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Effect of altitude and plant age on cyanogenic potential, dry matter, starch and sugar content in cassava genotypes

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Abstract. A study was conducted at three locations in Uganda (Bulisa: 650 m asl; Namulonge: 1150m asl and Kapchorwa: 1750 m asl) to evaluate the effect of altitude on dry matter, starch and sugar content, and cyanogenic potential in cassava. Ten genotypes from five different sources were used in a randomized complete block design with three replications, and data were repeatedly measured at three month intervals up to 15 months after planting. The mixed model analysis indicated significant ($p<0.001$) differences among genotypes at each elevation for dry matter production. Significant interaction between plant age and source and between genotypes within source and plant age at all elevations indicated genotypic differences among sources as well as among genotypes within sources in production and partitioning of assimilates. The study indicated that dry matter content was higher at high altitude than at low and mid altitude. Highly significant ($p<0.001$) differences for CNP were also observed between sources and among genotypes within source at mid altitude. Plant age effect was significant for CNP. Significant ($p<0.001$) interactions between plant age with source and with genotypes nested within source indicated that genotypes as well sources produced different amount of CNP during plant growth cycle, obtaining high levels at all elevations at around six months after planting. The study also showed that starch and sugar contents were high at higher altitude than at low and mid altitude. A similar trend was observed with dry matter content.

Introduction

Cassava (*Manihot esculenta* Crantz) provides the livelihood of up to 500 million farmers and countless processors and traders around the world (FAO, 2001). It is a basic staple for hundreds of millions of people in the tropical and subtropical belt, as well as being a feedstock for numerous industrial applications, including food, feed and starch. The wide adoption of cassava in Africa has been due to its suitability and adaptation to the traditional farming and food systems, and the social circumstances of farming communities. It yields more calories of food per unit of labor effort than any other crops. A major limitation to cassava use is the toxicity from the cyanide compounds found in the fresh root. The cyanide is concentrated in or near the skin of the root, and is rendered free when the skin or root is broken. The cyanide content, however, varies with species, and changes under environmental conditions, such as humidity, temperatures, and plant age (Ozerol, 1984). Dry matter and starch content percentage vary among genotypes (Simwambana, 1988) and is determined by availability of moisture and light within a range of temperatures (Connor *et al.*, 1981). Dry matter is believed to be correlated with starch content, and is genetically highly stable over a range of environmental conditions (CIAT, 1984). Akparobi (1992) reported from screen house experiments that total dry matter was reduced at low temperatures, however, Cock (1985) and Kawano *et al.* (1987) reported higher dry matter content in storage roots at high altitude than at low altitude. Genetic control mechanism and environmental influence on the important cassava characteristics are not clearly known. Carter *et al*. (1986) reported that 19% of the total cassava in Africa is found in mid altitude where trends in socioeconomic and physical environment favor increased production while earlier research work focused on the lower altitudes of tropics where cassava finds its most suitable growth environments (IITA, 1993; FAO, 1996). Ntawuruhunga (2000) reported a comparative study on cassava performance at three different altitudes. As cassava is being expanded into marginal high land-altitude where it was normally not adapted, it is then imperative to study and evaluate its performance in the new environment. This paper is reporting results of the effect of altitude on cyanogenic potential (CNP), dry matter, starch and sugar content production of cassava storage roots.

Materials and methods

Ten cassava genotypes from five different sources (Nyarukuhi, Nyarubekane, Migyera, SS4, Eala 07, Kiryumukwe/Serere, TMS 81/01365, TMS I 92/0057, TMS I 92/0067 and TMS I 91/0397) were planted at three different altitudes in Uganda. Field experiments were conducted at Bulisa, low-altitude **(**02° 02’ N latitude, 31° 25’ E longitude, 650 m a.s.l), Namulonge, mid-altitude (0° 32’ N latitude, 32° 53^{0}E longitude, 1250 m a.s.l) and at Kapchorwa high-altitude (01° 24’ N latitude, 34° 27’ E longitude, 1750 m a.s.l.) in Uganda during 1997/98 and 1998/99 growing seasons. A randomized complete block design replicated three times was used at each location. Data were recorded on three months basis using a destructive sampling method. Storage roots were sampled in the field according to Bokanga (1994) and analyzed for CNP. Root parenchyma samples were homogenized in 0.1M-orthophosphoric acid (50 g of storage roots tissues per 160 ml acid), the homogenate was centrifuged at 6,000 rpm for 15 minutes and the supernatant solution was used for analysis. CNP was determined as described by Essers *et al*. (1993). Ethanol (95%) was used to extract the sugars from starch in a sample of cassava flour. The sugars were quantified colorimetrically using phenol and sulfuric acid and the residue was hydrolyzed with perchloric acid into monosaccharides (Dubois *et al.*, 1956). The sugars obtained were converted into starch by multiple factor of 0.9. The results were expressed in mg of free sugar or starch per 100 g of cassava flour of sample. Dry matter content (%) was determined by the oven method at 85 ^{0}C according to Kawano *et al*. (1987) and included the peel of the storage roots.Storage roots dry matter content, sugar content, starch content, and cyanogenic potential were subjected to analysis of variance at each time of observation. Finally mixed model analysis for repeated measurement over time using SAS (SAS, 1990) were used to determine the effect of time on the cassava attributes in the three environments.

Results and discussions

Dry matter production and partitioning. Results of analysis of dry matter content of storage root (Table 1) show significant ($P < 0.001$) differences among sources at each location. There was a significant difference ($P <0.001$) between genotypes within sources at mid altitude and high altitude. The interactions of plant age x source and genotype within source x plant age were significant ($P < 0.001$) at all altitudes indicating genotypic differences among sources as well among genotypes within source for dry matter production.

Figure 1 shows effects of location (altitude) and plant age on dry matter variation in cassava genotypes. Dry matter increased between 6 and 12 MAP for all genotypes at all altitudes. On average, the increase was 8.4% from 28.1 to 36.5%. However, this increase continued at low altitude and high altitude between 12 and 15 MAP while it decreased in the mid altitude due to the use of storage root reserves after a spell dry season

(CIAT, 1984). Tan and Cock (1979) reported that dry matter in storage roots represents the surplus of dry matter after the plant has met the requirements for the production of new leaves, maintenance of exiting leaves, and development and maintenance of tissues in stems and branches.

The high altitude (Kapchorwa) location resulted in higher dry matter accumulation than low and mid altitude locations. Cock (1987) reported similar results from trials conducted in Colombia indicating that storage root dry matter is usually greatest when temperatures are low. Kawano *et al.* (1987)

Table 1: Analysis of fixed effects of dry matter content of cassava grown at low, mid and high altitude in 1997/1998 season.

Source	Probability (level of significance)				
	ndf	ndd	Dmc		
			Low altitude	mid altitude	High altitude
Source	3	78	0.041	0.006	0.006
Genotype(source)	4	78	0.064	0.010	0.009
Time	4	78	0.001	0.001	0.001
Source x time	12	78	0.001	0.001	0.001
Genotype (source) x time	16	78	0.001	0.001	0.001
-2 Res Log Likelihood			479.67	590.99	590.90
CV (%			13.71	16.84	15.92

Ndf: numerator of degree of freedom; ddf: denominator of degree of freedom; dmc: dry matter content.

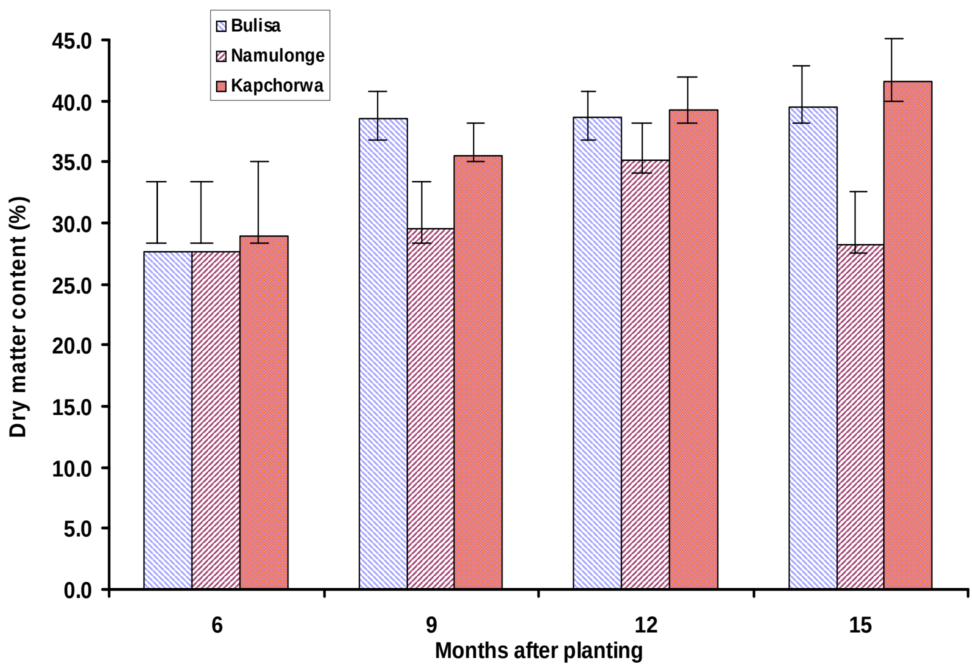


Figure 1: Effect of altitude and plant age on storage root dry matter production.

observed higher root dry matter percentage in 8-month-old plants harvested at the beginning of the dry season at a high altitude location than from plants 12 months old harvested at the beginning of the wet season at a low altitude location, indicating also a seasonal effect in storage root dry matter content. Based on this observation one could deduce from the present results that the cassava plant requires more dry matter for production and maintenance of its above ground biomass at low and mid altitudes than at high altitude, but this necessitates better physiological explanation. In potato production, cool night air temperatures are important because they affect the accumulation of carbohydrates and dry matter content in the tubers. Tubers initiation is reduced substantially if night air is above 20 ^{o}C and inhibited above 30^{o} C (Schaupmeyer, 1997).

Figure 2 shows the location effect on dry matter distribution in different plant parts. The storage root accumulated more dry weight followed by stem and then leaves across locations. IITA (1990) also reported that the allocation of dry matter to storage root varied from almost none during the early growth stage to as much as 80% of the daily dry matter production during the latter growth stage. At high altitude, genotypes allocated significantly ($P < 0.01$) lower dry yield to stems than at low and mid altitudes. Dry yield (fresh yield multiplied by dry matter content) allocated to leaves was much higher at mid altitude compared to low and high altitudes. At low altitude, genotypes allocated more dry matter to storage roots than at mid and high altitudes suggesting the suitability of cassava production at low altitude. TMS I 91/0057 and Nyarubekane were the best in allocating much higher dry matter yield to storage roots at low altitude, Migyera and TMS 81/01635 at mid altitude while TMS I 91/0397 and TMS 81/01635 were best at high altitude. Genotype Eala 07 produced low dry matter and distributed this equally in all plant parts at mid altitude and low altitude. Nyarubekane and Nyarukuhi produced no yield at high altitude because of their failure to sprout in this environment.

Cyanogenic potential in storage root. The results for analysis of cyanogenic potential (CNP) in storage root indicated highly significant ($P < 0.001$) differences between

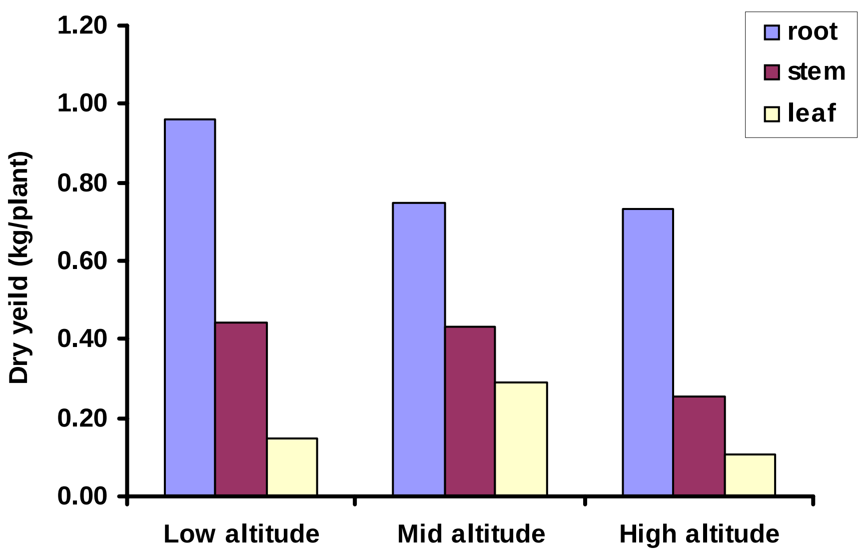


Figure 2: Effect of altitude on dry matter partitioning into storage root, stem and leaf of genotypes grown at Bulisa, Namulonge and Kapchorea in 1997/1998.

sources and between genotypes within sources at mid altitude (Table 2). Bokanga (1994) reported variations in CNP among genotypes adding that, they were larger in storage root than leaves.

Plant age effect was also significant (P < 0.001). There were significant (P < 0.05) interactions between plant age with source and with genotypes nested within source indicating that genotypes as well as sources produced different amount of CNP during the growth cycle. At low altitude, the results indicated significant (P < 0.01) variations and interactions were the same as at mid altitude. Genotypes within sources as well as sources effects at high altitude were significant (P < 0.001), but no significant interaction component was observed indicating that differences among genotypes and sources did not change over the growth period. Bokanga et al. (1994) and Githunguri *et al*. (2000) reported plant age, location and year effect on CNP, but no altitude effect was reported.

Figure 3(a) shows variation in CNP production by each genotype at each location. Eala 07 had the highest CNP and cyanogenic yield at low and mid-altitudes while the genotype Serere was the highest at high altitude. TMS 81/01635, TMS I 92/0057 and TMS I 92/0067, TMS I 91/0397 of the source 4 and source 5 respectively produced relatively low cyanogenic potential in their storage root across locations. Overall, CNP production was much significantly higher at high altitude than at low and midaltitude locations. The trend was similar to that of the storage root dry matter content.

Figure 4 shows the effect of altitude and plant age on cyanogenic potential and cyanogenic yield. There was variation during plant growth in storage root CNP among genotypes at the 3 locations. High levels of CNP were observed at all locations at 6 MAP. There was again a decrease in CNP at all locations at approximately 9 and 15 MAP following short dry spells. Anthony and Lisbeth (1994) reported that cyanogenic glycoside concentration in the root increases until 6 MAP, remains stable until the 14 MAP and decreases, and thereafter increases. This high CNP coincided with the vegetative growth phases when leaf formation was important and the plant had a high leaf area (Bokanga *et al.*, 1994).

The CNP trend seems to follow a pattern similar to crop growth rate, which is mostly determined by rainfall (Bokanga *et al.*, 1994). The high altitude had a high level of CNP, followed by mid altitude and then low altitude in the early stages of growth up to 12 MAP. This suggests that if cassava growing is going to be promoted in high altitudes, it is advisable to introduce genotypes with a very low level of CNP. The same order of ranking was

Table 2: Mixed model analysis of fixed effects for cyanogenic potential (CNP) of genotypes grown at low, mid and high altitudes during 1997/1998 season.

Source of variation			Probability		
	ndf	ndd	Low altitude	mid altitude	High altitude
Source	3	78	0.001	0.001	0.001
Genotype(source)	4	78	0.001	0.001	0.001
Time	4	78	0.001	0.001	0.001
Source x time	12	78	0.022	0.022	0.158
Genotype (source) x time	16	78	0.003	0.003	0.055
-2 Res Log Likelihood			1254.7	1254.6	891.30
CV (%			65.10	66.12	67.78

ndf: Numerator of degree of freedom; ddf: Denominator of degree of freedom.

maintained for the CN yield up to 9 MAP. CN yield increased throughout the growth cycle at low altitude, following the increase in storage root yield. It decreased after 12 MAP at mid and high altitudes but not at low. Bokanga *et al.* (1994) observed similar trend of cyanogenic yield. As storage root growth became the dominant sink (Ekanayake, 1993), CNP levels dropped, but the total cyanogenic yield continued to increase.

Sugar and starch content. The sugar content increased from 6 MAP in all genotypes and decreased at 9 MAP except for genotypes Nyarukuhi, Eala 07, and Serere whose sugar contents continued to increase. With

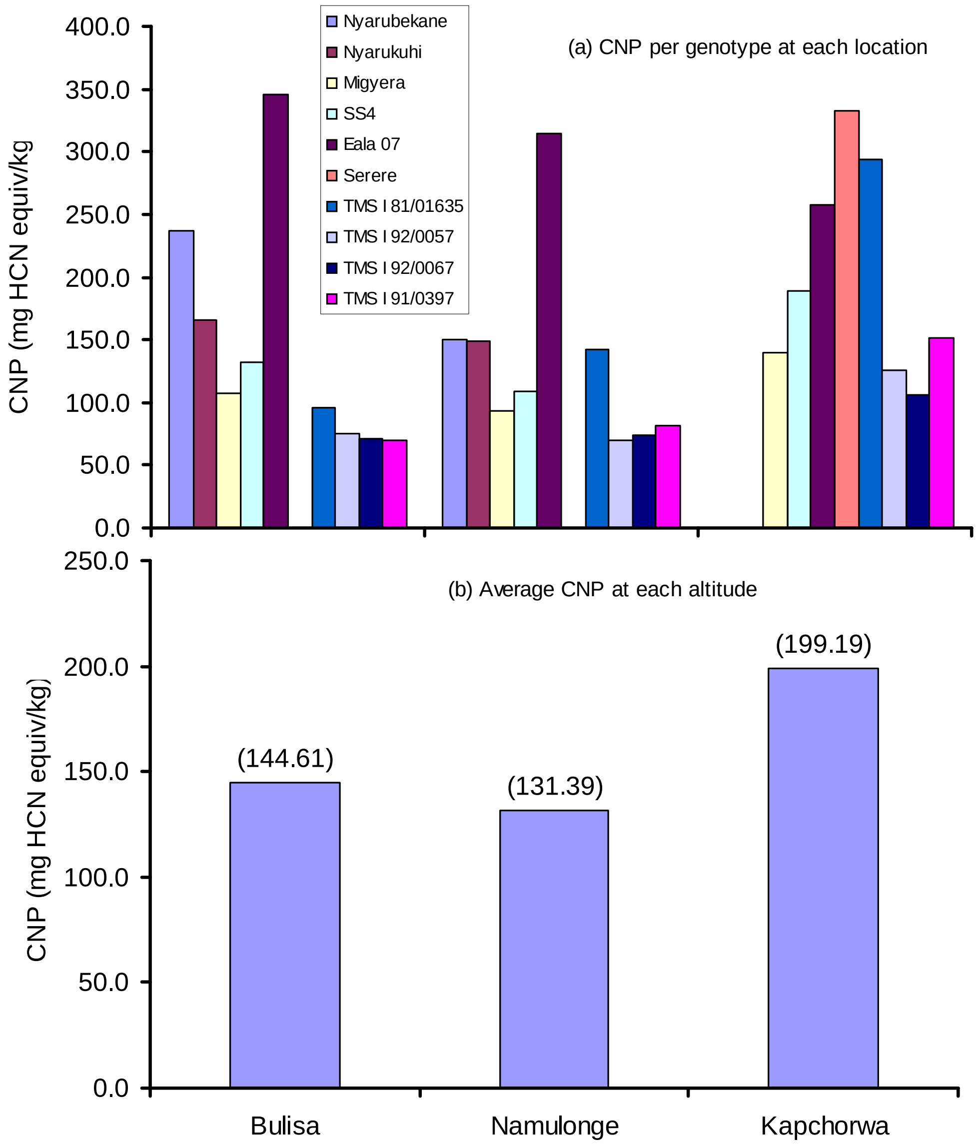
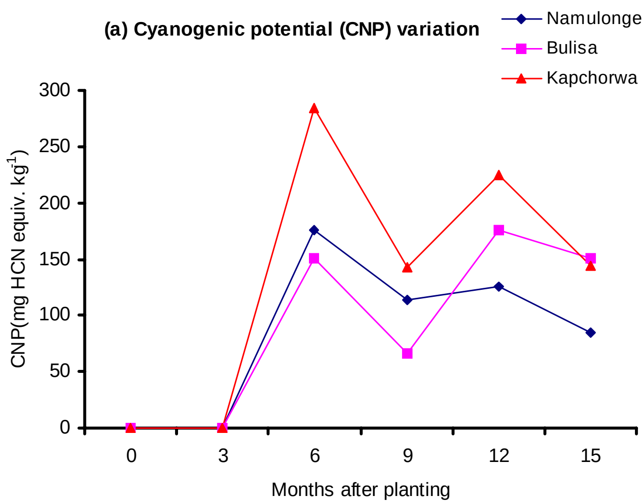


Figure 3: Cyanogenic potential in storage root per genotypes (a) and per location (b) of ten cassava genotypes grown at Bulisa, Namulonge, and Kapchorwa in 1997/1998 season.

increased growth, starch content showed an increasing trend in all genotypes. Figure 6 shows the effect of altitude on sugar and starch content in storage roots. Githunguri *et al.* (2000) reported that genotype and plant age had a significant effect on sugar content but not the zone and cropping system. Though lowest at high altitude before 10 MAP, the starch content increased and became higher than at mid and low altitudes. Sugar content was relatively higher at high altitude than at mid and low altitudes. The present results suggest that starch and sugar contents tend to be higher at high altitude than at low and mid altitudes, an observation similar to that found for dry matter content in this study. This seems to confirm the reports that starch content is a genetic characteristic almost parallel with dry matter content, and the two are highly correlated (CIAT, 1984; Kawano *et al.*, 1987). However, the reason why dry matter or starch content in storage roots is higher at the high altitude than at low and mid altitudes could be that cassava plant tends to use more



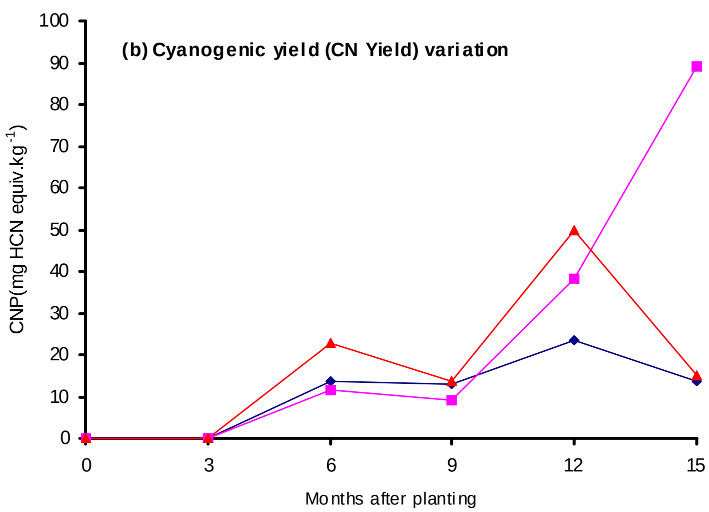


Figure 4: Effects of altitude and plant age on cyanogenic potential (a) and cyanogenic yield (b) in storage root of ten cassava genotypes grown at Bulisa, Namulonge, and Kapchorwa.

energy at high temperature to attain its performance than at low temperature but needs further investigation. In conclusion, the present study confirmed that the three cassava attributes investigated change with plant age and with environment. Specifically it has showed that cyanogenic potential is high at high altitude, and that storage root dry matter and sugar content increases with altitude.

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