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Occurrence and estimated losses caused by cassava viruses in Migori County, Kenya

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A farm survey was conducted in Kuria East and Suna West sub-counties to determine the incidence, severity and estimated losses of cassava brown streak disease (CBSD) and cassava mosaic disease (CMD) on cassava crops in farmers' fields. The results showed that cassava is the second most important staple crop after maize in Migori County. CMD incidence ranged from 0.0 to 56.7%) in Kuria East and 10.0 to 55.0% in Suna West. CBSD incidences were much higher at 5.0 to 74.0% in Kuria East and 10.0 to 77.5% in Suna West. Both CMD and CBSD had an effect on yield reduction and total root loss ranged from 10.7 to 47.2% in Kuria East and 11.5 to 33.2 in Suna West. The percent mean total root loss in Kuria East was 25.9%; equivalent to 1299.6 US dollars/ha while in Suna East was 24.7%; equivalent to 1259.5 US dollars/ha. The best performing variety with regards to low CBSD and CMD incidence, low root losses and high yield were TMS 30572 and MH95/0183. The findings of this study are expected to provide impetus for the development and promotion of new high yielding, locally adapted and resistant cassava varieties.

Key words: Cassava, CBSD, incidence, root necrosis, yield loss.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a staple food for more than 800 million people world-wide (Lebot, 2009). It was initially adopted as a popular famine reserve crop but in recent times has emerged to be a profitable cash crop of industrial significance in the world economy (Larsson et al., 2013; Tonukari et al., 2015). In Kenya, the crop is grown for both food and income on approximately 72,482 ha with an annual output of 1.1 million tonnes (FAOSTAT, 2013). Western Kenya, where Migori County is located, accounts for 60% of total cassava production in Kenya. In Migori County, cassava is a staple food crop occupying about 8800 ha with mean yields of 6 and 12

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t/ha for local and improved varieties, respectively and acts as an insurance crop due to its tolerance to drought and low external input requirements (GoK, 2013a,b).

Cassava production is constrained by several diseases, the major ones being the cassava mosaic disease (CMD) and cassava brown streak disease (CBSD). The CBSD is caused by two distinct viruses: cassava brown streak virus (CBSV) and Ugandan cassava brown streak virus (UCBSV), both of which have (+)ss RNA genomes belong to the genus *Ipomovirus* in the family *Potyviridae,* and generally produce similar symptoms in infected plants (Winter et al., 2010; Ndunguru et al., 2015; Vanderschuren et al., 2012; Legg et al., 2011). UCBSV has however been reported to cause milder symptoms than CBSV, and also lower pathogenicity (Vanderschuren et al., 2012). The disease causes economic losses resulting from damage to the aboveground parts characterized by leaf chlorosis and necrosis, elongated necrotic lesions on stems and secondary and tertiary vein chlorosis (Winter et al., 2010; Hillocks and Jennings, 2003). Root spoilage occurs due to constriction caused by dry corky necrotic rot on starchy tissues and stunted growth on infected plants (Winter et al., 2010; Hillocks and Jennings, 2003).

Necrotic lesions and/or discoloration of the roots due to infection render the roots unpalatable and unmarketable, and hence an explanation for most of the quantitative and qualitative losses (Nichols, 1950). The CBSD symptoms are usually variable and irregular, and depend on many factors including plant age, cultivar (genotype), environmental conditions (that is, altitude, temperature and rainfall quantity) and virus species (Mohammed et al., 2012; Hillocks and Jennings, 2003). Control strategies for CBSD have been focussing on host plant resistance especially with Amani hybrid genotypes that is, Kaleso (Namikonga) which has been used as a source of resistance in many breeding populations.

This variety has been reported to have the highest general combining ability for CBSD resistance (Kulembeka et al., 2012). CBSD resistance studies have revealed variations of symptoms in different genotypes (Pariyo et al., 2015; Kaweesi et al., 2014). Kaweesi et al. (2014) screened for CBSD resistance by quantitative PCR and reported four disease reactions including:

- Restricted disease symptoms and virus quantities which is a characteristic of resistant varieties that is, Kaleso,
- Restricted virus quantities with high disease symptoms (tolerant varieties),
- Restricted disease symptoms with high virus quantities (tolerant varieties) and,
- Accumulation of high virus quantities and very severe symptoms which is a characteristic of susceptible varieties that is, Albert. Different disease reactions prompt the need to consider breeding of genotypes with different disease reactions in order to achieve durable resistance.

Cassava mosaic disease (CMD) caused by cassava mosaic geminiviruses (CMGs) (Geminiviridae: Begomovirus) and transmitted in a persistent manner by the whitefly vector is an important constraint to cassava production in Africa (Legg and Fauquet, 2004). CMG infection results in symptoms comprising misshapen leaves with a mosaic-like chlorosis and general plant stunting, leading to reduced tuberous root production (root size and number) (Alabi et al., 2011). Most CMD-affected cassava plants produce few or no tuberous roots depending on the severity of the disease and the age of the plant at the time of infection (Alabi et al., 2011). Through the processes of virus–virus synergism, pseudo-recombination, and true recombination, CMGs have evolved into a diverse and highly successful group of plant pathogens, and seven species are currently recognized from Africa (Legg, 2008).

Rapid spread of a recombinant strain, East African cassava mosaic virus Uganda (EACMV-UG), has been associated with a pandemic of unusually severe CMD, which has affected much of East and Central Africa, leading to production losses of 47%, equivalent to nearly 14 million tonnes (Legg, 2008). Studies exploring the potential of CMD resistance in transgenic plants have been carried, and results demonstrated that resistance to ACMV could be achieved with high efficacy by expressing antisense RNAs against viral mRNAs encoding essential non-structural protein (Zhang et al., 2005). Recent control strategies have been focussing on host plant resistance and a high resolution map for dominant monogenic resistance (*CMD2*) discovered in local landraces was developed (Rabbi et al., 2014). This single gene resistance however lacks diversity rendering its long-term effectiveness precarious, given the potential to be overcome by CMGs due to their fast-paced evolutionary rate. Combining of the quantitative with the qualitative type of resistance may ensure that this resistance gene continues to offer protection to cassava, a crop that is depended upon by millions of people in Africa against the devastating onslaught of CMGs. High CMD (71.4 to 100%) and CSBD (20 to 100%) incidences have been observed in Western Kenya (Irungu, 2011).

A synergy effect in dual infections of CBSD and CMD was also reported where more severity was observed for both diseases compared to when the diseases are separate single infections. Mixed infections of CBSV and UCBSV with high prevalence, incidence and severity in the mid altitude areas (1181 to 1467 m above sea level (m asl)) of Western Kenya have been reported by Mware et al. (2009) and Osogo et al. (2014). In similar studies, Ndunguru et al. (2015) detected the presence of both CBSV and UCBSV in low, mid and high altitude areas of Tanzania disapproving the assumption that the viruses are limited by agro-ecological zones. The results in both studies demonstrate a wide distribution of the disease in almost all cassava-growing areas, which confirms that other areas in the East African region previously unaffected by CBSD are now at risk of spread and

Table 1. GPS coordinates for villages where farms were surveyed.

Sub county	Total no of farms surveyed	Village	Latitude	Longitude	Altitude (m asl)
Kuria East	40	Sanchawa	1.243° S	34.647° E	1608
		Getongoroma	1.302° S	34.664° E	1703
		Kegonga town	1.254° S	34.653° E	1653
		Sakuri	1.284° S	34.658° E	1661
		Nyamagenga	1.245° S	34.661°E	1596
		Ntimaru west	1.341° S	34.694° E	1817
Suna West	30	Sagero	1.093° S	34.432° E	1401
		Wasweta II	1.067° S	34.481° E	1478
		Mubachi	1.137° S	34.327° E	1413
		Giribe	1.105° S	34.290° E	1337
		Nyasoko	1.076° S	34.344° E	1406
		Oruba	0.968° S	34.527° E	1526

masl (meters above sea level).

increased prevalence of the disease.

Extensive studies have been carried out on CMD and CBSD diagnostics in Kenya but few have assessed cassava root losses resulting from these diseases. A farm survey was therefore conducted to determine the incidence, severity and estimated yield losses caused by CBSD and CMD on cassava crops in farmers' fields in Migori County, Western Kenya.

MATERIALS AND METHODS

Farm Survey: Sampling procedures and field observations

Two-stage farm surveys were conducted in Kuria East and Suna West sub-counties of Migori County, Kenya (Plate 1). The surveyed farms were located between latitude (1.243°S to 1.341°S), longitude (34.647°E to 34.694°E) and altitude (1596 to 1817 m asl) in Kuria East and latitude (0.968°S to 1.137°S), longitude (34.290°E to 34.572°E) and altitude (1337 to 1526 m asl) in Suna West. In the first survey (incidence) (June 24 to 28, 2013), a total of 70 cassava farms (40 in Kuria East and 30 in Suna West) with a crop aged 7 to 10 MAP, were sampled using stratified random sampling procedure (Levy and Lemeshow, 2008) (Table 1). The cassava farms were sampled randomly at regular intervals (5 to 10 km) along the main roads and occasionally traversing to the feeder roads. Five (5) plants were sampled per variety from the three main varieties in a diagonal manner across each field. The name of variety(ies) sampled and corresponding CBSD and CMD incidences were recorded. Each plant with CBSD symptoms was colour tagged for root necrosis sampling at crop maturity (harvest).

In the second survey (severity) (August 5 to 10, 2013), 23 and 20 farms from Kuria East and Suna West sub-counties, respectively were randomly sampled from amongst those sampled during the incidence survey. Most farmers were harvesting their crop leading to reduced number of farms sampled during the second survey. Data on CBSD root severity, root necrosis and yield traits (number and weight of roots) were obtained on cassava crops aged 9 to 12 MAP and ready for harvesting. Five (5) CBSD infected plants, previously tagged, were carefully uprooted and roots harvested. The number and weight of roots were recorded before longitudinally cutting the roots to check for necrosis and constrictions.

Roots were assigned root necrosis scores based on the standard five point scoring scale (Hillocks et al., 2015) where 1 = no necrosis symptoms, 2 = trace of necrosis, 3 = clearly defined areas of necrosis but necrotic areas can be easily removed, 4 = most of root necrotic but may still be possible to remove necrotic areas for home consumption and 5 = most or all roots necrotic and unsuitable for human consumption (Figure 1).

Data collection and analysis

Cassava variety popularity was determined by calculating the frequency of occurrence of each variety in the two sub counties. Crop importance was determined by calculating the sum per capita acreage for each crop and diving by the number of farms where crop is grown, to get the mean per capita acreage in the two sub counties. This information gave an insight on how important cassava is the surveyed region. Data were collected on CMD leaf incidence, CBSD incidence (foliar and root), root necrosis damage and root necrosis range. Root necrosis severity and incidence data were subjected to analysis of variance (ANOVA) using 'R' stastical software's generalised linear model with quasibinomial errors and a logit link (Kabacoff, 2011). Quasipoisson errors and a log link was used for analysis of count parameter (weight of roots) (Kabacoff, 2011). Variety means were separated using Tukey's HSD test at $P \leq 0.05$.

Spearman's correlation analysis was carried out to test the effect of both diseases on root yield. Percent mean root necrosis was estimated according to Hillocks et al. (2015) where the % of roots with root necrosis grade 3, 4 and 5 were multiplied by 25, 35 and 58% respectively. The percentages represented the average proportion of root tissue lost during cutting out of necrotic areas of the respective necrosis grades. The % sum of all the grades in a variety were divided by 100 to get % mean root necrosis loss. Percent root weight loss for each variety was estimated by comparing plants with CBSD and/or CMD symptoms with a symptomless plant in the same field. This was simillarly done for % root number loss. Percent mean root necrosis loss, % root weight loss and % root number loss were then computed into a total root loss. Yield losses in tonnes per hectare were converted to US dollars based on cassava value in Kenya (US$ 213.49/tonne)

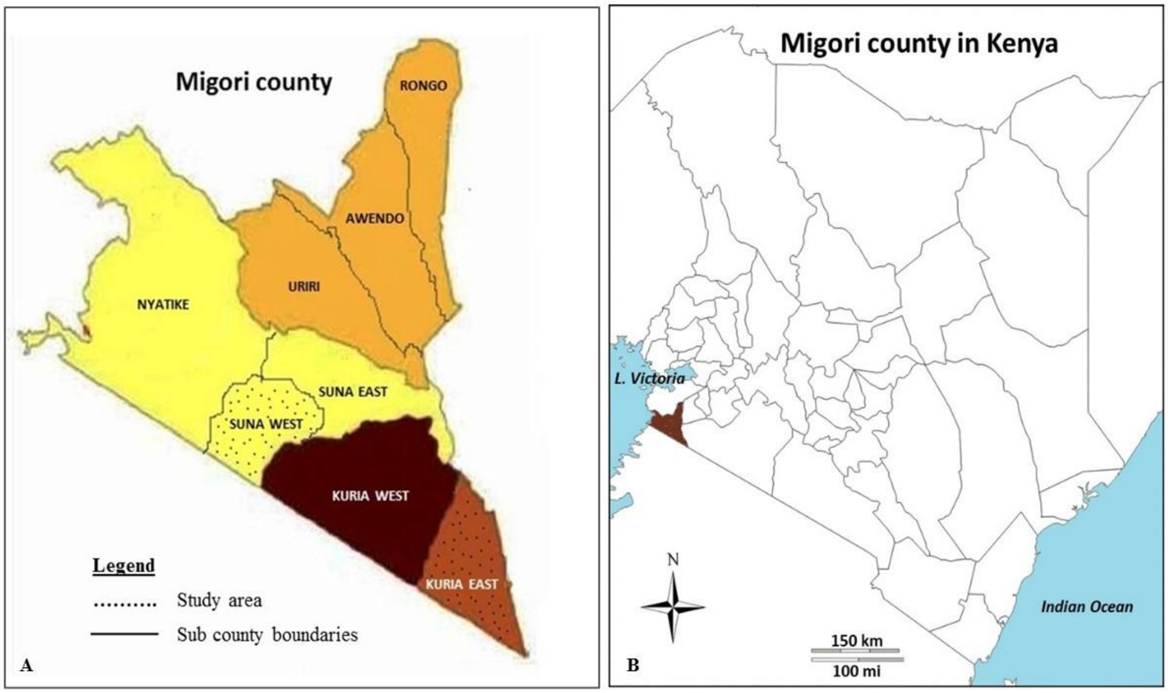

Figure 1. (A) Sub counties of Migori County; (B): Location of Migori County in Kenya.

Table 2. Mean per capita acreage and acreage allocated to different crops in Kuria East and Suna West sub-counties.

Variable	MCA (Acres)	Be	Cas	GN	Ma	Ban	Sor	S/pot	Veg/Fru	F/mil
Kuria East	4.84	0.94	1.04	0.57	2.29	0.47	0.39	0.38	0.29	0.31
Suna West	4.02	0.93	1.02	0.38	2.07	0.15	0.75	0.34	0.17	0

Mean capita acreage (MCA), Be – Beans, Cas - Cassava; GN - Ground nut; Ma - Maize; Ban – Banana, Sor – Sorghum, S/pot, Veg/fru – Vegetable/Fruit, F/mil – Finger millet.

(FAOSTAT, 2013). The roots harvested per variety without symptoms were weighed (kg) and the root yield (t/ha) per variety computed using formula (Equation 1):

$$\text{Yield (t/ha)/ variety} = \frac{\text{Weight (kg) x10,000 m}^2}{1\,\text{m}^2\text{x}\,1\text{,000 kg}} \quad (1)$$

The root loss (t/ha) per variety was computed as shown below

$$\text{Loss (t/ha)} = \frac{\text{Total root loss x yield (t/ha)}}{100} \quad (2)$$

This was then converted to US dollars/ha. Analysis was done using excel, frequencies, averages and percentages, and correlation using the social sciences analysis software statistical package for social sciences (SPSS) version 16.

RESULTS

Socio-economic importance of cassava in Migori County

Based on mean acreage allocated to different crops, cassava was ranked second most important crop after maize in Kuria East and Suna West sub-counties. Cassava was allocated mean acreage of 1.04 and 1.02 acres in Kuria East and Suna West, respectively compared to 2.29 and 2.07 acres, respectively, for maize (Table 2). On average, maize, cassava and beans were allocated 50, 25 and 20% of the total cultivated land per household (Table 2). Results further showed that the local cassava varieties were more popular at 88.6 and 75.6% compared to improved varieties at 11.4 and 24.4% in Kuria East and Suna West respectively (Figure 2).

CMD incidence

The average CMD leaf incidence was 49.0% in Kuria East and 46.7% in Suna West (Table 3a and b). CMD incidence in local varieties (25.0 to 70.0%) was generally high compared to improved varieties (0.0 to 33.0%). Improved variety Agric however had high CMD incidence (67%) while local variety Sudhe had low CMD incidence (15.0%) (Table 3a and b).

Table 3a. CMD incidence, CBSD incidence (foliar and root), root necrosis, root yield loss and yield traits for cassava varieties in Kuria East sub-county.

Variety	Type of variety	F	CBSD Leaf incidence ($\bar{x}$) (%)	CMD Leaf incidence ($\bar{x}$) (%)	Root necrosis ($\bar{x}$)	Root necrosis range	(%) Root necrosis incidence ($\bar{x}$)	Weight of roots (Kg)
Agric I	Improved	3.3	80.0±19.1	0.0±0.0	1.5±0.3^{ab}	1.0-4.0	30.7±15.7^{abc}	1.7±0.4^{b}
Agric II	Improved	3.3	10.0±14.3	33.0±18.6	1.9±0.3^{ab}	1.0-4.0	40.0±13.2^{abc}	2.8±0.4^{c}
Agric III	Improved	3.3	5.0±10.4	16.0±14.5	1.1±0.1^{a}	1.0-2.0	5.0±7.4^{a}	0.7±0.3^{ab}
Amakuria	Local	15.0	56.7±9.7	51.7±8.1	2.4±0.3^{b}	1.0-5.0	52.5±12.0^{bc}	0.6±0.2^{ab}
Manchoberi	Local	37.5	54.0±6.1	44.7±5.1	1.5±0.1^{ab}	1.0-3.0	29.9±6.7^{abc}	0.9±0.1^{ab}
Mwitamajera	Local	7.5	73.3±12.2	53.3±11.4	1.2±0.2^{a}	1.0-2.0	15.0±12.2^{ab}	0.7±0.3^{ab}
Mygyera (TMS 30572)	Improved	10.0	5.0±7.4	15.0±7.1	-	-	-	-
Nyakohanda	Local	12.5	74.0±9.4	40.0±8.7	2.2±0.3^{b}	1.0-5.0	60.0±9.6^{c}	0.4±0.1^{a}
Rumara	Local	6.7	15.0±12.1	25.0±12.1	-	-	-	-
Weite	Local	90	65.0±3.8	56.7±3.3	1.2±0.1^{a}	1.0-3.0	12.0±2.1^{ab}	0.9±0.1^{b}
Mean (μ)	-	-	58.5±6.3	49.0±5.6	1.4±0.3	1.0-5.0	20.9±4.8	0.9±0.1

F-Frequency; N-Number of farms; Agric - Agriculture (Unknown improved variety); ± -95% confidence interval for means; $\bar{x}$ - sample mean; μ-population mean; a, b, c letter codes denoting significance at P≤0.05.

Table 3b. CMD incidence, CBSD incidence (foliar & root), root necrosis, root yield loss and yield traits for cassava varieties in Suna West sub-county.

Variety	Type of variety	F	% CBSD Leaf incidence ($\bar{x}$)	% CMD Leaf incidence ($\bar{x}$)	Root necrosis ($\bar{x}$)	Root necrosis range	% Root necrosis incidence ($\bar{x}$)	Weight of roots (Kg)
Agric IV	Improved	16.7	20±20.5	37.0±23.4	3.7±0.3^{c}	1.0-5.0	100.0±0.0^{a}	1.3±0.3^{bc}
Mary go round	Local	43.3	52.1±6.9	40.0±14.4	1.2±0.1^{ab}	1.0-3.0	19.6±5.4^{bc}	0.9±0.1^{ab}
Agric MH (MH95/0183)	Improved	6.7	60.0±17.8	20.0±14.9	1.1±0.1^{a}	1.0-2.0	6.7±8.0^{c}	2.0±0.3^{c}
Mygyera (TMS 30572)	Improved	13.3	10.0±7.7	10.0±28.9	1.3±0.1^{ab}	1.0-3.0	14.9±6.8^{c}	2.3±0.2^{c}
Nyakasamuel	Local	3.3	70.0±23.5	70.0±22.8	1.5±0.2^{ab}	1.0-3.0	40.0±15.7^{bc}	1.6±0.3^{bc}
Nyakasanya	Local	33.3	67.3±7.3	55.5±19.9	1.1±0.1^{a}	1.0-2.0	9.7±4.4^{c}	1.2±0.1^{b}
Obarodak	Local	13.3	77.5±10.7	55.0±24.9	1.8±0.3^{b}	1.0-3.0	64.0±15.4^{ab}	1.7±0.4^{bc}
Ondielo	Local	20.0	64.0±11.0	60.0±24.4	1.2±0.1^{ab}	1.0-3.0	23.6±8.4^{bc}	0.4±0.1^{a}
Sudhe	Local	3.3	10±10.9	15.0±20.1	-	-	-	-
Mean (μ)	-	-	53.9±9.2	46.7±7.9	1.4±0.1	1.0-5.0	23.9±6.7	1.3±0.2

N-Number of farms; Agric - Agriculture (Unknown improved variety); ± -95% confidence interval for means; $\bar{x}$ - sample mean; μ-population mean; a, b, c letter codes denoting significance at P≤0.05.

CBSD incidence, root necrosis and root necrosis loss

Results showed significant (P≤0.05) variety dependent variations in CBSD incidence (foliar and root) and root necrosis. Most local cassava varieties had higher CBSD incidence compared to improved varieties (Table 3a and b). High foliar CBSD incidences were recorded in Kuria East (mean. 58.5%) with range of 54.0 to 74.0% observed in five local varieties; Manchoberi, Amakuria, Mwitamajera, Weite and Nyakohanda

Table 4. % Necrosis losses, root weight, root number and total root loss.

Sub county	Variety	Total no. of roots examined	Necrosis losses			Mean % necrosis loss	% Root weight loss	% Root number loss	% Total root loss
			% with score 3	% with score 4	% with score 5				
Kuria East	Agric I	27	11.1	3.7	0.0	4.1	44.7	0.0	16.3
	Agric II	35	14.3	14.3	2.9	8.7	29.7	27.1	21.8
	Agric III	51	0.0	0.0	0.0	0.0	25.7	6.3	10.7
	Amakuria	34	8.8	14.7	14.7	15.9	40.0	24.4	26.7
	Manchoberi	106	15.1	0.0	0.0	3.8	65.4	29.3	32.8
	Mwitamajera	16	0.0	0.0	0.0	0.0	80.0	0.0	26.7
	Mygyera	-	-	-	-	-	-	-	-
	Nyakohanda	47	12.8	23.4	2.1	12.6	84.8	44.1	47.2
	Rumara	-	-	-	-	-	-	-	-
	Weite	571	4.6	0.5	0.4	1.6	47.4	25.7	24.9
	Mean	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**25.9**
Suna West	Agric IV	27	25.9	14.8	37.0	33.1	48.8	10.0	30.6
	MH95/0183	24	0.0	0.0	0.0	0.0	34.4	0.0	11.5
	Mary go round	80	1.3	0.0	0.0	0.3	40.8	40.0	27.0
	Mygyera	62	6.5	0.0	0.0	1.6	24.0	13.9	13.2
	Nyakasamuel	12	25.0	0.0	0.0	6.3	58.3	35.0	33.2
	Nyakasanya	87	0.0	0.0	0.0	0.0	51.6	32.5	28.0
	Obarodak	15	20.0	0.0	0.0	5.0	40.0	25.0	23.3
	Ondielo	33	3.0	0.0	0.0	0.8	34.3	33.3	22.8
	Sudhe	-	-	-	-	-	-	-	-
	Mean	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**24.7**

Estimated from research that shows on average 25, 35 and 58% of tissue is removed when necrotic areas are cut-out before processing for CBSD necrosis grades 3, 4 and 5 respectively (Hillocks et al. 2015).

(Table 3a). A similar result trend was recorded in Suna West (mean. 53.9%) with a range of 52.1 to 77.5% in six varieties; Mary go round, Agric MH (MH95/0183) (improved), Ondielo, Nyakasanya, Nyakasamuel and Obarodak (Table 3b). High root necrosis scores, root necrosis incidence and % mean necrosis loss were observed in two local varieties, Amakuria (2.4, 52.5% 15.9%) and Agric IV (3.7, 100%, 30.6%), in Kuria East and Suna West sub-counties, respectively (Table 3a, b and 4). Varieties with high foliar and root incidence coupled with high root necrosis and necrosis loss are regarded as susceptible.

In Kuria East, lowest root necrosis, root necrosis incidence and % mean necrosis loss was observed in Weite (1.2, 12.0%, 1.6%); Mwitamajera (1.2, 15.0, 0.0) and Agric III (1.1, 5.0 0.0) (Table 3a, b and 4). A similar trend was observed in Suna West where lowest root necrosis, root necrosis incidence and % mean necrosis loss was observed in MH95/0183 (1.1, 6.7%, 0.0%), Nyakasanya (1.1, 9.7%, 0.0%) and Mygyera (TMS 30572) (1.3, 14.9%, 1.6%) (Table 3a, b and 4). Although varieties Weite, Mwitamajera, MH95/0183 and Nyakasanya had minimal or no root necrosis losses they had high foliar incidence and could be regarded as tolerant

Table 5. Spearman's correlation coefficients for correlation analysis.

Variable	% CMD	% CBSD	RN	% RNI	% MRL	% RWL	% RNL	% Total root loss
% CMD	1	-	-	-	-	-	-	-
% CBSD	0.44^{ns}	1	-	-	-	-	-	-
RN	0.05^{ns}	0.08^{ns}	1	-	-	-	-	-
% RNI	0.22^{ns}	0.26^{ns}	0.94**	1	-	-	-	-
% MRL	0.14^{ns}	0.08^{ns}	0.94**	0.87**	1	-	-	-
% RWL	0.42^{ns}	0.55*	0.25^{ns}	0.31^{ns}	0.24^{ns}	1	-	-
% RNL	0.35^{ns}	0.18^{ns}	0.01^{ns}	0.06^{ns}	0.22^{ns}	0.22^{ns}	1	-
% Total root loss	0.57*	0.35^{ns}	0.36^{ns}	0.40^{ns}	0.45^{ns}	0.85**	0.59*	1

*Correlation significant at 0.05 level (2 tailed), **Correlation significant at 0.01 level (2 tailed), ns – correlation not significant, % CMD - % CMD leaf incidence, % CBSD - % CBSD leaf incidence, RN - root necrosis, RNI - Root, % MRL - % Mean necrosis root loss, %RWL - % - % Root weight loss, % RNL - % Root number loss.

compared to resistant Agric III and Mygyera (TMS 30572) which had low foliar incidence and low root necrosis loss.

Cassava yield (weight of roots)

Results showed that cassava yield (weight of roots) was significantly (P≤0.05) influenced by variety cultivated in both sub-counties. Improved cassava varieties had more root weight compared to the local landraces. In Kuria East, improved varieties, Agric I and II had highest mean number (4.4 to 5.4) and weight (1.7 to 2.8 kg) of harvested roots compared to (3.9 to 4.6) and (0.4 to 0.9 kg) for all the local cassava varieties (Table 3a and b). Similar results were observed in Suna West where improved varieties, Agric IV, MH95/0183 and Mygyera (TMS 30572) had highest number (5.0-5.5) and weight (1.3 to 2.3 kg) of harvested roots compared to (3.3 to 4.3) and (0.4 to 1.7) for all local landraces.

Percent root losses

The highest % total loss was observed on Nyakohanda (47.2%) (Table 4). This variety had high CMD and CBSD foliar incidence, high root necrosis and root necrosis incidence, which all contributed to high total root loss. CMD and CBSD foliar incidences seems to have had negative impact on % root weigh losses and ranged from 25.7 to 84.8% in Kuria East and 24.0 to 72.7% in Suna West (Table 4). Percent root number loss was lower compared to root weight loss and ranged from 0.0 to 44.1% in Kuria East and 0.0 to 38.6% in Suna West (Table 4). This shows that most of the affected plants developed roots but they did not bulk and remained small thereby affecting subsequent root weight. The lowest % total root loss was recorded on improved varieties TMS 30572 (13.2), MH95/0183 (11.5) and Agric III (10.7) (Table 4). Local varieties like Weite, Mwitamajera, Mary go round, Nyakasanya and Ondielo had low % mean necrosis loss comparable to the improved varieties but their % total root loss was higher due to high CMD and CBSD foliar incidence which negatively affected resultant root weight and number. This shows that even if root necrosis losses are low in most of the local varieties, farmers are still losing significant yields due to high foliar incidences. Percent total root loss ranged from 10.7 to 47.2% with a mean of 25.9% in Kuria East while in Suna West was 11.5 to 33.2% with a mean of 24.7% (Table 4). Total losses were 1299.6 US$/ha in Kuria East and 1259.6 US$/ha in Suna West (Table 6).

Correlation analysis

There was a moderate positive correlation (r = 0.57, p≤0.05) between % CMD leaf incidence and % total root loss, and this showed that CMD incidence had a significant effect on total root loss as all plants with CMD symptoms also had root loss (Table 5). Positive correlation (r = 0.35) between % CBSD leaf incidence and total root loss wasn't significant since the incidence resulted into loss in root weight but not necessarily loss in root number (Table 5). Some varieties also had high CBSD incidence but with minimal or low root necrosis resulting to low total root loss that is, MH95/0183 in Suna West and Weite and Mwitamajera in Kuria East (Table 3a and b). Very high positive correlation (r = 0.94, p≤0.01) was observed between root necrosis, root necrosis incidence and % mean root necrosis loss (Table 5). Varieties with high root necrosis had high root necrosis incidence and consequently high % mean root necrosis loss that is, Agric IV (Table 5).

Dual infections for CMD and CBSD were observed in most varieties. Root weight loss (r = 0.85, p≤0.01) and root number loss (r = 0.59, p≤0.05) were positively correlated to total root loss (Table 4). These two traits contributed significantly to total root loss compared to % mean root necrosis loss and this was due to some varieties having high root weight and root number loss

Table 6. Cassava yield losses converted to US dollars.

Sub county	Variety	Yield of symptomless plants (Kg/m^2)	Yield of symptomless plants (tonnes/ha)	Total root loss (tonnes/ha)	Loss in US dollars/ha
Kuria East	Agric I	3	30	4.9	1046.1
	Agric II	4	40	8.7	1857.4
	Agric III	1.5	15	1.6	341.6
	Amakuria	1	10	2.7	576.4
	Manchoberi	2	20	6.6	1409.0
	Mwitamajera	2	20	5.3	1131.5
	Mygyera	-	-	-	-
	Nyakohanda	3	30	14.2	3031.6
	Rumara	-	-	-	-
	Weite	1.9	19	4.7	1003.4
	Mean	-	-	-	1299.6
Suna West	Agric IV	2.5	25	7.7	1643.8
	Agric MH (MH95/0183)	4	40	4.6	982.1
	Mary go round	2.25	22.5	6.1	1302.3
	Mygyera (TMS 30572)	3.5	35	4.6	982.1
	Nyakasamuel	3	30	10.0	2134.9
	Nyakasanya	2.5	25	7	1494.4
	Obarodak	2.5	25	5.8	1238.2
	Ondielo	0.6	6	1.4	298.5
	Sudhe	-	-	-	-
	Mean	-	-	-	1259.5

Cassava value in Kenya US$ 213.49/tonne (FAOSTAT, 2013), % losses adapted from % total root loss in Table 4.

with minimal or no % mean root necrosis loss that is, Nyakasanya in Suna West and Mwitamajera and Manchoberi in Kuria East (Table 3a and b). Dual infections of CMD and CBSD were observed in all varieties in both sub counties except Agric I which had high CBSD incidence (80.0%) but no CMD infection. CBSD incidence was also higher than CMD incidence except for varieties Agric III, TMS 30572 and Rumara. This could possibly explain the positive non-significant relationship (r = 0.44) observed between CMD and CBSD leaf incidence.

DISCUSSION

Farming is the predominant economic activity in Migori County with communities mainly generating income through sale of crops, cassava products, livestock and working as casual farm labourers. In the sub-counties of Kuria East and Suna West, cassava is ranked the second most important food crop after maize, which is also a staple food and the most important crop in Kenya (FAOSTAT, 2013). This is based on the amount of land resource allocated to different crop enterprises in Migori County. Farmers in Kuria East and Suna West sub-counties grew a wide range of varieties, which included both improved and local cassava varieties. Among the improved varieties, introduced in the 1990s by the Ministry of Agriculture to combat cassava mosaic disease (CMD), included four which were only identified as Agriculture I to IV in this study (GoK, 2006).

Popular varieties in Kuria East include *Weite*, which ranks first, followed by *Manchoberi* while in Suna West, *Mary go round* was most popular followed by *Nyakasanya*. These highest-ranking varieties are local types with diverse introduction histories. A majority of farmers in both sub-counties grow only one variety, usually the most popular. According to farmers, the popular varieties possess good processing attributes and yield high quality flours for ‘ugali’ and porridge. Farmers adopted a few improved varieties introduced by Ministry of Agriculture (GoK, 2006) because of their disease resistance and high yield. These varieties were mostly developed for resistance to CMD, which had been a major cause of low crop yields on the local varieties (GoK, 2006). Despite these efforts, the varieties are sparsely spread across the two sub-counties; farmers reported that the distribution criterion was poor and therefore adoption is low. This was evident in a survey by Tana et al. (2011) which revealed that as a majority of farmers sampled from Migori county >95.0% were

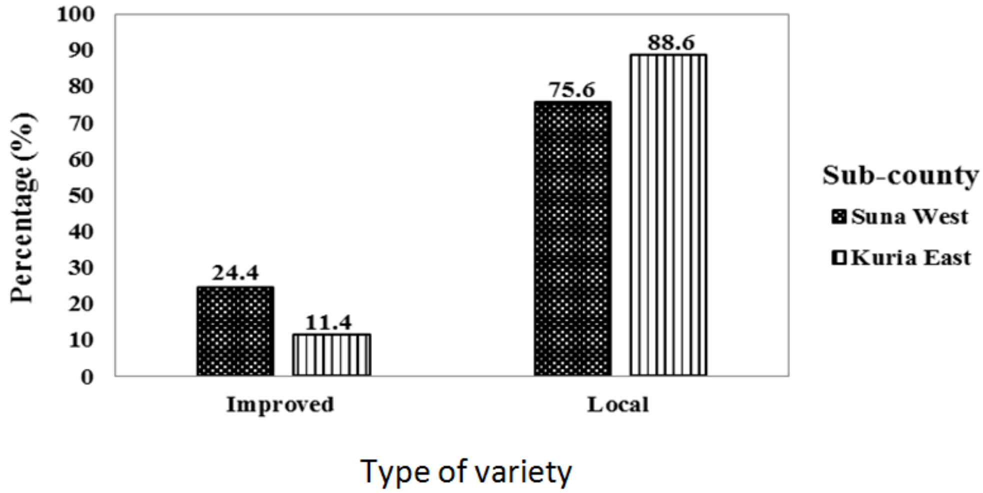

Figure 2. Cassava popularity in Kuria East and Suna West sub-counties.

growing local varieties, and only a few had adopted the improved varieties as a second option. In this study, it emerged that the improved cassava varieties were not very popular with the farmers in the two sub-counties.

The CBSD foliar incidence of about 50% in both sub-counties was relatively low and the disease was not new in the sub-counties because incidences of up to 100% and the presence of both UCBSV and CBSV has been reported in Western Kenya (Mware et al., 2009; Osogo et al., 2014). Most of the local varieties had high CMD incidences and were low yielding compared to the improved varieties. This was expected as the improved varieties are among the ones introduced to combat CMD and they are also high yielding (Dixon et al., 2010; Gok, *20*06). Different CBSD disease reactions similar to previous studies done (Pariyo et al., 2015; Mohammed et al. 2012; Hillocks and Jennings, 2003) were observed, depicting differential cultivar sensitivity to CBSD in both sub counties. Pariyo et al. (2015) classified the varieties into resistant, moderately resistant, susceptible and highly susceptible. In this study varieties were also classified but with a few modifications.

Varieties with high foliar and root incidences coupled with high root necrosis and root loss were regarded as susceptible that is, Nyakohanda, Amakuria and Agric IV. The improved variety Agric IV, was seriously affected by CBSD with many of its roots displaying the severe cocky necrosis characteristic of the disease. This is an improved variety for CMD resistance but is unfortunately very susceptible to CBSD. Varieties like Weite, Nyakasanya, Mwitamajera and MH95/0183 had high foliar incidences with minimal or low root necrosis, and were regarded as tolerant. Unfortunately, high CBSD and CMD incidences in Weite, Nyakasanya and Mwitamajera resulted to more % total root losses when compared to MH95/0183. Weite has earlier been reported to have CBSD foliar and root symptoms (Obiero et al., 2007) but in this study, even in fields with very high infection rates than other varieties, Weite produced clean roots. Most farmers reported observing CBSD root symptoms in their cassava crops for the past 2 to 3years. Literature survey showing CBSD symptoms in western Kenya were first reported by Obiero et al. (2007).

Improved variety Agric III and Mygyera (TMS 30572) were regarded as resistant since it had low foliar and root incidences coupled with low root necrosis and % root loss. The findings on TMS 30572 concur with the study of Pariyo et al. (2015) who selected this variety as one of the elite CBSD resistance sources. Overall, the best performing variety was high yielding Mygyera (TMS 30572) which had low incidence, severity and losses due to both CMD and CBSD. Apart from the high CBSD foliar incidence, MH95/0183 could also be regarded as a good performing variety with high yield, low CMD incidence and minimal root losses.

These observations may help explain why local varieties dominate cassava production in Migori County. While improved varieties are available, farmers seem to have quickly learnt that these improvements only targeted CMD resistance and not CBSD. With the new problem of CBSD, some of these new improved varieties severely succumb to it, making them unpopular with farmers due to the heavy losses incurred. Some of the local varieties grown seem to be mildly tolerant and still produce crops even with CBSD infections, hence the attraction of producers to them. To date, there are no CBSD tolerant or resistant cassava varieties released in Kenya.

High positive correlation between root necrosis, root necrosis incidence and % mean necrosis low implies that susceptible varieties suffer greatest losses necessitating the need for more tolerant/susceptible varieties. The positive correlation between CBSD, CMD and % total root loss showed that the diseases significantly affects root yield and this concurs with the study of Alabi et al. (2011) who reported that CMD affected plants have low root yield even if incidences and severity are low. The differential variety responses to CBSD infection and observed correlations, provide hope for incorporating locally adapted local cassava landraces and some improved varieties in the development of CBSD resistant varieties suitable for increased cassava production in western Kenya.

Conclusion

Cassava production in Migori County suffers from medium to high CMD and CBSD infection (foliar and root necrosis) with resultant substantial loss in root yield. The strong positive correlation between root necrosis/ incidence and percent root loss implies CBSD susceptible varieties suffer greatest loss. The findings of this study are expected to provide impetus for the development and promotion of new high yielding, locally adapted and CMD and CBSD resistant cassava varieties.

Conflict of interests

The authors have not declared any conflict of interests.

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