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Efficiency of Aphid and Thrips Vectors in Transmission of Maize Lethal Necrosis Viruses

Teresa Nyambura Kinyungu[1,*], James Wanjohi Muthomi[1], Sevgan Subramanian[2], Douglas Watuku Miano[1], Florence Mmogi Olubayo[1], Joseph Wagura Kariuki[1]

[1]Department of Plant Science & Crop Protection, University of Nairobi P. O Box 30197,-00625, Nairobi, Kenya
[2]International Centre of Insect Physiology and Ecology, P.O. Box 30772-00100, Nairobi, Kenya
*Corresponding author: teresakinyunyungu@yahoo.com

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Abstract Maize lethal necrosis disease occur in major growing regions of Kenya, causing losses of up to 100% estimated at 50 million US$ in 2014/15. The study was undertaken to evaluate the efficiency of thrips and aphids in transmission of maize lethal necrosis viruses. Maize seedlings were inoculated with adults and nymphs of Western flower thrip (*Franklinella occidentalis*), corn leaf aphids (*Rhapolosiphum maidis*) and Russian wheat aphid (*Diuraphis noxia*) carrying maize lethal necrosis viruses. Data collected included virus titre, disease incidence and severity and plant height. Area under disease progress curve (AUDPC) was calculated using the MLN severity data. Adults of *R. maidis* were the most efficient vector of *Sugarcane mosaic virus* (SCMV) but adults and nymphs of *F. occidentalis* did not transmit any of the maize lethal necrosis viruses. The highest titre of SCMV at 0.38 was noted in plants where adults of *R. maidis* were used to transmit viruses. Disease severity and AUDPC was highest at 44.4 % and 928.3 respectively in plants inoculated with viruses using adults of *R. maidis.* Inoculating maize plants with viruses using *R. maidis* reduced plant height by 15.1 to 18.2%. The study showed that adults of *R. maidis* are the most efficient in transmission of *Sugarcane mosaic virus.* Therefore, for effective management of maize lethal necrosis disease, management of aphid vectors is critical.

Keywords: *Disease vectors Diuraphis noxia, Franklinella occidentalis, Maize lethal necrosis, Rhapolosiphum maidis, Virus transmission*

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1. Introduction

Maize is the most important cereal crop in Kenya and it constitutes the biggest proportion of the Kenyan meal [1]. Plant viruses are mainly transmitted by vectors which act as vehicles that spread and introduce the virions into the living cells of susceptible host from another host [2,3]. For effective transmission of viruses by a vector, several successive steps are involved including acquisition from infected host, retention by vector and release of virions upon salvation or regurgitation [4]. Majority of vectors of plant viruses belong to the class, insecta and other vectors include mites, nematodes, fungi and plasmodiophorids [2,5]. Among the insects, aphids transmit viruses in eight families, with *Potyviridae* having exceptionally largest number of virus species [5,6,7]. To ensure efficient transmission of viruses, vectors that are infective prefers non-infected hosts while non-infective vectors prefer virus infected plants [8]. It is assumed that the volatile compounds or specialized transmission bodies formed within the infected plant are responsible of attracting or aiding a vector and hence enhance transmission of the virus [9]. These virus induced plant reactions are responsible for affecting insect vectors, physiology and insect vector's populations that favour virus transmission [10,11]. The vectors transmit plant viruses by three main modes; non-persistent, semi-persistent and persistent [2].

In non-persistent mode or stylet borne transmission of plant viruses, the vector acquires the virus from infected host within seconds, retains it and inoculates another host within a few minutes [5,12]. Most of the non-circulative viruses are assisted by a protein or indirectly rely on encoded non-structural protein called helper component for the virions to be retained in the stylet [13]. These proteins also expedite virion passage through the vector's body organs [14]. Most of the viruses are transmitted through non-persistent mode with the aphids transmitting more than 200 plant virus species [12]. Among the viruses associated with MLN, *Maize dwarf mosaic virus* is vectored by more than 23 species of aphids in a non-persistent manner [15,16]. *M. persicae, Schizaphis graminum, Aphis gossypii, R. maidis* and *R. padi* transmits SCMV in a non-persistent manner *[17]*.

The viruses that are transmitted in a semi-persistent are found in the foregut and they are acquired within minutes

to hours, while they are retained for several hours and transmitted within a short time [13,18,19]. *Maize chlorotic mottle virus* is spread by thrips, *Frankliniella williamsi* and *F. occidentalis* in a semi-persistent manner [18,20,21]. The virus is also transmitted in a semi persistent manner by six different species of chrysomelid beetles [22,23]. These beetles include cereal leaf beetle (*Oulema melanopa*), corn flea beetle (*Chaetocnema pulicaria*), flea beetle (*Systena frontalis)*, southern corn rootworm beetle (*Diabrotica undecimpunctata*), Northern corn rootworm (D. *longicornis)* and western corn rootworm *(*D.*virgifera)* [23]. In areas where maize is grown continuously, the spread of MCMV from older plants to younger plants is by adult and larva of beetles, although adults are the most efficient [22,24]. Restricted movement of the larva after hatching in the soil makes it not as effective as the adults in spreading of the virus [25]. The beetles transmit the virus after it has acquired it through spreading a layer of pre-digested materials called regargitant on the leaf surface as they feed and in the process also deposit virus particles at the feeding site [26]. Reference [27] reported that transmission of the virus is not inactivated by ingestion by the beetles and transmission can go on for up to three days. An experiment carried out by [28] demonstrated that regurgitant of *Cerotoma trifurcate, Epilachna varivestis* and *Diabrotica undecimpunctata* contained ribonucrease that was responsible for specificity of plant virus transmission. It was also reported that Mexican bean beetle; *Epilachna varivestis* placed viroids of *Cowpea Southern bean mosaic* and *Cowpea tobacco mosaic virus* on the leaves of broad beans while feeding [28].

Wheat curl mite *Aceria tosichella* infect over 90 grasses and it is an important vector of *Wheat streak mosaic virus* which is transmitted semi-persistent manner [29,30,31]. In persistent transmission of plant viruses, the vector require minutes to hours to acquire the virus which can be retained in the vector for a very long time [8,19,32]. The persistent viruses may or may not replicate in the body of the vector [25]. These viruses subdue the insect defense mechanism through binding to an endosymbiont, in case of aphids the chaperone protein symbionin is synthesized by symbiotic bacterium [33].

Management of MLN disease has mainly targeted the development of resistance maize varieties to MLN viruses rather than the vector [33,34]. However, some maize varieties have resistance to vectors of maize lethal necrosis viruses [35]. In Kenya, many pests of maize have been recorded, some of which are known vectors of MLN viruses. The efficiency of these vectors in transmission of MLN viruses has not been investigated. The aim of the study was therefore to assess the efficiency of aphid and thrips vectors in transmission of maize lethal necrosis viruses.

2. Material and Methods

2.1. Experimental Design and Layout

Experiments were conducted in screen house over two crop cycles in 2016 and 2017 using two commercial maize varieties, H614 and WE1101. Hybrid 614 is an old variety that has been in production for over 20 years and it is susceptible to MLN disease while WE1101 is drought tolerant. Seeds of the two maize varieties were sown in 60 x 45 cm polythene bags filled with medium comprising of loam soil, sand and manure in a ratio of 2:2:1, respectively, plus 25 g N.P.K (23:23:0) fertilizer per bag. Five seeds were sown in each bag and later thinned to three plants. Four weeks after sowing, plants were top dressed with Calcium Ammonium Nitrate (CAN; 26% N) at a rate of 15 gm per bag. The plants were inoculated at four weeks after emergence using vectors carrying MLN disease viruses. Inoculation was done using adults and 2nd stage nymphs of each of the following: Western flower thrip (*Franklinella occidentalis)*, corn leaf aphids *(Rhapolosiphum maidis)* and Russian wheat aphid (*Diuraphis noxia*), combination of nymphs of all three vectors, combination of adults of all the three vectors. Control plots consisted on non-inoculated plants. The experiment was set up as completely randomized design with split plot arrangement having three replications. The maize variety was the main plot while the type of vector was the subplot treatments. Data collected included virus titre, number of plants showing MLN disease symptoms, MLN disease severity and plant height.

2.2. Rearing of Thrip and Aphid Maize Lethal Necrosis Disease Vectors

The adult apterous of corn leaf aphids *(R. maidis)* and Russian wheat aphid (*D. noxia*) were collected from infested maize and wheat, respectively. The identification was done by known features for aphids using the key by [36]. Corn leaf aphids and Russian wheat aphids were multiplied on maize and wheat seedlings, respectively, sown in polythene bags placed inside cages in a screen house. Adult and second stage larvae colonies of western flower thrip (*F. occidentalis)* were obtained from the International Centre of Insect Physiology and Ecology (ICIPE) and identified using Thrips Lucid Key Server by [37]. The thrips colony was maintained on snap bean pods in plastic jars.

2.3. Inoculation of Maize with Maize Lethal Necrosis Disease Viruses Using Thrip and Aphid Vectors

At four weeks after emergence, the maize seedlings were placed in 60x60x150 cm cages covered with clear polyester clothing for the thrips and fine mosquito netting for the aphid vectors. The vectors were disengaged by taping the plant to avoid breakage of stylets. Each vector was put in a separate petri dish where they were picked using camel hair brush. The aphids were starved for three to four hours after which they were transferred to Petri dishes containing leaves harvested from MLN disease infected maize plants. The aphids were allowed acquisition access period of 20-35 minutes on the infected maize leaves while thrips were allowed a period of 30-60 minutes. The aphids and thrips were then transferred individually on to the young healthy maize seedling in cages and allowed an inoculation access period of 20-30 hours. A total of 12 vectors were transferred into the whorls of each plant using a camel hair brush. After the inoculation, the maize plants were sprayed with Katrin®

2.5 EC (Deltamethrin 25 g/l) to eliminate the vector, and a repeated spray was done after 7 days.

2.4. Detection of Maize Lethal Necrosis Disease Viruses in Maize Leaf Tissues

Young leaf samples were cut from the upper most leaves of each plant per treatment at 21 days after inoculation and they were stored at -20°C until analysis. Samples from healthy asymptomatic plants were included while known diseased samples were obtained from ICIPE. The viruses were detected using DAS-ELISA as described by [38]. The MCMV and SCMV antisera kit were purchased from the German Collection of Microorganisms and Cell Cultures (Leibniz Institute DSMZ), while the buffers were from AgdiaBiofords in Grigny, France. All the chemicals and all the samples Assays for MCMV and SCMV were carried out according to manufacturer's instructions.

Samples of 0.5 g per treatment were extracted with 2.0ml of extraction buffer (4.0g PVP-40000, 2.0g egg albumin). Specific antibody was diluted in coating buffer at a ratio of 20µl in 20 ml at a dilution of 1:1000. Each microtire plate was coated with 200 µl of coating buffer (0.318µg Na_2CO_3, 0.586µg $NaHCO_3$, 0.06µg NaN_3, and 18.0 ml distilled water) and the plates were covered tightly and incubated at 37°C for 3 hours. The plates were emptied and dried immediately using an absorbent paper. Each well was then washed three times with phosphate buffered saline-tween (8.0g NaCl, 0.2 g KH_2PO_4, 1.15 g Na_2HPO_4, 0.2g KCL, 0.195 g NaN_3, 1.0 litre distilled water, 0.5 ml Tween). Aliquots of 200 µl of the extracted samples were put into the wells and the plates sealed and incubated at 4°C overnight. Controls consisted of wells loaded with extraction buffer only, extracts from healthy plants and extracts from tissues known to contain the viruses. The plates were then washed with Phosphate buffered saline-Tween (PBS-T) and 100 µl of enzyme conjugate (0.4 g PVP-40000, 0.04 gm egg albumin) added to each well, followed by incubation at 37^{o}C for 3 hours. The plates were then drained and washed with PBS-T. Aliquots of 100 µl of substrate solution (17.46 ml Diethanolamine, 9.6 ml distilled water, 2.4 ml HCL (37%) in 10 ml of substrate buffer and thereafter were added to each well. The plates were then incubated for 30-60 minutes at room temperature. The plates were assessed visually and analyzed with spectrometric ELISA reader to determine absorbance at 405 nm. A positive reaction was indicated by development of a yellow colour and the colour intensity was determined by spectrophotometer at 405 nm wavelength. A sample was considered positive when the readings at 405 nm was twice the sum of mean and standard deviation absorbance values of healthy maize control at 405 nm while those below were grouped negative according to the relationship $x \geq \bar{\imath} *(2+0.5)$, where x = positive sample, ī = average value of healthy controls and 0.5 is the standard deviation.

2.5. Determination of Maize Lethal Necrosis Disease Intensity

Assessment of maize lethal necrosis disease incidence and severity commenced the 3rd week after inoculation. The number of plants showing characteristic MLN symptoms were counted in each plot and expressed as a percentage of total number of plant using equation 1.

Equation (1).

$$Percent\ disease\ incidence = \frac{Number\ of\ infected\ plant \times 100}{Total\ number\ of\ plants\ assessed}.$$

MLN disease severity was scored weekly for a period of four weeks on plants showing disease symptoms using modified Horsfall-Barrat scale [39] as per the 12 classes/category. Disease severity was calculated using Equation 2.

Equation (2).

$$Percent\ severity = \frac{n * v * 100\%}{N * V}$$

Where;
n= Number of plants in each category
v= Numerical value of symptoms category/code
N= Total number of plants
V=maximum numerical value of symptoms category.

Data on percent severity for each plot was used to compute area under disease progress curve (AUDPC) using the formula [40] using Equation 3.

Equation (3).

$$AUDPU = \Sigma\left[(Yi+1+Yi)*(0.5)*(Ti+1-Ti)\right]$$

where Y = disease severity at time T, and i = the time of the assessment (in days numbered sequentially beginning with the initial assessment).

Plant height was measured commencing 2nd week after inoculation for a period of eight weeks until the crop started tasselling.

2.6. Data Analysis

Data collected from virus titre, disease incidence, disease severity and plant height was subjected to analysis of variance using GenSat computer software package (Lawes Agricultural Trust Rothamsted Experimental Station, 2016). Separation of means was by the Fisher's protected Least Significant Difference (LSD) test at 5% confidence interval.

3. Results

3.1. Effect on Virus Type and Titre

The vector used to inoculate plant with virus significantly affected the SCMV titre for the crop planted during the two seasons (Figure 1 and Figure 2). Highest titre of SCMV *at* 0.38 was noted in maize variety H614 inoculated i with virus using adult *R. maidis* for the crop planted during the 2016 short rains (Figure 1). No virus was detected in leaves sampled from plants inoculated using adults and nymphs of *F. occidentalis.* Plants inoculated using *R. maidis* adults had significantly higher SCMV titre compared to all other treatments.

3.2. Effect on Maize Lethal Necrosis Disease Intensity

The vector used to inoculate maize plant with virus significantly affected the percentage maize lethal necrosis disease incidence during the two seasons (Table 1). The interaction between variety sown and the type of vector used to inoculate maize seedlings with MLN virus had a significant effect on disease incidence during the 2016 short rains crop. There were no disease symptoms in plants which were inoculated with viruses using adults and nymphs of *F. occidentalis* (Table 1). The variety sown had a significantly effect on the disease incidence in the crop which was planted during 2017 long rains. Maize lethal necrosis disease severity significantly differed among the maize plants inoculated with different vectors (Table 2). Highest severity of up to 44.4% was observed on variety H614. The adult of *R. maidis* was the most efficient in transmitting maize lethal necrosis as indicated by highest disease severity and AUDPC at 44.4% and 928.3, respectively (Figure 3 and Figure 4). The interaction between variety and the vector had no significant effect on the disease severity and AUDPC.

3.3. Effect on Plant Height

The vector used to inoculate maize plant with maize lethal necrosis virus significantly affected plant height during the two seasons. Inoculation with adults of *R. maidis* resulted in significantly shorter plants, with a reduction in plant height by up to 18.2% (Table 3). It was observed that the variety sown and the interaction between the variety and vector used to inoculate plants with viruses had no significant effect on plant height.

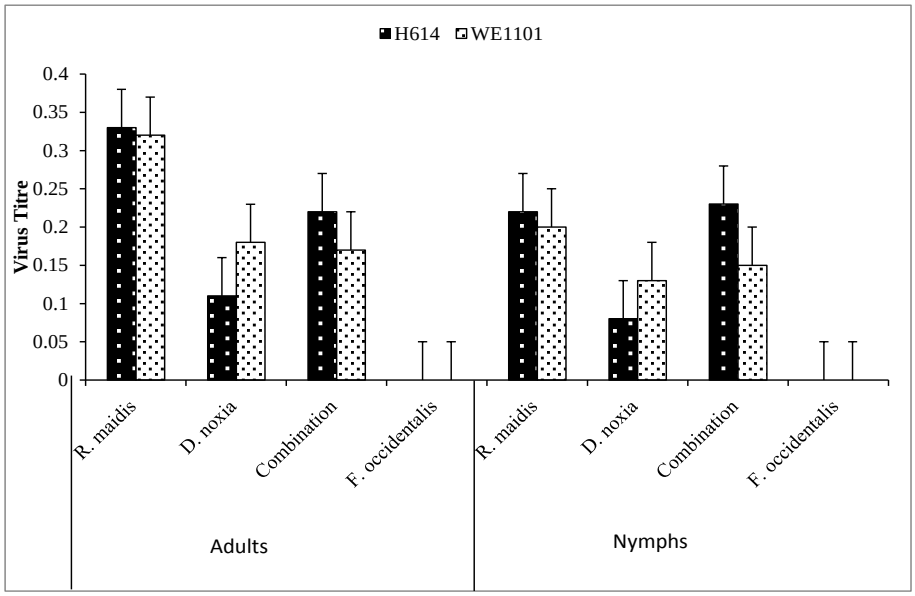

Figure 1. Titre of *Sugarcane mosaic virus* in two maize varieties inoculated with maize lethal necrosis disease viruses using thrips and aphid vectors during 2017 long rains

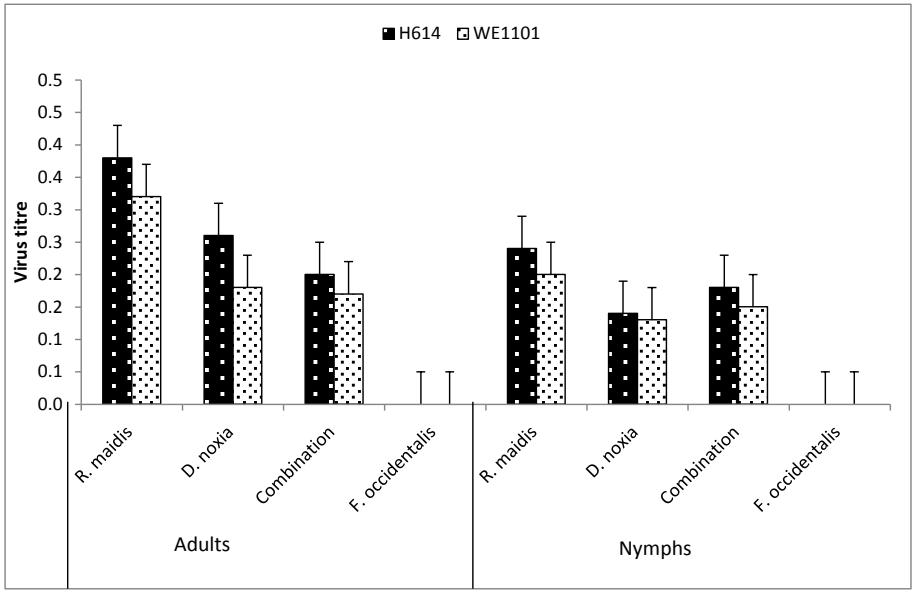

Figure 2. Titre of *Sugarcane mosaic virus* in two maize varieties inoculated with maize lethal necrosis disease viruses using thrips and aphid vectors during 2016 short rains

Table 1. Percentage maize lethal necrosis disease incidence of two maize varieties inoculated with maize lethal necrosis disease viruses using thrips and aphid vectors

Vector	Variety H614			Variety WE1101		
	2016 short rains	2017 long rains	Mean	2016 short rain	2017 long rain	Mean
R. maidis adult	100	100	100	100	100	100
R. maidis nymp	100	100	100	100	100	100
D. noxia adult	100	100	100	100	100	100
D. noxia nymph	100	77.8	88.9	100	100	100
combination of all adults	100	100	100	100	100	100
Combination of all nymphs	100	100	100	100	100	100
F. occidentalis adult	0	0	0	0	0	0
F. occidentalis nymph	0	0	0	0	0	0
Non-inoculated	0	0	0	0	0	0
Lsd $_{(p\leq 0.05)}$(V)	NS	5.3		NS	5.3	
Lsd $_{(p\leq 0.05)}$(I)	5.3	5.3		5.3	5.3	
Lsd $_{(p\leq 0.05)}$(VxI)	7.5	NS		7.5	NS	
CV (%)	2.3	2.3		2.3	2.3	

Lsd= Least significant difference; CV= coefficient of variation; V= Variety; I= Vector; VxI= interaction between variety and vector.

Table 2. Percentage maize lethal necrosis disease severity of two maize varieties inoculated with maize lethal necrosis disease viruses using thrips and aphid vectors

Vector	Variety H614			Variety WE1101		
	2016 short rains	2017 long rains	Mean	2016 short rains	2017 long rains	Mean
R. maidis adult	44.4	42.7	43.6	43.2	43.2	43.2
R. maidis nymp	40.4	37.8	39.1	40.6	31.7	36.2
D. noxia adult	28.9	42.0	35.5	28.3	39.7	34.0
D. noxia nymph	29.1	37.8	33.5	24.2	34.8	29.5
combination of all adults spp	37.8	42.3	40.1	37.8	36.3	37.1
Combination of all nymphs spp	19.4	40.1	29.8	36.3	39.9	38.1
F. occidentalis adult	0	0	0	0	0	0
F. occidentalis nymph	0	0	0	0	0	0
Non-inoculated	0	0	0	0	0	0
Lsd (p≤0.05)(V)	NS	NS		NS	NS	
Lsd (p≤0.05) (I)	4.4	5.5		4.4	5.5	
Lsd (p≤0.05) (VxI)	NS	NS		NS	NS	

Lsd= Least significant difference; CV= coefficient of variation; V= Variety; I= Vector; VxI= interaction between variety and vector.

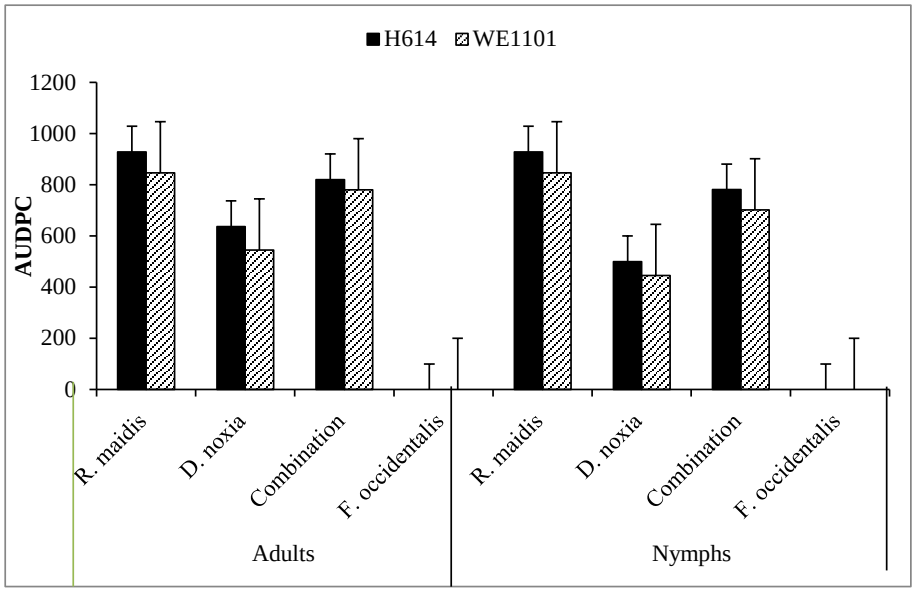

Figure 3. Area under disease progress curve of maize lethal necrosis disease on two maize varieties inoculated with maize lethal necrosis d isease viruses using thrips and aphid vectors during 2016 short rain season

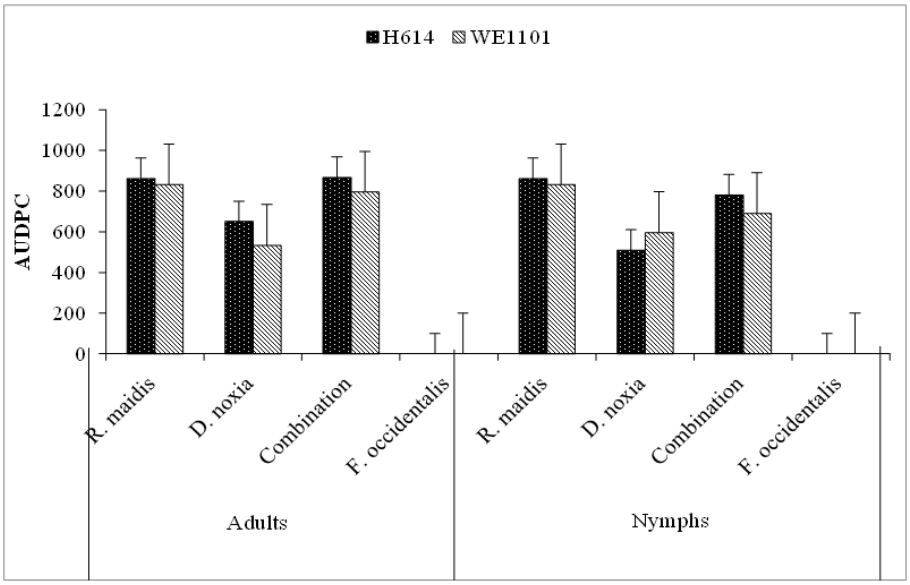

Figure 4. Area under disease progress curve of maize lethal necrosis disease on two maize varieties inoculated with maize lethal necrosis disease viruses using thrips and aphid vectors during 2017 long rain season

Table 3. Plant height of two maize varieties with maize lethal necrosis disease viruses using thrips and aphid vectors

Vector	Variety H614			Variety WE1101		
	2016 short rains	2017 long rains	Mean	2016 short rains	2017 long rains	Mean
R. maidis adult	157.7	160.9	159.3	153.4	155.9	154.7
R. maidis nymp	167.7	163.0	165.4	156.4	156.0	156.2
D. noxia adult	175.3	163.8	169.6	164.1	163.7	163.9
D. noxia nymph	174.2	170.6	172.4	168.0	159.7	163.9
Combination of all adults	166.1	147.9	157.0	154.9	142.2	148.6
Combination of all nymphs	168.4	160.7	164.6	158.4	151.3	154.9
F. occidentalis adult	177.6	178.3	178.0	169.8	171.8	170.8
F. occidentalis nymph	183.3	181.7	182.5	176.1	167.2	171.7
Non-inoculated	191.3	193.6	192.5	187.6	183.7	185.7
Lsd $_{(p\leq 0.05)}$(V)	NS	5.6		NS	5.6	
Lsd $_{(p\leq 0.05)}$(I)	6.4	5.1		6.4	5.1	
Lsd $_{(p\leq 0.05)}$(VxI)	NS	NS		NS	NS	

Lsd= Least significant difference; CV= coefficient of variation; V= Variety; I= Vector; VxI= interaction between variety and vector.

4. Discussion

The study found that *R. maidis* adult was the most efficient vector of SCMV. Hybrid 614 plants which were inoculated with virus using adult of *R. maidis* had the highest SCMV titre at 0.38. The finding is in agreement with results by [17] who demonstrated that *R. maidis and R. padi* were the most efficient vectors of SCMV in maize and the rate of transmission was at 92%. The results are also comparable with that of [41] who found that *R. maidis* as a very effective vector of SCMV from mature maize plants to maize seedlings. *Rhapolosiphum maidis* was also found to be the most competent vector of SCMV in sugarcane and sorghum [42,43]. An experiment conducted by [44] revealed that *R. maidis* was the most efficient vector of Isis isolate of SCMV-SC from sweet corn to sweet corn test plants and also from sugarcane to both young and old sugarcane test plants. In another study conducted by [45] found that *R. maidis, M. persicae*, and *R. padi* were the most efficient vectors of *Maize dwarf mosaic virus*-A (MDMV-A) and of two strains of *Sugar cane mosaic virus* (SCMV-MB and SCMV-A).

However, *R. padi* transmitted *Barley yellow dwarf virus* (BYDV) most frequently while others found to transmit the viruses were *R. maidis, R. insertum, Macrosiphum euphorbiae, Metopolophium dirhodum* and *Ceruraphis eriophori* [46]. According to [47] *R. padi* was more efficient in transmitting MDMV-A and MDMV-D than *R. maidis* or *M. persicae*, in maize and johnson grass. Similarly, *R. maidis* was moderately effective in the transmission of the *Cucumber mosaic virus* to snap beans while *Aphis gossypii, A. glycines, Acyrthosiphon pisum*, and *Therioaphis trifolii* were the most efficient [48]. In addition to *R. maidis* being a vector of viruses in *Poaceae* family, under laboratory condition, the aphid transmitted SCMV and *Abaca mosaic virus* from abaca (*Musa textilis*) to bananas (*Musa* sp.) [49]. Investigation by [50] found that *A. gossypii* was the most efficient vector in transmission of *Cucumber mosaic virus* in melon.

The high virus titre recorded in plants inoculated with *R. maidis* can be attributed to its high rate of probing and

palatability of the host [17,51]. The adult is likely to be more active as compared to the nymphs and hence they are likely to be a more efficient vector [52]. However, once the aphid identity's a suitable plant host, transmission of the virus is enhanced through sustained feeding from the phloem [13].

The study also showed that adults and nymphs of *F. occidentalis* did not transmission any of the viruses to maize plants. The study contradicts the finding by [21] that showed that *F. occidentalis* transmitted MCMV in maize. In other instances *F. occidentalis is* a known vector of *Tomato yellow ring virus in Petunia hybrida, Nicotiana tabacum* and *Lycopersicon esculentum* [53]. Probably *Frankliniella occidentalis* could not transmit the virus as a result of incompatibility of the vector and the MCMV strains [52]. Different vector populations transmit diverse isolates at varying rate and in some cases they may fail to transmit the virus [54]. Other factors that could have contributed in the vector not transmitting the virus may be as a result of the effect of the environmental on the vector behaviour which deterred it from transmitting the virus [11]. The environmental factors could also have had an effect on the thrips physiology leading to their inability to transmit any virus [55]. The host source of the virus may also determine the rate of transmission or lack of it [56]. However more study can be undertaken with *F. occidentalis* collected from different plants under different environmental conditions on possibility of transmission of MCMV in maize.

The study revealed that highest percentage of disease severity at 44.4 was recorded in H614 plants which were inoculated with viruses using adult *R. maidis* planted during 2016 short rain season. Hybrid 614 plants which were inoculated using *R. maidis* adult had the highest AUDPC of 928.3. No disease and virus was observed and detected respectively, in leaves sampled from control plots and those inoculated using nymphs and adults of *F. occidentalis*. The finding of the study is inconsistent with report by [57] that the efficacy of transmission of SCMV-MDMV-A by *Myzus persicae, R. maidis, R. padi* and *Schizaphis graminum* was at 16.6%, 23.3%, 36.6% and 73.3% while transmission of SCMV-MDMV-B was at 0%, 33.3, 26.6, and 56.6% respectively. The high disease severity in plants inoculated with viruses using *R. maidis* adult may be as a result of maize being the main host of the vector coupled with continuous piercing of plant tissues [17,58]. The adult may also be more aggressive in feeding in the maize and in the process it transmits the viruses which eventually exhibit visual symptoms of the disease [52]. The AUDPC for the virus was calculated from percentage severity during the assessment period [40]. Therefore, disease severity and AUDPC are indicators of the performance of vector's transmission of the viruses since it is expected that transmission of more virions would consequently culminate to higher disease intensity.

The study found that the vector used to inoculate plant with virus significantly affected plant height during 2016 short and 2017 long rain seasons. Inoculating maize plants with viruses using *R. maidis* reduced plant height by 15.1% to 18.2%. A study by [59] found that inoculation of maize seedling with SCMV and MDMV reduced plant height by 16.9%. Inoculation of rye, wheat and oats with *Brome mosaic virus* had plant height reduced by 24% to 47% [60]. The findings of the study is inconsistent with outcome of a study done by [61] that genotypes of tomato inoculated with *Cucumber mosaic virus* using *M. persicae* showed highly significance in plant height reduction in the inoculated plants compared to un-inoculated. According to [62], inoculation of banana (*Musa acuminata*) with *Banana bunchy top disease* using Banana aphid, *Pentalonia nigronervosa* caused significant reduction in height, pseudostem diameter and canopy size. Similar results by [63] revealed that inoculation of wild squash varieties; *Cucurbita pepo* plants with *Zucchini yellow mosaic virus* and *Cucumber mosaic virus* resulted to reduced population growth rate compared to un-inoculated. Reference [64] reported that infected maize plants with viruses were stunted and the level depended on the time of infection.

Under light infestation the stunting observed in the plants was mostly as a result of effect of the transmitted viruses into maize plant, rather than direct damage to the plant [51]. Generally the plants that are infected with viruses exhibit changes in the morphology of their cells [65]. The infected plants with SCMV develop mosaic irregularities that latter on general chlorosis and larger streaking hence reducing the photosynthetic area which affects the growth of plant with resultant reduced plant height [66]. Stomata density on the leaf areas are reduced by infection of plants with viruses which in turn minimizes the uptake of carbon dioxide for photosynthesis and transport of water and mineral nutrients [67].

5. Conclusions

Both adults and nymphs of *D. noxia* and *R. maidis* transmitted SCMV with adults of *R. maidis* being the most effective vector. The presence of aphids as vectors of maize plants viruses' pose a big threat to crop growth and eventually on yield. Control of the vectors can involve rogueing of diseased plants and practicing closed season. The seeds can be dressed with an insecticide that would remain effective when the plants are at susceptible stages. However, the most economical and sustainable method of controlling the vectors is by developing maize genotypes which are resistant to the maize lethal necrosis viruses. Profiling and conducting studies on other possible vectors and their importance in transmission of viruses causing MLN can be carried out. The strains of the existing *F. occidentalis* can be determined and study done to assess its ability to transmit maize lethal necrosis viruses under different environmental conditions. The information obtained during the study can be used as a basis of informed decision on management of the disease for improved maize productivity.

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