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Incidence and serological detection of viruses infecting tomato and cultural control practices in Kwara State of Nigeria

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ABSTRACT

Tomato *(Lycopersicon esculentum* Mill) is one of the major fruit vegetables in Nigeria and viruses cause significant losses in both field and greenhouse tomato production systems. The study was conducted in Kwara State of Nigeria to determine the incidence of virus diseases on tomato and detect the suspected viruses with serological assay. A field experiment was then initiated to evaluate varietal inherency, plant spacing and staking as cultural control practices on viral incidence. A virus disease survey of 35 major tomato producing farmlands in the study area was done to determine incidence of virus infection. Twenty (20) leafy shoot samples from each farmland were then randomly collected for serological study. The serological assay of samples was by ACP-ELISA; each tested for 3 viruses known to commonly infect tomato in Africa namely: Pepper veinal mottle virus (PVMV), Tomato spotted wilt virus (TSWV) and Tomato yellow leaf curl virus (TYLCV). The field experiment involved sowing 2 tomato varieties at varying plant spacing (30cm x 60cm and 60cm x 75cm) and either staked or non-staked. The experimental design was a factorial fitted into Randomized Complete Block Design (RCBD) of 8 treatments combinations with 4 replications. The result of the virus survey indicated incidence of 4.8% to 38.9% with an average value of 20.3%. The ACP-ELISA revealed major occurrence in the study area of the 3 viruses with PVMV being the most prevalent on the samples. The field experiment showed that Roma VF tomato variety, staked and at plant spacing of 30 x 75cm was the most effective in reducing the incidence of virus disease (2.2% - 6.1%), had the tallest plants (8.6cm–18.0cm), produced the highest average number of leaves per plant (13.7 – 20.5) and tomato fruit weight (406.7g). The study concludes that virus infection may become a serious threat to tomato production in the study area and therefore recommends a combination of resistant variety (Roma VF), plant spacing (30 x 75cm) and staking for effective virus management to ensure higher yield.

Introduction

Tomato (*Lycopersicon esculentum* Mill) is an annual warm-season crop that originated in the South America, belongs to the family Solanaceae and is one of the important most widely eaten vegetable crops (Willcox *et al.,* 2003). Tomato is produced in temperate, subtropical and tropical areas around the world (Blanca *et al.,* 2012) and it is the second horticultural crop produced in terms of yield in the world (FAO, 2016). Its total production of more than 150 million tons of fresh fruit, produced on 3.7 million hectares, exceeds all other crops, with the exception of the potato and sweet potato (FAOSTAT, 2010). It is a relatively short duration crop and is economically attractive and the area under cultivation is increasing daily (Naika *et al.,* 2005). In Africa, Egypt is the leading producer with the production of 39.5 metric tonnes and Nigeria is the fourth in Africa and leads in West Africa sub-region with an estimated output of 1.10 metric tonnes and average yield of 10 tonnes ha^{-1} (FAO, 2012). Tomatoes are known as a source of vitamins and pro-vitamins (vitamin C, pro-vitamin A, β carotene, folate), minerals such as potassium, and secondary metabolites such as lycopene, flavonoids, phytosterols and polyphenols which offer a lot of health benefits for the consumers (Nahar and Gretzmacher, 2002).

Plant diseases are one of the most limitation factors to tomato production. The most common diseases include bacterial, virus, fungal diseases, among others (Georgia, 2014). Among biotic factors, diseases caused by viruses are of great importance. About 130 viruses are known to infect tomato worldwide and they can cause 20-90% losses (Hanssen *et al.,* 2010; Adhikari *et al.,* 2017). Staking is a means of providing support for; minimizing diseases and rotting of fruits thereby increasing marketable yield (Ahmad and Singh 2005). Studies have shown that lower spaced vegetable crops are more susceptible to virus infection. This is due to closed up of canopy which creates conducive environment for disease development (AVRDC, 2003).

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Plant viruses are a major threat to agricultural production, especially in less developed countries (Thresh *et al.,* 1994). This is exemplified in particular by an escalation in disease epidemics caused by whitefly-transmitted geminiviruses (McDonald and Linde, 2002). Owing to their large population size and short generation time, viruses have a great potential to quickly evolve and adapt under natural selection pressure (Mansoor *et al.,* 2003). Few direct means of control exist for most viral plant diseases (Van Den Bosch *et al.,* 2006). The available disease management options include the organization of agricultural practice, cultural control, vector population control and use of host cultivars that support lower vector and virus populations (Moya *et al.,* 2004). The objectives of the study were to determine the incidence of virus diseases on tomato in Kwara State of Nigeria, use serological assay to identify the viruses; and assess the effect of cultural control practices on virus disease incidence and yield of tomato.

Materials and Methods

Enzyme-linked immunosorbent assay protocol

A virus survey of 35 major tomato producing farmlands in Kwara State (Table 1), was carried out between May and July 2019, to ascertain incidence of virus infection. Tomato plants were observed on the field for symptoms expression and observation on 20 plants were taken randomly by walking across on a field with 5 plants per side spaced at an equal distance from each other. Virus incidence was calculated based on:

$$\frac{\text{Number of infected plant (symptomatic plant)}}{20} \times 100$$

Thereafter, 20 leafy shoot samples were collected from each farmland into polythene bags and kept on ice packs in a cooler. The Antigen- Coated-Plate Enzyme Linked Immunosorbent Assay (ACP-ELISA) test to confirm the presence of viruses specific to Pepper veinal mottle virus (PVMV), Tomato spotted wilt virus (TSWV) and Tomato yellow leaf curl virus (TYLCV). The samples were blotted with absorbent paper to remove moisture, cut into pieces and ground in coating buffer with pH 9.6 (Na2CO3 1.59 g, NaHCO3 2.93g dissolved in one litre of distilled water) at a ratio of 1:10 weight per volume (w/v). The method of Cardoso *et al.* (1998), was adopted for the assay. The optical density (OD) values were measured at absorbance of 405 nm (A405), using a Biotek (ELx800, Universal Micro plate Reader). An optical density value greater than three times the mean of the negative controls i.e. virus – free plants, was considered as positive

Field experimental design and layout

The field experiment to evaluate effect of plant variety, spacing and staking on virus incidence and yield of two (Roma VF and UC-82B) tomato varieties was carried out at the University of Ilorin Teaching and Research Farm. The farm is approximately 307m above the sea level and located within the Southern Guinea Savannah ecological zone (8°29'N, 4°41'E) of Nigeria. The annual rainfall is between 1250mn-1500mm with mean temperature of between 20°c and 35°c, the soil type is a well-drained sandy loamy (Aliyu *et al.,* 2012). The experimental site area measured 450m² and was demarcated into 8 plots measuring 56.25m^2 and further divided into 4 sub-plots of 14.06m^2. The experimental design was a factorial fitted into Randomized Complete Block Design (RCBD) with 8 treatment combinations replicated four times. The two tomato varieties used were Roma VF and UC-82B at two plant spacing of 30cm x 60cm and 60cm x 75cm. The tomato plants were staked with wooden sticks (1.5-2m) at 2 weeks after transplanting or non-staked as the case may be. This gave the following 8 treatment combinations:

(i) Roma VF planted at 30cm x and staked
(ii) Roma VF planted at 30 x 75cm and staked
(iii) Roma VF planted at 30cm x 60cm non-staked
(iv) Roma VF planted at 30cm x 75cm non-staked
(v) UC-82B planted at 30cm x and staked
(vi) UC-82B planted at 30 x 75cm and staked
(vii) UC-82B planted at 30cm x 60cm non-staked
(viii) UC-82B planted at 30cm x 75cm non-staked

Data collection and analysis

Data were collected at 2 weeks after transplanting on plant height, number of leaves per plant, number of leaves showing characteristic virus symptoms and fruit weight at harvest. The percentage virus disease incidence was determined by total number of infected plants in each treatment in relation to the total number of plants sampled. The tomato fruits were harvested at maturity on each plot at interval days and weight of fruit were taken using electronic weighing balance. All data collected were subjected to analysis of variance (ANOVA) using the Statistical Package for Social Sciences (SPSS) version 16.0.Treatment means where significant, were separated using The New Duncan's Multiple Range Test at 5% level of probability.

Results

Percentage incidence of virus infection on tomato in Kwara state of Nigeria

The incidence of virus infection on tomato in the surveyed farmlands in Kwara State, Nigeria is shown in Table 2. The result signified varying incidence of virus infection on the crop across the locations. This infers susceptibility of the tomato varieties grown in Kwara State of Nigeria to virus infection with a range of 38.9% to 4.8%. The result showed that the top 5 virus incidence were at Ajia 1 (38.9%), Yakuba 1(36.2%), Edoji (35.5%), Danmo (34.1%) and Ahoro (33.4%). Conversely, the lowest incidences were at Wonpari (4.8%), Ibuimodo (5.6%), Tepaton oke (6.4%), Alata meta (9.2%) and Ojutaye (9.6%). The average virus incidence on tomato in the study area was 20.3%.

Table 1. Locations and coordinates of sample collection

S/N	Location	Latitude	Longitude	Altitude
1	Tunbe	$8^0$38.7490N	$4^0$51.7210E	301.3
2	Ojutaye	$8^0$38.7850N	$4^0$51.5890E	309.1
3	Isamu	$8^0$38.8540N	$4^0$51.5130E	317.9
4	Okeoloka	$8^0$38.9970N	$4^0$51.2660E	332.7
5	Wonpari	$8^0$39.1890N	$4^0$50.9510E	321.5
6	Ibuimodo	$8^0$39.2120N	$4^0$50.9020E	323.2
7	Alapa meta	$8^0$39.2100N	$4^0$50.8680E	325.5
8	Onipepe	$8^0$39.0490N	$4^0$50.9920E	310.2
9	Oni mongoro	$8^0$39.2650N	$4^0$50.8340E	323.8
10	Olokoo	$8^0$38.8610N	$4^0$51.3640E	309.5
11	Basanhin	$8^0$49.4850N	$4^0$55.3330E	281.8
12	Oloruntele	$8^0$49.5180N	$4^0$55.3960E	280.3
13	Oluode	$8^0$49.4780N	$4^0$55.6910E	305.5
14	Ahoro	$8^0$49.4600N	$4^0$55.3800E	279.7
15	Garuba	$8^0$49.4920N	$4^0$55.4810E	290.8
16	Gambo	$8^0$49.6550N	$4^0$56.0830E	328.3
17	Ndacheko	$8^0$49.4740N	$4^0$56.0390E	334.9
18	Danmo	$8^0$49.5600N	$4^0$56.0880E	329.8
19	Edoji	$8^0$49.3650N	$4^0$56.0180E	328.9
20	Ajia 1	$8^0$33.8770N	$4^0$36.4660E	293.7
21	Ajia 2	$8^0$33.8810N	$4^0$36.4710E	285.5
22	Ajia 3	$8^0$33.8770N	$4^0$36.4670E	287.2
23	Ajia 4	$8^0$33.0370N	$4^0$36.2800E	292.8
24	Ajia 5	$8^0$34.0330N	$4^0$36.1980E	285.8
25	Yakuba 1	$8^0$34.0330N	$4^0$36.2180E	281.7
26	Yakuba 2	$8^0$31.3990N	$4^0$35.7490E	277.7
27	Yakuba 3	$8^0$28.3120N	$4^0$37.7850E	332.9
28	Apatayakuba	$8^0$28.3190N	$4^0$37.7880E	333.6
29	Tepatan oke	$8^0$28.8530N	$4^0$38.4410E	299.1
30	Aleniboro	$8^0$28.8250N	$4^0$38.2380E	294.2
31	Alaya	$8^0$28.8260N	$4^0$38.2330E	297.5
32	Balogun	$8^0$28.3310N	$4^0$37.7960E	321.6
33	Omupo 1	$8^0$16.8740N	$4^0$47.2820E	359.3
34	Omupo 2	$8^0$17.2660N	$4^0$46.4500E	364.3
35	Omupo 3	$8^0$16.7990N	$4^0$46.1360E	363.5

Source: field survey 2019

Table 2. Percentage incidence of virus infection on tomato

S/N	Location	Virus incidence (%)
1	Tunbe	13.4
2	Ojutaye	9.6
3	Isamu	14.6
4	Okeoloka	16.8
5	Wonpari	4.8
6	Ibuimodo	5.6
7	Alapa meta	9.2
8	Onipepe	19.4
9	Oni mongoro	23.4
10	Olokoo	24.6
11	Basanhin	22.3
12	Oloruntele	24.1
13	Oluode	26.8
14	Ahoro	33.4
15	Garuba	32.1
16	Gambo	29.5
17	Ndacheko	14.4
18	Danmo	34.1
19	Edoji	35.5
20	Ajia 1	28.7
21	Ajia 2	26.2
22	Ajia 3	13.2
23	Ajia 4	12.1
24	Ajia 5	38.9
25	Yakuba 1	36.2
26	Yakuba 2	10.4
27	Yakuba 3	11.3
28	Apatayakuba	12.5
29	Tepatan oke	6.4
30	Aleniboro	15.5
31	Alaya	18.9
32	Balogun	24.5
33	Omupo 1	26.3
34	Omupo 2	22.6
35	Omupo 3	12.2

Serological analysis of samples by ELISA

The serological analysis of the samples using ACP-ELISA is presented in Table 3. The result indicated occurrence of either one or all of the three viruses tested on tomato in Kwara State of Nigeria. It however showed the most prevalence of PVMV as single infection in 13 locations and mixed viral infections with TYLCV and/or TSWV in 13 locations of the study area. TYLCV was present as single infection in 3 locations and combined with PVMV and TSWV in 13 locations. TSMV was the least predominant virus in the study area with single viral infection in 1 location and mixed viral infection with PVMV and TSMV in 2 locations. The overall result showed that 88.6% of the samples analysed were positive to at least one of the 3 viruses assayed.

Table 3. Enzyme Linked Immunosorbent Assay

S/No	Location	Virus		
		TYLCV	TSWV	PVMV
1	Tunbe	--	--	0.556 (+)
2	Ojutaye	--	--	--
3	Isamu	--	--	0.689 (+)
4	Okeoloka	--	--	0.969(+)
5	Wonpari	--	--	--
6	Ibuimodo	--	--	--
7	Alapa meta	--	--	--
8	Onipepe	2.031 (+)	--	--
9	Oni mongoro	2.012 (+)	--	--
10	Olokoo	1.632 (+)	--	1.772 (+)
11	Basanhin	--	--	2.641(+)
12	Oloruntele	--	--	2.719 (+)
13	Oluode	--	--	0.902 (+)
14	Ahoro	3.124 (+)	--	1.321 (+)
15	Garuba	2.131 (+)	--	1.889 (+)
16	Gambo	2.142 (+)	--	0.899 (+)
17	Ndacheko	2.053 (+)	--	--
18	Danmo	2.004 (+)	--	3.146 (+)
19	Edoji	2.132(+)	--	2.632 (+)
20	Ajia 1	2.040 (+)	--	1.796 (+)
21	Ajia 2	2.131(+)	--	0.824 (+)
22	Ajia 3	--	--	1.146 (+)
23	Ajia 4	--	1.139 (+)	--
24	Ajia 5	2.130 (+)	1.203 (+)	1.063(+)
25	Yakuba 1	2.241 (+)	1.072 (+)	1.416 (+)
26	Yakuba 2	--	--	1.542 (+)
27	Yakuba 3	--	--	2.362 (+)
28	Apata yakuba	--	--	1.964 (+)
29	Tepatanoke	--	--	--
30	Aleniboro	--	--	3.206 (+)
31	Alaya	--	--	2.643 (+)
32	Balogun	2.314 (+)	--	2.164 (+)
33	Omupo 1	2.416 (+)	--	2.316 (+)
34	Omupo 2	2.136 (+)	--	3.014 (+)
35	Omupo 3	--	--	1.316 (+)
Disease		2.147	3.814	1.618
Faulty		0.162	0.241	0.312
Healthy		0.172	0.238	0.275
Buffer		0.221	0.272	0.296

Note: TYLCV= Tomato Yellow Leaf Curl Virus; TSWV=Tomato Spotted Wilt Virus; PVMV= Pepper Veinal Mottle Virus; (+) = Presence of Virus disease. Figures in parentheses are Optical Density values of samples (nm).

Effect of treatments on virus incidence

The effect of the treatments on percentage virus disease incidence on tomato is shown in Table 4. It is indicated that the treatment effect significantly influenced virus incidence. However, the result showed that irrespective *of cultivar, staking and plant spacing of 30 x 75cm was* the most effective in reducing virus incidence. From the 2nd to 8th week after treatment, the lowest virus incidence ranged from 2.2% to 6.1% in Roma/30x75cm/staked and 2.1% to 7.5% in UC-82B/30x75cm/staked. The significantly highest virus incidence of 3.0% to 17.5% was in UC-82B/30x75cm/non-staked and Roma/30x 75cm/non-staked (2.6% to 16.2%).

Effect of treatments on plant height

Table 5 is the result of analysis of the effect of treatment on plant height. The significantly tallest plants (8.6cm-18.0cm) were in Roma/30x75cm/staked and UC-82B/30x75cm/staked (7.6cm – 17.0cm). Conversely, the significantly shortest plants were in UC-82B/30x75cm/non-staked (3.6cm-12.6cm) and Roma/ 30x75cm/non-staked (3.9cm-12.0cm).

Effect of treatments on number of leaves per plant

The effect of treatment on average number of leaves per plant (Table 6) showed that the treatments significantly affected the parameter. Plants with the significantly highest average number of leaves from the 2nd to the 8th week after treatment were in Roma/30x75cm/staked with a range of 13.7 to 20.5 and UC-82B/30x75cm/staked (12.6-19.0). The lowest average number of leaves per plant was in UC-82B/30x75cm/non-staked (7.2-13.9) and Roma/ 30x75cm/non-staked.

Table 4. Effect of treatments on percentage virus disease incidence

Treatment	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Roma VF/30x60cm/staked	2.5^{d}	4.6^{d}	4.9^{e}	5.7^{e}	7.7^{ef}	8.4^{e}	8.7^{e}
Roma VF/30x75cm/staked	2.2^{d}	2.9^{e}	3.4^{f}	4.0^{f}	5.5^{g}	5.9^{g}	6.1^{b}
UC-82B /30x60cm/staked	3.2^{c}	5.6^{c}	6.4^{d}	7.0^{d}	8.4^{e}	8.7^{e}	9.0^{e}
UC-82B/30x75cm/staked	2.3^{e}	3.6^{de}	4.3^{ef}	4.7^{f}	6.7^{f}	7.3^{f}	7.5^{f}
Roma VF/30x60cm/non-staked	3.6^{c}	6.0^{c}	7.0^{d}	8.2^{d}	10.0^{d}	10.4^{d}	10.6^{d}
Roma VF/30x75cm/non-staked	6.2^{b}	10.0^{a}	12.7^{b}	15.2^{b}	15.6^{b}	16.1^{b}	16.2^{b}
UC-82B /30x60cm/non-staked	4.4^{b}	7.7^{b}	9.5^{c}	10.5^{c}	11.3^{c}	11.9^{c}	12.2^{c}
UC-82B /30x75cm/non-staked	7.0^{a}	11.0^{a}	14.8^{a}	16.4^{a}	17.0^{a}	17.3^{a}	17.5^{a}
SEM	0.80	2.84	3.95	4.49	3.99	3.99	3.93

Means within a column followed by the same letter(s) are not significantly different using the New Duncan Multiple Range Test at $P \geq 0.05$. SEM = Standard error of means

Table 5. Effect of treatments on plant height (cm)

Treatment	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Roma VF/30x60cm/staked	6.4^{c}	7.1^{c}	9.1^{c}	12.1^{c}	14.2^{c}	15.2^{b}	15.5^{b}
Roma VF/30x75cm/staked	8.6^{a}	10.2^{a}	12.0^{a}	14.9^{a}	16.9^{a}	17.5^{a}	18.0^{a}
UC-82B /30x60cm/staked	5.3^{d}	6.9^{c}	9.1^{c}	12.0^{c}	13.9^{c}	15.2^{b}	15.5^{b}
UC-82B/30x75cm/staked	7.6^{b}	9.1^{b}	10.7^{b}	13.7^{b}	15.8^{b}	16.8^{a}	17.0^{a}
Roma VF/30x60cm/non-staked	4.9^{d}	5.6^{d}	7.5^{d}	10.7^{d}	12.5^{d}	13.5^{c}	14.0^{c}
Roma VF/30x75cm/non-staked	3.9^{e}	4.5^{ef}	6.7^{de}	9.9^{de}	11.9^{de}	12.6^{cd}	13.0^{cd}
UC-82B /30x60cm/non-staked	4.0^{e}	4.9^{e}	6.8^{de}	9.9^{de}	11.8^{de}	12.7^{cd}	13.3^{cd}
UC-82B /30x75cm/non-staked	3.6^{e}	4.1^{f}	6.3^{e}	9.4^{e}	11.1^{e}	12.4^{d}	12.6^{d}
SEM	1.76	2.12	2.00	1.95	2.05	1.97	1.97

Means within a column followed by the same letter(s) are not significantly different using the New Duncan Multiple Range Test at $P \geq 0.05$.

Table 6. Effect of treatments on number of leaves per plant

Treatment	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Roma VF/30x60cm/staked	11.4^{c}	14.7^{c}	16.8^{b}	17.6^{b}	17.7^{b}	17.8^{b}	18.2^{b}
Roma VF/30x75cm/staked	13.7^{a}	16.7^{a}	18.8^{a}	19.3^{a}	19.8^{a}	20.2^{a}	20.5^{a}
UC-82B /30x60cm/staked	10.2^{d}	13.0^{d}	14.9^{c}	15.7^{c}	15.9^{c}	16.1^{c}	16.4^{c}
UC-82B/30x75cm/staked	12.6^{b}	15.5^{b}	17.1^{b}	18.2^{b}	18.5^{b}	18.7^{b}	19.0^{b}
Roma VF/30x60cm/non-staked	8.3^{e}	11.3^{e}	13.3^{d}	14.2^{d}	14.6^{d}	14.7^{d}	15.0^{d}
Roma VF/30x75cm/non-staked	7.6^{ef}	10.6^{ef}	12.7^{d}	13.5^{d}	13.7^{d}	14.1^{d}	14.4^{d}
UC-82B /30x60cm/non-staked	7.9^{ef}	10.6^{ef}	12.8^{d}	13.8^{d}	14.0^{d}	14.1^{d}	14.3^{d}
UC-82B /30x75cm/non-staked	7.2^{f}	10.5^{f}	12.3^{d}	13.3^{d}	13.5^{d}	13.7^{d}	13.9^{d}
SEM	2.39	2.42	2.45	2.35	2.43	2.45	2.46

Means within a column followed by the same letter(s) are not significantly different using the New Duncan Multiple Range Test at $P \geq 0.05$.

Effect of treatments on fruit weight

The effect of the treatments on the weight of fruits is shown in Table 7. The result indicated that the significantly highest weight of fruits was in Roma/30x75cm/staked with a weight of 406.7g. This was followed by UC-82B/30x75cm/staked (345.2g) and Roma/30x60cm/staked (242.2g). The significantly lowest fruit weights were in UC-82B/30x75cm/non-staked (76.6g), Roma/30x75cm/non-staked (97.5g), UC-82B/30x60cm/non-staked (107.1g) and Roma/30x60cm/ non-staked (123.4g).

Table 7. Effect of treatments on fruit yield (g)

Treatment	Fruit yield at harvest
Roma VF/30x60cm/staked	242.2[c]
Roma VF/30x75cm/staked	406.7[a]
UC-82B /30x60cm/staked	201.2[d]
UC-82B/30x75cm/staked	345.2[b]
Roma VF/30x60cm/non-staked	123.4[d]
Roma VF/30x75cm/non-staked	97.5[e]
UC-82B /30x60cm/non-staked	107.1[d]
UC-82B /30x75cm/non-staked	79.6[e]
SEM	7.19

Means within a column followed by the same letter(s) are not significantly different using the New Duncan Multiple Range Test at P $\geq$ 0.05.

Discussion

The objectives of the study were to determine the incidence and serologically detect viruses infecting tomato and appraise the ameliorative effect of plant population density and staking on virus incidence and yield of two tomato cultivars in Kwara state of Nigeria. Viruses have always been a major cause of reduced quantity and quality of the worldwide tomato crop (Jones *et al.,* 1991). The present study indicated a virus incidence range of 4.8% to 38.9% which was similar to the values (5.2% to 39.7%) reported by Ayo-John and Odedara (2017) in South-West Nigeria. Most plant viruses are transmitted by vectors from one host to another and this action is characterized by some degree of specificity. The worldwide emergence of whiteflies, especially *Bemisia tabaci* has been implicated for the spread of plant viruses over large hectares. It can therefore be assumed that the varying incidence of viruses in the locations of the study was a factor of vector preponderance causing excessive virus spillover. This assertion is supported by Ng and Perry (2004); and Dombrovsky *et al.,* (2005).

The synergistic effects of mixed infections are of concern for tomato yield (Navatel *et al.,* 1983). The serological analysis of the samples using three different kits for the three viruses tested revealed the prevalence of PVMV in the study area. However, the virus was found either infecting tomato alone or occurring in mixed infection with TYLCV and TSWV. This is an indication of the sensitivity of the tomato varieties cultivated in Kwara State to members of the virus genus *Begomovirus* (Verbeek *et al*., 2007). This observation is a common phenomenon on tomato in some other parts of Nigeria and in the Republic of Benin (Arogundade *et. al.,* (2012); and Afouda *et. al.,* (2013).

The field experiment indicated the combination of Roma VF variety, staked and plant spacing of 30 x 75cm was the most effective in reduced virus incidence, enhanced plant growth and highest crop yield. There is abundant evidence from a wide range of crops of the importance of cultural practices in determining the prevalence of virus diseases and the losses they cause (Thresh, 1982). Resistant varieties is an effective, cheapest and environment friendly approach towards plant disease management (Strange and Scott, 2005), especially those caused by viruses (Tewari and Ramanujam, 1994). Pathogenesis is the process by which an infection leads to disease in plants; tomato Roma VF exhibited more resistance to viruses compared to UC-82B variety.

Where staking was used, there were lower incidence of viruses resulting in higher growth and yield than in unstaked plots. Staking could have improved air movement around the plants hence preventing the buildup of high relative humidity which favours disease development. The low virus incidence observed in staked tomato plants is consistent with studies by Muhammad and Singh (2007); and Norman *et al.*, (2015). The reduction in virus incidence observed in the spacing of 30 x 75cm compared to 30 x 60cm is evidence that plant density manipulation is potent in virus disease control. This positive assertion could be due to changes in environmental conditions within the canopy of the plant as agreed by Sconyers *et al.* (2005).

Conclusion

In conclusion, this study reported the incidence of virus diseases in all of the surveyed tomato growing farms of Kwara State, Nigeria. Furthermore, important plant viruses that infect tomato and other crops in some other parts of Nigeria and Africa were confirmed on tomato in the study area. This therefore raises a possibility of viruses becoming serious threats to attainment of optimum production of tomato in the State and Nation. The use of cultural control practices such as tolerant variety (Roma VF), optimum plant spacing (30 x 75cm) and staking, found in this study to reduce virus incidence and increase crop yield; can be adopted for virus disease management and increased crop yield.

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References

Adhikari, P., Yeonyee, O. and Dilip, R. P., 2017. Current status of early blight resistance in tomato: an update. *International Journal of Molecular Sciences,* 1: 22. https://doi.org/10.3390/ijms18102019

Afouda, L.A.C., Kotchofa, R., Sare, R., Zinsou, V. and Winter, S., 2013. Occurrence and distribution of viruses infecting tomato and pepper in Ahbori in Northern Benin. *Phytoparasitica*, 41: 271-276. https://doi.org/10.1007/s12600-013-0287-z

Ahmad, A. and Singh, A., 2005. Effects of staking and row-spacing on the yield of tomato (*Lycopersicon lycopersicum* Mill.) cultivar "Roma VF" in the Sokoto Fadama, Nigeria. *Nigerian Journal of Horticultural Science,* 10: 94-98. https://doi.org/10.4314/njhs.v10i1.3415

Aliyu, T.H., Balogun, O.S. and Gbadebo, F.M., 2012. Cowpea reaction to single and mixed viral infection with Blackeye Cowpea

Mosaic Virus and Cowpea Yellow Mosaic Virus. *Agrosearch,* 12(2): 174-183. https://doi.org/10.4314/agrosh.v12i2.5

Arogundade, O., Balogun, O.S. and Kareem, K.T., 2012. Occurrence and distribution of pepper veinal mottle virus and cucumber mosaic in pepper in Ibadan, Nigeria. *Virology Journal,* 9: 79-82. https://doi.org/10.1186/1743-422X-9-79

AVRDC (2003). Asian Vegetable Research and Development Centre, Shanhua, Tainan, progress report. Pp. 80-90.

Ayo-John, E.I. and Odedara, O.O., 2017. Serological detection of viruses infecting tomato and pepper in Southwest Nigeria and their distribution. *Nigerian Journal of Biotechnology,* 33: 78-82. https://doi.org/10.4314/njb.v33i1.11

Blanca, J., Izares, J. N. C., Cordero, L., Pascual, L., Diez, M. J. and Nuez, F., 2012. Variation revealed by SNP genotyping and morphology provides insight into the origin of the tomato. PLoS ONE, 7, e48198. https://doi.org/10.1371/journal.pone.0048198

Cardoso, T.C., Sousa, R.C.M., Alessi, A.C., Montassier, H.J. and Pinto, A.A., 1998. A double antibody sandwich ELISA for rapid diagnosis of virus infection and to measure the humoral response against infectious bursal disease on clinical material. *Avian Pathology,* 27: 450-454. https://doi.org/10.1080/03079459808419368

Dombrovsky, A., Huet, H., Chejanovsky, N. and Raccah, B., 2005. Aphid transmission of a potyvirus depends on suitability of the helper component and the N terminus of the coat protein. *Archives of Virology,* 150: 287-298. https://doi.org/10.1007/s00705-004-0407-7

FAOSTAT (2010). Food and Agricultural Commodities Production; Available online: http://faostat.fao.org (accessed 21 January 2020).

FAO. 2012. http://faostat.fao.org/site/339/default.aspx

FAO. 2016. Food and Agriculture Organization of the United Nations, Rome, Italy.

Georgia, T.U.O., 2014. Commercial Tomato Handbook - Bulletin 1312. The University of Georgia.

Hanssen, I.M., Lapidot, M. and Thomma, B.P., 2010. Emerging viral diseases of tomato crops. *Molecular Plant-Microbe Interaction,* 23: 539-548. https://doi.org/10.1094/MPMI-23-5-0539

Jones, J. B., Jones, J. P., Stall, R. E. and Zitter, T. A., 1991. Compendium of tomato disease. American Phytopathological Society, St. Paul, MN.

Mansoor, S., Briddon, R.W., Zafar, Y., and Stanley, J., 2003. Geminivirus disease complexes: an emerging threat. *Trends in Plant Science,* 8: 128–134. https://doi.org/10.1016/S1360-1385(03)00007-4

McDonald, B.A., and Linde, C., 2002. Pathogen population genetics, evolutionary potential, and durable resistance. *Annual Review of Phytopathology,* 40: 349–379. https://doi.org/10.1146/annurev.phyto.40.120501.101443

Moya, A., Holmes, E. C. and González-Candelas, F., 2004. The population genetics and evolutionary epidemiology of RNA viruses. *Nature Reviews Microbiology,* 2: 279-288. https://doi.org/10.1038/nrmicro863

Muhammad, A. and Singh, A., 2007. Yield of tomato as influenced by training and pruning in the Sudan Savanna of Nigeria. *Journal of Plant Sciences,* 2: 310-317. https://doi.org/10.3923/jps.2007.310.317

Nahar, K. and Gretzmacher, R., 2002. Effect of water stress on nutrient uptake, yield and quality of tomato (*Lycopersicon esculentum* Mill.) under subtropical conditions. *Die Bodenkultur,* 53: 45-51.

Naika, S., van Lidt de Jeude, J., de Goffau, M., Hilmi, M. and van Dam, B., 2005. Cultivation of tomato production, processing and marketing. Agromisa Foundation and CTA, Wageningen, pp 1–92.

Navatel, J. C., Trapateau, M. and Marchoux, G., 1983. La premonition: Methode deprotection des cultures contre le virus. Bilan de la lutte contre la mosaique du tabac. Quelques perspectives nouvelles. Pages 36-42 in: C.R.Col. ACTA Faune et flore auxiliaries en agriculture. Paris.

Ng, J.C.K. and Perry K.L., 2004. Transmission of plant viruses by aphid vectors. *Molecular Plant Pathology,* 5: 505-511. https://doi.org/10.1111/j.1364-3703.2004.00240.x

Norman, P.E., Whyte, J. B. A., Samura, A. E., Massaquoi, A., Sesay, L., Dixon, A. G. O., Fomba, S. N., Benya, M. T. and Sowa, M. M., 2015. Effect of staking and non-staking systems on disease severity, yield and quality attributes of Yams (*Dioscorea alata*). *Journal of Agriculture and Ecology Research International,* 2(4): 219-229. https://doi.org/10.9734/JAERI/2015/14713

Sconyers, L.E., Brenneman, T. B. and Stevenson, K. L., 2005. Effects of plant spacing, inoculation date, and peanut cultivar on epidemics of peanut stem rot and tomato spotted Wilt. *Plant Disease,* 969-974. https://doi.org/10.1094/PD-89-0969

Strange, R.N. and Scott, P., 2005. Plant Disease: A threat to global food security. *Annual Review of Phytopathology,* 43(1): 83-116. https://doi.org/10.1146/annurev.phyto.43.113004.133839

Tewari, V.P. and Ramanujam, S., 1994. Grow Pusa Jwala, a disease resistant high yielding chilli. *Indian Farming,* 24: 20-21

Thresh, J.M., 1982. Cropping practices and virus spread. *Annual Review of Phytopathology,* 20: 193-218. https://doi.org/10.1146/annurev.py.20.090182.001205

Thresh, J.M., Otim-Nape, G.W., and Lennings, D.L., 1994. Exploiting resistance to African cassava mosaic virus. *Aspects of Applied Biology,* 39: 51–60.

Van Den Bosch, F., Akudibilah, G., Seal, S., and Jeger, M., 2006. Host resistance and the evolutionary response of plant viruses. *Journal of Applied Ecology,* 43: 506-516. https://doi.org/10.1111/j.1365-2664.2006.01159.x

Verbeek, M., Dullemans, A. M., van den Heuvel, J. F. J. M., Maris, P. C., and van der Vlugt, R. A. A., 2008. Tomato marchitez virus, a new plant picorna-like virus from tomato related to Tomato torrado virus. *Archives of Virology,* 153:127-134. https://doi.org/10.1007/s00705-007-1076-0

Willcox, J. K., Catignani, G. L. and Lazarus, S., 2003. Tomatoes and cardiovascular health. *Critical Reviews in Food Science and Nutrition,* 43(1): 1–18. https://doi.org/10.1080/10408690390826437