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Optimum Time for Harvesting Cassava Tubers to Reduce Losses Due to Cassava Brown Streak Disease in Northeastern DRC

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Abstract

The present study aimed to determine the appropriate time to harvest cassava tuberous root which minimize the losses due to cassava brown streak disease (CBSD) in the region of Yangambi, DRC. To achieve the aim of the study, 38 cassava cultivars were evaluated in Yangambi INERA's Research Center for CBSD in the roots at harvest time between 9 and 13 months after planting (MAP). All the 38 cultivars tested showed CBSD root necrosis symptoms. Foliar symptoms occurred on 37.6% of the evaluated cultivars while CBSD root necrosis varied significantly among cultivars (7.0% to 82.5%) depending on susceptibility and the age of plant. This indicates the differential response of the cultivars to CBSD infection.

Whitefly population density decreased with age of cassava, it was of 3 whiteflies per plant (9 MAP) to 1 (10 MAP). We noticed that in older plants, whitefly population decreased from 1 at 11 MAP to none at 13 MAP. Although, some cultivars did not show CBSD symptoms up to 12 MAP, they were not necessarily less attractive to whitefly. Negative relationship ($r = -0.08$ and $r = -0.25$) has been found between whitefly number and foliar symptom severity or between whitefly and tuber necrosis severity. Beyond 12 MAP, CBSD necrosis (severity score 4) was present in the tubers of 3 cultivars (EUR/2011/0148, Yafelamonene and Ybi/2011/258). Our study shows that in order to mitigate the losses due to CBSD necrosis, the optimum harvesting time for cassava tubers in Yangambi is 9 MAP.

Keywords: *Manihot esculenta* Crantz, CBSD, disease severity, time of harvesting, Yangambi

1. Introduction

Cassava (*Manihot esculenta* Crantz) is a staple crop in Sub-Saharan Africa (FAOSTAT, 2009; Monde et al., 2013). In the Democratic Republic of Congo (DRC), cassava is economically important as it is a basic food for 70% of population, who consume both the leaves and the tubers (Molongo et al., 2015; Monde et al., 2013; Akinpelu et al., 2012). Cassava tubers harvest can take place between 9 and 12 months after planting (Monde et al., 2012), but in spite of this time range and its adaptability to pedoclimatic conditions, cassava yields in DRC remain low at < 5 t/ha (Vanlauwe et al., 2011). Cassava brown streak disease (CBSD), cassava mosaic disease (CMD) and bacterial diseases are the principal causes of low yields in DRC (Bakelana et al., 2018; Ingbabona, 2015; Legg et al., 2007).

CBSD is caused by two viruses belonging to the *Ipomovirus* genus, *Potyviridae* family. These viruses have been identified as cassava brown streak virus (CBSV) and Ugandan cassava brown streak virus (UCBSV) (Winter et al., 2010; Alicai et al., 2007; Monger et al., 2001). This viral pandemic was first described by Storey (1936) in Tanzania. In DRC, CBSD was first reported by Mahungu et al. (2003). Recently, both CBSV and UCBSV have been identified in DRC (Casinga et al., 2018; Mulimbi et al., 2012). The CBSV spread is attributed mainly to the use of infected cassava cuttings, although whitefly may also be a source of infection (Njoroge et al., 2017;

Ntawuruhunga & Legg, 2007; Thresh et al., 1994). However, Hillocks et al. (1996) also pointed out that CBSD can be difficult to detect because plants affected may not exhibit foliar symptoms even when tuber necrosis is present. Conversely, foliar symptoms are not always indicative of brown streaks on stems or tuber necrosis. The instable variation frequently observed in CBSD symptoms depends to several factors comprising plant age, cultivar (genotype), environmental conditions (altitude, temperature and rainfall) and virus species (Okul Valentor et al., 2018; Masinde et al., 2016; Mohammed et al., 2012; Hillocks & Jennings, 2003; Monger at al., 2001). CBSD symptoms include yellow-green margins or spots on mature leaves; on tubers the symptoms can appear as necrotic brownish or black tissues in the tuberous root pulp and may include constrictions on the tubers (Bakelana et al., 2018). Necrosis and constrictions due to CBSD are the two symptoms that have an economic impact on cassava production as studied by Masinde et al. (2016) in Kenya and Hillocks et al. (2015) in Tanzania, Uganda, Kenya and Malawi. The necrotic rots not only result in cassava losses in terms of produce harvested, but they also impact produce quality as they make the tubers unfit for human consumption (Bakelana et al., 2018; Hillocks et al., 2015). In the Northeastern region of DRC most affected by CBSD, farmers lose a great part of tuberous production at the harvest which is done generally at 12 months after planting (MAP).

This study aimed to determine the most favorable time for harvesting cassava tubers to minimize losses due to CBSD in DRC. Nonetheless similar studies have been done in other African countries for the same purpose which is to minimize tubers losses due to CBSD at harvest by Kanju et al. (2019, 2012), Ewa et al. (2017), Masinde et al. (2016), Hillocks et al. (2015, 2001), Kaweesi et al. (2014), Abaca et al. (2012), Benesi et al. (2008), Egesi et al. (2007), and Nichols (1950). Additionally to finding the right time to harvest cassava in the 12-month growing cycle can mitigate losses to CBSD, we hypothesized that the best time to harvest cassava tubers might be 9 MAP.

2. Materials and Methods

The study was conducted as part of research program at the National Cassava Program at INERA Research Center of Yangambi. Yangambi is in the equatorial climate type A_f according to Koppen classification. The geo-coordinates of the trial site were as follows: Lat/Long 0.82297222, 24.4665278 and 412 m Alt (Figure 1).

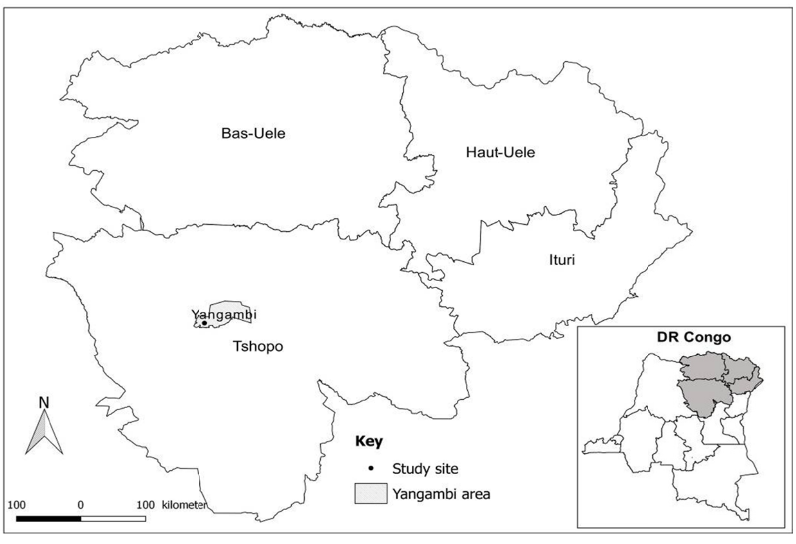

Figure 1. Map of Yangambi in northeastern DRC

Thirty eight (38) cultivars of cassava at INERA Yangambi were assessed in situ to determine the most favorable harvesting time. These comprised 4 local cultivars from farmers in Yangambi area with indigenous names and 34 improved cultivars from the International Institute of Tropical Agriculture (IITA) and the National Cassava Program of INERA DRC which were tested. Thirty four IITA genotypes were introduced in DRC in 1998/2004 through seeds and tissue culture plantlets. Then the National Cassava Program of INERA DRC implemented crossing through clonal trial and preliminary yield trial. Improved and local cultivars planting materials were obtained from the germplasm maintenance field at Yangambi with no visible CBSD symptoms prior to planting. One cultivar highly CBSD-susceptible Ybi/2011/258 (Figure 2) was used as positive control (Kaweesi et al., 2014).

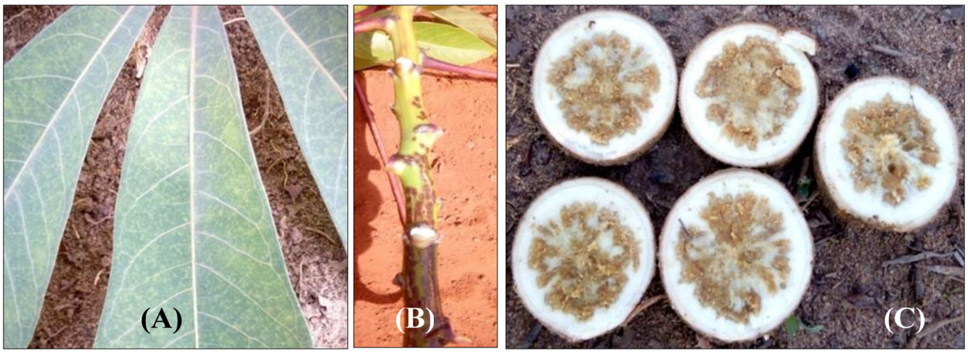

Figure 2. Typical CBSD associated symptoms on leaves (A), stem (B) and tuber pulp (C) on Ybi/2011/258 cultivar used as positive control in the trial

The trial plots were set up from March 2017 to March 2018 (season A) and from November 2018 to November 2019 (season B) using the Abaca et al. (2012), Kanju et al. (2019) randomized completely block design with three replicates. Each block of 456 plants measured 600 m² (long 40 m × 15 m width). Each row comprised 12 plants corresponding to a variety to be tested. Planting configuration was 1 m × 1 m. The blocks were set 1.5 m apart. Stem cuttings of Ybi/2011/258 used in the spreader rows were obtained in field that had CBSD incidence of 98% and a mean severity of 4 and 4.5 for shoot and root respectively (Kaweesi et al., 2014). The parameters assessed, adapted from Hillocks and Tresh (2000), Sseruwagi et al. (2004), and Kanju et al. (2019) for cassava leaves and tubers, were CBSD incidence, CBSD severity and whitefly abundance per variety. Incidence was calculated as follows:

$$\text{Incidence (\%)} = \text{Number of plants displaying CBSD/Total number of observed plants} \times 100 \quad (1)$$

For CBSD severity assessment, we used a scale of 1 to 5 as described in Hillocks et al. (1996), Gondwe et al. (2003), and Alicai et al. (2016). These scores are illustrated in Figure 3.

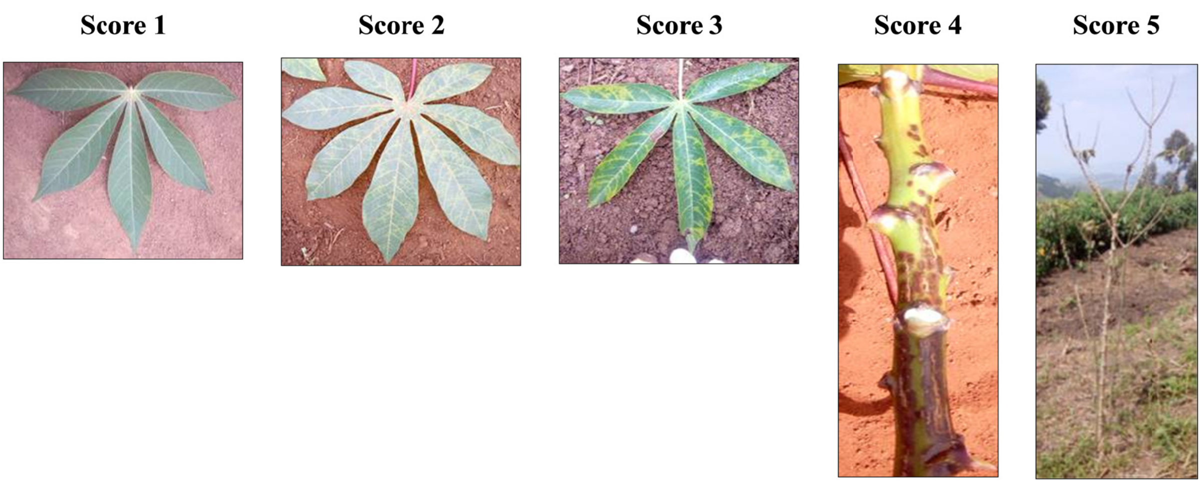

Figure 3. CBSD severity scale (1-5) on cassava leaves; 1 = no visible symptoms, 2 = mild vein yellowing or chlorotic blotches on some leaves, 3 = pronounced/extensive vein yellowing or chlorotic blotches on leaves, but no lesions or streaks on stems, 4 = pronounced/extensive vein yellowing or chlorotic blotches on leaves and mild lesions or streaks on stems, 5 = pronounced/extensive vein yellowing or chlorotic blotches on leaves and severe lesions or streaks on stems, defoliation and dieback (Hillocks et al., 1996; Alicai et al., 2016). Legend: Score from 1 to 5 are CBSD severity deferent level on leaves and stems

Whitefly population was determined through a systematic monthly whitefly counted on the 5 top young leaves.

From 9 to 13 months after planting (MAP), 3 plants per cultivar were systematically uprooted for visual CBSD investigation (Legg et al., 2017). Besides checking for constriction, the uprooted tubers were dissected transversely (using a slicing knife) to check for typical necrosis in the pulp. The necrosis severity scale described by Gondwe et al. (2003) was used for that assessment. This root necrosis severity scale is illustrated in Figure 4. Visual symptomatology used was confirmed by molecular diagnostic in NaCRRI virology Laboratory in Uganda.

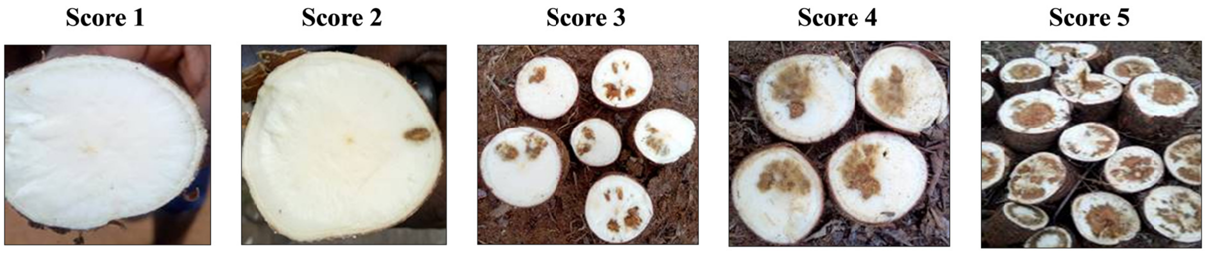

Figure 4. CBSD severity scale (1-5) on cassava tuberous root; 1 = No root symptoms; 2 = Less than 5% tissue necrosis tissue; 3 = 5-10% tissue necrosis; 4 = 10-50% tissue necrosis; 5 = More than 50% tissue necrosis (Gondwe et al., 2003). Legend: Score from 1 to 5 are CBSD severity deferent level on tuber pulp

Statistical analysis was carried out using the R statistical software version 3.4.0 (R Development Core Team, 2010) and included an ANOVA and multiple comparison of means using the Tukey test.

3. Results

Our 38 cultivars investigated for their response to CBSD during growth periods between 9 and 13 map, our results show that all the 38 cultivars (100%) developed various symptoms of CBSD at various growth periods on leaves and tubers. We found also that average CBSD tuber necrosis incidence varied significantly ($p < 0.001$) among these 38 cultivars, ranging from 7.0% to 82.5% (Table 1). Similarly, tuber necrosis severity was significantly ($p < 0.001$) different among cultivars, scores ranging from 2.0 to 4.6 (Table 1).

Table 1. Mean CBSD foliar and tuber incidence and severity and adult whiteflies per cultivar; N: number of cassava plants inspected per cultivar

No.	Cultivar	Cultivar status	N	CBSD foliar Inc. (%)	CBSD foliar Sev. (1-5)	CBSD tubers Inc. (%)	CBSD tubers Sev. (1-5)	Average No. whitefly
1	Bobalatata	Local	4	3.2	2.3	35.0	2.3	1.3
2	Itchatchabindo	Local	1	3.2	3.0	67.5	2.0	1.5
3	Kotumbakotumba	Local	1	3.2	2.0	67.5	2.0	1.0
4	Yafelamonene	Local	3	3.2	2.0	25.7	3.3	1.0
5	Disanka	Improved	3	3.2	2.7	45.7	2.3	4.0
6	EC/2014/004	Improved	1	3.2	2.0	7.0	3.0	0.0
7	EC/2014/010	Improved	4	3.2	3.0	36.1	2.5	1.5
8	EC/2014/0115	Improved	5	3.2	2.2	34.4	2.2	1.5
9	EC/2014/015	Improved	1	3.2	2.0	7.0	3.0	0.0
10	EC/2014/023	Improved	4	3.2	2.5	35.0	2.3	1.5
11	EC/2014/031	Improved	1	3.2	2.0	7.0	3.0	0.0
12	EC/2014/034	Improved	3	3.2	2.3	45.7	2.3	2.0
13	EC/2014/05	Improved	1	3.2	2.0	7.0	3.0	0.0
14	EC/2014/055	Improved	4	3.2	2.5	35.0	2.3	1.5
15	EC/2014/061	Improved	4	3.2	2.5	41.3	2.8	1.5
16	EPR/2015/017	Improved	3	3.2	2.3	31.7	2.7	2.0
17	EPR/2015/043	Improved	3	3.2	2.7	45.7	2.3	1.7
18	EPR/2015/052	Improved	3	3.2	3.0	45.7	2.3	1.3
19	EPR/2015/060	Improved	4	3.2	2.3	34.9	3.3	7.0
20	EPR/2015/082	Improved	1	3.2	3.0	67.5	2.0	2.0
21	EPR/2015/096	Improved	2	3.2	2.5	47.5	2.5	2.0
22	EUR/2011/0148	Improved	1	3.2	2.0	7.0	4.0	0.0
23	Lueki	Improved	1	3.2	3.0	27.5	3.0	2.0
24	Mahungu	Improved	3	3.2	2.3	45.7	2.3	2.0
25	Mvuama	Improved	4	3.2	2.5	40.1	2.3	1.3
26	MVZ/2012/030	Improved	4	3.2	2.5	35.0	2.3	1.5
27	MVZA/0015	Improved	3	3.2	2.3	45.7	2.3	4.5
28	MVZB/0015	Improved	4	3.2	2.3	35.0	2.3	1.3
29	Obama 1	Improved	3	3.2	2.7	52.5	2.3	2.0
30	Obama 2	Improved	4	3.2	2.5	40.1	2.3	1.3
31	PM/Ybi/01	Improved	1	3.2	2.0	7.0	3.0	0.0
32	PM/Ybi/032	Improved	4	3.2	2.3	35.0	2.3	5.7
33	Rav	Improved	4	3.2	2.5	40.1	2.3	4.5
34	Sawasawa	Improved	4	3.2	2.5	24.5	2.8	2.0
35	Vuvu	Improved	5	3.2	2.6	34.0	3.0	3.0
36	Winner	Improved	4	3.2	3.0	40.1	2.3	1.3
37	Ybi/2011/0184	Improved	1	3.2	3.0	67.5	2.0	3.3
38	Ybi/2011/258	Improved	5	3.2	3.0	82.5	4.6	0.0
Average				3.2	2.4	37.6	2.6	2.3
CV (%)				4.2	14.4	46.9	21.6	30.4

3.1 CBSD Incidence

CBSD foliar symptoms were observed on both all of the local and the improved genotypes. Differences in the average disease incidence did not vary (3.2%) among the 38 varieties (Table 1, 2). However, incidence of root necrosis varied significantly ($p < 0.01$) among varieties ranging from 7.0% to 82.5% (Table 1) and from 7% to 66% from 10 to 12 map respectively (Table 2). We also found that six (15.8%) of the improved genotypes had low CBSD root incidence (7.0%) nonetheless they displayed high necrosis severity: EC/2014/004, EC/2014/015, EC/2014/0031, EC/2014/05, PM/Ybi/01 (score 3.0 respectively) and EUR/2011/0148 (score 4.0).

Table 2. CBSD foliar and tuber incidence and severity, and adult whiteflies by harvest time

MAP	CBSD foliar		CBSD tuber		Adult whiteflies
	Incidence (%)	**Severity (1-5)**	**Incidence (%)**	**Severity (1-5)**	
9	$3.2±0.0_{ab}$	$2.0±0.0_{ab}$	$13.3±14.4_{ab}$	$2.2±0.6_{ab}$	$3.0±1.6_{ab}$
10	$3.2±0.0_{a}$	$2.6±0.6_{a}$	$7.0±8.9_{a}$	$2.5±0.9_{a}$	$3.0±1.6_{a}$
11	$3.2±0.0_{a}$	$2.4±0.5_{a}$	$62.5±0.0_{a}$	$2.2±0.6_{a}$	$1.0±0.4_{a}$
12	$3.2±0.0_{a}$	$2.5±0.5_{a}$	$66.0±11.7_{a}$	$2.3±0.7_{a}$	$0.0±0.0_{a}$
13	$3.2±0.0_{b}$	$2.5±0.6_{b}$	$16.2±16.7_{b}$	$3.2±0.5_{b}$	$0.0±0.0_{b}$

Note. MAP = Month after planting. ab, a, b letter indicating the high significance difference at $P < 0.001$.

3.2 CBSD Severity

The mean foliar CBSD severity scores varied significantly ($p < 0.01$) among varieties ranging from 2.0 to 3.0. The lowest foliar CBSD severity score (2.0) was observed in two local varieties (Kotumbakotumba and Yafelamonene) and the six improved landraces here above cited to display high necrosis se severity: EC/2014/004, EC/2014/015, EC/2014/0031, EC/2014/05, EUR/2011/0148 and PM/Ybi/01 (Table 1). The root necrosis severity scores were significantly ($p < 0.01$) different among varieties ranging from 2.0 to 4.6 (Table 1). The lowest severity root necrosis (score 2.0) was observed for the varieties: Itchatchabindo, Kotumbakotumba, Ybi/2011/0184 whereas, highest was observed in the genotypes: EUR/2011/0148, Yafelamonene and Ybi/2011/258 (Table 1). Cassava brown streak necrosis severity average on tubers (Table 3) varied from 2 to 3 with the age of the plant (from 9 to 13 MAP).

Table 3. Favorable harvesting time for cassava tubers by cultivar

Harvesting time	**Tolerable CBSD severity score**	**Harvestable cultivars with moderate tuber necrosis**	**Non-harvestable cultivars with severe tuber necrosis**	**Non-harvestable CBSD severity score**	**Number of harvestable cultivars**
9 MAP	2	All cultivars may be harvested	Ybi/2011/258, Vuvu (TMS/94/0330), EC/2014/0115	S: 3	35/38
10 MAP	2	Mvuama, Obama1, Obama2, Yafelamonene, EPR/2015/017, EUR/2011/0148, PM/Ybi/01, Ybi/2011/184, Lueki, Sawasawa, Bobalatata, Disanka, EC/2014/004, EC/2014/015, EC/2014/023, EC/2014/031, EC/2014/034, EC/2014/05, EC/2014/055, EPR/2015/043, EPR/2015/052, EPR/2015/082, EPR/2015/096, Itchatchabindo, Kotumbakotumba, Mahungu, MVZ/2012/030, MVZA/0015, MVZB/0015, PM/Ybi/032, Rav, Winner	Ybi/2011/258, Vuvu (TMS/94/0330), EC/2014/0115, EC/2014/010, EC/2014/061, EPR/2015/060	S: 3-4	32/38
11 MAP	2	EPR/2015/017, EUR/2011/0148, PM/Ybi/01, Ybi/2011/184, Lueki, Sawasawa, Bobalatata, Disanka, EC/2014/004, EC/2014/015, EC/2014/023, EC/2014/031, EC/2014/034, EC/2014/05, EC/2014/055, EPR/2015/043, EPR/2015/052, EPR/2015/082, EPR/2015/096, Itchatchabindo, Kotumbakotumba, Mahungu, MVZ/2012/030, MVZA/0015, MVZB/0015, PM/Ybi/032, Rav, Winner	Ybi/2011/258, Vuvu (TMS/94/0330), EC/2014/0115, EC/2014/010, EC/2014/061, EPR/2015/060, Mvuama, Obama1, Obama2, Yafelamonene	S: 3-5	30/38
12 MAP	2	Bobalatata, Disanka, EC/2014/004, EC/2014/015, EC/2014/023, EC/2014/031, EC/2014/034, EC/2014/05, EC/2014/055, EPR/2015/043, EPR/2015/052, EPR/2015/082, EPR/2015/096, Itchatchabindo, Kotumbakotumba, Mahungu, MVZ/2012/030, MVZA/0015, MVZB/0015, PM/Ybi/032, Rav, Winner	Ybi/2011/258, Vuvu (TMS/94/0330), EC/2014/0115, EC/2014/010, EC/2014/061, EPR/2015/060, Mvuama, Obama1, Obama2, Yafelamonene, EPR/2015/017, EUR/2011/0148, PM/Ybi/01, Ybi/2011/184, Lueki, Sawasawa	S: 3-5	22/38
13 MAP	2	None	Ybi/2011/258, Vuvu (TMS/94/0330), EC/2014/0115, EC/2014/010, EC/2014/061, EPR/2015/060, Mvuama, Obama1, Obama2, Yafelamonene, EPR/2015/017, EUR/2011/0148, PM/Ybi/01, Ybi/2011/184, Lueki, Sawasawa, Bobalatata, Disanka, EC/2014/004, EC/2014/015, EC/2014/023, EC/2014/031, EC/2014/034, EC/2014/05, EC/2014/055, EPR/2015/043, EPR/2015/052, EPR/2015/082, EPR/2015/096, Itchatchabindo, Kotumbakotumba, Mahungu, MVZ/2012/030, MVZA/0015, MVZB/0015, PM/Ybi/032, Rav, Winner	S: 3-5	0/38

Very high positive correlation (from r = 0.74 to r = 0.71 at $p < 0.01$) was obtained between root incidence and root severity and between foliar incidence and foliar severity. Additionally, there was a moderate correlation (r = 0.54, $p < 0.05$) between CBSD foliar incidence and root incidence. No significant correlation (r = 0.07, $p < 0.05$) was found between CBSD foliar incidence, and there was negative correlation (r = - 0.08, $p < 0.05$) between foliar severity and whitefly number (Table 4).

Table 4. Spearman correlation between CBSD foliar necrosis incidence, foliar necrosis severity, tuber necrosis incidence, tuber necrosis severity and the abundance of whiteflies

Variables	**Foliar chlorosis incidence**	**Foliar chlorosis severity**	**Whitefly abundance**	**Tuber necrosis incidence**	**Tuber necrosis severity**
Foliar chlorosis incidence	1	0.71^{***}	0.07^{ns}	0.54^{**}	0.50^{**}
Foliar chlorosis severity	0.71^{***}	1	-0.08^{*}	0.61^{***}	0.67^{***}
Whitefly abundance	0.07^{ns}	-0.08^{*}	1	-0.28^{*}	-0.25^{*}
Tuber necrosis incidence	0.54^{**}	0.61^{***}	-0.28^{*}	1	0.74^{***}
Tuber necrosis severity	0.50^{**}	0.67^{***}	-0.25^{*}	0.74^{***}	1

Note. ***: Correlation significant at p < 0.01 level; **: Correlation significant at p < 0.05 level; *: negative correlation; ns: non-significant correlation.

3.3 Favorable Moment for Harvesting Cassava Tubers

Our data in Tables 3 and 1 show that gradually all the cassava cultivars developed tuber necrosis symptoms from 9 to 13 MAP. Our results in table 3 show that at 9 MAP, 35 of the 38 cultivars produce the best yield (CBSD severity score 1). Exceptions to this are the remaining 3 cultivars exhibiting disease, namely Ybi/2011/258 (severity score 3), Vuvu (TMS/94/0330) and EC/2014/0115 (both with severity score 2).

At 10 MAP, 32 of the 38 cultivars were acceptable candidates for harvesting (Table 3). Their edible quality was moderately affected by their tuber severity score of 2. These 32 cultivars were Mvuama, Obama1 (TME 419), Obama2 (MV/2001/014), Yafelamonene, EPR/2015/017, EUR/2011/0148, PM/Ybi/01, Ybi/2011/184, Lueki (TMS/91/377), Sawasawa, Bobalatata, Disanka, EC/2014/004, EC/2014/015, EC/2014/023, EC/2014/031, EC/2014/034, EC/2014/05, EC/2014/055, EPR/2015/043, EPR/2015/052, EPR/2015/082, EPR/2015/096, Itchatchabindo, Kotumbakotumba, Mahungu (TMS/92/297), MVZ/2012/030, MVZA/0015, MVZB/0015, PM/Ybi/032, RAV and Winner (TMS/01/1229).

At 11 MAP, 28 of the 38 cultivars could be harvested, as they retained their root severity score of 1 to 2. These 28 cultivars were EPR/2015/017, EUR/2011/0148, PM/Ybi/01, Ybi/2011/184, Lueki, Sawasawa, Bobalatata, Disanka, EC/2014/004, EC/2014/015, EC/2014/023, EC/2014/031, EC/2014/034, EC/2014/05, EC/2014/055, EPR/2015/043, EPR/2015/052, EPR/2015/082, EPR/2015/096, Itchatchabindo, Kotumbakotumba, Mahungu, MVZ/2012/030, MVZA/0015, MVZB/0015, PM/Ybi/032, RAV and Winner (Table 3).

At 12 MAP, 22 of the 38 cultivars could be harvested (Table 3). The cultivars Bobalatata, Disanka, EC/2014/004, EC/2014/015, EC/2014/023, EC/2014/031, EC/2014/034, EC/2014/05, EC/2014/055, EPR/2015/043, EPR/2015/052, EPR/2015/082, EPR/2015/096, Itchatchabindo, Kotumbakotumba, Mahungu, MVZ/2012/030, MVZA/0015, MVZB/0015, PM/Ybi/032, RAV and Winner kept their quality for harvest. Beyond 12 MAP, we found that CBSD was present in the tubers of all the 38 cultivars tested (average root severity score 4).

At 13 MAP, 38 of the 38 cassava cultivars assessed had exhibited severe necrosis in their tubers (score 3 to 5), thus making them non-harvestable and unsuitable for human consumption. Consequently, the optimum harvest time for cassava tubers under Yangambi conditions is deemed to be 9 MAP (Table 3).

3.4 Whitefly Abundance per Cassava Plant

Table 1 shows that the cultivars which attracted a high density of whiteflies were MVZB/0015 (3 whiteflies/plant) followed by PM/Ybi/032, EC/2014/0115, Obama2 and Vuvu (TMS/94/0330) (2 whiteflies/plant respectively). During our investigations, we noted that the average whitefly population decreased from 1 (at 11 MAP) to zero (at 13 MAP) whiteflies per plant (Table 2). The above results suggest that the cultivar type is the one factor influencing the whitefly abundance.

4. Discussion

The principal objective of this study was to determine the most favorable time after planting to harvest cassava tubers in order to reduce CBSD losses. To achieve this, we assessed CBSD incidence and severity, using five harvesting times (9, 10, 11, 12, 13 MAP) on 4 local and 34 improved cultivars. Trial wasconducted in Yangambi Research Station during 2 seasons (from March 2017/2018 to November 2018/2019).

The important finding from this study showed that from 9 to 12 MAP, tubers CBSD incidence varied significantly (7.0% to 66% respectively), and foliar CBSD incidence did not vary and remained at 3.2%. Furthermore necrosis severity on tubers also varied, from score 2 to score 3. This implies that the harvesting time is influenced by the disease spread and is enhanced symptom severity in the roots. This situation might be explained by the factors that affect tuber CBSD necrosis which might have been affected by plant age, the cultivar (genotype) and environmental variations like rainfall, altitude, temperature, and soil conditions (Kaweesi et al., 2014; Mbanzibwa, 2011; Hillocks & Jennings, 2003; Nichols, 1950; Storey, 1936). At the other hand, relatively low temperatures that occur at high altitude areas (> 3500 feet) during winter can result in severe CBSD symptoms manifestation and eventually death of plants—as observed by Nichols (1950). Based on our study, we think that the high relative temperature (high temperature 33.5 °C) that occurs in Yangambi, the low altitude (400 m) zone could account for the reduction in foliar chlorosis. The significant difference in time of harvesting found in Uganda by Kanju et al. (2019), and by Kaweesi et al. (2014) is similar to the finding from our work. Previous studies had indicated that there can be variation in cultivar response to CBSV infection (Hillocks & Jennings, 2003; Calvert & Thresh, 2002).

The mean foliar CBSD severity scores varied significantly ($p < 0.01$) among both local and improved varieties ranging from 2.0 to 3.0. The root necrosis severity scores were significantly ($p < 0.01$) different among varieties ranging from 2.0 to 4.6. Furthermore, we found that six (15.8%) of the improved varieties had low CBSD root incidence (7.0%) when they displayed higher necrosis severity: EC/2014/004, EC/2014/015, EC/2014/0031, EC/2014/05, PM/Ybi/01 (score 3.0 respectively) and EUR/2011/0148 (score 4.0). This variation may be due to the low titer of the virus and on the other hand, to the susceptibility of the varieties to be infected. These results are in part similar to those observed by Abaca et al. (2012) in Uganda for severity of foliar and root necrosis which significantly differed among varieties. However, our results confirm the assumption that the symptoms generated by CBSD vary considerably according to the sensitivity of the cultivar (Kanju et al., 2019; Kaweesi et al., 2014; Abaca et al., 2012). With respect to the optimum time for harvesting cassava tubers and the cropping system practiced (association of many cassava varieties on the same land portion), the most important finding from our results show that cassava should be harvested at 9 months after planting due to the low level of tuber necrosis (severity score 1)—except for the improved cultivars, Ybi/2011/258, Vuvu (TMS/94/0330) and EC/2014/0115.

Beyond 9 MAP, the number of harvestable cultivars decreased noticeably, from 32 at 10 MAP to 22 at 12 MAP (Table 3). Since the vegetative cycle for cassava is 12 MAP, this timeframe is the limit at which farmers can mitigate their losses to CBSD in the Yangambi region.

Beyond 12 MAP, all 38 cultivars displayed a high level of CBSD symptoms in their tubers (average severity score 4). At this stage, tubers are non-edible and non-marketable, leading to serious yield losses for farmers. Given the severe CBSD presence in Yangambi region, we recommend harvesting cassava tubers at 9 MAP.

Furthermore, our results show that the two following local and improved cultivars respectively, exhibited high CBSD foliar chlorosis (severity score 3.0) and less CBSD necrosis in tubers (severity score 2.0): Itchatchabindo, Ybi/2011/0184. It is known that tuber necrosis can be delayed in certain cultivars, such as Nanchinyaya, which was identified in Tanzania (Abaca et al., 2012), and AR40-6, and Namikonga also known as Kaleso (Kulembeka et al., 2012), in Uganda by Kaweesi et al. (2014) to display more foliar symptoms but no root symptoms. Tuber necrosis seems to appear after 5 or 6 MAP for the more susceptible cultivars, but in the case of Nanchinyaya, necrosis was delayed until 12 to 18 months (Bakelana et al., 2018). Thereafter, it is likely that also these cultivars from our work possess characters that will interest CBSD resistance breeding and developing varieties for specific adaptation to the infected region (Kanju et al., 2019; Kaweesi et al., 2014).

Our results showed that the number of whiteflies registered per plant varied considerably between the cultivars tested. Besides, the analysis of our results also shows that cultivars not displaying CBSD symptoms up to 12 MAP were not necessarily the less attractive to whitefly. Moreover, our data showed negative correlation ($r = -0.08$ and $r = -0.25$) between whitefly numbers found on the five top leaves of the cultivars studied and their foliar and root severity (Table 4). This finding may be explain by Van-Halder and Van-Helden (1986), who suggested that plant age may be a key determining factor in whitefly attraction. They will be useful to cassava breeders when considering CBSD-tolerant varieties and clones for wider distribution (Alicai et al., 2016)

In conclusion, the CBSD necrosis assessment outlined in this manuscript shows that the optimum harvest time for cassava tubers under Yangambi conditions is 9 MAP. This is the first field trial evaluation in DRC that has addressed the appropriate harvesting time for cassava tubers. Establishing the optimum time, by cultivar, will be useful for cassava growers in their efforts to minimize crop losses attributable to CBSD. In the longer term, this information can contribute towards developing a management strategy against CBSD in Africa.

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