Short-duration cassava genotypes for crop diversification in the humid tropics: Growth dynamics, biomass, yield and quality

Article *in* Journal of the Science of Food and Agriculture · January 2010

DOI: 10.1002/jsfa.3781 · Source: PubMed

Research Article

Received: 12 November 2008 Revised: 1 September 2009 Accepted: 3 September 2009 Published online in Wiley Interscience: 9 November 2009

(www.interscience.wiley.com) DOI 10.1002/jsfa.3781

Short-duration cassava genotypes for crop diversification in the humid tropics: growth dynamics, biomass, yield and quality

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Abstract

BACKGROUND: Short-duration (6–7 months) cassava provides opportunities to smallholder farmers for effective utilisation of resources such as land, moisture and nutrients as well as diversification of enterprise and income. The variation in biomass production and partitioning, seasonal course of growth indices, yield, quality and nutrient uptake of ten short-duration/early-bulking genotypes of cassava and their impact on nutrient contents in soil in a lowland situation akin to rice fallow were examined in this study.

RESULTS: Triploid 2–18 gave the highest yield (38.34 t ha^{-1}), followed by triploid 4-2, Sree Vijaya, Sree Jaya and Vellayani Hraswa, which were on a par (30–32 t ha^{-1}). Vellayani Hraswa, Sree Vijaya and triploid 4-2 had significantly higher tuberous root dry matter content (370–380 mg g^{-1}) and fairly higher starch content (270–280 mg g^{-1}). All genotypes except triploid 4-2, triploid 2–18 and H-165 had low cyanogen content (29.2–43.8 μg g^{-1}), well within the tolerable limit. Tuberous root dry matter and total dry matter production, crop growth rate, tuberous root bulking rate and harvest index at the last phase, number of tuberous roots, mean weight of tuberous roots and nutrient uptake showed significant positive correlations with tuberous root yield. Principal component analysis also showed a similar trend.

CONCLUSION: The diploids Sree Vijaya, Sree Jaya, Vellayani Hraswa and Kalpaka are ideal for cultivation in rice fallow for food use owing to their high yield, good cooking quality and low cyanogen content. The triploids are better suited for industrial use owing to their high tuberous root dry biomass production.

Keywords: cassava; biomass production and partitioning; crop growth rate; tuberous root bulking rate; harvest index; tuberous root yield and quality

INTRODUCTION

Cassava (*Manihot esculenta* Crantz), a crop native to South America, with its centre of origin in northeastern and central Brazil,[1,2] has spread to all tropical and subtropical regions, where it is grown from sea level up to altitudes of 1800 m above sea level.[3] It is an important starchy staple in the tropics, providing 50% of the calorie requirement to 420 million people in 27 countries.[4] An estimated 70 million people in the tropics obtain more than 500 cal day^{-1} from cassava.[3] More recently, in Southeast Asia and South America it has been used increasingly for animal feed and industrial starch and is becoming an important source of cash income for a large number of small farmers. It is efficient in carbohydrate production, adaptable to a wide range of environments and tolerant to drought and acidic soil conditions.[5]

The normal harvesting age of cassava varies from 9 to 24 months, with most varieties being harvested at 10–12 months. The ongoing intensification of agriculture, with a focus on multiple cropping to increase productivity, has necessitated the development of short-duration cassava that can be grown intensively in cropping systems. Despite the ever-increasing demand for food production in Southeast Asia, there are vast areas of land left fallow following cultivation of rain-fed rice, and even following irrigated rice when there is insufficient irrigation water for year-round cropping. Hence, presently, there is a preference for early-maturing genotypes of cassava (that can be harvested by 6–7 months) for cultivation as a sequential crop in lowlands after the first crop of rice. Moreover, during the last two decades, cultivation of cassava as a monocrop in uplands has declined in these areas, while cassava is being increasingly cultivated in low-lying areas after the main crop of rice or rotated with banana and vegetables, for which short-duration genotypes hold promise.[6] Short-duration/early-bulking genotypes of cassava that can be raised with the stored moisture after rice harvest provide opportunities to smallholder rice farmers for effective utilisation of resources such as land, moisture and nutrients as well as diversification of on-farm enterprise and income. In addition, cassava has been changing its role from a traditional

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fresh human food to an efficient crop for animal feed and starch production.[5] At present, about ten short-duration/early-bulking genotypes are available for cultivation. The comparative performance of these short-duration cassava genotypes based on growth characteristics, biomass production, yield and quality will help in further delineation based on end use, i.e. food, feed and industry.

Information on the growth and development, growth physiology and dry matter production characteristics of cassava of 10–12 month cycle is available.[7–11] Although a few reports on short-duration cassava dealing with agronomy[6,12–14] and texture analysis[15] are available, information on the growth dynamics of short-duration cassava is lacking. Hence the present study was carried out to explore the extent of variation in biomass production and partitioning, temporal trend of various growth indices, yield, quality and nutrient uptake of short-duration/early-bulking genotypes of cassava as well as their impact on major soil nutrient status. Attempts have also been made to group the genotypes based on their growth dynamics, biomass, yield and quality attributes by cluster analysis and to correlate the above parameters with tuber yield by Spearman correlation and principal component analysis (PCA).

Table 1. Weather parameters during crop growth period

Month	Temperature (°C) Maximum	Temperature (°C) Minimum	Rainfall (mm)	Relative humidity (%)
2003–2004				
November	31.87	23.14	115.1	73.40
December	32.73	21.78	0.0	64.48
January	33.44	22.55	0.0	63.46
February	33.12	23.17	0.0	66.43
March	34.20	24.36	86.9	64.45
April	31.91	24.21	4.1	72.87
May	30.23	23.77	141.4	76.42
Total			347.5	
2004–2005				
November	31.89	22.90	72.3	71.95
December	32.75	21.85	14.5	60.99
January	33.30	24.53	0.0	62.98
February	31.23	25.27	0.0	70.64
March	34.30	25.10	18.4	67.00
April	32.90	24.70	292.4	74.00
May	33.20	25.60	187.4	73.00
Total			585.0	

MATERIALS AND METHODS

Experimental site

Field experiments were conducted during November–May in 2003–2004 and 2004–2005 at the Central Tuber Crops Research Institute (CTCRI), Sreekariyam, Thiruvananthapuram (8° 29′ N, 76° 57′ E, 64 m altitude), Kerala, India in a lowland situation akin to rice fallow in order to study the growth dynamics, biomass production characteristics, yield, quality and nutrient uptake of short-duration cassava genotypes as well as the soil nutrient status due to cultivation of these genotypes. The soil of the research site is a well-drained acid Ultisol with pH 4.35 and is characterised by low available N (251.98 kg ha^{-1}), high available P (28.13 kg ha^{-1}) and medium available K (150.82 kg ha^{-1}) and organic C (7.47 g kg^{-1}) contents. The site experiences a typical humid tropical climate. The mean annual rainfall was 1204.11 mm and the annual means of daily temperature maxima and minima were 31.65 and 25.02 °C respectively (Table 1).

Experimental design and treatments

Ten short-duration/early-bulking genotypes of cassava, comprising released varieties from CTCRI[16] and Kerala Agricultural University (KAU)[17] and indigenous selections and triploids from CTCRI, namely CI-732, CI-848, H-165, Kalpaka, Sree Jaya, Sree Prakash, Sree Vijaya, triploid 2–18, triploid 4-2 and Vellayani Hraswa, were evaluated for biomass production, yield, quality and nutrient uptake in a situation similar to rice fallow in a randomised block design (RBD) with three replications. The gross plot size was 5.4 m × 5.4 m (36 plants), accommodating 16 net plants. A brief description of the varieties/genotypes tested is given in Table 2.

Field culture

Planting and other agronomic practices were done in accordance with Ref. 17. The mound method of planting was used. Farmyard manure at 12.5 t ha^{-1} was applied at the time of planting. Urea, Mussoorie rock phosphate and muriate of potash were used to supply N : P : K at 100 : 50 : 100 kg ha^{-1}. The whole dose of P_2O_5 and half the doses of N and K were applied immediately after sprouting of the setts. After one month the remaining quantities of N and K were applied along with weeding and earthing up. The crop was planted during November in each year, mainly rain-fed and harvested after 6 months.

Sampling and measurements

Biomass

Biomass measurements were done at 2, 4 and 6 months after planting (MAP) by uprooting three plants at random per plot at each stage. Plants were separated into leaves, stems and tuberous roots, air dried and then oven dried at 70 °C to constant weight. The dry weight of each plant part was recorded and the total plant dry weights were computed.

Growth indices

From the values of dry matter the following growth indices were computed using the growth analysis techniques of Hunt.[18]

$$\text{Crop growth rate (CGR)} = [(W_2 - W_1)/(t_2 - t_1)](1/A)$$

where W_1 is the plant dry weight at time t_1, W_2 is the plant dry weight at time t_2 and A is the land area occupied by the plants.

$$\text{Relative growth rate (RGR)} = (\log_e W_2 - \log_e W_1)/(t_2 - t_1)$$

where W_1 is the plant dry weight at time t_1 and W_2 is the plant dry weight at time t_2.

$$\text{Tuberous root bulking rate (TBR)} = (W_2 - W_1)/(t_2 - t_1)$$

where W_1 is the tuberous root dry weight at time t_1 and W_2 is the tuberous root dry weight at time t_2.

$$\text{Mean TBR} = \text{average value of TBR at various growth phases}$$

$$\text{Harvest index (HI)} = \text{tuberous root dry matter/total dry matter}$$

CGR, TBR and HI computations corresponded to three distinct phases of crop growth, i.e. 0–2 MAP (phase 1), 2–4 MAP (phase 2)

Table 2. Description of varieties/genotypes of cassava grown in trials during 2003 and 2004

Variety	Pedigree	Special traits	Duration (months)	Average yield (t ha^{-1})
CI-732	Selection from indigenous germplasm maintained at CTCRI	Plant type short, non-branching; tubers have low cyanogen content (63–67 µg g^{-1}) and good cooking quality	5–6	20–25
CI-848	Selection from indigenous germplasm maintained at CTCRI	Plant type short, top branching; tubers have low cyanogen content and good cooking quality	5–6	20–25
H-165	Hybrid from CTCRI	Medium tall, erect branching, light grey stem and light brown emerging leaves; popular industrial variety in Tamil Nadu; tubers contain 230–250 mg g^{-1} starch; suitable as a sequential crop after rice in lowlands	8–9	33–38
Kalpaka	Selection released from KAU	Non-branching variety; suitable as an intercrop with coconut in reclaimed alluvial soils of Kuttanad; tubers contain 314 mg g^{-1} starch and 22.19 µg g^{-1} cyanogen	5.5–6	35–40
Sree Jaya	Selection from indigenous germplasm released from CTCRI	Early maturing; suitable as a sequential crop after rice; adapted to a wide range of agroclimatic conditions in southern, eastern and NE India; tubers contain 240–270 mg g^{-1} starch and are low in cyanogen (40–50 µg g^{-1})	6–7	26–30
Sree Prakash	Selection from indigenous germplasm released from CTCRI	Early maturing, erect, non-branching with high leaf retention; suitable for rotation in rice-based cropping systems in lowlands; tubers contain 290–310 mg g^{-1} starch	7	30–35
Sree Vijaya	Selection from indigenous germplasm released from CTCRI	Early maturing; suitable for rotation in rice-based cropping systems in lowlands; tubers contain 380–400 mg g^{-1} dry matter and 270–300 mg g^{-1} starch and are low in cyanogen (400–600 µg g^{-1}); adapted to a wide range of agroclimatic conditions in southern, eastern and NE India	6–7	25–28
Triploid 2–18	Triploid line maintained at CTCRI	Early bulking; high yield and high dry matter and starch contents	10	35–40
Triploid 4-2	Triploid line maintained at CTCRI	Early bulking triplod line; stable high yield and high dry matter (485 mg g^{-1}) and starch (302 mg g^{-1}) contents; in prerelease stage	10	38–40
Vellayani Hraswa	Selection released from KAU	Short stature, highly branching; high yield; tubers contain 270–280 mg g^{-1} starch and have good cooking quality	5–6	40–45

and 4–6 MAP (phase 3). RGR values of phases 2 and 3 only were computed.

Yield and quality

At harvest the number of tuberous roots per plant, the mean weight of tuberous roots (g) and the fresh tuberous root yield (t ha^{-1}) were computed based on the data taken from the net plants (16 plants). The contents of dry matter, starch and cyanogenic glucosides in tuberous roots were determined at harvest by standard procedures.[19,20] The dry matter content of tuberous roots was determined by drying fresh tuberous root samples of 100 g in an oven at 70 °C to constant weight and expressed as mg g^{-1}. The starch content was estimated by titrimetry (potassium ferricyanide method) and expressed as mg g^{-1} fresh weight. The cyanogenic glucoside content of tuberous roots was determined by colorimetry and expressed as µg g^{-1}.

Nutrient uptake and soil nutrient status

For the estimation of total N, P and K respectively in the various plant parts, a modified micro-Kjeldahl method, the vanadomolybdophosphoric yellow colour method and flame photometry[21] were used. The contents were calculated and expressed as mg g^{-1}. The plant uptake of N, P and K was calculated by adding the products of the nutrient contents in the various plant parts and respective dry weights of plant parts and expressed as kg ha^{-1}. Organic C and available N, P and K status of the soil was estimated by standard analytical procedures.[21,22]

Statistical analysis

Analysis of variance of the data was performed using GenStat[23] following the method described by Cochran and Cox.[24] The statistical analysis was done by considering the design as a factorial experiment in RBD. Years of study, short-duration genotypes and growth stages were the factors tested. Correlation of the various growth parameters, yield and quality attributes and soil parameters with tuberous root yield was also done. The means of the observed data on different characteristics were used for further analysis. Multivariate techniques such as PCA and clustering were applied to identify groups of characteristics that contributed to the total variation and to identify groups of genotypes that behaved similarly in growth dynamics, biomass characteristics, yield, quality and soil parameters. PCA removes the intercorrelation that may exist between variables by transforming the original variables into smaller hypothetical components (PCs).[25] The new PCs are orthogonal to each other, so that data expressed in each PC are uncorrelated with all other PCs.[25] Average values of a total of 25 characteristics describing the ten short-duration genotypes were analysed, including leaf, stem, tuberous root and total biomass production, growth parameters such as CGR, HI, RGR and TBR at the last phase, soil parameters such as organic C and available N, P and K, crop uptake of N, P and K, quality parameters such as dry matter, starch and cyanogenic glucoside contents and yield characteristics such as mean weight of tuberous roots, number of tuberous roots and tuberous root yield. The original mean data were standardised with the mean and standard deviation of each characteristic, since the original variables were in different units. The number of factors to be extracted was based on the proportion of variance explained. Scatter plots were also drawn using the two main PC scores of the characteristics. Hierarchical cluster analysis with squared Euclidean distance and average linkage algorithm was utilised for cluster analysis of the short-duration genotypes, and a dendrogram was drawn to show the clustering pattern.

RESULTS AND DISCUSSION

Dry matter production and partitioning

Total dry matter production and its relative distribution to leaves, stems and tuberous roots were significantly influenced by the independent and interaction effects of year, stage and cassava genotype. Total biomass production and its allocation to the various plant parts were significantly higher during the first year of study. The temporal pattern of total biomass production and its distribution to leaves, stems and tuberous roots was not consistent between years owing to the occurrence of year × stage × cassava genotype interaction in this study. As expected, in both years, with progressing plant age, total biomass production showed a significantly increasing trend in all short-duration cassava genotypes tested, consistent with the findings of Ramanujam and Lakshmi[9] and Ramanujam[11] in India and Akparobi *et al*.[26] in Nigeria in cassava clones of 10–12 months duration, Suja *et al*.[27] in *Dioscorea* species, Suja[28] in white yam and Suja and Nayar[29] in arrowroot. At 2 MAP, about 70% of the total biomass was diverted to leaves, 21% to stems and 9% to tuberous roots, indicating that the major share of total biomass (91%) was contributed by leaves and stems. In other words, leaves and stems became the dominant sink for assimilates at this stage. By 4 MAP, tuberous roots represented the most active sink in the plant, accounting for 52% of the total biomass; shoots exhibited a decrease in dry matter accumulation (48%, with 26% in leaves and 22% in stems). Ramanujam[11] also noticed that more dry matter accumulated in tuberous roots than in other plant parts after month 3 in cassava cultivars of 10 month duration. These contrasting patterns of dry matter accumulation in shoots and tuberous roots indicate a shift in sink capacities with plant age, as observed by Manrique.[8] By harvest (6 MAP), about 57% of the dry matter was allocated to tuberous roots, 23% to leaves and 20% to stems. As plants aged, leaves and stems had a limited sink capacity, while tuberous roots were the dominant competitor for assimilates, as reported by Williams,[30] Barros *et al*.,[31] Keating *et al*.[7] and Akparobi *et al*.[26]

During both years at 2 MAP, total biomass production as well as its distribution to leaves, stems and tuberous roots was almost the same in all short-duration genotypes tested (Fig. 1). At 4 MAP in 2003–2004, Sree Jaya, Sree Vijaya, Kalpaka and Vellayani Hraswa were found to be efficient in total and tuberous root biomass production. In the subsequent year at the same stage, Sree Jaya, Sree Vijaya and the triploids showed significantly higher tuberous root and total biomass production. At 6 MAP in 2003–2004 the triploids proved highly efficient in tuberous root and total biomass production. In the second year the tuberous root and whole plant biomass of Sree Vijaya, triploid 4-2 and Vellayani Hraswa was higher at 6 MAP. The increase in tuberous root dry matter showed similar trends to those of fresh yield (discussed later). The short-duration cassava genotypes did not follow a definite seasonal trend for leaf and stem biomass production during the years tested. In general, Sree Jaya, Sree Vijaya and the triploids produced significantly higher leaf and stem biomass. Thus the high source size in these genotypes might have contributed to high sink capacity, resulting in higher tuber biomass yield and ultimately total biomass production.

Growth indices

Crop growth rate (CGR)

Year imparted significant variation in CGR of the genotypes in the present study. As in the case of biomass production and partitioning, CGR values were mostly higher in the first year of study. The phasic course of CGR of the cassava genotypes followed a different pattern during the two years studied, as significant year × stage × genotype interaction was observed (Fig. 2). During both years in the first phase (0–2 MAP) the CGR of the short-duration genotypes of cassava was very slow and almost the same (1–2 g m^{-2} day^{-1}) owing to the similar and slow rate of total biomass production as well as biomass distribution to leaves, stems and tuberous roots at this phase. Similar results were reported by Suja *et al*.[27,32] in *Dioscorea* species. In the first year the CGR of Sree Jaya, Sree Vijaya and Kalpaka increased rapidly in the first two phases and peaked at the second phase (mean of 15.47 g m^{-2} day^{-1}), after which it declined slightly. The CGR of Sree Jaya, Sree Vijaya, Kalpaka and Vellayani Hraswa was higher and on a par at the second phase. However, triploids 2–18 and 4-2 had a slow growth rate during the first two phases. Thereafter they gained rapid momentum, with maximum values of 26.35 and 23.90 g m^{-2} day^{-1} respectively at harvest. However, in the second year the CGR of all short-duration genotypes of cassava increased progressively with advancing age of the crop, attaining peak values at harvest. During the second phase, all varieties except CI-732 and H-165 had higher and similar CGRs. It is worthy of mention that Sree Vijaya, triploid 4-2, triploid 2–18 and Sree Jaya had higher CGRs than the other genotypes. In the final phase, Sree Vijaya, Vellayani Hraswa and triploid 4-2 continued their superiority.

Relative growth rate (RGR)

Year of study did not impart significant variation in RGR (average of 26.87 mg g^{-1} day^{-1} in 2003–2004 and 25.49 mg g^{-1} day^{-1} in 2004–2005). However, the independent and combined effects of genotype and phase exerted a profound influence on RGR. On the whole, the RGR of triploid 4-2, Vellayani Hraswa, Sree Prakash, CI-848, Kalpaka and triploid 2–18 was higher, with values greater than 26 mg g^{-1} day^{-1} (Table 3). Between the two phases observed, RGR was significantly higher during phase 2 (2–4 MAP) than during phase 3 (4–6 MAP), indicating the declining trend of RGR with crop age. The effect of cassava genotype × phase × year interaction was not significant for RGR. However, the effect of cassava genotype × phase interaction was more conspicuous. During the growth phase between 2 and 4 MAP, Kalpaka, triploid 4-2, Sree Vijaya, Sree Jaya, Sree Prakash, Vellayani Hraswa and CI-848 added significantly higher dry matter per unit of original dry matter, resulting in higher RGR. During the last phase (4–6 MAP) the triploids, Vellayani Hraswa, H-165 and the CI lines proved

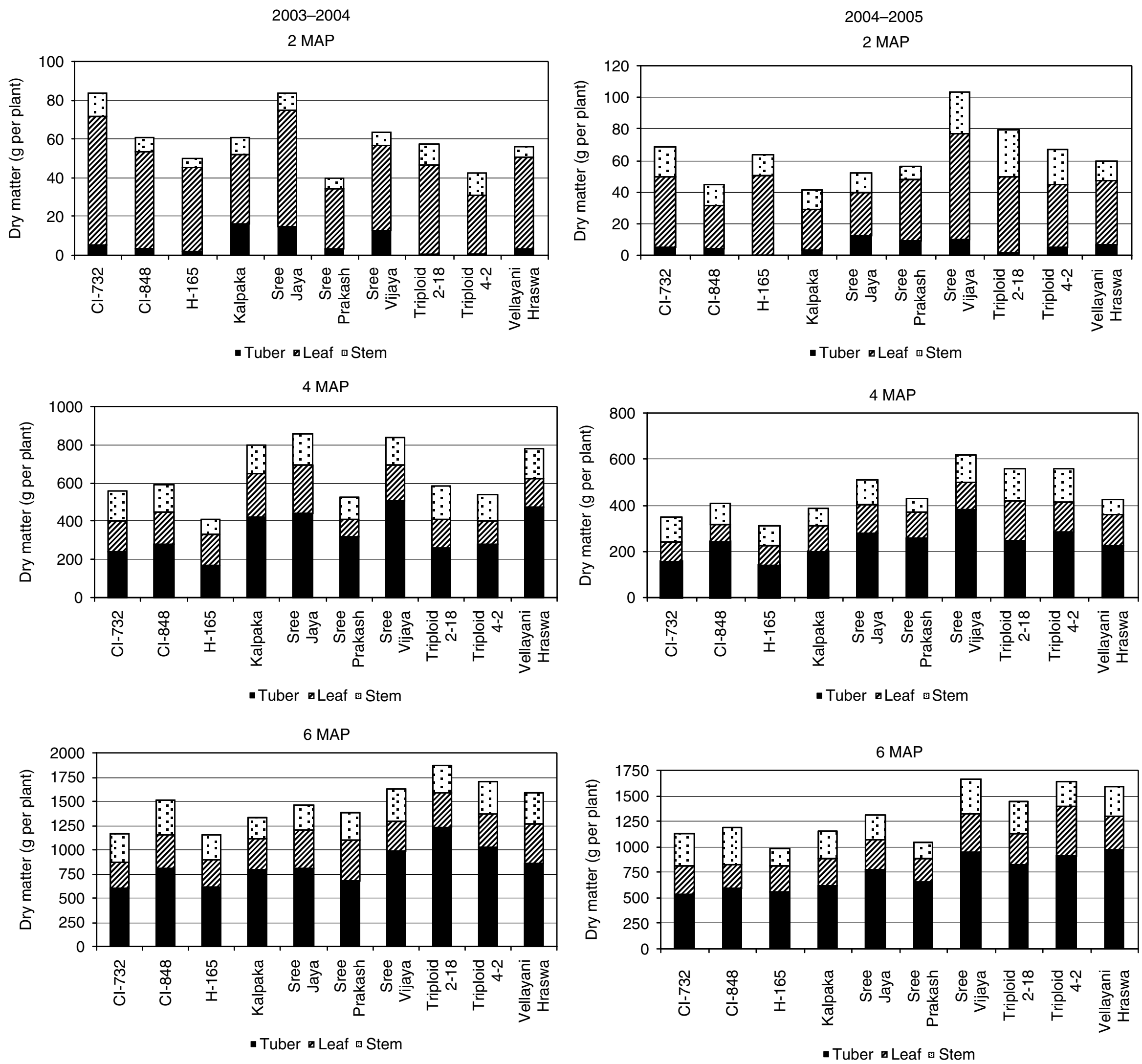

Figure 1. Phasic pattern of biomass distribution in short-duration cassava genotypes.

to be significantly efficient producers of new dry matter per unit of existing dry matter (16–18 mg g^{-1} day^{-1}).

Tuberous root bulking rate (TBR) and mean TBR

TBR showed significant variation ($P < 0.01$) due to the individual and combined effects of year, phase and genotype. The trend followed by TBR was similar to that of CGR. The temporal trend of TBR varied widely among the different genotypes during the period of study. In the first year the TBR of Sree Vijaya, Vellayani Hraswa, Sree Jaya and Kalpaka increased progressively during the initial and middle phases, attaining maximum values at phase 2 (7–8 g day^{-1}), and then declined slightly at the final phase (Fig. 2). The TBR of these genotypes was significantly higher and almost equal at the middle phase (8.24, 7.87, 7.15 and 6.76 g day^{-1} respectively). On the other hand, triploid 2–18 (16.30 g day^{-1}) and triploid 4-2 (12.39 g day^{-1}) attained maximum TBR at the final phase.

In contrast with the first season, the TBR of all short-duration genotypes of cassava increased progressively with advancing age of the crop in the subsequent year, attaining peak values at harvest. The TBR of Sree Vijaya, triploid 4-2, triploid 2–18, Sree Prakash, Sree Jaya and CI-848 was higher and almost the same at the middle growth phase. At the last phase the TBR of Vellayani Hraswa and triploid 4-2 was higher.

Mean TBR varied significantly among the short-duration varieties. Year of study significantly affected this attribute, with higher values in the first year. The effect of genotype × year interaction was not significant and the average trend indicated that the mean TBR of triploid 2–18 was the highest (5.732 g day^{-1}) and on a par with that of Sree Vijaya, triploid 4-2 and Vellayani Hraswa (5.1–5.4 g day^{-1}) (Table 4).

Harvest index (HI)

HI was significantly affected by the independent effects of genotype and stage and the interaction effect of genotype, stage and year. In general, increment in HI was noticed with progressive stages in most genotypes in both years owing to significantly greater diversion of photosynthates for tuberous root development with progressing plant age. Similar results were reported by Suja *et al.*[32] in *Dioscorea* species and Suja and Nayar[29] in arrowroot. In 2003–2004 in the first phase the HI of Kalpaka, Sree Vijaya and Sree Jaya was significantly higher than

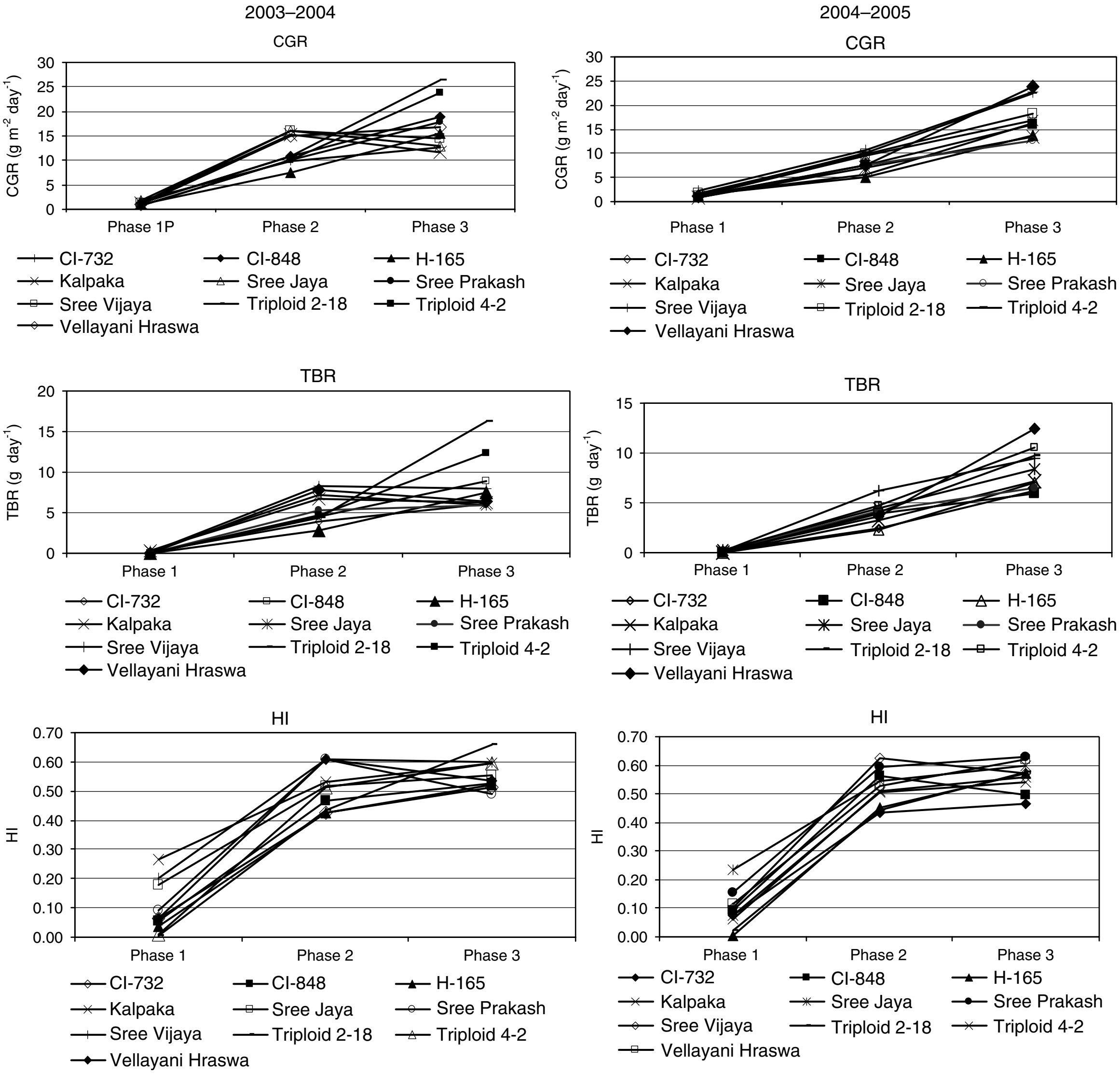

Figure 2. Growth dynamics of short-duration cassava genotypes.

Table 3. Trend of relative growth rate in short-duration cassava genotypes

	Relative growth rate (mg g^{-1} day^{-1})		
Genotype	2–4 MAP	4–6 MAP	Mean
CI-732	29.08	16.23	22.65
CI-848	37.37	16.80	27.08
H-165	30.81	18.28	24.54
Kalpaka	40.11	13.66	26.89
Sree Jaya	38.65	12.29	25.47
Sree Prakash	38.40	15.54	26.97
Sree Vijaya	36.51	13.72	25.11
Triploid 2–18	35.56	17.57	26.56
Triploid 4-2	38.65	18.90	28.78
Vellayani Hraswa	38.54	16.88	27.71
Mean	36.37	15.99	

LSD(0.05): genotype, 3.198; stage, 1.430; genotype × stage, 4.522.

that of other varieties but on a par (Fig. 2). In the next phase, Kalpaka and Sree Vijaya continued their superiority along with Sree Prakash and Vellayani Hraswa. By the last phase, Sree Vijaya, triploid 2–18, triploid 4-2 and Kalpaka were found to be highly efficient in translocation of assimilates for storage in tuberous roots, culminating in higher HI.

In the next year during the first phase, Sree Jaya and Sree Prakash had significantly higher HI than the other genotypes. By the second phase, CI-848 and Sree Vijaya also showed a higher efficiency for partitioning of dry matter to tuberous roots apart from Sree Jaya and Sree Prakash. By harvest, almost all short-duration genotypes were found to be promising, with significantly higher efficiency in distributing assimilates to tuberous roots compared with CI-732, CI-848 and Kalpaka.

Tuberous root biomass production and total biomass production

Tuberous root and total dry matter production varied significantly among the short-duration varieties. There was significant seasonal variation in these attributes, with higher values being observed

Table 4. Yield, biomass production and quality attributes of short-duration cassava genotypes (mean of two years)

Genotype	Fresh tuberous root yield ($t\ ha^{-1}$) 2 MAP	4 MAP	6 MAP	Mean tuberous root bulking rate ($g\ day^{-1}$)	Tuberous root biomass production ($t\ ha^{-1}$)	Total biomass production ($t\ ha^{-1}$)	Tuberous root dry matter ($mg\ g^{-1}$)	Cyanogenic glucosides ($\mu g\ g^{-1}$)	Starch ($mg\ g^{-1}$)
CI-732	0.366	7.37	20.62	3.146	6.99	14.22	338.7	30.7	248.8
CI-848	0.398	11.67	25.57	3.887	8.64	16.65	337.6	30.4	243.0
H-165	0.103	8.44	25.18	3.288	7.31	13.24	288.0	74.1	221.7
Kalpaka	0.362	11.23	24.95	3.960	8.80	15.40	352.1	35.2	239.6
Sree Jaya	0.489	11.91	30.31	4.401	9.78	17.14	328.5	43.8	241.3
Sree Prakash	0.705	12.24	27.71	3.695	8.21	14.99	295.8	37.3	244.9
Sree Vijaya	0.658	15.72	31.70	5.372	11.94	20.29	375.3	42.5	271.9
Triploid 2–18	0.337	13.31	38.34	5.732	12.74	20.43	330.6	76.2	253.0
Triploid 4-2	0.200	13.23	32.06	5.382	11.96	20.64	374.1	114.3	284.6
Vellayani Hraswa	0.514	12.55	29.81	5.079	11.28	19.63	382.1	29.2	283.9
LSD(0.05)	NS	2.680	2.459	0.8409	1.868	2.420	14.09	15.52	NS

in the first year. The interaction effect of genotype and year was not significant and hence the average values for the two years are given in Table 4. The tuberous root dry matter production of triploid 2–18 was the highest (12.74 $t\ ha^{-1}$) and similar to that of Sree Vijaya, triploid 4-2 and Vellayani Hraswa. This may be due to the significantly higher tuberous root bulking rate, tuberous root dry matter content and fresh tuberous root production observed in these varieties. The total dry matter production of triploid 4-2 was the highest (20.64 $t\ ha^{-1}$), remaining on a par with that of triploid 2–18, Sree Vijaya and Vellayani Hraswa (20.43, 20.29 and 19.63 $t\ ha^{-1}$ respectively).

Yield and yield attributes

There was no significant variation in tuberous root yield of the genotypes tested in different years, implying that yields were consistent over years. However, tuberous root yield varied significantly among genotypes. The interaction effect of cassava genotype and year was less pronounced. Fresh tuberous root yield did not vary significantly among genotypes at 2 MAP. At 4 MAP, Sree Vijaya, triploid 2–18 and triploid 4-2 produced significantly higher yield than the rest. The same trend continued during harvest. At harvest, of the ten short-duration genotypes evaluated, triploid 2–18 produced a significantly higher yield (38.34 $t\ ha^{-1}$) (Table 4). This was followed by triploid 4-2, Sree Vijaya, Sree Jaya and Vellayani Hraswa, which were on a par (30–32 $t\ ha^{-1}$). The variation in yield performance of the cassava genotypes could be explained on the basis of significant differences in canopy size, which largely determines the light utilisation efficiency and also affects the partitioning of dry matter for storage root growth.[11] Further, Ramanujam[11] concluded that the yielding ability of cassava cultivars is largely governed by total biomass production. Thus the high-yielding ability of triploids 2–18 and 4-2, Sree Vijaya, Sree Jaya and Vellayani Hraswa in this study may be attributed to their substantially larger canopy size, total biomass, CGR, mean TBR and HI. The early-bulking nature and superior yield performance of triploids 2-14 and 4-2 (34–35 $t\ ha^{-1}$),[33] Sree Jaya and Sree Vijaya (25–30 $t\ ha^{-1}$)[6,14] have been reported previously. Nassar[4] also reported that triploidy in *Manihot* species favoured higher yield.

Mean weight of tuberous roots and number of tuberous roots were significantly influenced by genotype and genotype × year interaction. In the first year, triploid 2–18 and H-165 had significantly higher but almost equal mean weights of tuberous roots. In the subsequent year the mean weight of tuberous roots of Sree Jaya, Kalpaka and Vellayani Hraswa was higher and on a par. On the other hand, Sree Vijaya had a significantly greater number of tuberous roots in both years.

Quality

The main and interaction effects of genotype and year significantly influenced tuberous root dry matter content. The seasonal influence was pronounced and tuberous root dry matter content was significantly higher in the first year. Among the genotypes tested, Vellayani Hraswa had significantly higher tuberous root dry matter content on a par with that of Sree Vijaya and triploid 4-2. During the first year, Vellayani Hraswa had significantly higher dry matter content (399.2 $mg\ g^{-1}$) on a par with that of Sree Vijaya, triploid 4-2 and Kalpaka. In the subsequent year also, Vellayani Hraswa had appreciably higher dry matter content (365.1 $mg\ g^{-1}$) on a par with that of Sree Vijaya and tripolid 4-2 (Table 4).

Cyanogenic glucoside content did not vary markedly between years, but it was profoundly influenced by the independent effect of genotype as well as genotype × year interaction. The cyanogenic glucoside content of all genotypes, except triploid 4-2, triploid 2–18 and H-165, was low and within the tolerable limit (29.2–43.8 $\mu g\ g^{-1}$), indicating the suitability of most of the genotypes for consumption as food (Table 4).

The starch content of all short-duration genotypes tested was fairly good and almost comparable (220–280 $mg\ g^{-1}$), though slightly higher levels were observed in triploid 4-2, Vellayani Hraswa and Sree Vijaya (270–280 $mg\ g^{-1}$) (Table 4). Sreekumari and Abraham[33] ascribed the reasonably high starch content of 310 $mg\ g^{-1}$ in triploid 4-2 at month 7 to triploidy *per se*. Thus the considerably higher tuberous root dry biomass production coupled with higher dry matter and starch contents in tuberous roots observed in triploid 4-2 make it ideal for industrial use. The cooking quality of Vellayani Hraswa, Kalpaka, Sree Jaya, Sree Vijaya, CI-732 and CI-848 was good.

Nutrient uptake

The uptake of N and P by the short-duration genotypes was not under seasonal influence. Uptake being a function of biomass production, the uptake pattern varied significantly among genotypes owing to the profound difference in total biomass production among varieties. N uptake was significantly higher for triploid 2–18 and Sree Jaya (283 and 277.30 kg ha^{-1} respectively), while P uptake was higher for triploids 2–18 and 4-2 (40.23 and 38.44 kg ha^{-1} respectively). However, the independent and combined effects of genotype and year imparted significant variation in K uptake. In the first year, triploid 2–18 exported significantly higher K, whereas, in the second year, Sree Jaya and Sree Prakash were heavy exporters of K (Fig. 3).

Soil fertility status

The average soil fertility status after two years of cropping the short-duration cassava genotypes indicated that the organic C and available N, P and K status of the soil was almost the same under the different genotypes (Fig. 4). The nutrient status did not vary much between years and was unaffected by genotype × year interaction. On average, organic C content was medium (6.1–6.2 g kg^{-1}), available N content was low (220–230 kg ha^{-1}), available P content was high (28–37 kg ha^{-1}) and available K content was low (130–142 kg ha^{-1}). The low status of available N and K in the soil after two years of cropping indicates the significance of replenishing the soil with adequate amounts of N and K through organic and inorganic sources of plant nutrients. Detailed investigations are being carried out at CTCRI on standardising the nutrient management practices for short-duration cassava.

Correlation of growth and yield parameters with tuber yield

The correlation coefficients of growth and yield attributes of the short-duration cassava varieties with tuber yield are given in Table 5. In all genotypes, almost all growth parameters at the last phase (4–6 MAP), i.e. tuberous root dry matter and total dry matter per plant, CGR, RGR, TBR and HI, exhibited significant positive correlations ($P < 0.01$) with tuberous root yield. Apart from these, tuberous root dry matter and total dry matter production (ha^{-1}), mean tuberous root bulking rate, tuberous root number,

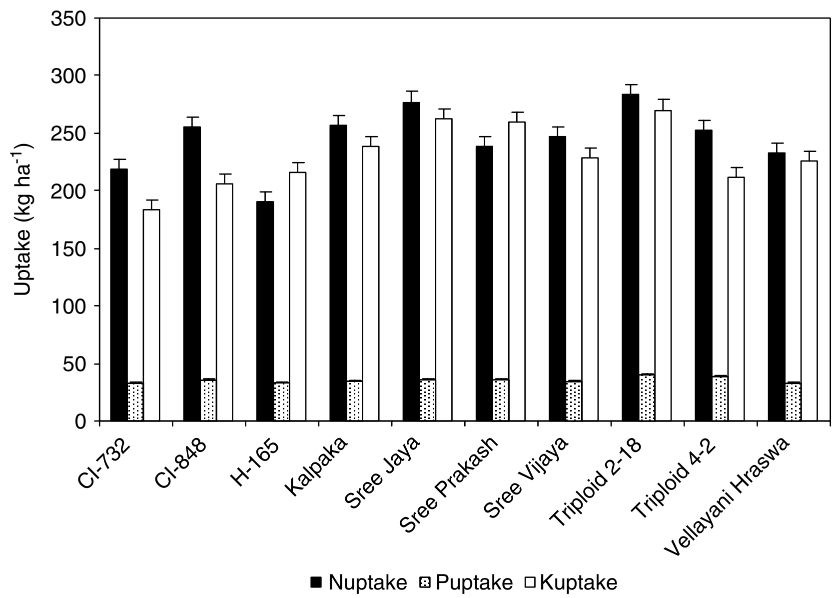

Figure 3. Nutrient uptake pattern in short-duration cassava genotypes (mean of two years).

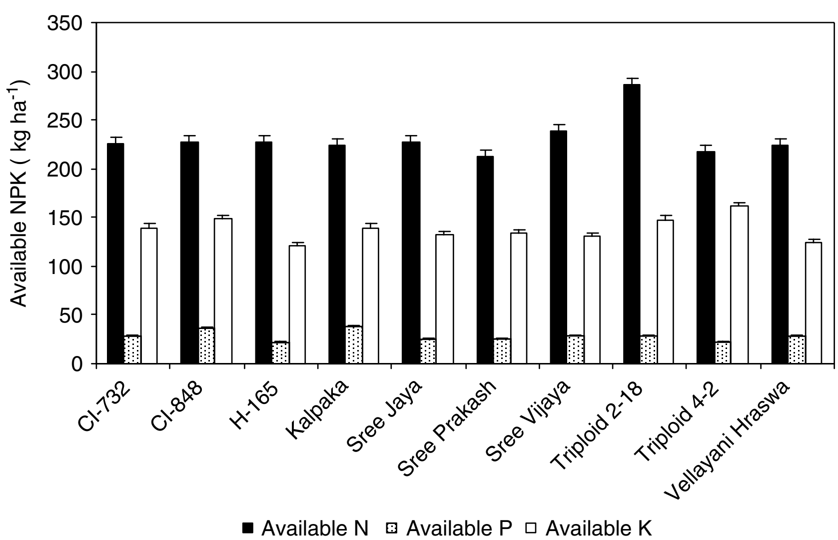

Figure 4. Soil fertility status under short-duration cassava genotypes (mean of two years).

Table 5. Correlation of growth parameters and yield attributes with fresh tuberous root yield

Growth parameter/yield attribute	Correlation coefficient with fresh tuberous root yield
Tuberous root dry matter at 6 MAP (g per plant)	0.8527**
Total dry matter at 6 MAP (g per plant)	0.7547**
Crop growth rate at phase 3	0.6948**
Tuberous root bulking rate at phase 3	0.8074**
Relative growth rate at phase 3	0.2654**
Harvest index at 6 MAP	0.6747**
Tuberous root dry matter production (t ha^{-1})	0.8527**
Total dry matter production (t ha^{-1})	0.7546**
Mean tuberous root bulking rate	0.8527**
Number of tuberous roots	0.4798**
Mean weight of tuberous roots	0.3166*
N uptake	0.3963**
P uptake	0.5228**
K uptake	0.4770**

* Significant at 5% level; ** significant at 1% level.

mean weight of tuberous roots and N, P and K uptake showed significant positive associations with tuberous root yield. However, biomass produced during the early growth period (2 and 4 MAP) and CGR, RGR, TBR and HI at the initial and middle phases could not significantly influence the final tuberous root yield, as the correlation coefficients in these cases were not significant. Moreover, tuberous root yield remained uncorrelated with dry matter and starch contents in tuberous roots.

It is worthy of note that in the present study the physiological parameters influenced tuber yield mainly through their positive effect on biomass production, as observed earlier by Ramanujam[11] in cassava genotypes of 10 month duration. Therefore lines with high biomass production potential coupled with higher partitioning efficiency may be considered as a desirable plant type from the yield point of view in short-duration genotypes as well.

Table 6. Principal component (PC) scores, eigenvalues and proportions of total and cumulative variance for first three PCs for 25 characteristics under study

Characteristic	PC 1	PC 2	PC 3
Available K	−0.876	−1.682	**−1.450**
Available N	0.514	−0.708	−0.768
Available P	−1.369	**−4.115**	1.105
Crop growth rate at last phase	−1.004	1.466	−1.217
Tuberous root dry matter content (mg g^{-1})	**−2.784**	−0.223	1.284
Cyanogenic glucoside	0.713	0.294	**−2.190**
Harvest index	**2.241**	1.108	0.920
K uptake	**3.728**	−0.417	1.056
Leaf dry matter at last stage (g per plant)	−0.054	1.502	0.575
N uptake	−0.062	1.422	0.646
Organic C	1.464	−0.556	**−1.672**
P uptake	1.118	−1.247	1.343
Relative growth rate at last phase	**2.672**	**−3.151**	0.165
Stem dry matter at last stage (g per plant)	1.916	−0.478	−1.128
Starch content	−1.206	−0.402	**−3.665**
Mean tuberous root bulking rate	−2.003	1.249	0.299
Tuberous root bulking rate at last phase	**−3.535**	−1.435	−0.250
Total dry matter production (t ha^{-1})	−0.130	1.158	−1.097
Total dry matter at last stage (g per plant)	−0.777	1.321	0.611
Tuberous root dry matter production (t ha^{-1})	−0.776	1.322	0.611
Tuberous root dry matter at last stage (g per plant)	−0.062	1.420	0.647
Tuberous root weight	−0.062	1.422	0.646
pH	0.268	0.666	1.278
Number of tuberous roots	**1.483**	1.351	0.112
Tuberous root yield	**−1.419**	−1.284	**2.140**
Eigenvalue	2.866	2.368	1.793
Proportion of variance	28.66	23.68	17.93
Cumulative proportion	28.66	52.34	70.27

Principal component analysis

The first three PCs described 28.66, 23.68 and 17.93% of the variation respectively, accounting for about 70% of the total variation. The factor scores for the different growth, biomass, yield, quality and soil characteristics under study along with eigenvalues and proportions of total and cumulative variance are given in Table 6. PC 1 had a high absolute score for tuberous root yield, which was found to be closely related to K uptake, tuberous root bulking rate at the last phase, tuberous root dry matter content, RGR, HI and number of tuberous roots per plant. PC 2 had highest scores for available P and RGR. PC 3 exhibited high scores for tuberous root yield, starch content, cyanogenic glucoside content, available K and organic C status of the soil. The results based on PCA also suggested that all characteristics in the correlation analysis except N uptake and mean weight of tuberous roots are closely related. While RGR did not figure prominently in the correlation analysis, PCA suggests that RGR at the last phase may also influence tuber yield. Moreover, tuberous root dry matter content and starch content also exhibited close relationships with tuberous root yield in the first and third PCs. The biplot of PC1 *versus* PC2 (Fig. 5) shows that high tuberous root yield was positively related to HI, TBR, CGR, leaf dry matter and tuberous root dry matter per plant and total dry matter production.

Cluster analysis

Cluster analysis was carried out to group the ten short-duration genotypes based on growth, biomass, yield and quality attributes and soil parameters. When the dendrogram was cut at a distance of 0.85, four clusters were obtained – cluster I: Sree Vijaya and Vellayani Hraswa; cluster II: Kalpaka, Sree Jaya, Sree Prakash, CI-732 and CI-848; cluster III: H-165; cluster IV: triploid 2–18 and

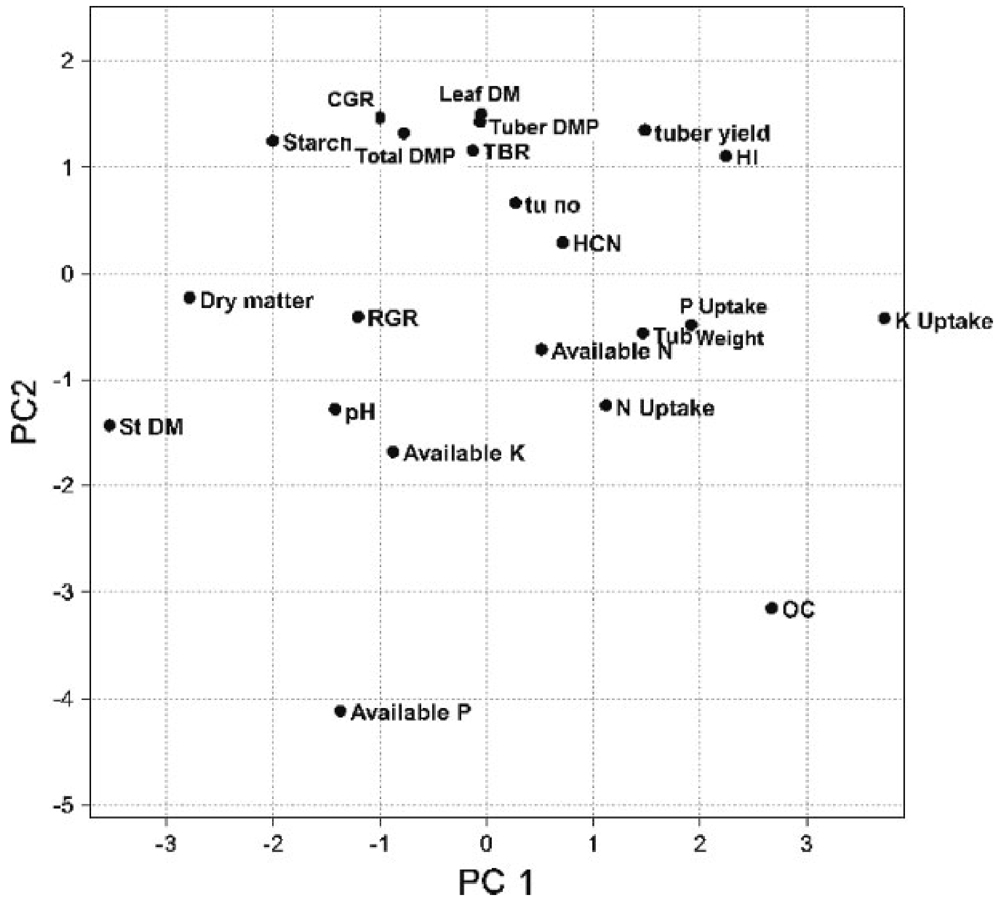

Figure 5. Biplot of principal component scores of growth, yield, quality and soil parameters of short-duration cassava genotypes.

triploid 4-2 – showing that the genotypes Sree Vijaya and Vellayani Hraswa were closely related with respect to growth dynamics, yield characteristics, biomass characteristics and soil parameters. The genotypes Kalpaka, Sree Jaya and Sree Prakash also behaved similarly and were closer to CI-732 and CI-848. The triploids (2–18 and 4-2) were clearly separated from the rest. H-165 was found to be the most dissimilar in growth dynamics, biomass, yield and quality. This information may be helpful in future breeding and varietal improvement programmes for selecting varieties with similar growth, yield and quality attributes.

CONCLUSION

The present study revealed that tuberous root yield, mean TBR, tuberous root biomass production and total biomass production (ha^{-1}) at harvest as well as quality parameters such as starch and cyanogen contents were not under seasonal influence, though they varied among short-duration varieties. In other words, the yield and quality attributes of the short-duration genotypes were consistent over years. Among the short-duration genotypes tested, Sree Vijaya, Sree Jaya, Vellayani Hraswa and Kalpaka appeared promising for cultivation in rice fallow for food use owing to their high yield, good cooking quality and low cyanogen content. Triploids 2–18 and 4-2 proved ideal for industrial use owing to their high tuberous root dry biomass production. In all genotypes, almost all growth parameters during the last phase (4–6 MAP), i.e. tuberous root dry matter and total dry matter per plant, CGR, RGR, TBR and HI, exhibited significant positive correlations with tuberous root yield. Apart from these, tuberous root dry matter and total dry matter production (ha^{-1}), mean tuberous root bulking rate, number of tuberous roots, mean weight of tuberous roots and N, P and K uptake showed significant positive associations with tuberous root yield. Therefore genotypes with high biomass production potential coupled with higher partitioning efficiency may be considered as a desirable plant type from the yield point of view in short-duration genotypes as well.

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