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Article

Farmers' Knowledge on Whitefly Populousness among Tomato Insect Pests and Their Management Options in Tomato in Tanzania

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Abstract: Whitefly is a populous insect pest among tomato insect pests, causing significant crop loss through direct and indirect attacks. The current study aimed to assess the knowledge of tomato farmers on the populousness of whiteflies compared to other tomato insect pests and explore the management options available in their farming context in three tomato-growing regions, Arusha, Morogoro, and Iringa, in Tanzania. The study used a questionnaire to collect the data with backup information obtained through key informants' interviews and focus group discussions. The study findings indicated whitefly to be populous among tomato insect pests. However, tomato farmers showed varying knowledge of whitefly aspects, including differing control options for the pest. Such findings indicated a knowledge gap between farmers' understandings of the pest and their practices in fighting it compared to the standard and required practices in controlling the pest.

Keywords: whitefly populousness; knowledge; farmers' perception; pest control and pesticides application skills

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1. Introduction

Whitefly (*Bemisia tabaci*-Gennadius) is a devastating insect pest of tomatoes in all production systems worldwide [1]. The insect is very polyphagous, affecting both cultivated and weed plant species [2]. Whitefly causes substantial crop losses through direct and indirect effects on the host plants [3]. Adults and nymph directly suck the plant phloem sap, which is rich in nitrogen in the form of free amino acids, soluble proteins, and soluble carbohydrates, causing significant nutrient competition among the host plant and the insect pest [4]. Indirectly, whiteflies vector more than 350 pathogenic plant viruses that threaten the production of tomatoes and other crops in the tropics and subtropics [5] and impair the trade of agricultural commodities [6]. The most prevalent virus that affects tomato production are tomato yellow leaf curl virus (TYLCV) from the genus Begomovirus which cause tomato yellow leaf curl disease (TYLCD) in the tropics and subtropics, Tanzania included [7]. The virus is the most devastating among the Begomovirus, threatening tomato production globally [8]. This virus is very common and widespread in Tanzania, especially in a hot summer, where it can lead to 100% of tomato losses [9]. Its prevalence is high in Dodoma, Morogoro, Dar Es Salaam, Iringa Kilimanjato, and Arusha, as reported by the same study. Tomato mosaic virus is also a threat to tomato production in many parts of the world [10].

Whitefly is very destructive among tomato insect pests, causing tomato losses of up to 100%, which amounts to more than one hundred million dollars each year [11]. For example, in Nepal, whiteflies were reported to be populous and the leading insect pest in tomato production [12]. The loss is counted from the costs involved in purchasing the pesticides and other control measures, time spent applying the control measures, and the crop loss due to the insect pest attack in quantity and quality.

Most farmers use synthetic pesticides to control whiteflies as the preferred pest control method due to their fast action and mass insect-killing manner [13]. They also mix different pesticides to increase their synergy [13]. Additionally, tomato farmers use biological, cultural, and mechanical methods to control whiteflies [14]. Despite all these efforts, the whitefly insect pest continues to dominate tomato production in tropical and subtropical areas [15] where Tanzania is inclusive. This failure is anticipated from whitefly colonization strategies, such as the ability of whiteflies to hide under the leaf surface of the host plant [2], wide genetic diversity [16], wide host range [17,18], small body size and short life cycle [19], the ability to develop insecticides resistance, and high invasiveness [20], which give whiteflies advantages to survive the applied control methods.

To have effective whitefly control, apart from having the control measures in place, the awareness of farmers on whitefly, including their understanding of it as a pest and the wise selection and use of a control measure, is important. Therefore, farmers' awareness of whitefly, major tomato insect pests, control options available, and the use of pesticides to mitigate them with emphasis on the control methods, type of pesticide used, pesticide application frequency, and their perception of the best practices need to be assessed. As such, the current study was carried out to determine the knowledge of tomato farmers on whitefly populousness among the major tomato insect pests and explore the options for their management in Tanzania.

2. Materials and Methods

2.1. Study Sites and Data Collection

The study on the assessing of the tomato farmers' knowledge and practices against whiteflies (*Bemisia tabaci*-Gennadius) in Tanzania was conducted from June to September 2022. The study used a semi-structured questionnaire with both open- and closed-ended questions. Purposive sampling was used to select regions that are core tomato producers in the country where Arusha (3.3869° S, 36.6830° E), Morogoro (6.8278° S, 37.6591° E), and Iringa (7.7681° S, 35.6861° E) were chosen as indicated in Figure 1. Then, purposive sampling was carried out to select one district from each region, where Meru (3.4470° S, 36.6741° E), Mvomero (6.2555° S, 37.5535° E), and Kilolo (7.8835° S, 36.0893° E) districts were selected, respectively. Finally, respondents who are tomato farmers were selected randomly from tomato farmers of the three districts, where 50 respondents were chosen per district, making a total of 150 tomato farmers. These respondents were a representative sample of 62,663 households reported to engage in tomato production in Tanzania mainland [21].

The questionnaire was pre-tested on ten tomato farmers from the Meru district in the Arusha region, where the farming context is similar to the study area. Before starting the interview, we sought consent from the respondents by providing them with a form that introduced and explained the aim of the research and they were asked for approval to continue with the interview. Then, the questionnaire was administered to the respondents to enquire about their understanding and awareness of whiteflies and if it is a common pest in their area, its damaging stage and peak population during tomato growing season. Additionally, respondents were enquired to provide information related to the whitefly control strategies, such as the whitefly control methods they use, the most effective methods, pesticide usage, pesticide products used, and pesticide application frequency in their area (Table 1). Finally, an informants' interview and focus group discussion was conducted through an organized community meeting to supplement the data provided by the respondents. During the process, guiding questions were asked to provoke discussion regarding tomato production challenges and the management option highlighting the most effective methods.

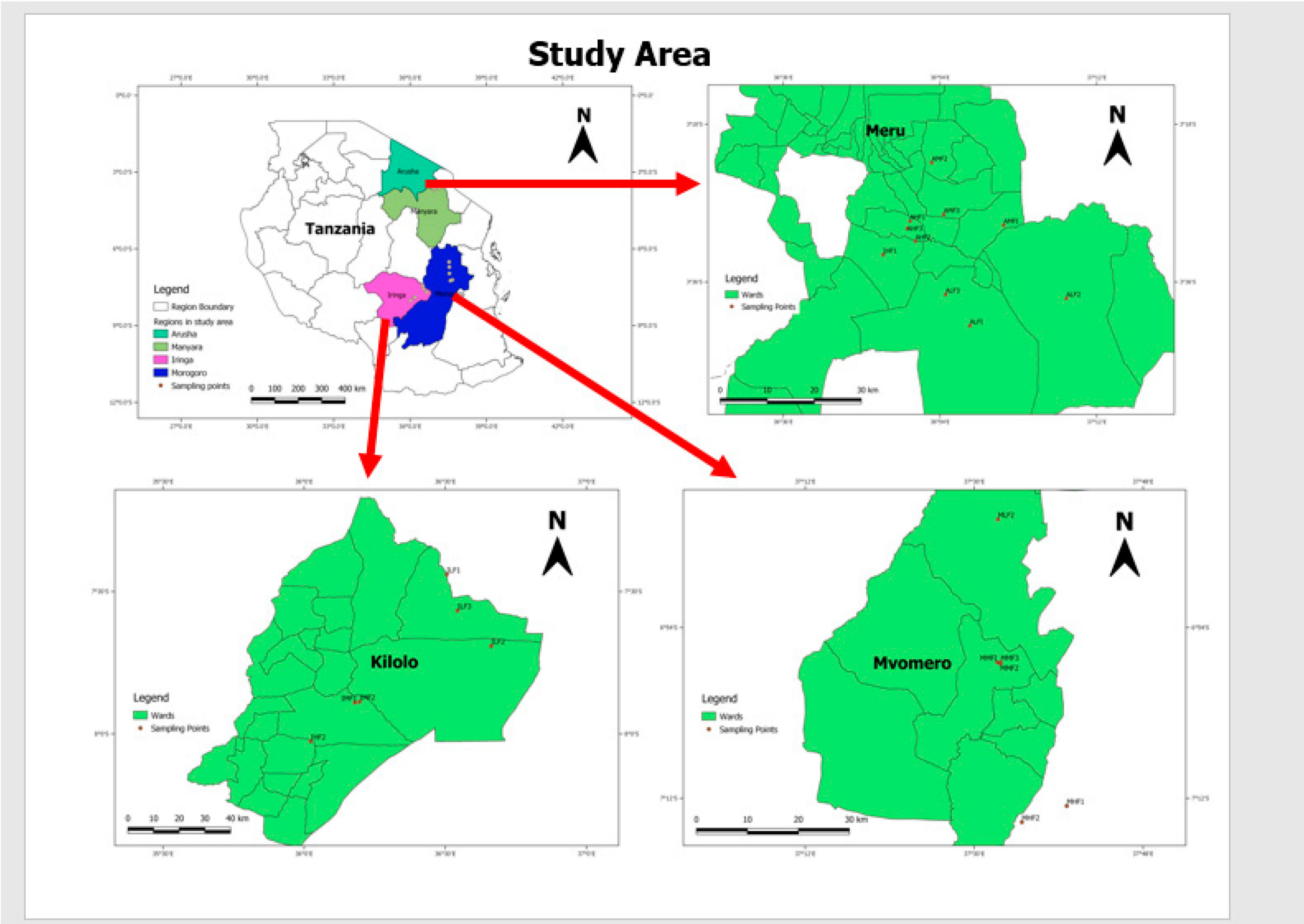

Figure 1. Map of Tanzania showing the study area.

Table 1. Overview of the questions included in the questionnaire used to assess the farmer's knowledge on whiteflies populousness among tomato insect pests and their management options in tomato in Tanzania.

Data Group	Description
Respondents' demographic data and farm characteristics	Gender, age, marital status, education, farm size, yield
Farmers' knowledge and perception of tomato pests	Common tomato production problems, critical tomato production problems, a common insect pest of tomato, if tomato producers are aware of whitefly, whether whitefly is a common insect pest in the respondent's area, destruction stage of whitefly, damage symptoms of whiteflies and whitefly peak time, perceptions of the impact of whitefly on tomato yields and whether whitefly is a populous insect pest in tomato production in the respondents' area.
Whitefly management practices perception	Whitefly control methods, control method that works better, pesticide use; pesticide products; pesticide spraying frequency in the field

2.2. Data Analysis IBM SPSS Statistics for Macintosh, Version 25.0

The statistical package for social science software - IBM SPSS Statistics (Version 16) summarized the survey data into descriptive statistics, such as percentages and means. Percentages were calculated for each group of similar responses from multiple answered questions. A Chi-square was used to assess the differences in knowledge and perception of the respondents on tomato pests, including whiteflies and their management practices.

3. Results

The outcome of this study shed light on the farmers' understanding of the best methods of whitefly control, whitefly peak time within the production season, the damaging stage, and symptoms that will assist in developing whitefly management approaches for increased tomato production in Tanzania, as discussed hereunder.

3.1. Distribution of Respondents across Demographic Variables

The study explores the demographic characteristics of the study respondents as they contribute to their perception of various life aspects. Details of each variable are presented in Table 2.

Table 2. Socio-economic characteristics of the study respondents and their tomato yield.

Variable		Frequency	Percentage
Gender	Male	116	77.3
	Female	34	22.7
	Total	**150**	**100**
Age	15–24	4	2.7
	25–34	24	16.0
	35–44	69	46.0
	45–55	37	24.7
	55–64	14	9.3
	65+	2	1.3
	Total	**150**	**100**
Marital status	Married	133	88.7
	Single	17	11.3
	Total	**150**	**100**
Education level	Primary	121	82.0
	Secondary	21	14.0
	Tertiary	8	4.0
	Total	**150**	**100**
Farm size in Ha	0.2–0.4	99	66.7
	0.6–0.8	42	28.7
	>0.8	9	4.6
	Total	**150**	**100**
Farming experience in years	2	31	20.7
	4	57	38.0
	5+	62	41.3
	Total	**150**	**100**
Tomato harvest/Ha	6–9	9	6.1
	9.5–11	23	15.3
	11.5–15	62	41.3
	15.5–19	56	37.3
	Total	**150**	**100.0**

3.2. Farmers' Knowledge and Perception of Tomato Production Problems

Respondents of the study had diverse knowledge and perceptions of aspects relating to tomato pests. When it comes to the variety of tomatoes cultivated, most of them (54.7%) grow hybrid tomato varieties. On the other hand, 25.3% grow hybrid and open-pollinated tomato varieties, while 20% grow open-pollinated tomato varieties.

Furthermore, the respondent reported different problems that they faced during tomato production, as indicated in Table 3. Of the 150 respondents, 71.3% reported insect pests, while 16% reported insect pests and diseases. Bad weather was reported by 6% of the respondents, while 5.3% reported diseases as a barrier to tomato production. Only 1.3% reported poor soil fertility as a tomato production problem. Respondents were asked if they were aware of whiteflies as an insect pest in tomato production, where about 74.7% and 25.3% reported yes and no, respectively. Since insect pests were mentioned as a major tomato production problem, the study asked for common tomato insect pests. Whiteflies ranked first, occupying 65.3% of the respondents. Tomato leaf miner and American ball worm were reported by 21.3% of the respondents, while 12.1% and 1.3% reported Tomato leaf minor and American ball worm, respectively.

Table 3. Farmers' knowledge and perception on various aspects of tomato pests in the study area.

Variable		Frequency	Percentage
Tomato varieties cultivated	OPV	30	20.0
	Hybrid	82	54.7
	OPV and Hybrid	38	25.3
	Total	**150**	**100**
Common tomato production problems	Insect pest	107	71.3
	Diseases	8	5.3
	Bad weather	9	6.0
	Poor soil fertility	2	1.3
	Insect pests and disease	24	16.0
	Total	**150**	**100**
If the respondent is aware of whiteflies	Yes	112	74.7
	No	38	25.3
	Total	**150**	**100**
Common insect pests of tomato in the area of respondent	Tomato leaf miner	18	12.1
	American Ball worm	2	1.3
	Whiteflies	98	65.3
	Tomato leaf miner and American ball worm	32	21.3
	Total	**150**	**100**
Destruction stage of whiteflies	Adult	100	66.7
	Nymph	27	18.0
	Both adult and nymph	23	15.3
	Total	**150**	**100**
Whiteflies damage symptoms	Leaf yellowing and curling	61	40.7
	Plant stunting	26	17.3
	Plant wilting	31	20.7
	Do not know	32	21.3
	Total	**150**	**100**
Peak whiteflies population in tomato growing season	In the nursery	1	0.7
	The first month after transplanting	36	24.0
	Flowering stage	61	40.7
	All the production season	52	34.7
	Total	**150**	**100**

Respondents were asked if they were aware of the destruction stage of whiteflies, and 66.7% and 18% pointed out adult and nymph, respectively. Destruction by both nymph and adult whiteflies were mentioned by 15.3% of the respondents. Whitefly damaging symptoms were also a question of interest, of which 40.7% of the respondents pointed out leaf yellowing and curling while 20.7% said plant wilting. Plant stunting was mentioned by 17.3%, and 21.3% had no idea about the whitefly damage symptoms. Additionally, the peak whiteflies population in tomato growing season was inquired, and 40.7% and 34.7% responded during the flowering stage and all of the production season, respectively. Another 24% reported that it is in the first month after transplanting, while 7% reported it in the nursery.

3.3. Whitefly Management Practices

The study also enquired about the knowledge and perception of the respondents on the whitefly management practices in their areas as indicated in Table 4. Their responses were distributed such that 78.7% perceived the chemical method and 10% the field and surroundings sanitation. About 9.3% perceived using integrated pest management (IPM), and 2% used cultural practices. The response on the respondents' perception of whitefly control methods that work better in their farming context was as follows: 82.7% perceived the chemical whitefly control method to be better, while 9.3% and 8% perceived cultural and IPM methods to be better, respectively. The pesticide application knowledge of respondents was enquired about as it affects the performance of a particular pesticide. The responses indicated only 15.3% know, with the majority, 84.7%, applying pesticides with no pesticide application knowledge, which may have contributed to the populousness of whiteflies in tomato farming in Tanzania.

Table 4. Farmers' perception on various aspects of whitefly management practices.

Variable		Frequency	Percentage
Respondents Whitefly management practices	Chemical method	118	78.7
	Cultural method	3	2.0
	IPM	14	9.3
	Field and surroundings sanitation	15	10.0
	Total	**150**	**100.0**
Whitefly management option(s) that work(s) better	Chemical method	124	82.7
	Cultural method	14	9.3
	IPM	12	8.0
	Total	**150**	**100.0**
If respondents have pesticide application knowledge	Yes	23	13.3
	No	127	84.7
	Total	**150**	**100**
If respondents use synthetic pesticides to control whiteflies	Yes	124	82.7
	No	26	17.3
	Total	**150**	**100.0**
Type of synthetic pesticide a respondent use	Snow tiger-Chlorfenapyr10%	26	17.3
	Snow thunder-Thiamethoxam3% + Emamectin Benzoate 1%	41	27.3
	Profecron- Profecros750G/L	22	14.7
	Dudu will—Cypermethrin	20	13.3
	Snow thunder and snow tiger	18	12.0
	Profecron and snow tiger	20	13.3
	Snow tiger and Duduwill	3	2.0
	Total	**150**	**100.0**
Source of extension services in tomato production	Government	64	42.7
	Private	56	37.3
	Both government and private	30	20.0
	Total	**150**	**100.0**
Guidance on the pesticide rate of application	As per label instruction	74	49.3
	Experience	22	14.7
	As per the extension officer's advice	31	20.7
	None	23	15.3
	Total	**150**	**100.0**
Frequency of pesticide application in the tomato growing season	Once	33	22.0
	Twice	8	5.3
	Three times	61	40.7
	More than three times	26	17.3
	None	22	14.7
	Total	**150**	**100.0**
Amount of crop loss due to whiteflies infestation if not controlled	Total crop loss	65	43.3
	20%	7	4.7
	More than 20%	48	32.0
	Do not know	30	20.0
	Total	**150**	**100.0**

On the type of synthetic pesticide used by a respondent to control whitefly, 27.3% used Snow thunder (Thiamethoam3% + Emamectin Benzoate 1%) and 17.3% used Snow tiger (Chlorfenapyr10%). About 14.7% used Profecron (Profecros750G/L), and 13.3% and another 13.3% used Dudu will (Cypermethrin and Profecron) and snow tiger, respectively. About 12% used Snow thunder and Snow tiger, while a small proportion of the respondents (2%) used Snow tiger and Dudu will. Respondents were also asked from which source they received extension services during tomato production, where 42.7% received assistance from the government, 37.3% from private sector, while 20% received it from both of the two sources. On whom guided them on the pesticide rate of application, their responses were such that 49.3% were by the pesticide label instruction, and 20.7% received extension services that guided them on the matter. About 14.7% apply pesticides based on their experience, while 15.3% did not use any guide in determining the pesticide application rates. Pesticide application frequency during the tomato production season was such that 22% of respondents applied pesticide once, while 5.3% applied it twice, 40.7% applied it three times, and 17.3% applied more than three times. About 14.7 did not use pesticides to control whiteflies during tomato production. The respondents' views on the amount of crop loss due to whitefly attack were very diverse. Most of respondents (43/3%) reported a total loss, while 4.7% reported a loss of 20%. A total of 32% of respondents reported a loss of more than 20%, while 20% of respondents could not estimate the amount of crop loss in this regard, tomatoes, attributed to whiteflies.

3.4. Association among the Study Variables by Crosstabulation

The study variables were compared to determine whether they associate with each other. The variable relationship sheds light on how to deal with them as they influence each other or not. A crosstabulation between the level of education a respondent attained and the amount of tomato that the same individual harvested in tons per hectare was significant ($p = 0.000$). Therefore, these two variables are associated with each other, as in Table 5.

Table 5. Respondents' education level. Tomato yield (tons/Ha) crosstabulation.

			Tomato Harvest				**Total**
			6–9	**9.5–11**	**11.5–15**	**15.5–19**	
Respondent education level	Primary	Count	14	34	58	15	121
		Expected Count	11.3	29.0	52.4	28.2	121.0
	Secondary	Count	0	1	6	14	21
		Expected Count	2.0	5.0	9.1	4.9	21.0
	Tertiary	Count	0	1	1	6	8
		Expected Count	0.7	1.9	3.5	1.9	8.0
Total		Count	14	36	65	35	150
		Expected Count	14.0	36.0	65.0	35.0	150.0
$X^2 = 43.54$, df = 6, $p = 0.000$							

There was also an association between the number of years a respondent has been in tomato production and the number of tomatoes harvested with $p = 0.000$ (Table 6).

Further, an association was shown between the farmers' age in years and the tomato farming experience one has accumulated with $p = 0.000$ (Table 7).

Table 6. Tomato farming experience in years. Tomato harvest crosstabulation.

			Tomato Harvest				Total
			6–9	**9.5–11**	**11.5–15**	**15.5–19**	
Years you have been in tomato production	2	Count Expected Count	3 1.7	9 5.0	12 12.7	7 11.7	31 31.0
	4	Count Expected Count	3 3.1	12 9.2	29 23.3	13 21.4	57 57.0
	5+	Count Expected Count	2 3.3	3 9.8	20 25.0	36 22.9	61 61.0
Total		Count Expected Count	8 8.0	24 24.0	61 61.0	56 56.0	149 149.0
$X^2 = 25.4$, df = 6, $p = 0.000$							

Table 7. Farmers' age in years. Tomato farming experience in years crosstabulation.

			Years You Have Been in Tomato Production			Total
			2	**4**	**5+**	
Age of respondent	15–24	Count Expected Count	4 0.8	0 1.5	0 1.6	4 4.0
	25–34	Count Expected Count	18 5.0	6 9.2	0 9.8	24 24.0
	35–44	Count Expected Count	9 14.1	47 26.0	12 27.8	68 68.0
	45–54	Count Expected Count	0 7.7	4 14.2	33 15.1	37 37.0
	55–64	Count Expected Count	0 2.9	0 5.4	14 5.7	14 14.0
	65 and above	Count Expected Count	0 0.4	0 0.8	2 0.8	2 2.0
Total		Count Expected Count	31 31.0	57 57.0	61 61.0	149 149.0
$X^2 = 1.47$, df = 10, $p = 0.000$						

4. Discussion

The current study aimed to gauge farmers' knowledge and practices in managing whiteflies in tomato production in Tanzania. Demographic characteristics of the studied population were important in the study. Study results in Table 2, showed that most of land ownership and allocation in various production activities seem to be determined by gender, where men were more favored. As a result, women are discriminated against in land ownership and utilization, despite contributing to 52% of the agricultural labor force in Tanzania [22]. This discrimination affects their decision to engage in farming and their perception of agriculture in general. However, reports narrate that less than 15% of landholders worldwide are women [23]. Suppose there could be equality in land ownership among men and women; women as a key provider of the farming labor force could be encouraged to devote more energy to the sector. In one way or another, this could affect their perception of farming aspects, including fighting crop insect pests. Other studies conducted in the Mvomero district in the Morogoro region and in the Musoma municipality also reported men to dominate tomato production [24,25]. Men are reported to have more access to capital, therefore have more power to fund tomato production activities, as it is labor intensive [26].

Age is another factor influencing one's perception of farming as it relates to a person's experience with something. In the current study, most respondents are aged 15–64, the active labor force age in Tanzania [23]. Such a labor force is expected to actively participate in the study. Studies reported a positive correlation between age and the efficiency of economic inputs [23]. The same age group was reported to the active group engaging in crop production [26]. On top of that, most study respondents with active age had four and above years of experience in tomato farming (X^2 = 1.47, df = 10 and p = 0.000) that can allow them to take an active part in economic activities, as indicated in Table 7. The education of respondents varied significantly. However, all respondents could read and write as they had a reasonable formal education ranging from primary to tertiary. Such an ability can influence the respondents' perception of tomato pests and the decision to choose and apply a control measures, as education is a determinant factor in the adoption of innovations [27]. It also influences their resource allocation in tomato production, such as land and yield, as revealed in this study.

All farmers under the study were small-scale producers, as the majority had farms at most 2 ha [28]. The study findings align with other studies that reported tomato production on farm sizes of 0.56 Ha and 0.4 Ha in Morogoro and Kenya, respectively [26,29]. However, these farmers have accumulated enough farming experience, as most have been in farming for four and more than five years. Such accumulated farming experience helped farmers to have more tomato yield/Ha, as further indicated by the crosstabulation results between farming experience and the tomato yield obtained in tons/Ha, shown in Table 6. The results align with another study that reported that farmers' characteristics influence their farming behavior [30].

4.1. Farmers' Knowledge and Perception of Different Aspects of Tomato Pests

Results from Table 3 indicated farmers differ in their choice of tomato variety selection whether hybrid or open-pollinated varieties (OPV). However, the majority selected hybrids, as they are bred for specific qualities through plant breeding, such as pest resistance, and therefore are preferred over OPVs due to their ability to resist various production problems. The findings are in line with another study that reported that the hybrids of horticultural crops could tolerate environmental stresses [31]. Additionally, in Table 3, respondents reported problems they encounter during tomato production, with insect pest ranking first. These study findings align with other studies that reported insect pests as the major threat to crop production [32,33].

Further, respondents outlined a list of insect pests facing tomato production in their farming context. Whiteflies occupied the largest share among tomato insect pests, ranking first in the list, indicating whiteflies to be populous and a big problem in tomato production in the country. This understanding also indicates that respondents were aware of whitefly. The same insect pest was reported to threaten tomato production worldwide [2] The populousness of whitefly as an insect pest was also reported in Nepal [12].

Other insect pests of importance to tomatoes were leaf minor and American ball worm, as reported by [34]. Interview results of the key informants also outlined insects as a key problem in tomato production, emphasizing whitefly as a threat to tomato production.

The fact that all the respondents possessed a formal education and most of them are in the active labor force group may have contributed to their ability to identify the tomato pests precisely. However, regarding the whitefly destruction stage, respondents need knowledge on the same as most need to learn exactly what stage in the whitefly lifecycle is destructive. Actually, both the nymph and adults are responsible for the host plant destruction [35].

Awareness of a pest's destructive stage helps target it at the right time and shed light on the right control means. Therefore, it is important to facilitate farmers' understanding of the matter. In connection to understanding the whitefly destruction stage, understanding the damaging symptoms caused by whitefly is also important as it sharpens the focus on applying the pest control method. Most respondents did not understand this aspect as they could not point out all the damaging whitefly symptoms. A plant attacked by whiteflies will develop symptoms such as leaf yellowing and curling, plant wilting, and plant stunting, and impaired fruit ripening. Such signs were also reported by other studies [36]. Respondents have differing perceptions of the peak whiteflies population in the tomato growing season. Their responses varied greatly indicating their need for more awareness. The whitefly population starts progressively from the nursery and continues to grow from transplanting, the first month of the crops in the field. As the crops progress in the field, the whitefly population grows larger if uncontrolled. At the fruit setting stage, this insect's population is as large as reaching the economic threshold, where the cost of applying control measures cannot justify the crop recovered. Tomato producers must understand this to use the control measure before this time. It is even more alarming as studies reported whitefly as a disastrous insect pest worldwide [37,38], where only one adult/leaf and four nymph/leaf are enough to cause mediated economic injury that calls for control measure application [39].

4.2. Whitefly Management Practices

Whitefly management practices are measures against whiteflies. They vary among individuals within the farming context of a particular area. The same scenario happened when the study respondents used varying whitefly control measures due to their different perceptions of which method works better, as in Table 4. From this study, whitefly control methods applied by the respondents varied from chemical pesticides to field and surroundings sanitation, cultural practices, and integrated pest management (IPM). Most respondents used the chemical method, and backup information from the focus group discussion mentioning chemical pesticides as the main method of pest control in their areas. This information agrees with other studies that reported chemical pesticides as the main and first bullet in dealing with insect pests in crop production [40,41]. The reasons for the first choice of pesticides may be due to pesticides' ability to kill many insects within a short period making the method convenient and highly effective [42]. The respondent's ability to read and write, as determined by their education level, may also have guided them in the selection of this method of pest control. Additionally, the experience the farmers build through engagement in tomato production for more than four years for most of them is an added advantage selecting pest control methods. Experience is said to be the best teacher, as in Table 2. However, chemical insect pest control is said to be ineffective, as whiteflies can develop pesticide resistance, especially when a pesticide with a single mode of action is used repeatedly [40]. Other methods that showed promise in controlling whiteflies were cultural and IPM methods, as also found effective in controlling the same pest in other places [43]. Some respondents outlined cultural practices: crop rotation, intercropping, and proper fertilizer usage and irrigation regulation.

Tomato farmers used a variety of synthetic pesticides in controlling whiteflies either singly or even in combination by mixing several chemical molecules aiming at increasing chemical synergies. However, the case may differ as the farmers need to gain knowledge of pesticide application techniques [13], which may include a low knowledge of pesticide compatibility. Therefore, mixing pesticides may accelerate their harmful effects on the environment and the ecosystem in general while raising the production costs through the purchase of the pesticide, application time, and the loss of the crop produced due to pesticide contamination or destruction by the insect pest as a result of loss of pesticide effectiveness [44]. Pesticide mixing in an attempt to control insect pests in crop production, particularly whiteflies, was also reported by another study [45]. Still on the contrary, they were not effective on the target. The farmers' decision to mix insecticides with no prior information on the effectiveness of the resultant product and its effect on the environment and the non-target organisms may be attributed to the low level of education possessed by most of the respondents, as indicated in Table 2. Similar results were reported by other studies as well [14,46].

Furthermore, the source of farmers' guidance on proper pesticide usage differed, as shown in Table 4. However, a very small proportion of farmers (20.7) used pesticides based on extension advice. Lack of understanding of the proper pesticide usage, and the primary school education level possessed by most farmers, can compromise the quality of the farmers' practices, such as the pesticide application rate used. Pesticides are harmful substances, and their handling and application require a prior understanding of their side effects when mishandled. Additionally, a lack of guidance renders pesticides less effective and increases the chances of insect pests developing pesticide resistance, making them even more difficult to manage [14]. However, the government is the main source of extension services, where the services are less effective as they are not delivered in a timely manner due to the dispersed nature of rural farmers. Such a scenario necessitates the joined efforts of both the public and private sectors to raise the farmers' knowledge on safe pesticide usage. These findings are in line with other studies reporting related results [47].

Pesticide application frequency within tomato growing indicated a dangerous pesticide application frequency trend, as in Table 4. Tomato growing season takes only three months, and pesticide application frequency of more than three times per season can lead to pesticide overuse which contaminates the environment and the crop produced while increasing the production costs on the farmers' side [48]. It also increases cha chances of the pest developing pesticide resistance to those particular pesticide molecules [44]. Additionally, a single pesticide application within the tomato growing season can be the underutilization of pesticide, which can also lead to ineffective control of the pests. Such discrepancies are attributed by most farmers (84.7%) to a lack of pesticide application knowledge, as reported in this study. For instance, the study findings in Table 5 reported a positive relationship between education level and the tomato yield obtained ($X^2 = 43.54$, df = 6 and $p = 0.000$). However, the relationship between the respondents' education level and the pesticides application rate was insignificant, as in Table 8, due to farmers relying on experience.

Table 8. Education level of the respondent. Rate of application of pesticides in tomato production crosstabulation.

Count						
		Rate of Application of Pesticides in Tomato Production				**Total**
		As per Label Instruction	**Experience**	**As per Extension Officer's Advice**	**None**	
Education level of the respondent	Primary	59	20	22	20	121
	Secondary	10	2	7	2	21
	Tertiary	5	0	2	1	8
Total		74	22	31	23	150
						$X^2 = 4.82$, df = 6, $p = 0.567$

Pesticide application knowledge sheds light on application rate, method, frequency, stage of pest, and crop. It is, therefore, highly needed for the benefit of the farmers' health, economic benefit, and the betterment of the environment and the ecosystem in general.

Finally, the perception of farmers on the amount of crop losses due to whiteflies was different among them. Their responses varied from total loss to ≥20% failure, with others unable to tell the amount of loss attributed to whiteflies. However, studies reported a loss of up to 100% equating to a hundred million dollars per year [11]. The variation in these responses indicates the need for awareness creation to bring farmers' understanding to the same level in the fight against whiteflies.

5. Conclusions

The study on farmers' knowledge on whitefly populousness among tomato insect pests and their management options in tomato in Tanzania found out that tomato production in Tanzania is practiced by small-scale active-age farmers. The farmers' demographic characteristics are different among themselves, which in turn determined their knowledge on various aspects of whitefly control. The farmers possess differing knowledge on whitefly as a pest and on its control means.

Viewing the results from this angle, there is a need for imparting tomato farmers with knowledge on tomato production aspects, particularly insect pests. Their understanding of the whitefly damaging stage, the damaging symptoms, their peak population, and crop loss need to be updated. They also need a common understanding of the best whitefly control practices that are available in their farming context to practice them and have whiteflies controlled with minimal efforts for increased tomato production and productivity. Therefore, both the government and the private sector are called upon to partner to reach as many farmers as possible and impart them with the needed knowledge to economically benefit tomato production. Additionally, more research on whitefly control methods that seem to be the best is needed to keep the number of whiteflies low enough to mitigate their negative impacts on the crop and eventually on the economy of the tomato farmers and the country as a whole.

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