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Farmer knowledge of bacterial wilt and root-knot nematodes and practices to control the pathogens in high tunnel tomato production in the tropics

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ABSTRACT

Sustainable production of tomato (*Solanum lycopersicum* L.) under high tunnels is threatened by bacterial wilt (caused by *Ralstonia solanacearum*) and root-knot nematode (*Meloidogyne* spp.). Knowledge was generated about the concomitant occurrence of these diseases from January to September 2016, and knowledge and experience of farmers about practices to control them were investigated. The study involved a survey during which 32 farmer groups in 6 subcounties of Kiambu County, Kenya, were interviewed. About 78.1% of high tunnels were in use for 1–2 years and 62.5% of farmers taking part in the study could identify symptoms caused by both causal organisms, which resulted in crop loss of 50%–100%. Seventy-one percent of respondents had positive feelings about high tunnel tomato production. About 82.6% had the soil in which they produced tomato in the tunnels analyzed for nutrition and presence of pathogens, but the majority (71.7%) never followed recommendations on how to amend their soils nutritionally and against the major soil-borne diseases. These findings indicate that more research and information are required so that farmers can optimize high tunnel production of tomato under tropical conditions.

KEYWORDS

Solanum lycopersicum; focus group discussions; *Meloidogyne* spp; protected cultivation; *Ralstonia solanacearum*; smallholder farmers

Tomato (*Solanum lycopersicum* L.) suffers from attack by soil-dwelling pathogens (Bolton, 2009; Kluepfel et al., 2015; Ramasamy and Ravishankar, 2018). Among them, root-knot nematode (*Meloidogyne* spp.) (RKN) and bacterial wilt (BW) caused by *Ralstonia solanacearum* are the most prevalent (Mbaka et al., 2013; Wanjohi et al., 2018). Cultivation of tomato in Kenya by 40%–60% of small- and medium-scale farmers has mainly been done under open field until recently when modified high tunnels were introduced (Anonymous, 2016a). Sustainable and profitable, high tunnel production is threatened by RKNs and BW (Schäfer et al., 2006).

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RKNs are sedentary, endoparasitic, phytonematodes that occur worldwide (Jones et al., 2013). Yield loss of 30%–100% to RKN infection in high value vegetables may occur (Onkendi et al., 2014). The second stage juvenile (J2), the infective stage, locates and penetrates suitable host roots intercellularly to initiate nutrient sinks from vascular cells (Bird et al., 2009; Perry et al., 2009). Nematode-induced wounding of crop roots also increases the occurrence of disease complexes caused by soil pathogens (Jones and Goto, 2011; Stanton and Stirling, 1997). Smallholder farmers are often unaware of such pathogen complexes (Coyne et al., 2006a, 2006b), with control of RKNs becoming increasingly difficult due to banning of effective but highly toxic, nematicides (Martin, 2003).

BT is a serious disease in the tropics and subtropics, causing severe losses in many agricultural crops (Hayward, 1991). The pathogen, *Ralstonia solanacearum*, enters plant roots through natural openings and wounds, invades xylem vessels, and spreads to aerial parts where it multiplies leading to wilting and death of the plant (Genin, 2010). The lethality of *R. solanacearum* is enhanced by its ability to survive in soil for many years where it forms latent infections within indigenous weeds that makes its eradication in cropping systems difficult (Hayward, 1991). Despite adverse effects of chemical pesticides to the environment, and non-target organisms, alternative safer options such as crop rotation, field sanitation, and use of cultivars resistant to this disease are often ineffective (Ji et al., 2003; Saddler, 2005).

A knowledge, attitude, and practice (KAP) study, referring to a focused evaluation of a human population that informs on what is perceived, believed, and acted upon toward a certain situation, led to development of personal protective measures against adverse effects of pesticides (Yuantari et al., 2015). Such an approach has been followed in this study to define the KAP to control BW and RKNs among high tunnel tomato farmers in the tropics.

Materials and methods

The study was conducted from January to September 2016 in high tunnels (18–25 m length × 8 m wide × 2 m high) covered with translucent UV-treated plastic sheeting in the subcounties Gatundu North, Gatundu South, Juja, Kiambu, Ruiru and Thika of Kiambu County, Central Kenya. The county is divided into the broad topographical zones of Upper Highland, Lower Highland, Upper Midland, and Lower Midland. Kiambu County is characterized by the presence of broad categories of soils: high-level upland soils, plateau soils, and volcanic footbridge soils (Anonymous, 2015a). The high-level upland soils, which are from volcanic rocks, are fertile. Low fertility soils are mainly found in the middle zone and the eastern areas such as Juja, Thika, Ruiru, Gatundu North, and Gatundu South subcounties. The soils are either sandy or clay.

Mean temperature in the area is 26°C with temperatures ranging from 7°C in some parts of Gatundu North and Gatundu South subcounties, to as high

as 34°C in Thika subcounty. This temperature range can support tomato production even under protected cultivation.

Purposive sampling was used to select the sample size. Based on information from county and subcounty crop officers, 80 high tunnels, managed by a group of 8–30 farmers, were constructed by the Kiambu County Government and the National Irrigation Board for horticultural production in 2014. Of these, 32 high tunnels located in the subcounties were selected based on previous challenges farmers experienced with pests and diseases in tomato production (Anonymous, 2015b). This comprised a sample size of 40% (of the 80 tunnels that exist), which is a good representation of the target population (Mugenda and Mugenda, 2003). The selected high tunnels comprised 311 respondents (141 males and 170 females).

Data were collected using focused group discussions using a checklist with open-ended questions. The checklist was constructed in consultation with a statistician to ensure that questions were written correctly and would allow for valid statistical analysis. The checklist was pretested among subcounty crop officers and enumerators (10 respondents) before administration in its final form. The checklist consisted of sections that included farmer: (1) knowledge, (2) attitude, and (3) practices in high tunnel tomato production in relation to the key target pests. The knowledge section consisted of 12 questions used to compute a knowledge score. For each question, a correct response was assigned as 1; a wrong response, or “don’t know,” 0. The number of correct responses for the 12 questions was summed to calculate the group knowledge and subsequently respective subcounty scores. In the attitudes section, three “yes/no” questions on the impact of BW and RKNs toward high tunnel tomato production were asked. Those who said yes were considered to have a positive attitude; those that said no were considered to have a negative attitude. For the practices section, questions were asked using the “When, Where, What, Which, Who, and How method” to evaluate precautionary measures respondents took against BW and RKNs. One point was assigned for each measure and a 0 if a measure was not mentioned in subsequent responses. A practice score for each group was computed by summing the number of responses out of 10 questions. The data were analyzed with SPSS (ver. 22, Released 2013, IBM SPSS Statistics for Windows, Armonk, NY). Means, frequencies, and percentages were calculated and separated using Tukey’s HSD test.

Results

Characteristics of farmers and high tunnels in Kiambu County varied (Table 1). More female than male farmers used high tunnels. Most high tunnels had been utilized for 1–2 years, with a few exceeding 2 years. Half of the high tunnels had been used for two cropping cycles within a year. The majority of farmers grew tomato in high tunnels for commercial purposes

Table 1. Characteristics of respondents and high tunnels used by farmer groups in Kiambu County, Kenya, as part of a survey study about prevalence and control of bacterial wilt and root-knot nematode pathogens.

Source	Frequency (n)	Proportion (%)	P value
<i>Subcounty</i>			
Thika	8	25.0a ^a	<0.001
Juja	5	15.6b	
Gatundu South	6	18.6b	
Kiambu	8	25.0a	
Ruiru	2	6.3c	
Gatundu North	3	9.4c	
<i>Respondent gender</i>			
Male	141	45.3a ^a	0.271
Female	170	54.7a	
<i>Age of high tunnels</i>			
<1 year	5	15.6b	0.007
1–2 years	25	78.1a	
>2 years	2	6.3c	
<i>Cropping cycles</i>			
1	9	28.1b	<0.001
2	16	50.0a	
3	5	15.6c	
>4	2	6.3d	
<i>Purpose of growing tomato</i>			
Sale (commercial) (a)	25	78.1a	<0.001
Subsistence (b)	0	0	
Both (a and b)	7	21.9b	

^aValues in columns followed by the same letter are not significantly different, $P \leq 0.05$; Tukey's HSD test.

(Table 1). Relative to other tomato diseases, BW and RKNs were ranked as the most problematic diseases in high tunnel tomato production with the former being more important than the latter (Table 2). All respondents in Gatundu South and Ruiru subcounties considered BW as the most problematic; fewer from other subcounties shared the same opinion. RKN was reported as the main production constraint in some subcounties (Table 2).

Knowledge of the farmers about BW and RKNs varied between the subcounties. The respondents had a knowledge score that indicated a moderate and high knowledge of RKNs (Figure 1a) and BW (Figure 1b), respectively. About 35% of farmer groups indicated that diseases were the main contributors to the decline in tomato production in Kiambu County (Figure 2). Of these, 81.2% perceived BW and RKNs as major pathogens (diseases) that were responsible for 45%–65% crop loss across the subcounties, and up to 100% in individual high tunnels. Despite the challenges, 71% of farmer groups retained an interest in high tunnel tomato production.

'Tylka F1' was the most preferred tomato variety grown in high tunnels by nearly half of farmer groups (Table 3). The county government mainly provided tomato seedlings. Most farmers dug up soil in the high tunnels to obtain planting media, with the soil not being treated before establishing the crop. Although most farmers took soil samples for analysis, they did not

Table 2. Importance of bacterial wilt and root-knot nematodes relative to other diseases, according to 311 farmer respondents, in tomato producing high tunnels in 6 subcounties of Kiambu County of Central Kenya.

Rank	Challenge	Subcounty						P value	Kiambu County (overall mean %)
		Thika (%)	Juja (%)	Gatundu South (%)	Kiambu (%)	Ruiru (%)	Gatundu North (%)		
1	Bacterial wilt	75b ^a	80ab	100a	75b	100a	66.7b	0.042	82.8a
2	RKNs	50c	60ab	83.3a	75a	50c	66.7b	0.027	64.2a
3	Blight	50b	60b	100a	37.5c	50b	33.3c	0.019	55.1b
4	Fusarium wilt	62.5a	40b	66.7a	75a	0c	33.3b	0.002	46.3b
5	Blossom end rot	37.5c	40c	83.3a	12.5d	50b	33.3c	0.001	42.8b
6	Powdery mildew	50c	80a	66.7b	25e	0f	33.3d	<0.001	42.5b
7	Tomato yellow leaf curl	25c	0d	50a	37.5bc	0d	0d	0.018	18.8c
8	Root rot	12.5c	0d	50a	0d	0d	33.3b	0.006	16c
	P value								0.0073

^aValues in rows followed by the same letter are not significantly different, $P \leq 0.05$; Tukey's HSD test. RKNs: Root-knot nematodes.

follow the recommendations. Most farmers used ≈ 10 g of fertilizer at planting or as top dressing per planting hole (Table 3). Although a diverse number of methods were used by farmers to control BW and RKNs, uprooting and soil fumigation were the main practices used. Despite their numbers, these methods were considered not to be effective because most farmers disposed off diseased plants outside the high tunnels. Most farmers practiced crop rotation, while a minority used other tomato varieties alledged to be resistant to BW for rotation. The most common methods of irrigating plants were with water from shallow wells and rivers (Table 3).

Discussion

In Kenya, tomato has been grown mainly under open field until recently when high tunnels were introduced. Nearly all groups interviewed had/were growing tomato in high tunnels. This was not unusual as the crop was ranked first in a prioritization study of vegetable crop value chains in Kenya (Anonymous, 2012, 2016b). Most high tunnels had only been in existence for 1–2 years indicating farmers were yet to realize the full potential of producing tomato in these structures.

Most farmer groups reported BW and RKNs as problematic in high tunnel tomato production. Despite this general perception, there was an indication of a moderate level of knowledge on RKNs based on overall knowledge scores. The low level of knowledge for RKNs could be due to farmers inability to identify damage symptoms caused by these pests which occur below-ground

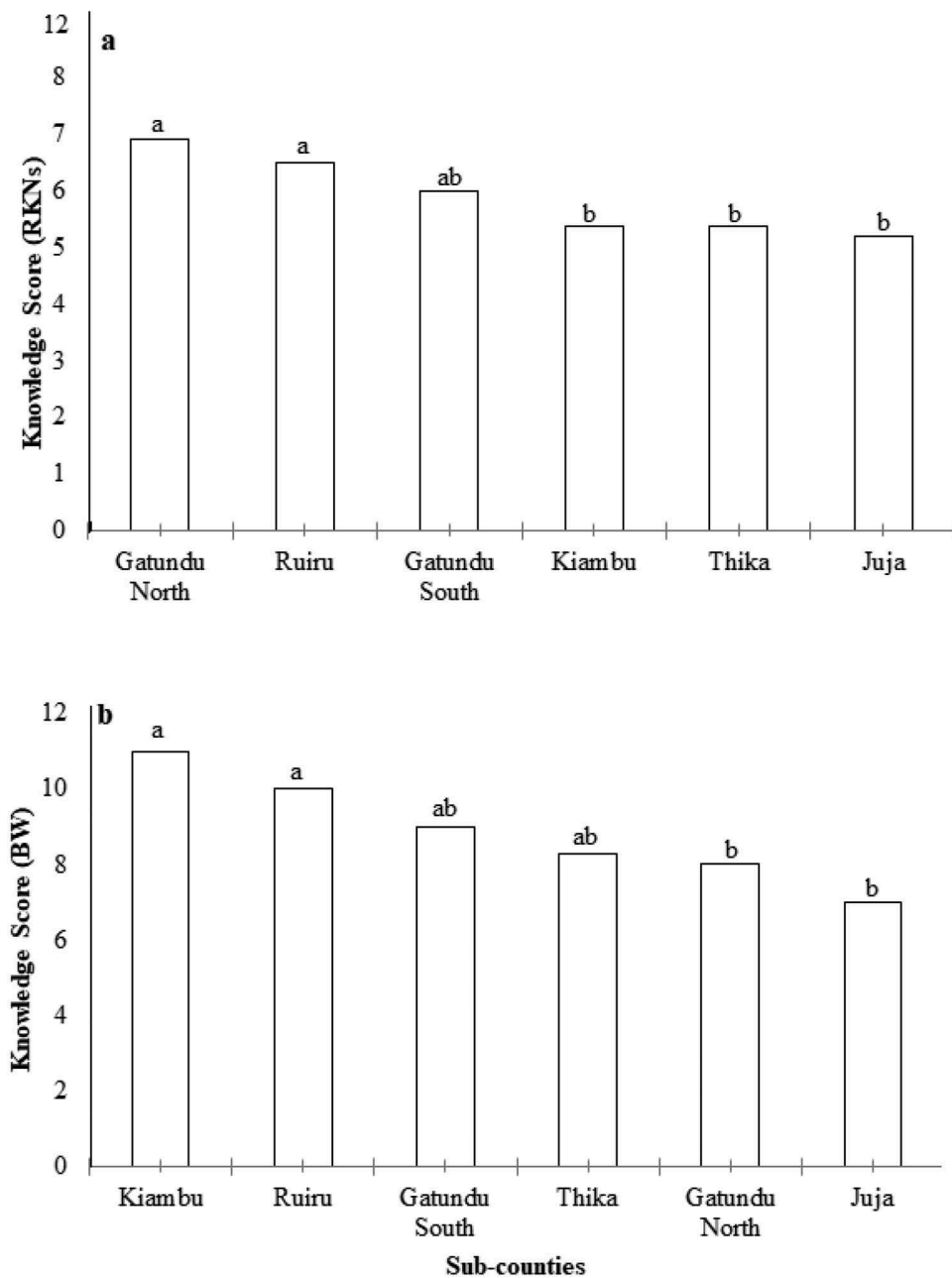


Figure 1. Knowledge score on (a) root knot nematodes (RKNs) and (b) bacterial wilt (BW) among high tunnel tomato farmers in Gatundu North, Gatundu South, Juja, Kiambu, Ruiru and Thika subcounties in Kiambu County ($P \leq 0.05$).

before aerial symptoms become visible (Mitkowski and Abawi, 2003). The farmers had a good knowledge about BW which may be attributed to wilt symptoms being visible on aerial parts of the plants (Hayward, 1991). Despite individual farmer groups experiencing crop losses of 50%–100%, and average

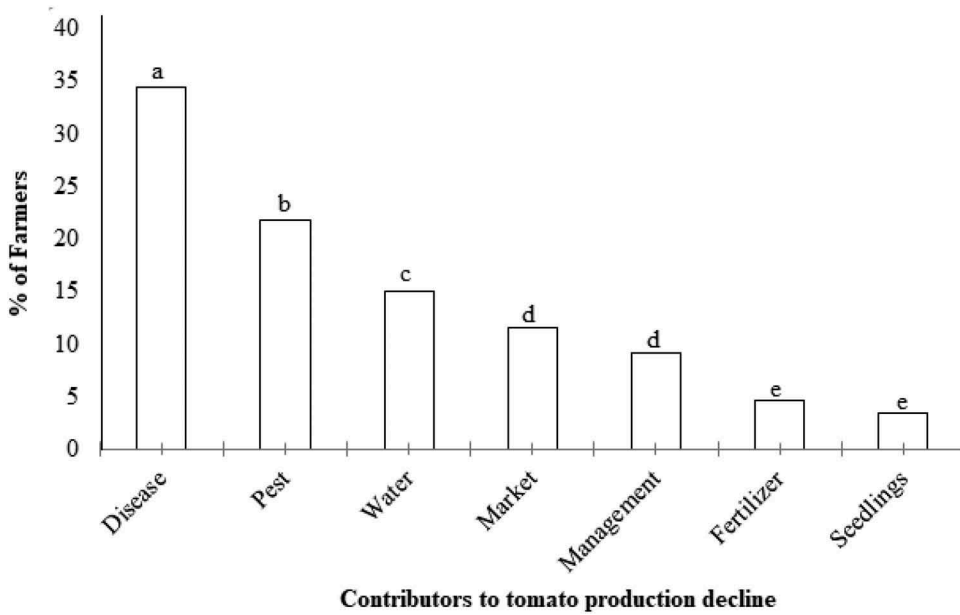


Figure 2. Perception of farmers on major contributors to tomato production decline in Kiambu County.

individual subcounty loss between 45% and 65%, there was a high interest in producing tomato in high tunnels. Most farmers desired to know more about the pathogens that infect tomato and methods to control them.

Farmers have poor practices toward the prevention of BW and RKNs. Farmers did not obtain clean planting material, did not sterilize the soil, and disposed off diseased plants outside the high tunnels in which problems were experienced. BT and RKNs are soil-borne pathogens (Hayward, 1991), and only good farming practices are predictors of prevention (Yuliar and Toyota, 2015). Previous reports indicated that improved cultural practices including planting clean healthy seed, crop and field sanitation, and disinfection of agricultural tools reduced incidence of BW disease and led to increased yield (Lemaga et al., 2005; Yu, 1999). Amendment of soil with organic and/or inorganic fertilizers under field conditions reduced BW incidence on *Solanum tuberosum* L. (Lemaga et al., 2005) and increased yield. Crop rotation has been shown to suppress nematode pest populations (Guerena, 2006). Studies using these field-tested practices need to be conducted in high tunnels where this study was done to establish their impact on BW and RKNs.

Baseline information about the current knowledge of farmers about BW and RKNs and practices to manage such pathogens in high tunnel tomato production indicates that more work is required to optimize this technology. With appropriate production practices, the use of high-tunnel tomato production may be optimized and applicable for smallholder farmers in the tropics.

Table 3. Farmer practices in tomato producing high tunnels in six subcounties of Kiambu County from survey done to generate knowledge about prevalence and control of bacterial wilt and root-knot nematode pathogens.

Source	Subcounty					P value	Kiambu County (Overall mean %)	
	Thika (%)	Juja (%)	Gatundu South (%)	Kiambu (%)	Ruiru (%)			Gatundu North (%)
Tomato variety								
Tylka F1	40c ^a	71.4a	71.4a	45.5c	50b	20d	0.003	49.7a
Anna F1	10c	14.3c	28.6b	9.1c	0c	60a	<0.001	20.3b
Chonto F1	10b	0c	0c	18.2b	25a	20ab	0.037	12.2c
Bravo F1	10c	0d	0d	18.2b	25a	0d	0.034	8.9c
Prostar F1	0b	14.3a	0b	0b	0b	0b	0.237	2.4c
Unknown	30a	0b	0b	9.1b	0b	0b	0.04	6.5c
P value								0.021
Planting material								
Seed	11.1c	28.6b	42.9a	25ab	0c	0c	0.007	17.9b
Seedlings	88.9a	71.4b	57.1b	75a	100a	100a	0.04	82.1a
P value								<0.001
Source of planting materials								
County government	60a	71.4a	57.1a	66.7a	66.7a	66.7a	0.08	64.8a
Agrovets	20b	28.6a	28.6a	22.2b	0c	0c	0.039	16.6a
Seed company	0c	0c	14.3b	0c	33.3a	33.3a	0.006	13.5b
High tunnels contractor	20a	0c	0c	11.1b	0c	0c	0.0174	5.2b
P value								0.001
Source of planting media								
High tunnel earth	100a	100a	83.3a	100a	100a	100a	0.431	97.2a
Forest	0b	0b	17.7a	0b	0b	0b	0.038	2.8b
P value								<0.001
Media treatment								
No	87.5a	80ab	66.7b	87.5a	100a	100a	0.041	86.9a
Yes	12.5b	20b	33.3a	12.5b	0c	0c	0.033	13.1b
P value								0.001
Soil test								
Yes	37.5c	100a	83.3c	75bc	100a	100a	0.07	82.6a

(Continued)

Table 3. (Continued).

Source	Subcounty					P value	Kiambu County (Overall mean %)
	Thika (%)	Juja (%)	Gatundu South (%)	Kiambu (%)	Ruiru (%)	Gatundu North (%)	
No	62.5a	0c	16.7b	25b	0c	0c	17.4b 0.0018
P value							
<i>Following recommendations</i>							
No	66.7b	80a	50b	83.3a	50b	100a	71.7a
Yes	33.3a	20b	50a	16.7b	50a	0c	28.3b
P value							0.0022
<i>Fertilizer quantities used</i>							
10 g	50a	40a	50a	62.5b	100c	66.7b	61.5a
5 g	50bc	60c	33.3b	37.5b	0a	33.3b	35.7b
>10 g	0b	0b	16.7a	0b	0b	0b	2.8c
P value							0.001
<i>BW and RKN control method</i>							
Uprooting	38.1a	41.7a	50a	26.9ab	18.2b	14.3b	31.5a
Soil fumigation	23.8b	41.7a	30a	23.1b	18.2b	21.4b	26.4a
Chemical	9.5a	8.3a	20a	15.4a	18.2a	21.4a	15.5b
Door management	9.5a	0b	0b	15.4a	18.2a	21.4a	10.8b
Ashes	4.8b	8.3b	0b	3.8b	18.2a	7.1b	7b
Side nets	4.7a	0b	0b	7.7a	9.1a	0b	3.6b
Footbath	9.5a	0b	0b	7.6a	0b	0b	2.9b
Traps	0a	0a	0a	0a	0a	14.3b	2.4 b
P value							0.014
<i>Effectiveness of method</i>							
No	62.5b	40c	33.3c	50bc	100a	33.3a	53.2a
Yes	37.5c	60a	66.7a	50ab	0d	66.7a	46.8a
P value							0.051
<i>Crop rotation</i>							
Yes	87.5a	80a	100a	87.5a	100a	100a	92.5a
No	12.5b	20a	0c	12.5b	0c	0c	7.5b
P value							<0.001
<i>Crops for rotation</i>							
Other tomato varieties	40a	14.3c	27.3b	42.9a	50a	42.9a	36.2a
Onions	26.7a	28.6a	18.2b	14.3b	0c	28.6a	19.4b

(Continued)

Table 3. (Continued).

Source	Subcounty					Ruiru (%)	Gatundu North (%)	P value	Kiambu County (Overall mean %)
	Thika (%)	Juja (%)	Gatundu South (%)	Kiambu (%)					
Spinach	6.7c	28.6a	18.2b	14.3b		25a	0d	0.005	15.5b
Kale	13.3b	14.3b	9.1b	0c		25a	0c	0.0039	10.3c
Cucumber	6.7b	0c	0c	21.4a		0c	14.3b	0.02	7.1d
Capsicum	0c	0c	18.2a	7.1b		0c	14.3b	0.015	6.6d
Coriander	0b	14.3a	9.1a	0b		0b	0a	0.021	3.9 e
P value									0.019
<i>Disposal of diseased plants</i>									
Piling outside the high tunnel	25d	80a	57.1b	57.1b		50c	33.3d	0.03	50.4a
Burning	62.5a	0d	28.6c	28.6c		50b	33.3c	0.014	33.8b
Burying	12.5c	20b	14.3c	14.3c		0d	33.3a	0.008	15.7c
P value									<0.001
<i>Irrigation water source</i>									
Shallow wells	22.2c	0d	37.5b	66.7a		0d	60a	0.01	31.2a
River	55.5a	33.3b	37.5b	22.2c		20c	0d	0.004	28.1b
Rain	11.1d	33.3a	25b	0e		20c	20c	0.019	18.2c
Water pans	0d	16.7b	0d	11.1c		40a	20b	0.019	14.6c
Water company	11.1b	16.7a	0c	0c		20a	0c	0.019	7.9d
P value									0.0036

^aValues in rows followed by the same letter are not significantly different, $P \leq 0.05$; Tukey's HSD test.

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