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Epidemic Pressure of Cassava Mosaic and Brown Streak Diseases on Ten Exotic Cassava (*Manihot esculenta* Crantz) Cultivars in Kisangani, DRC

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Abstract

The crucial obstacle to cassava production in most of African countries is the diseases and pests. The present study assessed in field the epidemic pressure of Cassava mosaic disease (CMD) and Cassava brown streak disease (CBSD) on 10 exotic cassava genotypes in Kisangani. To assess the disease impact, trials were established in two sites in Kisangani, Tshopo Province in DRC. The experiment was laid out in randomized completed block design and thrice replicated. Sixty stem cuttings per variety were planted in a plot of 7 rows each measuring 25 m long. Results showed a relatively important CBSD pressure on all the ten exotic cassava genotypes tested (incidence close 60%, severity score 2 and 3.5 whiteflies/plant) and low CMD pressure (incidence 3.3%, severity score 2 and 3.5 whiteflies/plant). CMD remained relatively negligible depending on low symptom manifestation of the tested genotypes. Whitefly population varied according to the genotype and the crop age. The most abundant population was recorded on cultivar 'Mayombe' (17 whiteflies/plant). A negative relationship was statistically established between the abundance of whiteflies and the incidence and severity as well as for CBSD and for CMD. The production in terms of percentage of marketable tubers was (74.9%) for cultivar 'Mayombe', (70.3%) for 'Obama 1', (69.9%) for 'Obama 2' and (65.3%) for 'Ngandajika'. CBSD resulted in variable yield loss on all cultivars tested. The cultivar 'Butamu' (85%) recorded the highest loss rate, followed by the cultivar 'Mvuama' (70.8%) and 'Muzuri' (64.3%). The yield in cassava tubers was destroyed (< 5 t/ha) by large necrotic spots of the brown streak in the pulp. This loss is due to the depressive of viral pandemia pressure on the output of ten exotic cassava cultivars studied in Kisangani. Our study highlighted that the best moment of harvesting cassava in Kisangani is 9 MAP, this moment would be ideal to minimize harvesting losses due to CBSD root necrosis.

Keywords: epidemic pressure, Cassava brown streak disease, Cassava mosaic disease, Kisangani

1. Introduction

The importance of cassava (*Manihot esculenta* Crantz) in Africa cannot be underestimated as it is considered a resilient crop, urban and rural staple food and an industrial raw material (Nweke *et al*., 2002). Cassava roots provide 500 cal/day of food to over 70 million people (Chavez *et al*., 2005).

Cassava is widely consumed in Sub-Saharan Africa and parts of Asia. Nigeria is the world's largest producer of cassava with an estimated production of about 37 million tons (FAOSTAT, 2019). In Democratic Republic of Congo (DRC), the crop is grown on 50% of cultivated land with an output of 15 million tons (FAOSTAT, 2019). The crucial obstacle to cassava production in most of African countries is the diseases and pests. One of the most important is Cassava mosaic disease (CMD) caused by the single stranded DNA viruses in the family *Geminiviridae* , genus *Begomovirus* (Fauquet *et al*., 2005) and the Cassava brown streak disease (CBSD) caused by the single stranded RNA viruses in the family *Potyviridae,* genus *Ipomovirus* (Mbanzibwa *et al*., 2009; 2011).

These diseases severely attack local and improved cultivars of cassava causing characteristic severe distortion, leaf stunting almost on the entire plant and root necrosis (Bakelana *et al*. 2018; Sing'ombe *et al*., 2015). According to Otim-Nape *et al*. (1994); Thresh *et al*. (1994); Hahn *et al*. (1989), CMD caused losses of 20-95% of cassava production in various parts of the world.

In DRC, these viral pandemics affect production of cassava in the major cassava growing of Eastern region (Muhindo *et al*., 2020b; Casinga *et al*., 2018; Mulimbi *et al*., 2012; Monde *et al*., 2010). The characterized CMD viruses worldwide are nine with seven of them reported from Sub-Saharan Africa (Alabi *et al*., 2011). They include EACMV, ACMV, EACMCV (Fondong *et al*., 2000) EACMKV (Bull *et al*., 2006), EACMZV (Maruthi *et al*., 2004), EACMMV (Zhou *et al*., 1998), and the SACMV (Berrie *et al*., 1998).

For CBSD, two viruses have been characterized in East and Central Africa including CBSV and UCBSV (Mbanzibwa *et al*., 2009; Winter *et al*., 2010). It is known that Cassava mosaic begomoviruses (CMBs) and Cassava brown streak ipomoviruses (CBSIs) are vectored by whiteflies, *Bemisia tabaci* (Njoroge *et al*., 2017; Tocko-Marabena *et al*., 2017; Legg *et al*., 2011) and spread by infected cuttings that are routinely used by farmers (Sing'ombe *et al*., 2015). There are many methods of controlling plant pest and disease pathogens which include chemical application, use of biological control, phytosanitation and utilization of resistant varieties.

In DRC no studies have been done on the CBSD epidemic pressure of cassava improved cultivars under field conditions using sensitive diagnostic tools. The aim was to assess the impact of CMD and CBSD on exotic cassava cultivars while determining the density of whitefly vectors of the viruses. Thus, this study not only contributed knowledge on these issues but also is important for virus indexing to avail to breeders clean materials for further breeding efforts.

2. Materials and Methods

2.1 Experimental Site

Trials were established (from July 2017 to October 2018) in two sites in Kisangani Tshopo Province in DRC. One in Cimestan area (Latitude N 0°29'56.5", Longitude E 25°15'05.4", Altitude 408 m) and other in Lindi area (Latitude N 0°29'56.5", Longitude E 25°15'05.4", Altitude 405 m) in Kisangani. Kisangani is located at an altitude of 405 m above sea level (masl). It receives mean annual rainfall of 1500 mm and mean annual temperature of 27.6 °C and the soil of Kisangani is a sandy-clay soil type (Lokinda *et al*., 2018).

2.2 Experimental Methods

The experiment (Figure 1) was laid out in randomized completed block design and thrice replicated. Sixty stem cuttings (two per place) per variety were planted (in horizontal position) in a plot of 7 rows each measuring 25 m long. There was a spacing of 1 m between rows and 1 m within rows. A plot of 105 plants represented one variety. Ten cassava exotic cultivars (Table 1) were indexed CMD and CBSD free by PCR. Plots were separated by 1.5 m and kept weed-free.

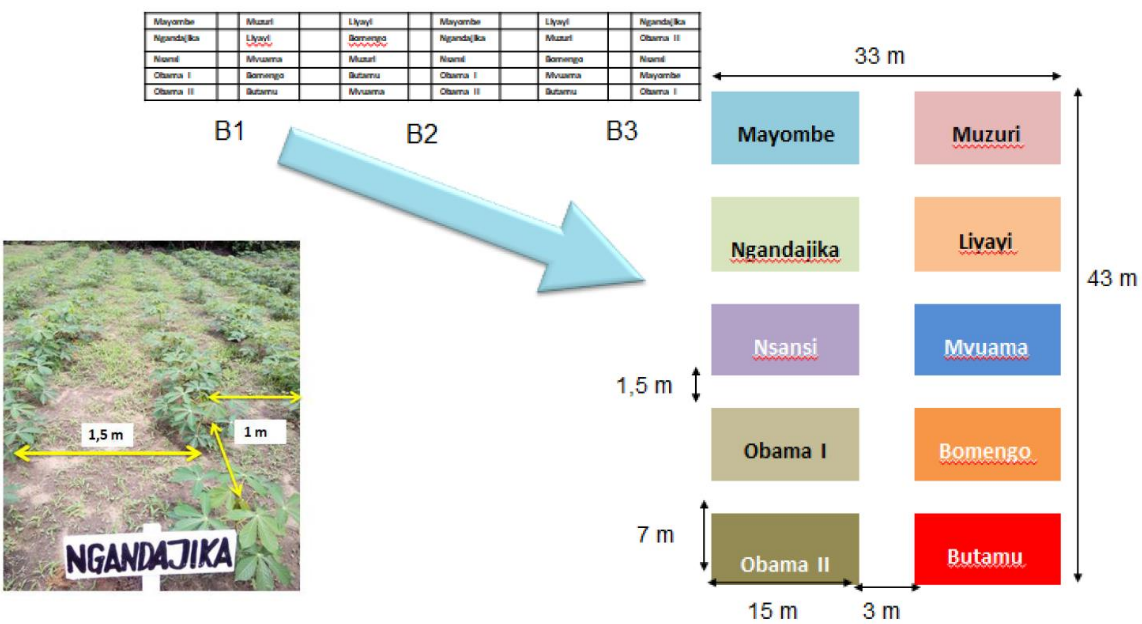

Figure 1. Representation of the experimental design by plot and bloc

Table 1. General characteristics of the ten exotic cassava cultivars (IITA, 2019)

No	**Cultivars**	**Code**	**Resistance**		**Pulp**	**Yield (t/ha)**	
			CBSD	**CMD**		**On Station**	**Off station**
1	Bomengo	M98/115	-	+	White	30-40	25-35
2	Butamu	MV 99/0395	-	+	Yellow	25-40	10-20
3	Liyayi	MM96/0287	-	+	Yellow	35	18
4	Mayombe	MM96/8353	-	+	Yellow	30-40	12-15
5	Muzuri	2006/073	-	+	Yellow	30-40	25-35
6	Mvuama	83/138	-	+	Yellow	25	15
7	Ngandajika	MV99/150	-	+	White	NA	NA
8	Nsansi	I95/0160	-	+	White	25-40	15-25
9	Obama1	TME419	-	+	White	45	20-30
10	Obama2	MV/2001/014	-	+	White	45	20-30

Legend: - : Susceptible to CBSD +: Resistant to CMD NA: Not applicable

2.2.1 Cassava Leaf Symptom Assessment

Three cassava plants from each variety were randomly selected within each plot and tagged for data collection. The CMD and CBSD leaf severity was recorded from 3 to 9 months after planting (MAP) using scale described in table 2.

Table 2. Diseases rating and corresponding symptom expression of Cassava mosaic disease (CMD) and Cassava brown streak disease (CBSD)

Rating	**CMD Symptoms** (Hahn *et al*., 1980)
1	No visible symptoms
2	Mild chlorotic pattern on entire leaflets or mild distortion at base of leaflets
3	Strong mosaic pattern on entire leaf, and narrowing cum distortion of one-third leaflet
4	Severe mosaic distortion of two-thirds of leaflets and general reduction in leaf size
5	Severe mosaic distortion of four fifths or more leaflets, twisted and misshapen leaves
	CBSD Foliar Symptoms (Alicai *et al*., 2016)
1	No visible symptoms
2	Slight symptoms on lower leaves, no lesion on the stem;
3	Foliar chlorosis, mean lesions, no Die-back;
4	Foliar chlorosis and marked lesions on the stem, no Die-back;
5	Defoliation with lesions on the stem and pronounced Die-back.
	CBSD Root Symptom (Bakelana *et al*., 2018)
1	No visible symptoms
2	Less than 5% necrotic tissue;
3	5-10% necrotic tissue;
4	10-50% necrotic tissue;
5	More than 50% necrotic tissue.

2.2.2 Disease Incidence

The CMD and CBSD incidence corresponds to the ratio of the number of plants displaying the disease symptoms on the total inspected plants (Toualy *et al*., 2014). This incidence is obtained by the following mathematical relation (Equation 1):

$$\text{Incidence (\%)} = \frac{\text{Total nomber of plants with disease symptoms}}{\text{Total nomber of observed plants}} \text{ x } 100 \quad (1)$$

2.2.3 Whitefly Survey

Adult whitefly populations in the tagged plants were counted on the five topmost leaves (Ariyo *et al*., 2005) of each plant of the various cassava genotypes from 3 to 9 MAP (Sseruwagi *et al*., 2004).

2.2.4 Cassava Root Symptom Assessment

To make sure of the presence or absence of CBSD root necrosis, three plants per genotype were uprooted. The entire roots were transversally dissected in five sections using a knife to determine the CBSD necrosis evolution. This cassava tubers CBSD severity was recorded from 12 to 14 MAP using the scoring scale of 1-5 (Table 2).

2.3 Evaluation of Yield and Root Loss

The roots of the three plants harvested per variety (Masinde *et al*., 2016) were weighed (kg) and the yield (t/ha) per variety computed using formula (Equations 2 and 3):

$$\text{Yield } \left(\frac{\text{t}}{\text{ha}}\right) \text{per variety} = \frac{Weight\ (kg) \text{x } 10{,}000\ m^2}{1m^2 \text{x } 1{,}000\ kg} \quad (2)$$

The root loss (%) per variety was computed as shown below

$$\text{Loss (\%)per variety} = \frac{Total\ Root\ Weight\ (kg) - Weight\ of\ Marketable\ Root\ (kg)}{Total\ Root\ Weight\ (kg)} \text{X100} \quad (3)$$

2.4 Statistical Analyses

The data were entered into the Excel spreadsheet. Analysis of variance (ANOVA), frequencies, means, percentages, and Pearson correlations were performed using R software version 4.4.0 (R Core Team, 2020). Multiple comparisons of means by Tukey's test were performed.

3. Results

3.1 Diseases Incidence and Severity

Field incidence and severity of CBSD and CMD from 3 to 11 months after plantation (MAP) expressed by 10 exotic cassava cultivars are showed in table 3. With respect to CBSD, the cultivars ‘Mayombe’, ‘Mvuama’ and ‘Nsansi’, did not show symptoms on the leaves. Up to 5 MAP, no CBSD foliar symptom was visible on tested cassava plant. CBSD symptoms started to appear at 6 MAP and became severe from 7 MAP varied among cultivars. At 7 MAP, the incidence reached 100% for the cultivars ‘Bomengo’ and ‘Muzuri’ whereas it was null on cultivars ‘Mvuama’ and ‘Nsansi’ (Table 3).

Likewise, severity of CBSD foliar symptoms has significantly varied by cultivars from score 1 to 4 (F pr.<0.001). High severity rates started to be observed from 6 MAP and reached score 3 to 4 for cultivars ‘Muzuri’ and ‘Obama 2’ respectively, starting from 11 MAP. Whereas, for cultivars: ‘Bomengo’, ‘Butamu’, ‘Liyayi’, ‘Ngandajika’ and ‘Obama 1’, severity remained of level 2 (Table 3).

The incidence and severity of CMD was 3.3% and score 2 from two cultivars ‘Obama 2’ and ‘Bomengo’ at 6 MAP and 8 MAP respectively (Table 3).

3.2 Aleurodes Densities

The number of adult whitefly per plant has sensibly varied within cassava cultivars tested during the plant cycle. The cultivar ‘Liyayi’ has carried 11 whiteflies per plant at 3 MAP followed by cultivar ‘Muzuri’ (10 whiteflies per plant) and ‘Ngandajika’ and ‘Nsansi’ (8 whiteflies per plant). On the other hand, the cultivar ‘Mvuama’ did not attract any whitefly at 3 MAP. At 8 MAP, the cultivar ‘Mayombe’ carried 17 whiteflies per plant followed by cultivar ‘Bomengo’ (7 whiteflies). Globally, whiteflies abundance decreased with the age of cassava. From 9 MAP, whiteflies were not visible any more on the plants of all the cultivars (Table 4).

Regarding the number of whiteflies per plant (Table 4), it is noted that the cultivar ‘Mayombe’ the most attracted whiteflies (on average 6 whiteflies per plant) and followed by ‘Nsansi’ (3 whiteflies per plant) whereas the cultivar ‘Mvuama’ almost did not attract whiteflies during the culture.

3.3 CBSD Severity Effect on the Yield of Ten Cassava Cultivars

The production in terms of number of marketable tubers per cultivar show that the cultivar ‘Mayombe’ produced 11 and 12 marketable tubers (in Cimestan and Lindi respectively) followed by the cultivar ‘Obama 2’ (8.4 and 10.2 tubers in Cimestan and Lindi) and the cultivar ‘Obama 1’ (7.8 and 8 tubers) (Table 5).

Production expressed as a percentage of the marketable tubers was highest in cultivar ‘Mayombe’ (74.5 and 75.3%) followed by the cultivar ‘Obama 1’ (68.3 and 72.3%), cultivar ‘Obama 2’ (68.8 and 71.1%) and cultivar ‘Ngandajika’ (65.2 and 65.3%) in Lindi and Cimestan respectively (Table 5, Figure 3).

Concerning yield loss, cultivar ‘Butamu’ recorded the highest percentage loss (83.3 and 86.7%) followed the cultivar ‘Mvuama’ (66.7 and 75%) and the cultivar ‘Muzuri’ (61.8 and 66.7%) in Cimestan and Lindi respectively (Table 5).

3.4 Correlation between Diseases Incidence and Severity, Aleurodes Density and Yield Parameters

A positive correlation is recorded between the CBSD root necroses severity and the weight of one root in a tuft (WRt) (r = 0.21), the weight of one marketable root in a tuft (WMRt) (r = 0.20), the marketable root yield (MRY) (r = 0.18), the total root yield (TRY) (r = 0.17) and the percentage of the marketable roots (PMR) (r = 0.15) (Figure 2.A).

The CBSD necroses severity for major roots (marketable and non-marketable) has reached score 4 at 14 MAP (Figure 1.C) and significantly reduced the output (< 5t/ha) of these cultivar roots (marketable and nonmarketable) from 12 to 14 MAP (Figure 2.B and D, Figure 3).

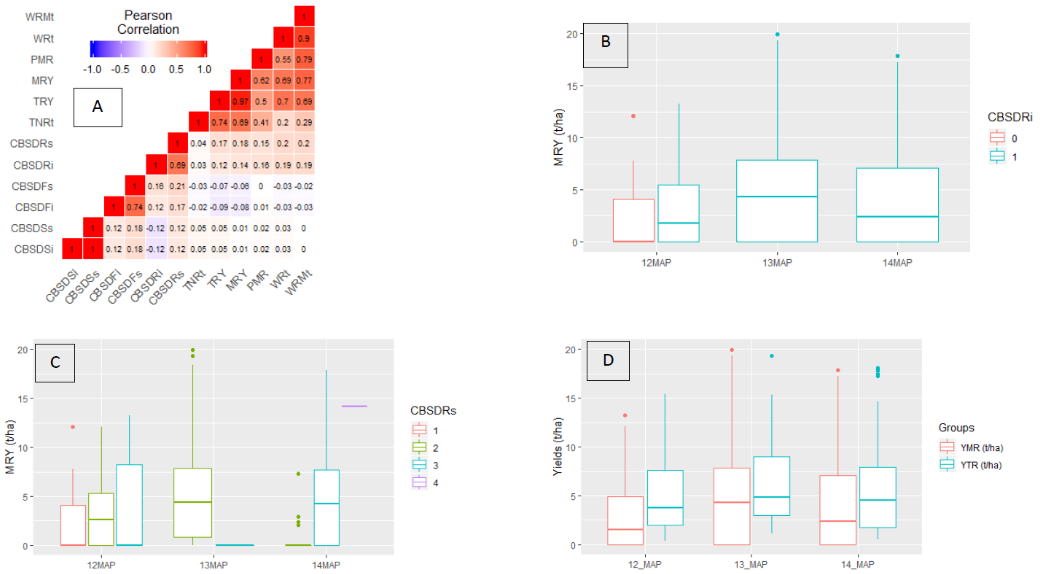

Figure 2. A= Pearson correlation between CBSD incidence, severity (foliar, stem, and root) of ten exotic cassava cultivars and B = Box-Plots of CBSD incidence from 12 MAP to 14 MAP and cassava tuber yield; C = Box-Plots of CBSD severity from 12 MAP to 14 MAP and cassava tuber yield; D = Box-Plot total yield and marketable roots from 12 MAP to 14 MAP

Note: Pearson correlation for CBSDfs: CBSD Foliar severity (1-5); CBSDfi: CBSD Foliar incidence (%); CBSDss: CBSD Stem severity (1-5); CBSDsi: CBSD Stem incidence (%); CBSDrs: CBSD root severity (1-5); CBSDri: CBSD Root incidence (%); TRY: Total Root Yield (tonne/ha); MRY: Marketable Root Yield (tonne/ha); PMR: Percentage of Marketable Root (%); WRt: Weight of one Root in a tuff (kg/tuff); WRMt: Weight of a Marketable Root in a tuff (kg/tuff); TNRt: Total number of root per tuff.

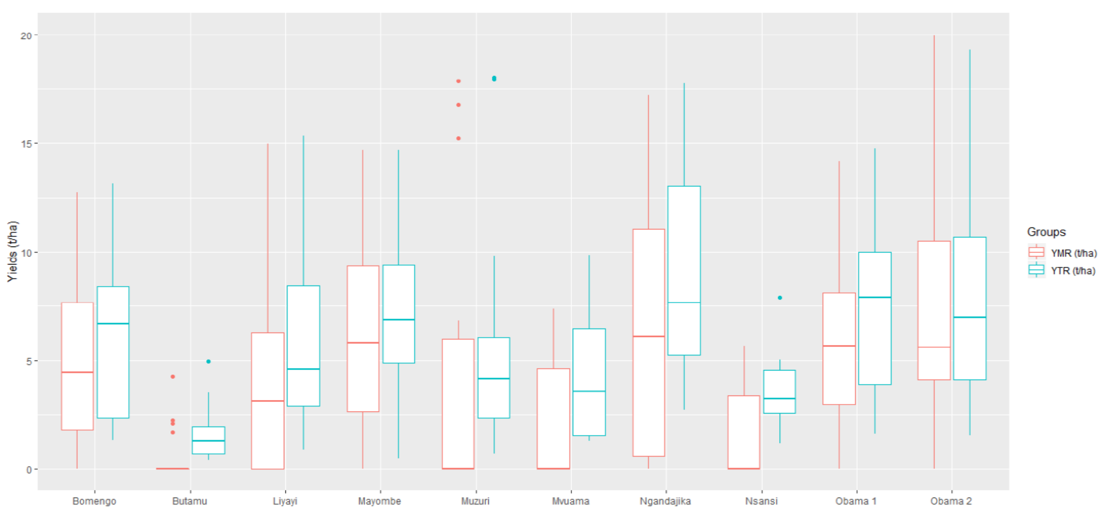

Figure 3. Box-Plot for total yield and marketable cassava roots per variety from 12 MAP to 14 MAP and cassava tuber yield

3.5 Discussion

Results from this study showed that all the ten cassava exotic cultivars displayed low visible CBSD symptoms (Incidence 53.4%, severity score 2) on leaves and tuberous roots. Major of these cultivars had foliar and root symptoms. Indeed, Casinga *et al.* (2018); Bigirimana *et al*. (2011); Mulimbi *et al*. (2012) showed in their work in the Great Lakes zones that low CBSD symptoms were observed on leaves.

CBSD leaf incidence and severity significantly varied with the ten tested cultivars (from 0.0% to 100% and from score 1 to 4, F pr.<0.001). The cultivar 'Bomengo' and 'Muzuri' reached 100% incidence at 6 MAP. However, the cultivar 'Mvuama' and 'Nsansi' remained < 10% incidence. The increase severity started from 5 MAP to reach score 3 or 4 for the cultivar 'Muzuri' and 'Obama 2' respectively. According to Abaca *et al*. (2012); Kanju *et al*. (2019), in their investigations in the East and the Center of Uganda, the manifestation of the CBSD symptoms on cassava leaves evolved/moved with the age of cassava plant. In general, it can be retained that during the experimentation in the area of Kisangani, the CBSD pressure on the ten exotic cultivars tested was of average (53%) incidence and average (score 2) severity.

It is retained that the cultivar 'Bomengo' presented a high CBSD foliar incidence (94.5%) and moderate severity (score 2). On the other hand, the cultivar 'Obama 2' displayed a high CBSD incidence (30%) and a high severity (score 3). It was also observed that all the exotic cassava cultivars displayed CBSD foliar symptoms presented CBSD root necrosis in various incidence and severity degrees (Table 3).

Indeed, the cultivar 'Mvuama' remained CBSD healthy regarding no foliar and root CBSD chlorosis and necrosis. However, for the cultivar 'Mayombe' and 'Nsansi', in the absence of CBSD foliar symptoms they expressed root necroses during harvests. This observation shows that some cultivars dissimulate CBSD symptoms on their shoot parts whereas they are sensitive to the CBSD.

Regarding the CMD symptoms, the disease incidence remained low from 0 to 3.3%. This low incidence occurred from 6 MAP for the cultivar 'Obama 2' and from 8 MAP for the cultivar 'Bomengo'. The fact of no CMD symptom observed on the other cultivars 'Butamu', 'Liyayi', 'Mayombe', 'Mvuama', 'Muzuri', 'Ngandajika', 'Nsansi' and 'Obama 1' confirms their CMD resistant character. It is noted that the CMD infection of the two cultivars might be relatively negligible owing to the fact that the CMD total incidence and severity remained low (3.3% and score 2). It can be understood that the two infected cultivars probably started to lose their on farm CMD-resistance character. Globally, these performed cultivars still better face to CMD in Kisangani (Table 3).

In Yangambi, RDC, Monde *et al*. (2013) noted a depressive effect of the CMD on the growth and the production of the fourteen improved and local cassava cultivars. The impact of the disease on the production was overall more significant for the local cultivars and was negligible for the resistant cultivars.

In Yaoundé, Cameroun, Ambang *et al*. (2007), studied the tolerance to the CMD of the three cassava cultivars (the local 'Alot-Bikon' and the two improved: 'IITA8034' and 'IITA8061'), they recorded a low level of CMD infection (17.2%) on plants of the wild species. This wild species was seemed to be more tolerant to CMD whereas the cultivar 'IITA8061' was fairly resistant to CMD incidence. While the cultivars 'IITA8034' and the local 'Alot-Bikon', were found more sensitive to CMD.

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Table 3. CBSD and CMD foliar Incidence and severity on ten cassava cultivars at different growth stages

		3 MAP		**4 MAP**		**5 MAP**		**6 MAP**		**7 MAP**		**8 MAP**		**9 MAP**		**10 MAP**		**11 MAP**		**Mean**	
Disease	**Cultivar**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S(1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**
CBSD	Bomengo	0.0	1	0.0	1	0.0	1	66.7	2	100.0	2	100.0	2	100.0	2	100.0	2	100.0	2	94.5	2
	Butamu	0.0	1	0.0	1	0.0	1	0.0	1	43.3	2	43.3	2	43.3	2	43.3	2	43.3	2	43.3	2
	Liyayi	0.0	1	0.0	1	0.0	1	0.0	1	10.0	2	10.0	2	10.0	2	10.0	2	10.0	2	10.0	2
	Mayombe	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Muzuri	0.0	1	0.0	1	0.0	1	36.7	2	100.0	2	100.0	2	100.0	2	100.0	2	100.0	3	89.5	2
	Mvuama	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Ngandajika	0.0	1	0.0	1	0.0	1	0.0	1	60.0	2	60.0	2	60.0	2	60.0	2	60.0	2	60.0	2
	Nsansi	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Obama1	0.0	1	0.0	1	0.0	1	33.3	2	50.0	2	50.0	2	50.0	2	50.0	2	50.0	2	46.7	2
	Obama2	0.0	1	0.0	1	0.0	1	0.0	1	30.0	2	30.0	2	30.0	2	30.0	2	30.0	4	30.0	3
	Mean	**0.0**	**1.0**	**0.0**	**1.0**	**0.0**	**1.0**	**45.6**	**2.0**	**56.2**	**2.0**	**56.2**	**2.0**	**56.2**	**2.0**	**56.2**	**2.0**	**56.2**	**3.0**	**53.4**	**2.0**
	CV (%)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**51.9**	**24.2**	**68.9**	**24.2**	**68.9**	**24.2**	**68.9**	**24.2**	**68.9**	**24.2**	**68.9**	**31.4**	**67.3**	**31.6**
CMD	Bomengo	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	3.3	2	3.3	2	3.3	2	3.3	2	3.3	2
	Butamu	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Liyayi	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Mayombe	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Muzuri	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Mvuama	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Ngandajika	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Nsansi	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Obama1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Obama2	0.0	1	0.0	1	0.0	1	3.3	2	3.3	2	3.3	2	3.3	2	3.3	2	3.3	2	3.3	2
	Mean	**0.0**	**1**	**0.0**	**1**	**0.0**	**1**	**3.3**	**2**	**3.3**	**2**	**3.3**	**2**	**3.3**	**2**	**3.3**	**2**	**3.3**	**2**	**3.3**	**2**
	CV (%)	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**31.6**	**15.8**	**31.6**	**15.8**	**42.4**	**21.1**	**42.4**	**21.1**	**42.4**	**21.1**	**42.4**	**21.1**	**42.2**	**21.1**

MAP: Month After Plantation, I: Incidence, S: Severity, CV: Coefficient of variation

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The number of adult whitefly per plant varied with the ten cultivars tested and the plant growth stages. From 3 MAP, the cultivar 'Liyayi' was found with 11 whiteflies per plant followed by cultivar 'Muzuri' (10 whiteflies per plant) and 'Nsansi' (8 whiteflies per plant). However, the cultivar 'Mvuama' did not attract any (0) whitefly at 3 MAP. These cultivar 'Mvuama' and 'Nsansi' remained < 10% CBSD incidence. It is observed by Muhindo *et al*. (2020a) that the presence of whitefly does not indicate necessarily the presence of diseases (Table 4).

At 8 MAP, the cultivar 'Mayombe' recorded a high number of whiteflies (17 whiteflies per plant) followed by the cultivar 'Muzuri' (7 whiteflies per plant). From 9 MAP, adult whiteflies were not visible any more on the plants of all the ten cultivars. This disappearance of whiteflies would be explained by the low childhood of cassava leaves which does not attract any more whiteflies (Table 4).

Table 4. Whiteflies abundance per plant on 10 cassava exotic cultivars at different growth stages

No	Cultivar	3 MAP	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	$Mean_a$	CV (%)
1	Bomengo	2.0	0.0	1.0	1.8	1.3	6.6	0.0	2.5	91.7
2	Butamu	5.5	1.5	2.1	1.3	4.0	4.2	0.0	3.1	55.2
3	Liyayi	11.2	0.0	1.0	1.0	2.0	3.7	0.0	3.7	111.8
4	Mayombe	7.1	1.0	2.9	2.5	2.0	17.4	0.0	6.4	97.1
5	Muzuri	10.0	1.0	1.0	1.4	3.0	4.6	0.0	3.9	89.4
6	Mvuama	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.2	204.1
7	Ngandajika	8.1	1.0	1.7	1.8	1.0	5.1	0.0	3.5	82.5
8	Nsansi	8.4	1.0	1.4	1.5	2.0	5.4	0.0	3.7	80.6
9	Obama1	3.4	1.0	1.2	1.1	2.0	4.1	0.0	2.4	55.2
10	Obama2	5.1	0.0	0.0	1.8	2.0	4.4	0.0	2.7	79.5
	$Mean_b$	**6.8**	**1.5**	**1.5**	**1.6**	**2.0**	**6.2**	**0.0**	**3.5**	**72.0**
	CV (%)	**52.4**	**38.7**	**58.7**	**41.4**	**45.8**	**72.7**	**NA**	**44.4**	**28.6**

Our results show that CBSD and CMD incidences were highly (p<0.0001) positive (R^2= 0.83 and R^2= 0.96) correlated to CBSD and CMD severities on leaves. This relationship was also observed between CBSD incidence and CBSD severity (R^2= 0.83) on roots. Whereas, fairly positive relationship was obtained between the CBSD incidence on roots and CBSD severity on leaves (r = 0.13 to r = 0.52). Moreover, negative correlations were obtained between the CBSD and CMD incidences and severities on leaves and the abundance of whitefly per plant (r = -0.13 and r = -0.19) and (r = -0.06 and r = -0.06) correspondingly (Figure 2 A).

Our observations corroborate results found by Muhindo *et al*. (2020a) which found that the abundance of whiteflies was not in direct relationship with the CBSD and CMD incidences. On the other hand, Njoroge *et al*. (2017) concluded that the higher density (20 to 25 individuals) of whiteflies led to the higher transmission of the diseases. This statement highlights that the origin of the plant infection of the ten exotic cultivars tested in our study does not come from whitefly transmission but from cultivar sensitivity.

The analysis of our results shows that the production in terms of percentage of marketable tubers was as ranged from cultivar 'Mayombe' (74.9%), 'Obama 1' (70.3%), 'Obama 2' (69.9%) and 'Ngandajika' (65.3%). The effect of the CBSD on this cassava yield of all the tested cultivars got output loss that varied by cultivars. The most leading of these improved cultivars that got great loss were the cultivars 'Butamu' (85%), 'Mvuama' (70.8%) and 'Muzuri' (64.3%) (Table 5).

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Table 5. CBSD foliar, stem and root incidences and severities (from 12 to 14 MAP) and root weight and yield and loss of ten cassava cultivars

Site	Cultivars	F	CBSD Incidence (%)			CBSD Severity (1-5)			TNR	Weight (Kg)			Yield (t/ha)			%Loss
			Foliar	Stem	Root	Foliar	Stem	Root		NMR	MR	TRW	TNR	MR	%MR	
Cimestan	Bomengo	3	1.0	0.0	0.0	2.0	1.0	2.1	4.6	0.22	0.16	0.38	5.2	4.0	65.3	57.9
	Butamu	3	0.9	0.0	0.0	1.9	1.0	2.0	2.3	0.15	0.03	0.18	1.6	0.5	14.1	83.3
	Liyayi	3	1.0	0.7	0.7	2.0	1.7	1.8	3.9	0.23	0.15	0.38	4.9	3.4	57.7	60.5
	Mayombe	3	0.9	0.0	0.0	1.9	1.0	2.2	6.5	0.33	0.28	0.61	13.0	11.7	74.5	54.1
	Muzuri	3	1.0	0.2	0.2	2.4	1.2	2.1	4.3	0.21	0.13	0.34	5.1	3.6	42.6	61.8
	Mvuama	3	0.9	0.0	0.0	1.9	1.0	1.7	4.4	0.18	0.06	0.24	4.2	2.1	28.9	75.0
	Ngandajika	3	0.7	0.0	0.0	1.7	1.0	2.2	5.1	0.32	0.22	0.54	8.6	6.7	65.3	59.3
	Nsansi	3	1.0	0.0	0.0	2.0	1.0	2.1	3.6	0.21	0.11	0.32	3.4	1.5	34.3	65.6
	Obama1	3	0.9	0.2	0.2	1.9	1.2	2.4	5.2	0.36	0.28	0.64	10.2	7.8	68.3	56.3
	Obama2	3	0.9	0.1	0.1	1.9	1.1	2.3	4.7	0.40	0.33	0.73	9.8	8.4	68.8	54.8
	Mean[b]		**0.9**	**0.1**	**0.1**	**1.9**	**1.1**	**2.1**	**4.5**	**0.26**	**0.18**	**0.44**	**6.6**	**5.0**	**52.0**	**59.1**
	CV (%)		**26.8**	**275.9**	**275.9**	**16.9**	**28.8**	**28.9**	**60.8**	**61.4**	**112.3**	**173.7**	**106.9**	**143.4**	**85.0**	**35.3**
Lindi	Bomengo	3	0.8	0.0	0.0	1.8	1.0	2.2	4.0	0.31	0.24	0.55	6.4	5.0	66.7	56.4
	Butamu	3	1.0	0.0	0.0	2.3	1.0	2.2	2.6	0.13	0.02	0.15	1.6	0.3	11.4	86.7
	Liyayi	3	1.0	0.7	0.7	2.1	1.7	2.1	4.3	0.31	0.21	0.52	6.6	4.4	58.9	59.6
	Mayombe	3	0.9	0.0	0.0	2.0	1.0	2.3	5.7	0.39	0.34	0.73	13.1	12.0	75.3	53.4
	Muzuri	3	1.0	0.2	0.2	2.6	1.2	2.5	4.1	0.24	0.12	0.36	5.6	3.6	37.7	66.7
	Mvuama	3	0.6	0.0	0.0	1.6	1.0	2.0	4.2	0.22	0.11	0.33	4.5	2.5	33.3	66.7
	Ngandajika	3	0.7	0.0	0.0	1.7	1.0	2.3	4.8	0.35	0.25	0.60	8.7	6.7	65.2	58.3
	Nsansi	3	1.0	0.0	0.0	2.0	1.0	2.4	3.6	0.21	0.12	0.33	3.7	2.1	47.6	63.6
	Obama1	3	0.9	0.3	0.3	2.1	1.3	2.5	5.5	0.38	0.28	0.66	11.1	8.0	72.3	57.6
	Obama2	3	0.9	0.1	0.1	2.1	1.1	2.3	4.9	0.47	0.39	0.86	12.1	10.2	71.1	54.7
	Mean[b]		**0.9**	**0.1**	**0.1**	**2.0**	**1.1**	**2.3**	**4.4**	**0.30**	**0.21**	**0.51**	**7.3**	**5.5**	**53.9**	**58.8**
	CV (%)		**37.4**	**262.0**	**262.0**	**25.6**	**29.7**	**28.3**	**50.0**	**65.1**	**106.0**	**171.1**	**97.3**	**129.8**	**78.0**	**38.0**

Notes: F= Frequency; TNR= Total Number of Root; NMR=Not Marketable Root; MR=Marketable Root, TRW=Total Root Weight, %MR=Percentage of Marketable Root, %Loss=Percentage of Loss; CV=Coefficient of Variation

The marketable roots yield was then more reduced according to the presence of CBSD necrosis in the pulp of the tuberous roots of all the tested cultivars. This reduction is also linked to the fact that the marketable root yield was slightly positive correlated (r = 0.18) to the CBSD necrosis severity for all the cultivar roots that has attained severity score 4 at 14 MAP and reduced the output (< 5t/ha) of these cultivar tuberoses roots (Figure 2 and 3). The visible negative effect of the CBSD on this cassava yield of all the tested cultivars got important output loss because of the fact that these roots became nonedible and nonmarketable roots.

In determining of the moment of harvest of cassava in order to minimize losses due to CBSD, results from this work showed that from 9 to 14 MAP all the tested exotic cassava cultivars were infected. This root infection was characterized by a spot necrotic of 10-50% necrotic tissue of the cassava tuberous roots. Thus, these cultivars could be harvested by 9 MAP a favorable moment also identified by Muhindo *et al*, (2020a) in Yangambi, DRC. Results from this work agree with those found by Kanju *et al*. (2019) which found that the best moment (12 MAP) for harvesting cassava under the CBSD-infected conditions of Uganda.

Multi-local studies through the various agro-ecological zones are also recommended to determine the total response of these cassava genotypes for virus infections.

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Declaration

The authors declare that they have any conflicts of interest.

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