms denote characteristics that avert or reduce attack. On the other hand, tolerance mechanisms do not prevent attack, instead, they minimize or counterbalance the effects on the plant fitness by altering the plant's physiology thereby cushioning the effects of herbivory or diseases. Tolerance ordinarily encompasses some measure of compensation for pest injury. Conversely, resistance strategies include techniques that quickly clear herbivory or infection (hypersensitive response), and mechanisms that reduce the distribution of damage within the host [16].

Intervention

Much as smallholder tomato farmers used some cultural control practices and sporadically some homemade botanical and non-botanical pesticides, pest management was mainly through the use of synthetic pesticides. The high dependence on synthetic pesticides could be indicative of the fact that the farmers may not have been aware of other pest control tactics that are inexpensive, effective and favourable to the environment [30].

The choice of intervention differed significantly between years, location and causative agent. With the passage of time, more and more farmers attempted to manage crop pests and abiotic stressors, albeit unsuccessfully. Increase in the number of farmers instituting management practices has been credited to public agricultural extension services and mass communication media. Both have been credited for introducing farmers to new technologies and farming practices [35]. Beyond the introduction of new technologies and farming practices to farmers, little investments may have been made in farmer education, in the wide sense of growing their abilities to comprehend, innovate and adapt to the changing dynamics. This lack of care may have led to smallholder farmers employing sub-optimal management practices which, in turn, may have resulted in increased incidences of crop pests [10,35].

The increase in incidences of certain categories of biotic and abiotic stressors (such as insects), over time, may have led to heightened use of specific chemical pesticides (e.g. insecticides) in their management [1].

Conclusion and recommendations

There is male dominance and insufficient youth participation in the smallholder tomato production in Kenya. Coupled with this, a majority of smallholder farmers cultivate tomatoes in areas not exceeding an eighth of an acre. When it comes to the choice of tomato varieties, most smallholder farmers opt for cheaper tomato varieties. Also, there is an overwhelming preference by smallholder farmers for determinate varieties and varieties ideal for processing. Furthermore, a diverse range of constraints impede tomato production. These include pests and abiotic factors. The major groups of pests and abiotic factors impeding tomato production are insects, fungi, bacteria, nutrient deficiency, mites, virus, nematodes and water moulds. Factors influencing the occurrence of biotic and abiotic constraints include time, tomato variety and location. Finally, for the management of biotic pests, much as smallholder tomato farmers used some cultural control practices and sporadically some homemade botanical and non-botanical pesticides, pest management was mainly through the use of synthetic pesticides. The choice of intervention (including the option not to act) is mostly influenced by time, location and problem type.

Much as women in Kenya play a crucial part in satisfying the food and nutrition requirements of their families by means of food production, economic access to food, and nutrition security, they are inadequately resourced. Thus, removing constraints confronting them and granting them access to resources available to their male counterparts could significantly impact their participation in tomato production. To increase women participation in tomato production, the government, both at the national and in the devolved units, must take policy steps to increase women's physical and human capital. This may include safeguarding women's traditional rights to land, provision of effective agricultural extension services to women, increasing education for girls, particularly in rural areas, and supporting the training of more women in agricultural and related sciences. In addition, both national and county governments should be deliberate in increasing women's ability to generate and control income and in protecting women's health and nutritional status. Increasing youth participation in tomato production is equally crucial since young people are both a source of labour and a potential entrepreneurial force for job creation. Towards this, there is need to rebrand agriculture as the new uncharted territory for growth in business prospects and not as a last resort for those unable to make a livelihood elsewhere. Access to land and finance are the main factors impeding youth participation in agriculture. Consequently, efforts should be made towards motivating young entrepreneurs in agriculture through the development of financial packages tailored to varied conditions of the sector, with the government, both national and county, providing guarantee schemes that would underwrite the uncertainties surrounding such packages. In addition, the government should promote land reforms and formulation of laws that ensure young people are not disenfranchised when it comes to land ownership.

Implementing deliberate strategies of competitiveness along the crop's value chain is crucial in poverty mitigation. This, in turn, will facilitate the transformation of tomato production from subsistence production to market-oriented production. Consequently, the government should explore public-private partnerships that enable farmers' to access and fully exploit available technologies such as improved seeds and other inputs. Such partnerships would involve bulk purchasing and local manufacturing of inputs; investments in transport infrastructure corridors linking productive zones and main markets within and across the regions; creation in rural areas of partnership opportunities for market-related infrastructure investments that will integrate smallholder farmers into local and export value chains; and encouragement of private investment in market-related infrastructure to hasten integration of smallholder farmers into the value chain.

The high proportion of smallholder farmers attempting to control crop pests shows they are cognizant of the losses attributed to biotic stressors. The predominant management practice reported by the smallholder farmers was the application of synthetic pesticides. However, in applying synthetic pesticides, smallholder tomato farmers appeared unable to distinguish pest control chemicals (particularly for the management of pathogens). Diversification of management strategies is likely to improve the effectiveness of control and perhaps lead to the reduction in the costs associated with managing biotic and abiotic stressors. Smallholder tomato farmers, therefore, need to know an array of management options, including biological control agents (BCAs). BCAs are a crucial component of integrated pest management (IPM) strategy for the control of diseases, arthropod pests and weeds. Traditionally, cost and availability have been at the heart of limited uptake of BCAs by farmers. To address this, the country requires a wider array of registered, affordable and available BCAs. This can be expedited by development, by the government, of a regulatory pathway appropriate for BCAs.

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Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:[10.1016/j.sciaf.2018.e00014](https://doi.org/10.1016/j.sciaf.2018.e00014).

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