Cassava Mosaic Disease Yield Loss Assessment under Various Altitude Agro-ecosystems in the Sud-Kivu Region, Democratic Republic of Congo

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Summary

Cassava mosaic disease (CMD) is reported as the most important constraint on cassava production in Sub-Saharan Africa. Yield losses of 25-95% are reported. The use of resistant genotypes is one of the components for its integrated management. However its impact on genotype behavior depends on infection period, age of the infected plants, environment and virus species or strain. This study was carried out to assess its impact in farmers' fields and the behavior of 14 genotypes under high epidemic pressure in the Sud-Kivu province, in the East of Democratic Republic of Congo (DRC). Early infections have induced 77.5% to 97.3% of yield losses whereas 44.9 to 80% were recorded for cassava plants infected during thirteenth to twenty-fourth weeks after planting. The highest yield losses were recorded in low altitude where more EACMV-UG and dual infections were reported. Improved resistant genotypes MM96/002, MM96/0157 and MM96/1920 allowed harvesting more than 30 T/ha and didn't show any symptoms whereas MM96/6967 and Mvuama have developed symptoms at harvest. Local landraces were susceptible to CMD and developed symptoms during the whole season until harvest. However two of them, Pharmakina and Cizinduka yielded more than 50 T/ha of tubers and associated symptoms were moderate. Two improved and two local cassava genotypes are recommended in this area always making sure to use healthy cuttings.

Résumé

Evaluation des pertes de rendements dues à la mosaïque africaine du manioc dans les agro-écosystèmes d'altitude au Sud-Kivu, République Démocratique du Congo

La mosaïque africaine du manioc est la principale contrainte à la production du manioc en Afrique Sub-saharienne. Le recours à l'utilisation des génotypes résistants et productifs est le moyen le plus utilisé dans la gestion de la maladie. Cependant, l'impact de celle-ci sur le comportement de la plante dépend de l'âge de la plante à l'infection, du génotype et des virus en présence. Une évaluation de l'impact en champs paysans ainsi que le comportement de quatorze génotypes en conditions de forte pression des maladies virales a été réalisée dans la province du Sud-Kivu, à l'est de la République Démocratique du Congo (RDC). Des infections précoces, durant les trois premiers mois de la culture, ont induit 77,5% à 97,3% des pertes de rendement alors que 44,9 à 80% des pertes ont été enregistrées lorsque l'infection a lieu plus tard. Les pertes les plus élevées sont enregistrées en basse altitude où sont signalées la prédominance des souches EACMV-UG et des taux élevés infections mixtes. Les génotypes améliorés MM96/002, MM96/0157 et MM96/1920 ont donné des rendements supérieurs à 30 tonnes à l'hectare sans manifester des signes de maladie jusqu'à la récolte. Les génotypes locaux Pharmakina et Cizinduka ont produit des rendements de l'ordre de 50 tonnes à l'hectare avec une sensibilité modérée à la maladie. Les génotypes améliorés et les deux génotypes locaux identifiés au cours de cette étude sont donc recommandables aux producteurs de la région, tout en restant attentif à la nécessité de ne diffuser que des matériels de plantation sains.

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Introduction

Cassava is a key food security crop in Africa and DR Congo as more than 60 percent of the population uses it as an important staple and cash crop. Cassava mosaic disease (CMD) is the most important constraint (9). Its causal agents have been described and recognized in what is now known as African Cassava Mosaic Virus (ACMV) and East African Cassava Mosaic Virus (EACMV) both from Family Geminiviridae, Genus Begomovirus (9). ACMV occurred in all cassava growing areas in Africa while EACMV was mainly encountered in Eastern Africa. During the 1990s, consequent to CMD pandemic observed in Uganda, detection and diagnosis studies revealed a new virus, the East African Cassava Mosaic Virus-Uganda (EACMV-UGV), a recombinant form between the ACMV and EACMV (17).

EACMV-UGV rapid spread associated to dual infections with ACMV and high vector population were described as the main factors driving the severe epidemic disease in several African countries (9).

Actually, eight CMBs are occurring in Sub-Saharan Africa, the African Cassava Mosaic Virus (ACMV)(7), the East African Cassava Mosaic Virus (EACMV) and EACMV-like strains (7, 9, 17), the East African Cassava Mosaic Cameroon Virus (EACMCV) (5), the East African Cassava Mosaic Malawi Virus (EACMMV) (18), the East African Cassava Mosaic Zanzibar Virus (EACMZV) (11), the South African Cassava Mosaic Virus (SACMV) (2), the Indian Cassava Mosaic Virus (1) and the South East African Cassava Mosaic Virus (SEACMV) recently reported by Harimala et al. (6) and proposed as a new species.

Neuenschwander et al. (14) and Monde et al. (12) studies showed that only ACMV and EACMV-UGV are occurring in DR Congo in single or mixed infections. The direct consequence of the CMD epidemic spread led to serious crop failure and yield losses, ranging from 25 to 95% which seriously affected the local farmer's livelihood in Sub-Saharan Africa (8).

Following the epidemic spread of CMD, yield loss study was reported by Fargette et al. (4) in Ivory Coast. They observed greater yield decrease when plants were infected from cuttings than when it was realized by whiteflies. Yield losses were estimated at 40%.

In Uganda, Owor et al. (15) field study showed that CMD is responsible for 82% yield decreasing due to double infection ACMV-EACMV-UG2 'severe', while ACMV alone, EACMV-UG2 'mild' and ACMV-UG2 'severe' induced respectively 42%, 12% and 68% of yield losses. In Tanzania, Legg et al. (9) recorded 72 to 90% of yield loss on the three most cultivated local varieties in different locations. Malowa et al. (10) have recorded 68% of yield loss in Kenya.

This study was the planned to provide more information on CMD impact, considering cassava genotypes behavior, virus species involved, plant age at infection and the environment in which they are involved, especially in DR Congo where available data on CMD are limited.

Materials and methods

This study was realized in the Sud-Kivu province, in Democratic Republic of Congo. A survey was undertaken in different villages splited up in three altitude agro-ecosystems. In the first agro-ecosystem corresponding to the tropical zone in low altitude (climate type AW1-3, altitude < to 1000 m, rainfall < 1300mm/year, annual mean temperature >24°C), Luvungi, Sange and Kiliba villages were selected as the survey sites. Within the second area corresponding to tropical zone mid-altitude (climate type AW3, altitude 1000-1400 m, rainfall > 1300 mm/year, annual mean temperature 20-23 °C), the villages of Kalehe, Katana, Kavumu, Mudaka were selected. Within the third agro-ecosystem corresponding to tropical zone in high altitude (climate type CW, altitude >1400 m, Rainfall >1300 mm/year, annual mean temperature 12-19 °C), the villages of Walungu and Nyangezi were selected. For the soil characteristics in the area of the study, it can be noticed that in Mid and high altitude, clay soils are predominant while in low altitude a predominance of sandy soils with alluvial deposits is observed. A field experiment was carried out to assess genotypes behavior under high CMD epidemic pressure.

Data collection from farmer's fields

The CMD impact on yield loss in farmer's fields was assessed in nine selected villages regarding ecological conditions, cultivated varieties, local farmer's practices and the CMD pressure (incidence and severity). In each village, three cassava fields were selected and in each field, three groups of 40 plants each were observed for the assessment. The three categories of groups were subdivided as following: (i) a group of CMD asymptomatic plants, (ii) a group with plants which showed CMD symptoms from plantation to twelfth week after planting (WAP) and (iii) a group with plants which showed CMD symptoms during the period from thirteenth to twenty-fourth WAP. A total of 2520 cassava plants were observed during the survey. Cassava farmer's fields were monitored since the plantation until harvest. The parameters like CMD severity score, plant growth and yield data were recorded. Yield loss was expressed as a percentage of the diseased plants yield compared to asymptomatic plants yield.

Yield loss under field experimental conditions

Field experiment was installed at Sange, at 3°05 S and 29°17' East, 890 m of altitude. Climate is semi-humid with two rainy seasons and two dry seasons, annual mean temperature is around 27 °C range from 22 °C to 32 °C. Stem cuttings of ten most commonly cultivated local genotypes and five improved genotypes were used for the experiment. Cuttings were planted at 1 m x 1 m in a completely randomized block with three replications spaced 2 m apart. Severely diseased plants of local variety Nambiyombiyo were planted all sides of each plot to reinforce the inoculum pressure. Each replication comprised 15 plots of 20 m^2 spaced 1 m apart. All routine cultural practices were adopted and no fertilizer was applied. The trial was installed during the 2007 September rainy season. Field data were recorded from plantation to harvest. The severity of CMD was scored using a scale of 1-5 where 1 represents a plant with no symptoms and 5 represents very severe symptoms including chlorosis, leaf distortion and stunting (16). CMD virus species was diagnosed by PCR. The plant height, stem diameter, leaf square and yield were taken into consideration to attribute the score for CMD severity. Cassava tuber roots were separated in two groups (marketable and non marketable tubers) considering their size and weight. The total number, marketable and non-marketable tuber roots percentage per plant were also recorded.

Collected data were compared with general analysis of variance (ANOVA) using GenstatDiscovery edition 3 (www.vsni.co.uk) and yield loss was expressed as a percentage of the diseased plants yield compared to healthy and improved varieties plants yield.

Results

Collected results on the CMD impact in farmers' fields and field experiment are respectively summarized in tables 1 and 2.

Table 1 shows the effect of CMD appearance period on the yield and its components in different locations both in high and low altitude and low altitude. In the high altitude locations, when the disease appeared early, the yield varied from 1.34 tons per hectare at Katana to 3.16 at Kavumu.

For mid-term infection plants, it produced 3.78 tons per hectare at Katana to 10.91 at Kavumu while healthy plants have produced 7.6 and 19.8 tons per hectare in those two locations.

In low altitude, the yields of early infected plants was comparable to those recorded in high altitude and varied from 1.47 tons par hectare at Sange to 4.33 tons at Kiliba. When infected at the mid-term of the crop cycle, the yield was 2.67 tons per hectare at Luvungi to 22.67 at Kiliba while when infected late the yield ranged between 14 tons per hectare at Luvungi and 54 tons at Sange. The recorded values of the yield components (tubers' number per plant, tubers' weight par plant, tubers' diameter and tuber length) described the same tendency as the global yield.

Table 2, is presenting field trial results, total tubers yield, biomass yield, percentage of dried matter, tubers' number per plant, percentage of marketable tubers and tuber's cyanide content.

Concerning the total tuber yield, improved have produced more than local genotypes. Among the improved varieties, the highest yield, 64 tons per hectare, was harvested with MM96/002 and the

Table 1

Impact of CMD infection period on cassava yield in farmer's field under different agro-ecosystems in South-Kivu, DRC (CMD= cassava mosaic disease, WAP= week after planting).

Agro-ecosystems	Villages	CMD symptoms appearance	Total yield t/ha	Tuber weight/plant(kg)	Tubers number/plant	Tuber diameter (cm)	Tuber length (cm)	Severity score
NORTH (altitude >1000m, clay soils, rain > 1400mm/year, mean t°<24°C)	Kalehe Ihusi	0-12 WAP	1.89 ± 0,20 i	0,17±0,022 h	0,86±0,190 h	4,26±1,28 e	16,67±0,943 e	4
		13-24 WAP	4,01 ± 0,37 h	1,76±0,171 d	1,53±0,330 g	5,87±0,74 d	21,86±1,68 d	3
		Asymptomatic	7,6±0,87 g	2,67±0,810 b	4,63±0,442 d	7,63±0,45 bc	33±7,35 bc	1
	Katana	0-12 WAP	1,34±0,34 i	0,10±0,018 ih	1,33±0,074 g	2,97±0,40 g	15,96±1,38 e	3
		13-24 WAP	3,78±0,60 h	0,17±0,018 h	2,33±0,234 f	4,24±0,65 e	21,14±2,34 d	3
		Asymptomatic	17±1,17 d	0,73±0,046 fg	4,67±0,415 d	6,64±0,74 c	31,43±4,43 bc	1
	Kavumu	0-12 WAP	3,16±0,46 hi	0,17±0,022 h	2,33±0,117 f	3,43±0,43 f	17,1±1,58 e	3
		13-24 WAP	10,91±1,37 f	0,43±0,043 hg	3,33±0,355 e	4,71±0,75 e	23,29±2,87 d	3
		Asymptomatic	19,8±1,51 c	0,83±0,101 f	4,76±0,686 d	5,43±0,97 de	30±3,83 c	1
	Mudaka Kalambo	0-12 WAP	3±0,53 hi	0,13±0,020 ih	2,33±0,179 f	3,43±0,47 f	16,43±2,30 e	3
		13-24 WAP	4±0,37 h	0,13±0,026 ih	2,67±0,180 f	4,71±0,75 ef	21,86±1,68 d	2
		Asymptomatic	13,37±1,24 e	0,54±0,028 g	5±0,289 cd	5,43±0,95 de	33,86±5,40 b	1
SOUTH (Altitude <1000m, sandy soils with alluvial deposits, rain <1300mm/year, mean t°>24°C)	Uvira Luvungi	0-12 WAP	1,67±0,10 i	0,18±0,020 h	0,63±0,090 h	5,37±0,75 de	21,43±2,65 d	4
		13-24 WAP	2,67±0,17 hi	0,27±0,043 h	1,54±0,190 g	7,47±0,74 bc	31,71±3,50 bc	3
		Asymptomatic	14±1,19 e	1,4±0,072 e	4,63±0,281 d	9,76±1,47 a	43,14±3,53 a	1
	Uvira Sange	0-12 WAP	1,47±0,10 i	0,15±0,021 ih	0,63±0,054 h	5,71±0,95 de	21,43±2,64 d	4
		13-24 WAP	18,33±1,68 cd	1,83±0,179 d	5±0,563 cd	8,09±1 b	33±2,77 bc	3
		Asymptomatic	54±3,96 a	5,4±0,486 a	8,67±0,626 b	9,3±2,03 a	45,29±1,97 a	1
	Uvira Kiliba	0-12 WAP	4,33±0,66 h	0,43±0,043 hg	1,7±0,173 g	5,71±1 de	21,43±2,64 d	4
		13-24 WAP	22,67±2,70 b	2,27±0,314 c	5,17±0,390 c	7,36±1 bc	33,57±3,55 b	3
		Asymptomatic	53±4,2 a	5,3±0,469 a	9,1±0,893 a	9,64±1,11 a	43,57±2,82 a	1
			Lsd= 1,674	Lsd= 0,264	Lsd= 0,399	Lsd= 1,073	Lsd= 3,323	

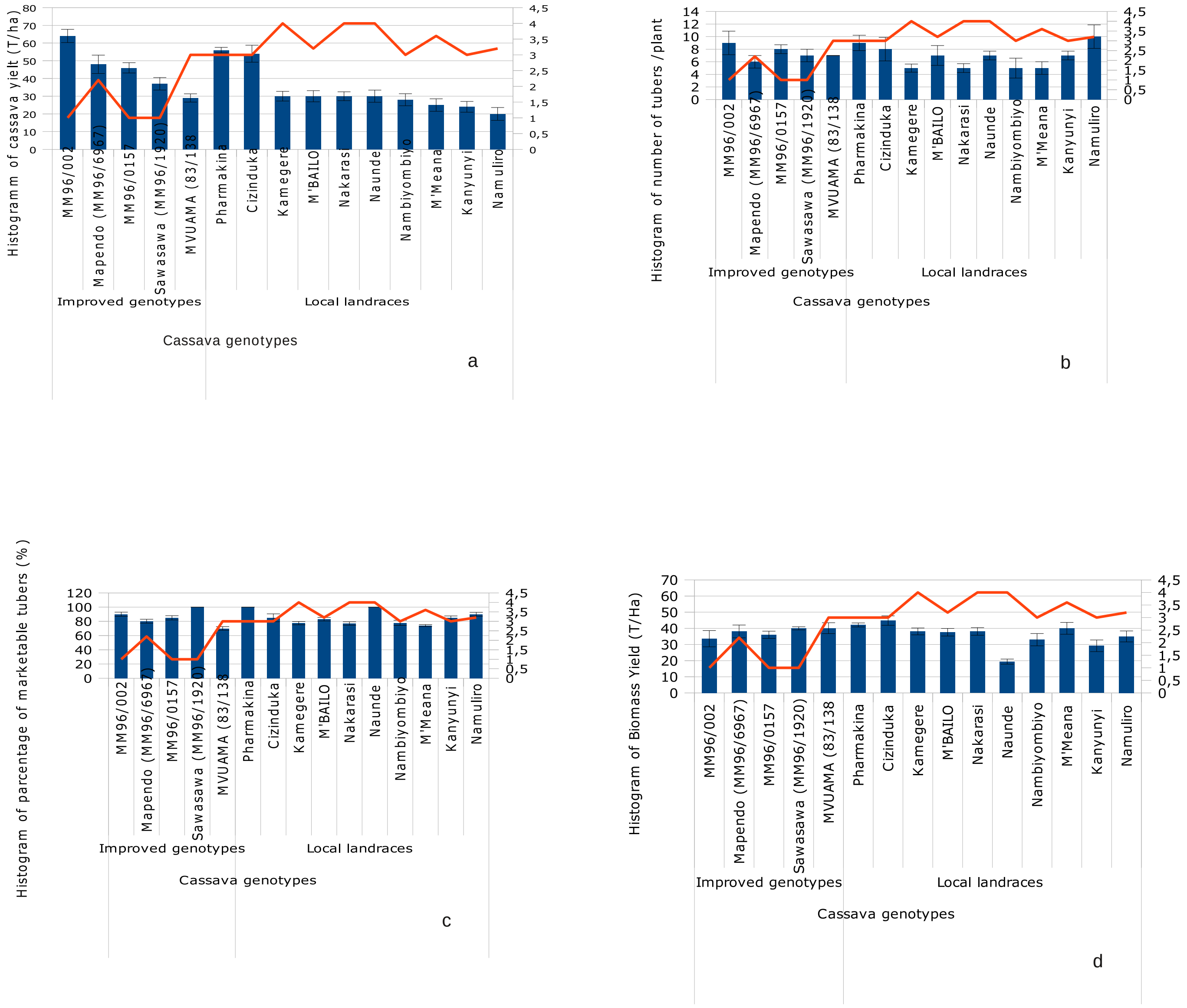
Collected data were analyzed by general analysis of variance (ANOVA) using GenstatDiscovery edition 3 (www.vsni.co.uk). WAP: Week after plantation.

Table 2

CMD impact on cassava growth and yield in field trial at Sange, DRC.

Improved genotypes	Genotype name	Yield (t/ha)		Biomass yield (t/ha)		% of dried matter		Num. of tub/pl		% market. tubers		Comp.HCN (ppm)		Mean sev	
	MM96/002	64 ± 3,74	a	54 ± 5,02	a	33,6 ± 4,16	f	9 ± 1,87	ab	90 ± 2,92	b	20 ± 2,55	e	1 ± 0	e
	Mapendo (MM96/6967)	48 ± 5,20	c	49 ± 3,94	b	38,1 ± 3	cd	6 ± 1	de	80,2 ± 2,77	de	100 ± 1,16	c	2,2 ± 0,44	d
	MM96/0157	46 ± 2,92	c	39 ± 2,24	c	36 ± 1,87	de	8 ± 0,70	bc	85 ± 3	c	105 ± 3,74	c	1 ± 0	e
	Sawasawa (MM96/1920)	37 ± 3,54	d	27 ± 0,94	e	40 ± 2,55	bc	7 ± 1	cd	100 ± 0	a	30 ± 1	e	1 ± 0	e
Local landraces	MVUAMA (Pronam 83/138)	29 ± 2,35	e	25 ± 3,39	e	40,1 ± 1,43	bc	7 ± 0	cd	70 ± 2,45	h	50 ± 3,39	d	3 ± 0	c
	Pharmakina	56 ± 1,58	b	50 ± 1,22	b	42,1 ± 1,19	b	9 ± 1,22	ab	100 ± 0	a	50 ± 4,18	d	3 ± 0	c
	Cizinduka	54 ± 4,18	b	51 ± 2,92	ab	44,8 ± 3,42	a	8 ± 1,87	bc	85 ± 5,52	c	200 ± 4,9	b	3 ± 0	c
	Kamegere	30 ± 2,74	e	31 ± 2,12	d	38,1 ± 1,82	cd	5 ± 0,64	e	77,5 ± 2,29	f	100 ± 2,35	c	4 ± 0	a
	M'BAILO	30 ± 3,16	e	28 ± 2,35	de	37,6 ± 3,65	de	7 ± 1,58	cd	83 ± 2,45	cd	600 ± 30,7	a	3,2 ± 0,44	c
	Nakarasi	30 ± 2,49	e	31 ± 2,35	d	38,1 ± 0,22	c	5 ± 0,70	e	77 ± 2,35	f	100 ± 3,54	c	4 ± 0	a
	Naunde	30 ± 3,43	e	50 ± 1,58	b	19,4 ± 1,52	h	7 ± 0,70	cd	100 ± 0	a	100 ± 0,71	c	4 ± 0	a
	Nambiyombiyo	28 ± 3,39	ef	26 ± 3,81	e	33 ± 1	f	5 ± 1,58	e	77,9 ± 3,54	ef	200 ± 24,8	b	3 ± 0	c
	M'Meana	25 ± 3,54	fg	26 ± 3,67	e	40 ± 2,83	bc	5 ± 1	e	74 ± 1,41	g	200 ± 18,1	b	3,6 ± 0,54	b
	Kanyunyi	24 ± 3,08	g	26 ± 3,61	e	29,2 ± 3,11	g	7 ± 0,70	cd	85 ± 2,55	c	200 ± 3,7	b	3 ± 0	c
	Namuliro	20 ± 3,61	h	39 ± 3,39	c	35 ± 2	ef	10 ± 1,87	a	90 ± 2,74	b	105 ±5,34	c	3,2 ± 0,44	c
Lsd values		3,56		3,36		2,67		1,48		3		14,27		0,31	

The HCN composition is a cyanide acid rate have been determined tubers. The biomass yield was determined as the total weight of the aerial part of the plant when the total yield has been estimated was a total in tubers weight of the harvested plants per hectare. Numbers with different alphabetic letters are significantly different at p 0.05 level.



CMD impact was assessed on total tuber yield (a), number of tubers per plant (b), biomass yield (c), percentage of marketable tubers (d).

Figure 1: Cassava mosaic disease (CMD) severity and its impact on cassava genotypes growth and yield under field experiment conditions at Sange.

lowest, 37 tons per hectare, with Sawasawa. Nine of the ten local genotypes have produced 30 tons per hectare or less than it, while two of them (Pharmakina and Cizinduka) has produced 54 and 56 tons per hectare more than some of the improved genotypes.

The biomass yield described almost the same tendency as the total tuber yield, three of four improved varieties (excluding Sawasawa) and three local varieties (Pharmakina, Cizinduka and Naunde) have produced the high biomass quantity.

The percentage of dried matter didn't show any difference between improved and local genotypes, the best percentage was recorded for local genotypes Pharmakina and Cizinduka which also yielded a percentage of marketable tubers comparable to those of improved genotypes. The tuber cyanide content was higher in local than in improved genotypes.

Discussion

CMD yield losses in farmers' fields in various agro-ecosystems

Yield data collected from cassava farmers' fields in various agro-ecosystems showed a significant decrease of cassava yield depending on the period from when cassava plants have been infected. There are homogenous results of yield loss when cassava plants are infected from cuttings (0-12 WAP) independently of the agro-ecosystem, no significant difference has been observed within this group, total yield was less than 2 t/ha and yield losses were estimated in the range of 77.5% at Mudaka to 97.3% at Sange.

Within the second group (diseased plant during the period between 12-24 WAP), cassava yields were 3.8 t/ha; 4 t/ha; 4 t/ha and 10 t/ha respectively for Kalehe, Mudaka, Katana and Kavumu in high altitude while it was 18 t/ha and 22.67 t/ha for Sange and Kiliba in low altitude. Cassava yield significantly differed depending on the agro-ecosystems characteristics (climate and soil). In altitude, low temperature is responsible of cassava yield decrease resulting in growth reduction and crop cycle extension.

The associated percentages of yield loss induced by the CMD presence varied from 44.9% to 76% in high altitude and 58% to 80% in low altitude.

Healthy plants didn't produce the same cassava tubers volume depending on the agro-ecosystems characteristics (climate and soil). At Uvira (Kiliba and Sange) in low altitude, cassava yield recorded was 53-54 t/ha whereas it was 7-19 t/ha in high altitude agro-ecosystems.

These results demonstrate a greater yield decrease in low altitude mainly induced by the predominance of more virulent CMBs (EACMV-UG) alone or in mixed infections with ACMV which is associated to severe CMD symptoms and more damage than in high altitude where less virulent CMBs (ACMV alone) were predominant. Additionally, both in high and low altitude agro-ecosystems, early infection on cassava plants is responsible of more than 50% of tubers yield losses but the yield decrease is significantly high in low altitude agro-ecosystems. Curiously, it's the first time highest yield losses percentages are recorded comparing to those which have been recorded elsewhere with a high virulent CMBs diversity (13).

The great percentages of total yield losses measured in this study were induced by several factors combination. The predominance of susceptible cassava genotypes in farmers' fields in the surveyed area, the plant age when plants were infected, the virus species and their interaction with the environment in which they are involved were combined to produce severe symptoms and yield losses greater than when each factor is considered alone. These results are similar with those of Fargette et al. (4) report, only the infection date and one virus species was considered, yield losses were low. Owor et al. (15) report in Uganda, measured yield loss induced by CMD virus species in single and dual infections EACMV-UG/ ACMV on a local susceptible variety, yield losses were higher in dual infection than in single infection. Legg et al. (9) report in Tanzania has considered the cassava genotypes in combination with the growth environment and showed that yield losses depend on the environment where cassava is grown.

Evolution of the CMD severity during the cultivation period

The development of the disease on local varieties from healthy and less diseased plants showed a CMD symptom progression from moderate to severe symptoms. The fact that at harvest, CMD recorded scores were ranged from 3 to 4, suggests that local landraces are all sensitive at different level. Three varieties Kamegere, Nakarasi and Naunde were the most severely diseased and presented high susceptibility to the disease with CMD score of 4. On the other hand, the varieties M'Bailo, Nambiyombiyo, Namuliro, Cizinduka, Pharmakina and Kanyunyi are less susceptible or tolerant to the disease and they showed CMD score 2 to 3. The new improved varieties were separated in two different groups for their susceptibility to CMD. The first group contains two varieties (Mapendo and Mvuama) which showed CMD symptoms at harvest while the second contains three varieties which didn't show any symptom (MM96/002, MM96/0157 and Sawasawa) (Table 3).

This situation is different from the one which has been observed in epidemic zones of Uganda where all local and susceptible genotypes have been rapidly abandoned (9). New improved varieties showed a satisfactory resistant level and didn't show CMD symptoms until harvest except Mapendo and Mvuama which showed less severe symptoms (severity score 2.2 and 3. Mvuama has been introduced as improved variety but due to its susceptibility it's about to be removed). There is a confirmation of what is regularly mentioned in many epidemic zones where some of the new improved and resistant genotypes can rapidly become susceptible when CMD pressure is high. One of the management key of such situation will be to test a large number of cultivated genotypes under epidemic area.

Regarding the various altitude agro-ecosystems, CMD severity score has rapidly progressed in low altitude than in high altitude. In low altitude agro-ecosystems, diseased plants CMD severity score was of 3-4 while in high altitude any diseased plant have exceeded CMD severity score 3. As described by Colvin et al. (3), such observations can be attributed to whitefly population combined to great prevalence of dual virus infections. In low altitude environment, CMD incidence is great, high whitefly population and more EACMV-UG and ACMV-EACMV-UG in mixed infections. Otherwise, in high altitude more ACMV in single infection, low incidence and limited whitefly number were predominant. Temperature is probably the environment factor which is greatly influencing these results.

CMD severity and its impact on cassava varieties yield

CMD is known to be responsible for economic losses on cassava yield. In the present study, yield losses depended on local varieties sensitivity, the virus species and the period from when cassava plants were infected in interaction with the agro-ecosystem. The most of local varieties severely affected have produced 30 or less than 30 tons per hectare while the resistant varieties produced more than 35 tons per hectare. The highest yield level (64 t/ha) was reached by the resistant variety MM96/002. Nevertheless, the two local landraces Cizinduka and Pharmakina have produced a second best volume of tubers (54 t/ha and 56 t/ha) even when the CMD score was moderate or high (score 3-4). The disease didn't induce a great decrease of total yield and yield parameters (tubers number per plant, biomass yield and percentage of marketable tubers). The two local landraces produced 8 to 9 tubers/plant and 85 to 100% of marketable tubers which occasioned 12.5 to 15.6% of yield loss only. The most CMD affected landraces produced a limit number of tubers (5-6/plant) and yielded the lowest values, and consequently the highest values of yield losses (53.1 to 68.8%) (Figures 1a, b ,c and d). These results are demonstrating the obvious impact of genotype diversity and suggest more careful on the choice of genotypes. Regarding the results of this study, where new resistant genotypes are yet available for the great number of farmers, local landraces are expected to be planted and produce economic yield provided that healthy cuttings have been used for new cassava plantation (9). Additionally, these local landraces have frequently more associated advantages including the quality traits, flour and cyanide content, resistance to other cassava pests and diseases, long conservation of tubers roots in the soil before harvest. These are probably the main reasons of the upholding of the local landraces in rural areas even where new improved and resistant varieties have been tested and introduced. These observations provide more evidence of benefit of the use of a wide number of tolerant and resistant varieties to benefit from the genotypes mixtures observed in Uganda, resistant varieties were providing protection to CMD-susceptible varieties when growing together.

The percentage of dried matter and the cyanide acid content in cassava tubers haven't been influenced by the CMD severity. In fact, these parameters are varietal heritable characteristics. Local landraces Pharmakina and Cizinduka have the highest percentage of dried matter compared to improved varieties which is also an interesting quality for harvest especially for market and when cassava products are used for local flour consumption.

Conclusion

Based on the results of this study, cassava mosaic disease is responsible of 77.5 to 97.3% of yield loss when local susceptible genotypes were infected early (from cuttings) and of 45-76% when cassava plants were infected during the three early months. Two improved genotypes (MM96/002 and MM96/0157) produced the highest volume of cassava tubers and didn't show any disease symptoms whereas two local genotypes (Cizinduka and Pharmakina) were less susceptible and produced more than 50 tons per hectare. These results showed that highest yield losses were recorded when the disease appeared earlier, on local genotypes infected by virulent virus species while the lowest yield losses were recorded when the disease appeared later on local genotypes infected by less virulent species. Resistant non-diseased plants produced the highest yield. The environment in which cassava is cultivated has a great impact on the disease impact. Highest yield losses were recorded in non favorable conditions (high altitude) while in low altitude, the disease has induced lowest losses.

From these results we can highlight the importance of cassava resistant genotypes diversity and their adaptation to environment are important for the disease management strategies. The use of diseased-free materials and phytosanitation of local genotypes are also important where new improved genotypes are yet available.

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