Research Article

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Screening cassava for time of maturity to respond to various market needs: Case study in African sub-tropical zones

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Abstract

BACKGROUND: Cassava evaluation trials are mostly harvested at 12 months after planting (MAP) irrespective of their actual maturity date, which includes the maximum accumulation of dry matter in tuberous roots. Depending on the market needs, some producers prefer to keep their crops up to 24 MAP and harvest sequentially when needed. Such varieties should mature early at 12 MAP and maintain or enhance their root dry matter rather than losing it. A modified breeding scheme has been suggested to evaluate selected lines from 12 to 24 MAP. In a harvest scheme such as this, many of the improved varieties lose their dry yield as starch is converted to sugar. Hence the breeding program in DR Congo started screening both early and late bulking varieties to identify those that can bulk early and keep their economically profitable dry root yield until late in the growing cycle. Six varieties and one local variety were subjected to several harvest dates ranging from 9 to 24 MAP.

RESULTS: In general, the best harvests occurred at 15 MAP. Variety Zizila continued to increase its dry root yield from 15 t ha^{-1} at 15 MAP to 20 t ha^{-1} at 24 MAP. However, the varieties Butamu and Disanka both with dry yields of 15 t ha^{-1} at 15 MAP reduced their dry root yields to 5 t ha^{-1} at 24 MAP, thus limiting themselves to early maturing varieties.

CONCLUSION: By assessing early generation populations in the clonal trials, study results revealed that breeders may lose around 15% of superior clones with good dry root yield from 12 to 24 MAP when limiting the selection at 12 MAP.

Keywords: cassava varieties; maturity times; agro-ecological zones; market needs; dry yield

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) production, as evaluated to date, is primarily based on fresh tuberous root weight. However, the performance of a good variety must integrate the possibilities of maintaining it on-farm dry matter content (DMC) over time, especially as it is well known that farmers and commercial producers practice selective or partial harvesting in cassava farming systems. Many improved varieties are considered early maturing and lose dry matter when they reach a relatively advanced age. At this stage, starch is converted to sugar by hydrolysis in the presence of an acid.[1] Cassava leaves are deciduous and shed profusely when the plant goes beyond its normal cycle. At this time, the plant tends to draw sugar that has accumulated in the roots in the form of starch to compensate for the deficiency of chlorophyll synthesis. The roots become watery and barely soften when cooked. Given that tuberous root DMC, to some extent, is directly proportional to the amount of starch present in the tuberous root, a reduction in DMC results in a decrease in starch and thus in the quantity and quality of the root's useful material. The highest carbohydrate proportions are allocated to the storage roots during periods of low vegetative growth.[2]

In DR Congo, a comprehensive program for the selection of cassava varieties per their maturity has been developed. It aims at screening the so-called early varieties that mature from 6 months after planting (MAP) and tend to convert their starch as early as possible. These varieties have the advantage of reducing the

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length of the cassava cycle, which is considered too long for economic profitability in the cassava value chain but are disadvantageous as farmers would have to carry out labor-intensive harvests that are often not feasible for smallholder farmers, even for commercial producers when their processing capacity cannot keep up with field harvests. This would explain the low adoption rate of these varieties in certain regions, especially the forest regions where tuberous root yield is higher because of relatively better soil fertility compared to savanna regions.

Germplasm development is usually carried out according to a classical cycle known as the selection cycle starting from the evaluation of seedlings obtained from parental diversity in different environments, going through clonal evaluation, preliminary yield trial, advanced yield trial, and finally uniform yield trial. Promising clones selected during this selection cycle are evaluated in various ecologies under the management of farmers in their local agroecological zones.

Since 2011, a new selection scheme has integrated the maturity date in the various stages of varietal selection while considering farmers' desired traits. This process consists of: (i) diversifying gene sources by accelerated recurrent selection, (ii) recombining and incorporating desirable genes for germplasm improvement (free crosses in fields and crossing blocks), and (iii) introducing collected seeds from improved varieties (multiple resistances, beta-carotene content, DMC, cyanogenic potential, etc.) and local varieties (local adaptation, product quality, etc.).

When clones are conventionally selected at 12 MAP, as is the current practice in most cassava breeding programs in Africa, a significant number of superior clones, generally those with late maturity cycle, are lost during the selection process. However, some clones that perform well at 12 MAP become less productive as they reach ages that are more advanced. Others develop more dry matter beyond the normal cassava cycle (12 MAP) and become more valuable when harvested later.

Late-maturing varieties, however, are targeted in the selection program because they perfectly meet the needs of most smallholders who harvest roots sequentially and reduce excessive postharvest losses. The choice of varieties also depends on end uses. Thus, varieties rich in dry matter are more suitable to produce flour and starch while others, rich in sugar, are suitable for the production of ethyl alcohol, a popular biofuel.

Concentration of root DMC varies for different cassava varieties.[3] Certain varieties show increasing concentration with increasing harvest dates while others lose it. Breeders give particular emphasis on varieties that retain their DMC as long as possible, allowing them to maintain their useful production (dry weight) for a long period of time. Constituting the bulk of the useful product in processing cassava, Hahn[4] asserts that the rate of dry product production, such as *gari* in Africa, is a linear function of the dry matter of the cassava root. Similarly, Kawano *et al.*[5] assign changes in dry matter to the varietal factor, the duration of the cropping cycle, and its setting in the climate cycle involving the presence of more or less numerous fibers that play an important role in dry matter formation. Segnou[6] notes that during the dry season, dry-leafed varieties conserve most DMC, as those with dense, deciduous leaves deplete their root starch reserves during the marginal vital periods of cassava to compensate for the deficit in dry matter photosynthesis. The presence of starch is proportional to the DMC in the cassava roots.[7] Although cassava is a predominant crop in the sub-Saharan savanna and forest zones, where many new varieties have been released to farmers, very little information has been provided regarding the proper timing of harvest for each variety capable of generating more efficient and rational harvests.

At the consumer level, some cassava products require sufficient or no dry matter and/or starch in the roots. In forest areas, for example, where most of the population consume cassava directly in boiled and pounded forms, varieties that are soft and starchy and which can keep their DMC longer are the most adopted. In the savanna zones and in certain forest regions, the majority of the population ferments the chips into water before processing to fufu or 'chikwangue'. This choice considers less the taste of tuberous roots, the hydrocyanic acid content, and the DMC of roots. It is therefore necessary to identify the various cassava varieties per their most suitable harvest dates to achieve optimum market requirements.

The dimensions of the tuberous roots are of great importance in cassava cultivation. Their size is often influential in cassava market. Larger roots are more easily sold than smaller roots, which are generally more difficult to peel for processing. Large roots are therefore often regarded as having high commercial value.[8]

Our hypothesis is that different cassava genotypes have different times of maturity and cassava tuberous root maturity decreases as starch is converted to sugar. Hence, the objectives of this study were to screen cassava varieties and early generation clones for time of maturity to identify early, medium- and late-maturing cassava genotypes for different markets and uses. At harvest, which is typically regarded by breeders as 12 MAP, a good number of cassava genotypes are not at their peak maturity in terms of dry yield (DMC). As a result, they are destroyed before their genetic potential is sufficiently expressed late in their growth cycle.

MATERIAL AND METHODS

Six elite varieties that have been selected and a local control currently grown in DR Congo were subjected to several harvest dates from 9 to 24 MAP in two different agroecological zones of the country. The improved varieties evaluated included: Nsansi (low branching, broad, and persistent leaves up to 15 MAP), Butamu (low branching, abundant flowering and fruiting, and small, deciduous leaves in the dry season), Disanka (high branching and broad leaves), Mvuazi (low branching, abundant flowering and fruiting, and small but persistent leaves even in the dry season), Obama (high branching sometimes absent, flowering and fruiting rare or absent, leaves wide and persistent), and Zizila (high branching sometimes absent, flowering and normal fruiting, persistent leaves). The data sheets presenting the characteristics of these varieties are summarized in Table 1.

Two recurrent breeding trials were conducted in the savanna zone at Mvuazi site: Latitude -5°26'48.25'', Longitude 14° 53'44.3'', 431 m a.s.l (Savanah zone) and the forest zone of Litoy site: Latitude 0°42'48'', Longitude 25°14'31'', 420 m a.s.l in western and northeastern regions of DR Congo, respectively. Each location was assigned a distinct local variety (Boma at Mvuazi and Mbongo at Litoy) considering their high utilization by farmers. The study sites at Mvuazi and Litoy are characterized by a bimodal rainfall pattern with a 30-year annual average of 1500 and 1800 mm, respectively. The major cropping season is from October to February and the minor one from March to May followed by a long dry season from May to September in the savanna region (Mvuazi) where annual rainfalls during the study period were 1510.9 mm (2012), 1812.4 mm (2013), and 1485.2 mm (2014). In the forest zone (Litoy), the major cropping season is from March

Table 1. Characteristics of cassava varieties studied

Genotypes	Agronomic characteristics	Average fresh yield (t ha^{-1})	Technical characteristics	Resistance to pest and diseases
Obama	Color: large green leaves; reddish green erected stem; brown tuber epidermis; flowering rare or absent	30–45 t ha^{-1} (station); 20–30 t ha^{-1} on-farm; yield of leaves: average	Sweet variety; dry matter content approximately 45%; cyanogenic potential: ≤5 mg 100 g^{-1}	Resistance to mosaic, blight and anthracnose; susceptible to brown streak; tolerance to green mite, mealy bug and root scale
Disanka	Color: broad dark green and young purple leaves; red petiole; brown stem; brown tuber epidermis; high branching; flowering at 4 months	25–35 t ha^{-1} (station), 20–25 t ha^{-1} (on-farm) low leaves yield	Bitter variety; cyanogenic potential: 5 mg 100 g^{-1}; dry matter content: 39%	Resistance to mosaic, blight and anthracnose; susceptible to pests: tolerance to green mite
Butamu	Color: broad dark green and young light green leaves; green petiole; dark brown stem; brown tuber epidermis; low branching; flowering at 3 months	25–40 t ha^{-1} (station), 20-cyanogenic 25 t ha^{-1} (on-farm) Low leaves yield	Sweet variety; cyanogenic potential: 5–10 mg. 100 g^{-1}; dry matter content: 39.5%	Susceptible to diseases: resistance to mosaic, blight and anthracnose; susceptible to pests: tolerance to green mite
Nsansi	Color: broad dark green and young light green leaves; green and red petioles; white tuber epidermis; white lignified stem; low branching; flowering at 3 months.	25–40 t ha^{-1} (station), 20–25 t ha^{-1} (on-farm) average leaves yield	Sweet variety; cyanogenic potential: 5–10 mg 100 g^{-1}; dry matter content: 39%	Susceptible to diseases: resistance to mosaic, blight and anthracnose; susceptible to pests: tolerance to green mite
Zizila	Color: small purple leaves; red petiole; grew lignified stem; dark brown root epidermis; erected stem; late maturity	25–35 t ha^{-1} (station), 10–20 t ha^{-1} (on-farm) average leaves yield	Bitter variety; cyanogenic potential: 5–10 mg 100 g^{-1}; dry matter content: 38%	Susceptible to diseases: resistance to mosaic, blight and anthracnose; susceptible to pests: tolerance to green mite
Mvuazi	Color: large dark green leaves; young purple leaves; red petiole; grey stem; brown root epidermis; low branching flowering at 4 months	25–50 t ha^{-1} (station), 20–25 t ha^{-1} (on-farm) average leaves yield	Bitter variety; cyanogenic potential: 5 mg 100 g^{-1}; dry matter content: 35%	Susceptible to diseases: resistance to mosaic, blight and anthracnose; susceptible to pests: tolerance to green mite
Local control	Erected stem; elongated roots; dark greenish red stem, with short nodes; dark green leaves; red petiole; early bulking variety but maintains its dry matter longer	7–10 t ha^{-1} (station), 10–15 t ha^{-1} (on-farm) average leaves yield	White, soft, relatively fibrous roots; dry matter content: 38%	Susceptible to mosaic at 100%

to August and a minor one from September to December followed by a short dry season from January to February. The annual rainfalls during the study period were 2044.8 mm (2012), 1897 mm (2013), and 1892 mm (2014).

The soils are mainly clay-sandy in Mvuazi and sandy in Litoy.[9] Data on laboratory analyses conducted at the soil and water facilities at the University of Kisangani (UNIKIS) in Tshopo province and the Kongo University (KU) in Kongo Central province in DR Congo are summarized in Table 2. In the savanna zones, soils are characterized by low fertility. The Mvuazi site has a textured soil with predominantly aluminic and ferritic clay and very low pH around 4.5. At this site, trials are usually conducted at the catchment of the Mvuazi River, which gives the site its name and where soil conditions are relatively more fertile because of alluvial deposits that accumulate after floods.

Experimental design and statistical analysis

The experimental design was a completely randomized block design (CRBD) with the cassava varieties planted using the recommended plant spacing of 1 m × 1 m yielding a plant density of

Table 2. Soil parameters of experimental sites

Sites	pH		Exchangeable bases (ppm)	Total carbon (ppm)	Phosphorus (ppm)	Nitrogen (ppm)	Sulfur (ppm)
	Water	Potassium chloride					
Savanna zone (Mvuazi)	5.31	—	20	—	8.5	13	13.2
Forest zone (Litoy)	5.19	5.94	—	2.33	15.29	3.6	—

10 000 plants ha^{-1}. The trial consisted of seven cassava varieties replicated two times in four blocks. Plot size was 7 m × 13 m and repeated four times. A total of eight partial harvests were made in each plot every 2 months from 9 MAPs up to 24 MAPs. The last harvest was done after 3 months instead of 2 months to coincide with 2 years of cassava cropping. A four-plant subplot was harvested from a main plot of 91 plants at each harvesting date and assessed, leaving out its border lines. The harvested roots were thoroughly cleaned by removing all the particles from the soil that flowed to the roots and were weighed one by one using a precision balance of up to 8 kg.

Planting was done early in the growing season. The parameters evaluated included the size of the tuberous roots and fresh and dry yields. Other parameters affecting dry yield such as major prevailing pests and diseases; plant biomass, lodging, etc. were measured. The cassava fresh roots were weighed and then dried in an oven at 121 °C until a constant weight was attained that made it possible to calculate the DMC from the equation:

$$\text{Dry matter\%} = \frac{\text{Dry weight (constant weight after baking)}}{\text{Fresh weight}} \times 100$$

Statistical analyses were carried out using GenStat discovery Edition 4.10. These statistical evaluations focused on the analysis of variance which made possible the identification of differences between factors observed, notably the different cassava varieties and the differences in cassava harvest dates. The frequent comparisons of averages also enabled the computation of the least significant difference (LSD) between averages.

Some graphs were obtained with Statgraphic centurion 17.1.04 and PAST software.

Cassava selection scheme for maturity date (Fig. 1).

RESULTS

Size of tuberous roots *vis-à-vis* harvest dates

There were no statistical differences between cassava roots harvested at different dates in terms of size. The trend was the same in all the varieties evaluated. In the forest zone, average root lengths were 27 cm at 9 MAP, 31 cm at 11 MAP, 31 cm at 13 MAP, 33 cm at 15 MAP, and 36 cm at 17 MAP, while those in the savanna zone were 28 cm at 9 MAP, 36 cm at 11 MAP, 33 cm at 13 MAP, 32 cm at 15 MAP, and 37 cm at 17 MAP. The average diameters were 7.3 cm in the forest zone and 6.1 cm in the savanna [LSD.05 = 1.1 cm and coefficient of variation (CV) = 11.07%].

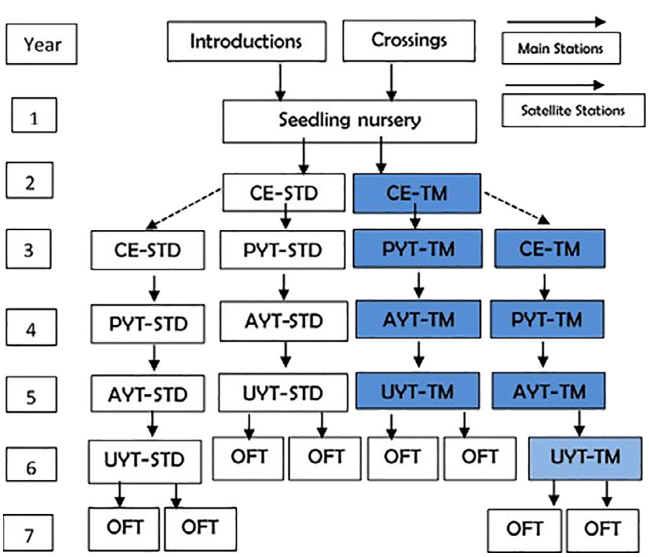

Figure 1. Cassava selection scheme (IITA-DR Congo, 2011). AYT, advanced yield trial; CE, clonal evaluation; OFT, on-farm trial; PYT, preliminary yield trial; STD, standard; TM, time of maturity.

Cassava yield in forest zone (Litoy)

Statistical analysis was performed to verify whether harvest dates influenced cassava tuberous root yield at Litoy. Study results revealed differences in yields between harvest dates. Cassava dry yield was highest for most varieties at 15 MAP and decreased thereafter. For instance, yield peaks were reached at 15 MAP with 10.51 t ha^{-1} for Butamu, 9.86 t ha^{-1} for Disanka, 27.76 t ha^{-1} for Mvuazi, 21.69 t ha^{-1} for Nsansi, 36.47 t ha^{-1} for Obama, and 7.14 t ha^{-1} for the local control before subsequently declining. Zizila, however, portrayed a rising yield trend up to 24 MAP. The local variety Mbongo at Litoy yielded 8 t ha^{-1} between 9 to 24 MAP, indicating stable DMC from 9 MAP.

Analysis of covariance between fresh and dry yields showed significant variations amongst varieties at different harvest dates. There were also statistically significant margins in variety × date combinations. Cassava varieties showed yields that varied according to harvest dates at 9, 11, 13, 15, or 17 MAP. Highly significant interactions were observed after statistical analysis.

Dry and fresh root yields decreased after 15 MAP for Butamu, Disanka, Mvuazi, and Obama. Nsansi variety showed increasing fresh root yield up to 21 MAP while its dry yield decreased earlier from 15 MAP. Statistically significant differences were obtained for dry yield when comparing harvest dates (LSD.05 = 1.84 t ha^{-1}, CV = 7.7%) and cassava varieties (LSD.05 = 1.72 t ha^{-1}, CV = 21%). Variations observed in dry yields at different harvest dates depended on cassava varieties (LSD.05 = 4.87 t ha^{-11}, CV = 19.4%) (Fig. 2).

Cassava yield in the savanna zone (Mvuazi)

In this zone, the highest dry yields were obtained at 17 MAP for most varieties. The dry yields were in the order of 12.96 t ha^{-1} for Butamu when harvested at 17 MAP instead of 10.05 t ha^{-1} when harvested at 12 MAP as usually obtained by cassava producers. Yield increases were greater for Nsansi (17.65 t ha^{-1} when harvested at 17 MAP instead of 6.0 t ha^{-1} at 12 MAP t ha^{-1}), Mvuazi (19.18 t ha^{-1} when harvested at 17 MAP instead of 8.01 t ha^{-1} at 12 MAP t ha^{-1}), Obama (11.98 t ha^{-1} when harvested at 17 MAP instead of 8.35 t ha^{-1} at 12 MAP t ha^{-1}), Disanka (14.48 t ha^{-1} when harvested at 17 MAP instead of 9.27 t ha^{-1} at 12 MAP t ha^{-1}) and Zizila (15.15 t ha^{-1} when harvested at 17 MAP instead of 7.09 t ha^{-1} at 12 MAP t ha^{-1}). These values decreased at 19 MAP except for Mvuazi, and Zizila whose respective dry yield increased by 6.9% at 19 MAP (20.54 t ha^{-1}) and 24 MAP (14.73 t ha^{-1}). Dry yields revealed significant differences between cassava varieties (LSD.05 = 2.145 t ha^{-1}, $P < 0.001$) and harvest dates (LSD.05 = 2.293 t ha^{-1}, $P < 0.001$) (Fig. 3).

The Mvuazi variety was the most efficient at the Mvuazi site. Its performance increased with delayed harvesting achieving dry yields of 8.39 t ha^{-1}at 9 MAP, 14.52 t ha^{-1}at 13 MAP, and 20.54 t ha^{-1}at 17 MAP. Zizila dry yield increased from 6.48 t $ha^{-1}$to 14.73 t ha^{-1}at 9 and 17 MAP, respectively. Nsansi and Disanka portrayed unstable decreasing dry yields from 15 MAP as with Obama and Butamu (LSD.05 = 1.37 t ha^{-1}, $P < 0.001$). The dry

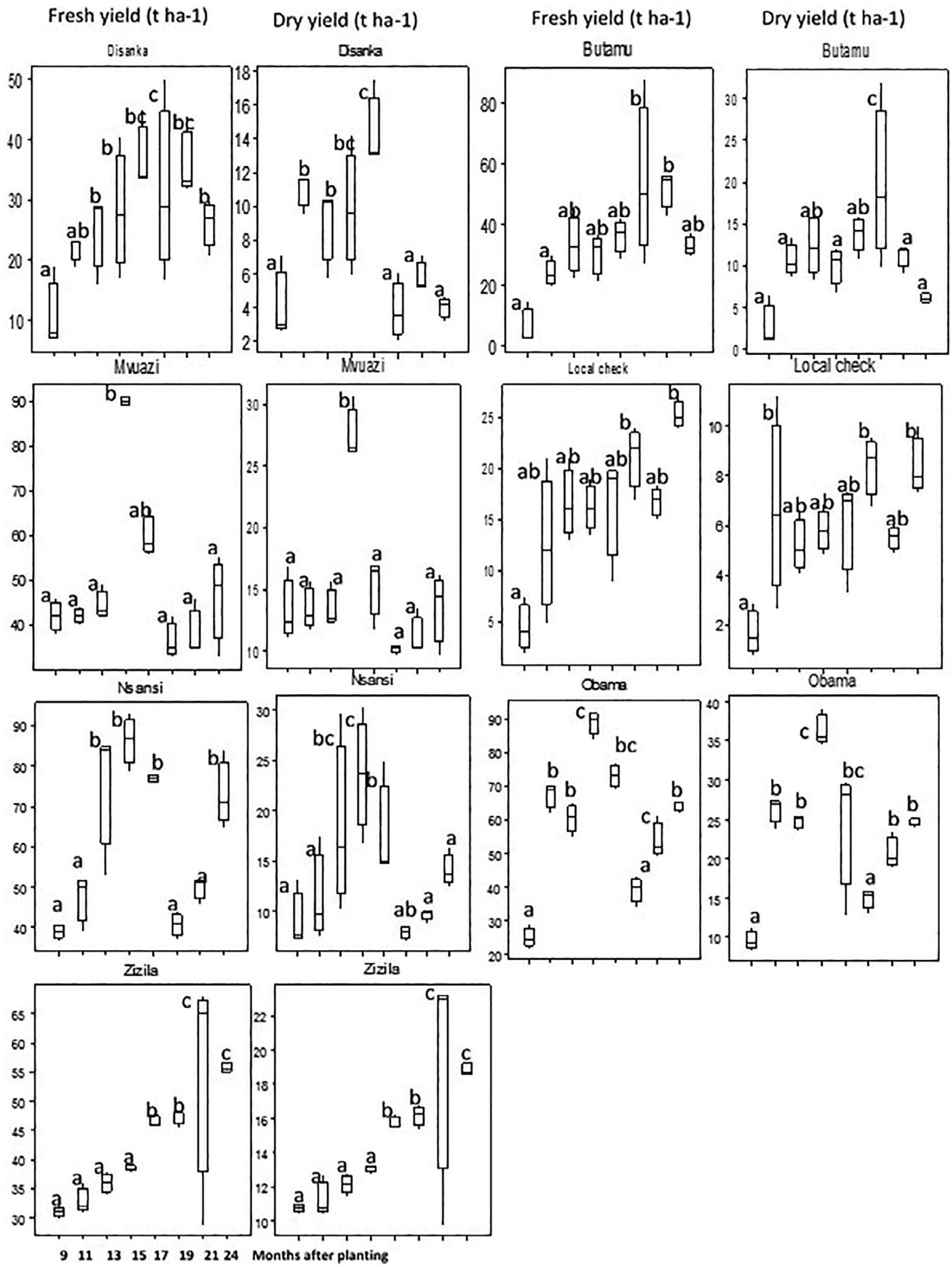

Figure 2. Differences in dry tuberous root yield of seven cassava varieties in Litoy from 9 to 24 MAP (a different to b and b different to c).

yield of the local variety Boma did not vary from the date of harvest, remaining around 6 t ha^{-1}.

Clonal assessment at varying harvest dates

In the clonal trial at Mvuazi, a total of 39 clones were identified during the selection process, including 33 clones at 12 MAP (84.6%) as well as ten clones at 12 and 24 MAP, respectively (30.3% of the clones retained at 12 MAP). Six of the clones discarded at 12 MAP (about 15.4%) became valuable when kept up to 24 MAP due to better yield. In the forest zone at Litoy, 26 clones were selected for a preliminary yield trial, of which 23 were retained at 12 MAP (88.5%) and 18 at 12 and

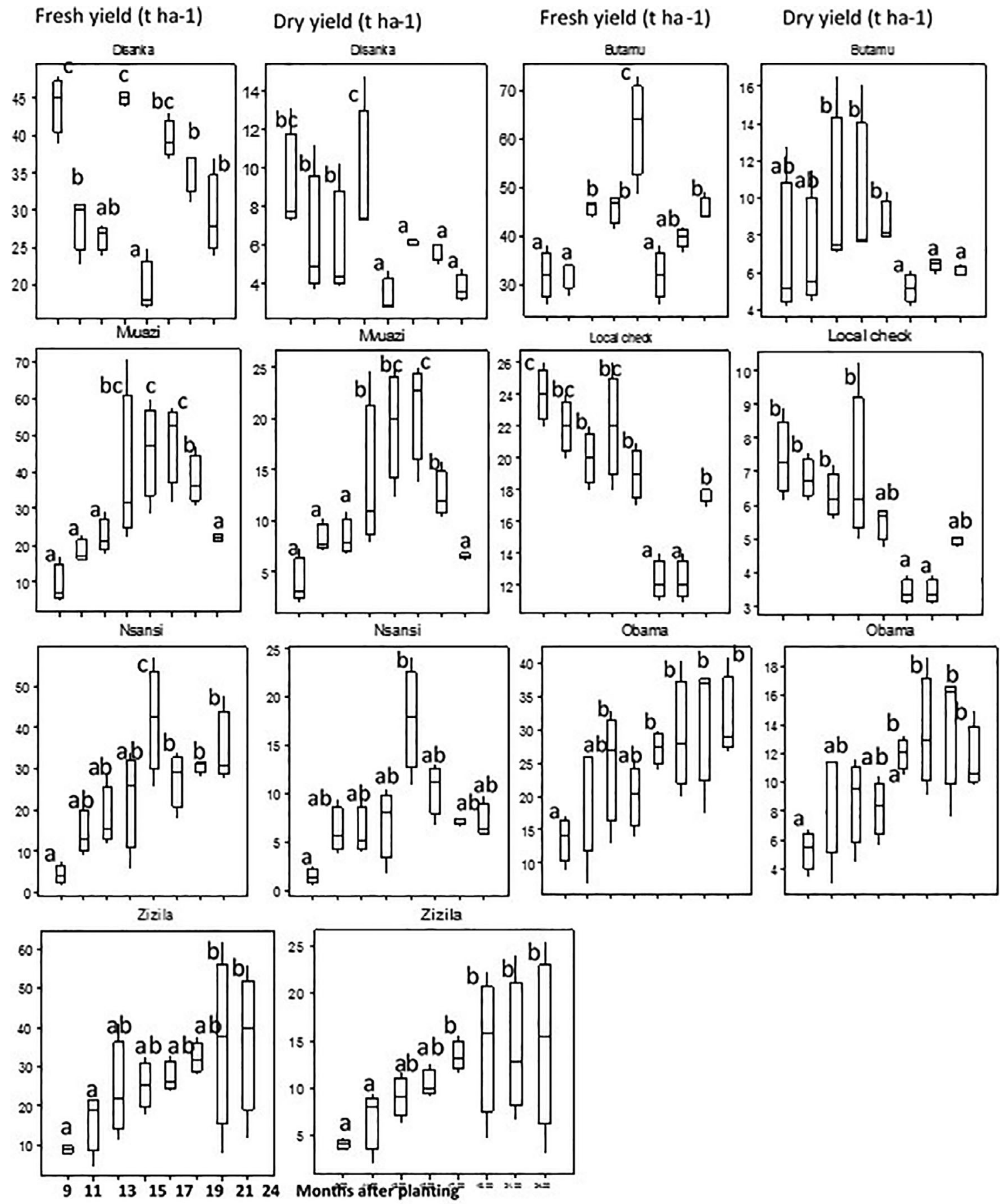

Figure 3. Differences in dry tuberous root yield of seven cassava varieties in Mvuazi from 9 to 24 MAP (a different to b and b different to c).

24 MAP (i.e. 78.3% of clones retained at 12 MAP). Three of the clones not selected at 12 MAP (11.4%) were retained at 24 MAP. A loss of superior genetic material is therefore estimated at around 15% when the selection is limited to 12 MAP (Fig. 4).

DISCUSSION

Fresh weight is an indicator of the amount of cassava tuberous root, which is vital when the product to be marketed is fresh cassava roots. Meanwhile, for cassava processors, the value of the root lies on its dry weight. At Litoy, the same trend was observed for fresh and dry yields; that is, for most varieties, a maximum of fresh cassava production was obtained at 15 MAP. This situation is attributed to a significant loss of its DMC from 15 MAP. This variety is characterized by defoliation at 15 MAP, which would justify this trend.

In this section, the harvest date corresponding to the optimum production of cassava root is evaluated. Conventionally and sometimes irrationally, cassava roots are harvested at

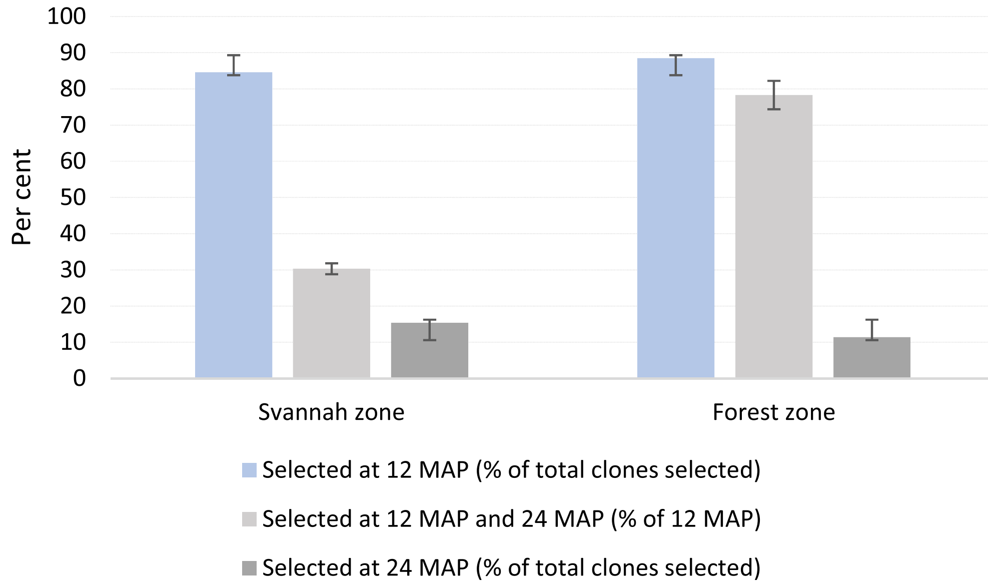

Figure 4. Proportion of clones selected at 12 and 24 MAP in the savannah and forest zones with errors bars using standard deviation 1.0.

12 MAP. At this age, some varieties lose useful material from the root and have less economic value. However, others do not reach the required maturity and have relatively lower yields and are sometimes even discarded in genetic breeding work when they could potentially be effective if harvested at the appropriate date.

This is an essential feature in the choice of varieties as it allows the root to keep these qualities in relation to the needs of farmers. The roots have both good starch and DMC from 9 MAP, thus keeping them uniform throughout the cropping cycle. This would explain the persistence of some farmers in keeping local varieties to the detriment of improved varieties, whose tuberous root yield and DMC vary enormously with harvest dates.

Concerning the harvest dates of tuberous roots, it is evident that the right period for harvesting most cassava varieties in the two main agroecological zones of DR Congo is between 15 and 17 MAP (Fig. 5). During this time of harvest, there are substantial yield increases peaking at 49% for fresh root yield and 48.3% for dry root yield. Beyond this period, there is a reversal of starch into sugar in most cassava varieties and consequently a decrease in root dry weight (Fig. 5).

Statistically significant yield differences were observed at varying harvest dates of cassava tuberous roots. Positive yield increases were obtained when harvesting was done at 15 MAP for most varieties at both study sites, Mvuazi and Litoy. Moundzeo[10] made similar observations on a study conducted with two

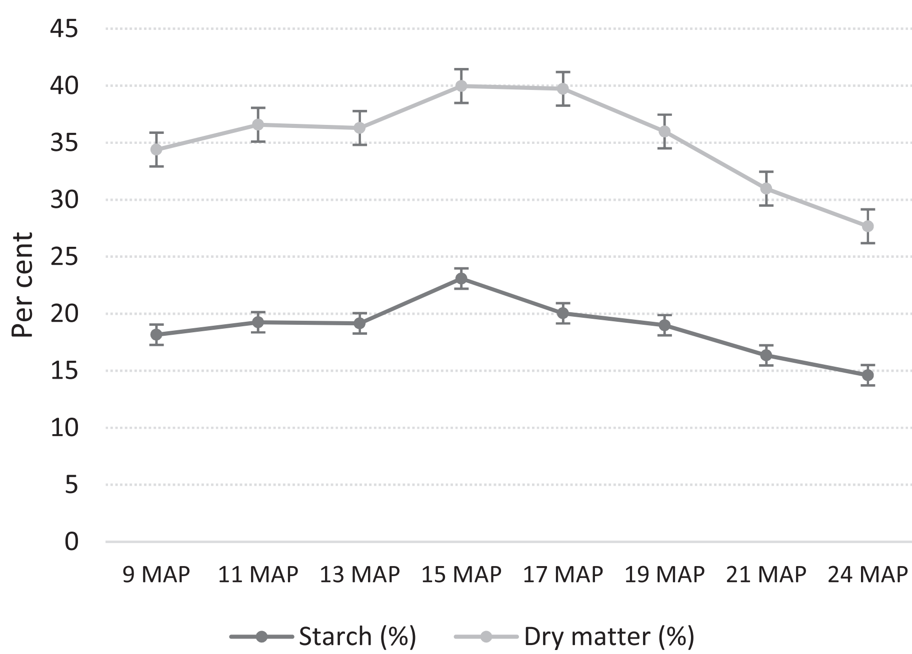

Figure 5. Evolution of starch and DMC in cassava roots according to the dates of harvest with errors bars using standard error.

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cassava varieties at Niari Valley, Brazzaville in Republic of Congo. Significant differences were observed on root yield by comparing early harvests at 6 MAP with 5.2 t ha^{-1} to other harvest dates ranging from 8 to 14 MAP. They found that the yield at 8 MAP was different from those of 10, 12, and 14 MAP with 10.6, 28.3, 30.2, and 43.2 t ha^{-1}, respectively. In addition, they noted that yields of cassava varieties I92-0325 (improved) and Boulabipaki (local) increased with the phenological stages of the plant, and further specified that these yield increases were considerable and showed yield differences which were statistically significant. Akpan and Udoh[11] observed significant differences at 4, 6, 8, and 10 MAP for the circumference of roots, number of roots, and root yield of cassava in terms of genotypes. In a study comparing 70 varieties of cassava in Ivory Coast,[12] obtained fresh root yields of 45 t ha^{-1} at 15 MAP against 39 t ha^{-1} at 18 MAP. They observed that yields of these varieties decreased by 15% from 18 MAP. Similarly, they also found that DMC of these varieties was 38% at 15 MAP and decreased to 36% at 18 MAP.

It is on this note that Osiru *et al.*[13] found that cassava varieties bearing cylindrical ports have the potential to develop greater leaf mass from early stages of plant development. They therefore assumed that this plant architecture was appropriate to allow good accumulation of more carbohydrates such as starch in the roots and then have high DMC; resulting in higher productivity for crops harvested beyond 12 MAP. This period corresponds to greater aging of leaves and a remarkable reduction in photosynthesis. The high branching Zizila variety, whose leaves are persistent throughout its growing cycle, showed an increase in both fresh and dry root yields. Such leaf retention would have allowed this variety to keep root yield throughout the growing cycle. Butamu, Disanka, and Nsansi, however, shed most of their leaves during the dry season. This was confirmed by Raffaillac and Akakpo[3] who found that the difference in fresh tuberous yields at harvest and their dry matter concentration were attributed to the volume of the leaves (i.e. number of leaves and leaf area) that the variety can develop, the interception of sunlight by the leaves, its photosynthetic activity, and the speed of translocating nutrient reserves from the leaves to the roots.

Furthermore, Kawano *et al.*[5] reported that dry matter concentration in cassava roots was seasonal and increased during the dry season while decreasing with the return of rainfall when the soil is more moist, and the roots are more easily fed with water. A study by Sinthuprama[14] that combined planting periods and harvest dates concluded that cassava root yields are influenced by planting dates and time taken before harvesting roots. Yields varying between 20 and 57 t ha^{-1} at 8 and 18 MAP respectively were achieved when planting at the beginning of the rainy season. At late planting dates, however, yields of 8 and 33 t ha^{-1} were recorded at 8 and 18 MAP, respectively. Osiru *et al.*[15] equally found out that improved germplasm exhibited higher productivity at this vegetative stage of the plant. They observed that improved germplasm in an optimal phase of biomass favors strong transpiration and thus a low water use efficiency beyond 9 and 10 MAP. This observation confirms the fact that local cassava varieties develop by using rationally the elements essential to their growth and the production of dry matter. This period corresponds to the vegetative stage at which tuberous roots have the most fresh weight and the highest dry matter concentration.[14] When tuberous roots are left standing beyond this time, waterlogging and starch concentration cause the roots to burst in the soil. The exact time for harvesting a cassava crop depends on several factors such as the cultivar, rainfall, soil conditions and temperature regime.[16] It is better to harvest cassava at a time when tuberous roots are mature enough and have accumulated a sufficient amount of starch but not too old as to have become excessively woody or fibrous. Late-maturing cassava cultivars are ready for harvesting at 12 MAP, while some early-maturing cultivars are ready at 7 MAP. Studies have shown that several cassava cultivars reach optimum fresh weight at about 18 MAP, corresponding to the time of highest starch accumulation. A survey conducted by Agwu and Anyaeche[17] on 118 randomly selected cassava farmers in South Local Government Area of Anambra State (Nigeria) using structured interview schedule, to determine the use of improved cassava and local cassava cultivars in the area, found that most of the respondents (64%) cultivated both local and improved cassava cultivars. Variations in maturity period played an important role in farming systems of cassava farmers and therefore constituted one of the major reasons for which farmers cultivated various cultivars. There is a distinct variation between cultivars that mature early and those maturing late. They noted that the focus of germplasm development in Nigeria is to produce improved cultivars that have high yield, early maturity and pests/disease resistance. Jennings[18] also observed that early maturity of cassava cultivars is desirable in some areas and are usually more palatable. Field observations showed that farmers who desired early maturity attribute cultivated only improved cassava cultivars. However, in terms of late maturity, the local cultivars were highly preferred to the improved ones. These cultivars mature late and can stay for 2–3 years in the soil without roots rotting. This was one of the desired attributes given by farmers as a major reason for still maintaining local cassava cultivars found in the area. Oluwaranti *et al.*[19] conducted research on determining the maturity of maize planted at the end of the rainy season in the forest zone of Nigeria and concluded that planting of the late maturing varieties of maize should not be delayed beyond the last week in August for optimum yield. The response of the yield to the different dates of planting in the late and early seasons indicated that the varieties generally performed better in early season when compared to the late season's plantings. By varying harvesting dates, Kenneth and Richardson[20] actually found yield differences in sweet potato tubers and significant effects of harvest time were observed on yield components such as total number of tubers, number of marketable tubers, total tuber weights and weight of marketable tubers. Hue *et al.*[21] showed that harvesting interval affected the chemical composition of the cassava foliage and significantly higher DMC was obtained at 9 months cut in both three harvest and two harvest treatments while the highest DMC was found in the single harvest treatment. In the same way, Kenneth and Richardson[22] state that the fat content of cassava is determined by age of plant when harvested, variety and environmental conditions being also among other factors. The mean percentage of crude fat found within the fresh cassava pulp ranged from 0.20% to 0.41%.

In Nigeria, results from a survey conclude that cassava farmers in all the regions of the study prefer high yielding and early maturing cassava that can remain underground for at least 1 year after maturity without rotting.[22]

Considering the cassava farming system in DR Congo where farmers apply successive harvests, Zizila variety proves to be the most promising as it shows an upward curve from 9 to 24 MAP. This trend is equally observed for Mbongo (local variety); thus, justifying smallholders' choice for this variety as dry matter is maintained as long as possible during its growing cycle. Study results revealed that Zizila dry yield increases when root harvest is delayed for an extended period. From 17 MAP, this variety gave higher dry yield than all other varieties (LSD.05 = 3.13 t ha^{-1}, $P < 0.001$). However, varieties Butamu and Disanka reached maturity at 15 MAP with their dry yield declining to 4.1 t ha^{-1} at 17 MAP. These varieties reached maturity at 15 MAP beyond which they become less attractive due to decreasing dry yield.

Obama variety has a significant production potential (47.6 t ha^{-1}) that decreases significantly after 15 MAP. This trend is equally observed for Nsansi and Mvuazi with dry yield averaging 44.4 t ha^{-1} and 30.3 t ha^{-1} at 15 MAP, respectively. These yields decreased at 17 MAP but remained in the quadrant of optimum yields. Butamu and Disanka varieties are not expected to be harvested beyond 15 MAP because their dry yield decreases below the local variety with values ranging from 5 t ha^{-1}.

Cassava yield at Litoy and Mvuazi

The combined data from the two sites revealed a stable dry yield for Zizila variety with progressive increases ranging from 7.3 t ha^{-1} at 9 MAP to 18.8 t ha^{-1}at 24 MAP. With this variety, it is possible to obtain an increase in dry yield of about 46.2% when harvest is done late at 24 MAP instead of the conventional harvest generally done at 12 MAP. The maximum value for most Zizila variety in DR Congo averages 13.7 t ha^{-1} at 15 MAP. This value is statistically significant when compared to averages of 9.8 t ha^{-1} at 9 MAP, t ha^{-1}at 11 MAP, 13.7 t ha^{-1}at 13 MAP, and 12.8 t ha^{-1}at 17 MAP. The dry yield of the local variety barely increases by 2.5% when the harvest is done between 9 and 17 MAP compared to 77.8% for Zizila, 59% for Obama, 63.7% for Disanka, 74.1% for Butamu, and 35.6% for Nsansi.

CONCLUSION

Although cassava varieties do not reach maturity at the same time, the current harvest period of 12 MAP, used by national and international research programs, irrespective of the variety in most agroecological zones in sub-Saharan Africa is irrational. There are cassava varieties that reach physiological maturity earlier and if roots are not harvested in a timely manner, they lose their useful dry matter especially if they are to be used for added-value products. At the same time, some varieties are harvested too early when their production potential is not yet optimal.

In the case of DR Congo, most varieties developed by the cassava breeding program are suitable for harvest beyond 15 MAP. However, the best yields are observed at 15 MAP when fresh and dry yields are highest. Except for Butamu and Disanka that lost DMC considerably, all the other varieties, including the local ones, can tolerate late harvest that must not exceed 17 MAP. Observations done at two sites showed that Zizila variety is the most interesting because its dry weight increases till 24 MAP. However, it should be noted that at various stages of harvesting, the choice of varieties to be used also depends on the product to be obtained at the end of the value chain. Varieties with low DMC are not suitable to produce flour and starch. Zizila would therefore be more appreciated by large and small producers of chips, flour, and starch. It enables harvesting over a longer period of time due to the dry matter's long shelf life, which exceeds 24 MAP. Butamu and Disanka, however, are not suitable for the production of flour and starch when harvested beyond 15 MAP. Loss of superior genetic material is therefore estimated at plus or minus 15% when selection is limited at 12 MAP. Using cassava varieties which yield early and keep their economic root yield up to 24 MAP will assist in identifying molecular markers for early to late time of maturity and reduce costly field testing up to 24 months and keep the harvests at 12 MAP.

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CONFLICT OF INTEREST

No conflict.

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