Proceedings of the Tenth Symposium of the International Society for Tropical Root Crops, held in Salvador, Bahia, Brazil, October 23-29, 1994

IMPROVING THE GENETIC BASE OF CASSAVA IN THE SEMI-ARID TROPICS

C. Iglesias*, W. Fukuda†, and M. A. El-Sharkawy*

Abstract

Cassava can be adapted to semi-arid regions because of its tolerance of both sporadic and extended drought. This is important for those regions where human populations are expanding into marginal agricultural areas, particularly semi-arid sub-Saharan Africa and North-East Brazil. Research on cassava physiology has demonstrated the ability of certain genotypes to withstand and subsequently recover from prolonged drought. During prolonged water deficit, plants reduce leaf canopy and top growth, partially close their stomata, and yet maintain reasonable photosynthetic rates. The most adapted genotypes reduce water use per unit of accumulated dry matter in the roots. They can also extract deep soil water when it is available. The greatest genetic diversity of cassava germ plasm for semi-arid adaptation is found in North-East Brazil. A project is being developed in that region, bringing together the germ plasm, human, and material resources of Brazilian national and state research programmes. The basic components of the project's strategy are to collect landrace varieties, screen germ plasm at representative sites, develop improved gene pools, and transfer improved populations to breeding programmes in homologous regions of the world. A set of cassava accessions has been selected at each of four evaluation sites. Some accessions were selected for their broad adaptation across sites; others for specific traits of value to the recombination programme. Major selection criteria considered were germination rate, root yield potential, mite and drought resistance or tolerance, and dry matter and root cyanide contents. Selected genotypes have been multiplied and included in on-farm evaluations. Selected and complementary accessions have been recombined; and segregating progenies are under evaluation and adaptive selection in North-East Brazil, northern Nigeria, and the Atlantic coastal region of Colombia. Diffusion of improved germ plasm for semi-arid ecosystems will help enhance food security in these regions.

Introduction

Cassava is a significant source of food energy for many tropical countries. Because of its outstanding performance under marginal climatic and soil conditions, cassava is frequently identified as a famine-alleviation crop that can provide some sustenance when other food crops fail.

* Cassava Program, CIAT, A.A. 6713, Cali, Colombia.
† EMBRAPA-CNPMF, Cruz das Almas, Bahia, Brazil.

The situation in sub-Saharan Africa and North-East Brazil is particularly critical. These regions are experiencing food crises as a consequence of a reduced growth rate of cultivated land, technological stagnation, accelerated environmental degradation, and climatic factors. Such areas desperately need new alternatives for agricultural development: to increase and sustain food production, decrease dependence on imported foods and promote increased welfare of the poor rural and urban populations.

Even though, in the absence of production constraints, cassava ranks second among tropical crops (after sugar cane) in terms of its potential as an energy source, breeders have tended to focus on cassava's well-known ability to tolerate prolonged water stress. As a result of its high adaptability, the crop provides an important part of the energy intake of rural populations in drought-prone areas. During the last 30 years, cassava production has shifted considerably from relatively favourable environments to marginal ones. Because environmental and equity concerns are closely linked and because cassava can be used as a food security crop in drier ecosystems, breeders have concentrated on improving the crop's inherent potential, not only to cope with stressful environments, but also to form a component of sustainable technologies (El-Sharkawy 1993).

In our paper we show that cassava is a crop adapted to marginal semi-arid environments. We also analyse the physiology and genetic variability for drought tolerance-related traits, and describe breeding efforts being made for this ecosystem.

Physiology of Water Stress Tolerance in Cassava

Cassava cultivars with differential reactions to water stress have been studied. The physiological mechanisms behind the response of cassava to water stress and the possibility of using them to improve the efficiency of selecting for more tolerant genotypes have been established through comparisons of water-stressed and normally watered field-grown plants. Water stress significantly reduces leaf canopy across genotypes (CIAT 1992a, 1992b; El-Sharkawy et al. 1992), but the reaction depends on the genotype. Reduction in leaf canopy cannot be attributed solely to leaf fall as stressed crops shed fewer leaves than unstressed ones. When subjected to stress after full canopy establishment, the plants react by reducing top growth. The level of that reduction compared with that of well-watered plants is significant for some genotypes, while others can maintain adequate levels of top growth to support considerable root yield at the end of the crop cycle.

Genotypic differences were not only manifest in the ability to cope with prolonged dry periods, but also in their capacity to recover top growth when released from stress. El-Sharkawy et al. (1992) have shown that, during water stress, cassava leaves retain as much as 50% of their original photosynthetic activity. After recovering from stress, the mature leaves can recuperate their photosynthetic activity to levels comparable with those of unstressed leaves. Moreover, the new leaves that are formed in previously stressed plants can, after recovery, photosynthesize at higher rates than new leaves from control plants (CIAT 1992a, 1992b; El-Sharkawy 1993).

As a result of the canopy and leaf metabolic adjustment mechanisms, surprising results have been found when genotypes are exposed to water stress at different periods of their development. Table 1 presents data on dry root yield, dry weight of top biomass, and harvest index for early, intermediate, and late water stress. Even when prolonged water stress occurs in either the early or late stage, average root yields across all clones were not significantly different from those for unstressed crops. Yields with midseason water stress are significantly higher than those for unstressed crops. These data confirm the high degree of tolerance that cassava has of prolonged water stress.

An important conclusion from these studies was that emphasis should be given to leaf retention while selecting for drought tolerance in cassava (El-Sharkawy et al. 1992). Even under severe stress, cassava plants can regulate their CO_2 uptake, allowing gas exchange during periods of lower atmospheric water demand, and partially closing their stomata during demand peaks (El-Sharkawy and Cock 1984).

Recent studies on the level of activity of different enzymes related to the photosynthetic pathway of cassava have revealed significant shifts in activities as a response to water stress. One early hypothesis on the role of the enzyme phosphoenolpyruvic carboxylase (PEPC) was that it was active in reducing photorespiratory CO_2 loss, particularly under drought conditions (El-Sharkawy and Cock 1990). When cassava leaves developed under water stress were tested, PEPC activity was 13% greater than in the unstressed crop (Table 2). In contrast, the activity of rubisco (ribulose diphosphate carboxylase) decreased (by 42%) under stress. These results support the original hypothesis that PEPC plays a significant role in cassava photosynthesis during drought.

Cassava is highly efficient in using every unit of absorbed water. Genotypes vary in their ability to extract water available in the soil. In all stress treatments cassava withdrew more water from deep soil layers (Figure 1). The water uptake from deep layers increased as stress progressed, particularly under late stress. Because cassava can explore deep soil layers through its fibrous root system, genotypes with profuse rooting ability should therefore be selected. Evaluating this trait in the field is extremely difficult. We are now studying the feasibility of screening cassava germ plasm in the glasshouse at early stages of development as a way of evaluating large numbers of genotypes in a breeding programme.

Given that the average cassava genotype responds to water stress by increasing the levels of cyanogenic glycosides in the roots, evaluating the genetic variability for this trait under stress conditions is important. The reaction of different genotypes under water stress and normal conditions was studied (Figure2). Under stress, two clones maintained relatively stable cyanide contents, while another two showed a significant increment (El-Sharkawy 1993). The introduction of genetic variability for low cyanide content, and the evaluation and selection under semi-arid environments is of paramount importance for developing improved gene pools targeted towards human use in areas where processing is inadequate for consumption.

The results obtained under simulated drought conditions helped define selection criteria for field screening germ plasm (i.e., leaf retention), resulting in a selected genetic base for traits such as photosynthetic capacity under water stress and profuse root development, which is being incorporated in recombinant progenies targeted towards semi-arid ecosystems.

Cassava Breeding for Semi-Arid North-East Brazil

A major semi-arid region where cassava is grown is North-East Brazil. Here, cassava has evolved over a long time, resulting in a wealth of genetic diversity and a tradition for using this major staple. A project was started in that region with the objective of developing improved germ plasm for semi-arid environments.

North-East Brazil: its geographic position and demography

North-East Brazil is located between 2° and 18° south and 35° and 42° west. The region is formed by nine states—Bahia, Sergipe, Alagoas, Pernambuco, Paraiba, Rio Grande do Norte, Ceará, Piauí, and Maranhão—and the overseas territory of Fernando de Noronha. It covers an area of almost 1.6 million km^2 or 18.3% of Brazil (Table 3).

In 1991, the region had a population of 42.4 million people, with a projection of 50.1 million for the year 2000. In Latin America, only the rest of Brazil and Mexico have higher populations. Population density in North-East Brazil is 22.5 inhabitants/km^2, higher than other regions of the country. The limited environmental conditions for making a living, especially the amount and distribution of rainfall (Table 4), however, encourage people to leave the area. Net emigration was 19.46% in 1991, the highest in the country (IBGE 1992).

According to SUDENE (1985), North-East Brazil can be divided into five rainfall areas: (1) 31.9% of the region with >1,000 mm (forest); (2) 19.6% with 750-1,000 mm (shrub); (3) 36.9% with 500-750 mm (savannah); (4) 11.4% with 250-500 mm (semi-desert); and (5) 0.2% with <250 mm (desert). Some states in North-East Brazil and northern Minas Gerais are within what is known as the "Polygon of Drought", with an area of 534,379 km^2, representing 56.7% of the north-eastern region. This area has the following characteristics: rainfall = 400-800 mm, concentrated in 3 to 5 months; mean annual temperature = 23°C-27°C, with a peak during the dry season; mean solar radiation period = 2,800 h/year; relative humidity = 50%; and average evapotranspiration = 2,000 mm/year (Estevam Neto 1987).

Nutritional status and other regional social indicators

More than 31 million people—equivalent to 9 million families—are estimated to suffer from hunger in Brazil (Frente Parlamentar de Ação pela Cidadania 1993). About half of these people live in the north-eastern region, where 300,000 children die every year before reaching their first birthday. About 70% of the Brazilian population receive neither adequate food nor nutrition to sustain a healthy life. The low availability of good-quality proteins, vitamins, and minerals has been responsible for the high infant mortality rate during the 1970s and 1980s when the infant mortality rate for Brazil was 8.5% in urban areas and 9.5% in rural areas. In North-East Brazil, these rates were 12.4% and 11.8%, respectively (IBGE 1991).

Although malnutrition can be found at all socio-economic levels throughout Brazil, it is highly correlated with poverty. A consequence of child malnutrition is a prolonged growth period before adulthood, which has negative effects on the capacity to work (Rezende 1993). A potential solution to these problems is to grow food crops adapted to the prevailing environmental conditions, particularly drought.

Cassava as a major food alternative

Because it is one of the few edible crops that can survive under the stressful growing conditions of semi-arid North-East Brazil, cassava is a viable alternative for solving, or at least minimizing, nutritional problems. During prolonged drought, cassava is the only species in the region that maintains green leaves. The crop is considered one of the most complete species in every sense. Apart from its hardiness and adaptation to drought, it produces roots with high levels of carbohydrates (up to 35%), and the foliage is high in proteins, vitamins A and C, iron, and other minerals (da Silva 1993; Lutaldio 1983). The crop has traditionally been used as a source of carbohydrates for human consumption and the foliage for animal feed. Analysis of the crop's evolution in terms of area, production, and yield from 1970-1990 does not reflect its true importance for the country's lowest socio-economic strata (Table 5).

Studies conducted by Vitti et al. (1972) with dried leaves from six cassava cultivars demonstrated the variability in proteins, vitamin A, and cyanide content (Table 6). Pro-vitamin A components varied from 11,090 to 16,292 IUs—levels that are superior to those found in maize, maize flour, oats, and other food components of the traditionally consumed diet. With respect to proteins, the mean concentration of almost 24% (dry wt) is comparable with the best grain legumes used in human nutrition. The composition of roots and leaves depends on both the genetic potential of cultivars and the edapho-climatic conditions under which they have been grown. Selection and recombination can certainly improve the levels of the most important nutrient components.

Considering the social and nutritional status of people in semi-arid North-East Brazil, cassava becomes a strategic food source, given its capacity to produce carbohydrates, proteins, vitamins, and minerals. It is estimated that 15 million tons of foliage are directly recycled to the soil annually. Part of this could be used as a supplement in human nutrition (Homen de Carvalho 1989).

Cassava germ plasm development for the semi-arid regions of Brazil

Since 1990, a project has been conducted to improve the adaptability and productivity of cassava in the semi-arid ecosystems of Brazil. The project is implemented by the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA, the Brazilian agricultural research agency), with technical support from CIAT and financial support from the International Fund for Agricultural Development (IFAD). The overall objective of the project is to develop, for the semi-arid regions of Brazil, sustainable cassava production components that have potential for use in homologous regions of Africa. The main strategy is to select and recombine genotypes with greater potential and stability for root production and quality for different end uses such as foodstuffs, animal feed, and industrial processes.

The major activities are (1) broadening the germ plasm base through the collection and introduction of cassava accessions from regions of interest, (2) evaluating that germ plasm base in representative sites, and (3) recombining selected accessions to produce segregating progenies that will be incorporated into the region's breeding programme and similar breeding programmes in Africa.

From 1991 to 1992, more than 1,000 accessions from the germ plasm collection held at the Centro Nacional de Pesquisa de Mandioca e Fruticultura (CNPMF, part of EMBRAPA) were evaluated at four sites. These sites together represented the range of edapho-climatic conditions predominating in semi-arid North-East Brazil: Itaberaba (Bahia), Petrolina and Araripina (Pernambuco), and Quixadá (Ceará).

The main objectives for evaluating germ plasm accessions were to (1) identify promising genotypes to be recommended to farmers for the short term, (2) select accessions with outstanding features for recombination, and (3) produce segregating progenies for testing in North-East Brazil and sub-Saharan Africa.

The major selection criteria were root yield, dry matter (DM) content, cyanide content, resistance to mites, and drought tolerance. The frequency distribution for the evaluated germ plasm accessions is presented in Figures 3-6. Results from the 1992 germ plasm evaluation at Petrolina (Pernambuco) serve to illustrate the crop's potential:

The 1992 crop cycle was (1) planted at the end of the rainy season; (2) all months during the cycle were dry for cassava (average monthly rainfall was <60 mm), with no rain at all for 5 months (May-Sept); (3) total rainfall during the growth cycle was 175 mm; (4)

estimated annual evapotranspiration was 2,000 mm; (5) inherent soil fertility was low, with no fertilizer applied; and (6) mite attack was heavy.

Despite these constraints, 11 of the 500 germ plasm accessions evaluated were significantly superior to the local check with respect to the most important selection criteria (Table 7). Average production of the elite accessions was equivalent to 4.3 t/ha of cereal grain (12.5% moisture). Given the severe drought during what would have been a cereal crop's flowering and grain-filling periods, even sorghum or millet would not have established as well or produced as much.

Of the 1,008 germ plasm accessions evaluated, three groups of genotypes were selected. They had the following characteristics:

> *Specific adaptation.* Outstanding agronomic performance at each evaluation site. The proportion of accessions selected for specific adaptation was 22.5% in Itaberaba, 12% in Petrolina, 19% in Araripina, and 18% in Quixadá.
>
> *Broad adaptation.* Comparing performance across sites with that of local checks, 54 accessions (5.3%) were selected after two cycles of evaluation, showing good performance at all sites. These accessions have been multiplied for on-farm evaluation trials.
>
> *Accessions with special traits.* Accessions were selected for recombination if they were outstanding in desirable traits (e.g., high dry matter content, low cyanide content, and resistance to mites) and had an acceptable agronomic performance in at least 2 of the 4 sites. About 40,000 recombinant seeds were produced. Half of that seed was planted for evaluation under semi-arid conditions in North-East Brazil. The other half was distributed to the International Institute of Tropical Agriculture (IITA, based in Nigeria) and CIAT (in Colombia) for evaluation under homologous conditions.

Conclusions and Perspectives

Cassava can certainly be a vehicle for alleviating malnutrition in marginal and impoverished regions of the world. The foregoing results demonstrate the considerable potential of the genetic variability available in Brazil for improving cassava adapted to semi-arid conditions. Accessions selected for broad adaptation had the capacity to produce considerable root yield under an annual rainfall of <400 mm. These genotypes are being evaluated in on-farm trials to determine their acceptability to farmers in the region. The nutritional value of both roots and leaves of selected material needs to be evaluated in terms of protein, vitamin, and mineral contents.

In terms of root yield potential, dry matter and cyanide contents, and mite resistance, the project was successful in (1) identifying genotypes for immediate evaluation on farm and subsequent diffusion of the most acceptable ones; (2) identifying genotypes with outstanding characteristics for recombination; and (3) reducing the time required for impact through simultaneous evaluation at several representative sites.

The project now expects to:

Validate, with farmer participation, selected material across a wider range of agro-climatic conditions; and use feedback from farmers to improve selection efficiency and probability of effective impact.

Intensify the screening of segregating progenies at selected sites; and incorporate selected germ plasm into multidisciplinary research on production systems—improved cultivars would be only one of the technological components used for improving cassava production in semi-arid regions.

Evaluate the nutritional value of elite germ plasm and its potential impact in terms of improving the nutritional status of populations living in semi-arid regions.

Improve interinstitutional cooperation in North-East Brazil so that available resources (whether human, financial, or infrastructure) are used more efficiently, and interactions fostered with other on-going projects in the region such as those for the integrated control of cassava pests and diseases and for the integrated development of cassava production and marketing in North-East Brazil.

Support other national programmes in homologous regions with information and germ plasm to improve the viability of the crop in some of the world's most marginal areas.

Based on the set of selection criteria, a representative germ plasm base has been gathered and screened; and a group of elite genotypes, selected. The use of improved cultivars for semi-arid environments is only one of several technological components to be used for promoting cassava production in these regions. Efforts to improve cultivars must be coordinated with those in integrated crop management research, cassava processing, and marketing.

The highly promising results obtained from this and other projects should contribute to any plan focused on the socio-economic development of semi-arid regions.

References

CIAT. 1992a. Cassava Program 1987-1991. Working document no. 116. Cali, Colombia. p 43-54.

CIAT. 1992b. Cassava Program annual report 1992. Working document no. 142. Cali, Colombia.

da Silva JRB. 1993. Mandioca: Uma riqueza incomparável e irreconhecida. Associação dos Productores e Industriais de Mandioca do Estado de São Paulo, Candido Mota, SP, Brazil.

El-Sharkawy MA. 1993. Drought-tolerant cassava for Africa, Asia, and Latin America. BioScience 43:441-451.

El-Sharkawy MA; Cock JH. 1984. Water use efficiency of cassava. I. Effects of air humidity and water stress on stomatal conductance and gas exchange. Crop Sci 24:497-502.

El-Sharkawy MA; Cock JH. 1990. Photosynthesis of cassava (*Manihot esculenta*). Exp Agric 26:325-340.

El-Sharkawy MA; Hernández AP; Hershey CH. 1992. Yield stability of cassava during prolonged mid-season water stress. Exp Agric 28:165-174.

Estevam Neto J. 1987. O DNOCS-ontem e hoje: Sustentáculo da nascente civilização da seca. DNOCS, Fortaleza, CE, Brazil.

Frente Parlamentar de Ação pela Cidadania. 1993. Brasília, DF, Brazil.

Homen de Carvalho JL. 1989. A manidoca: Rais e parte aerea na alimentação animal. Centro Nacional de Pesquisa de Mandioca e Fruticultura, Empresa Brasileira de Pesquisa Agropecuária, Cruz das Almas, BA, Brazil.

IBGE (Instituto Brasileiro de Geografia e Estadísticas). 1991. Anuário estatístico do Brasil. Rio de Janeiro, RJ, Brazil. Vol 31-51.

IBGE (Instituto Brasileiro de Geografia e Estadísticas). 1992. Anuário estatístico do Brasil. Rio de Janeiro, RJ, Brazil. Vol 52, p 205-209.

Lutaldio NB. 1983. Evaluation of cassava clones for leaf production in Zaire. In: Terry EV; et al., eds. A tropical root crop: production and uses in Africa. Cameroon. p 41-44.

Rezende F. 1993. A metamorfose do Estado de São Paulo. Edicões Ahag., São Paulo, Brazil.

SUDENE (Superintendência de Desenvolvimento de Nordeste). 1985. Brasil: Recursos naturais do Nordeste, investigação e potencial (sumáio da atividade). 4th ed. Recife, PE, Brazil.

Vitti P; Figueredo IB; Angelucci E. 1972. Folhas de mandioca desidratadas para fins de alimentação humana. Colect Inst Tec Aliment 4:117-125.

Table 1. Dry root yield (DRY, t/ha), dry weight of top biomass (tops, t/ha), and harvest index (HI) at final harvest (12 mo) as affected by early (102 days, starting 79th day after planting), midseason (93 days, starting 140th DAP), and late water stress (157 days, starting 198th DAP).

Clone	**Unstressed**			**Early stress**			**Midseason stress**			**Late stress**		
	DRY	**Tops**	**HI**	**DRY**	**Tops**	**HI**	**DRY**	**Tops**	**HI**	**DRY**	**Tops**	**HI**
CM 523-7	10.9	3.6	0.75	15.5	4.7	0.77	15.7	5.6	0.74	11.6	3.8	0.75
CM 507-37	14.7	4.5	0.77	12.5	3.2	0.80	14.4	5.6	0.72	12.3	3.2	0.79
M Col 1468	9.9	6.4	0.60	9.0	4.3	0.68	10.9	5.8	0.65	10.3	4.4	0.70
M Col 1684	10.3	2.6	0.80	10.5	2.0	0.84	11.4	3.3	0.78	9.9	2.6	0.79
Average	11.5	4.3	0.73	11.9	3.6	0.77	13.1	5.1	0.72	11.0	3.5	0.76
Change through stress (%)				+3	-16	+5	+14	+19	-1	-4	-19	+4
LSD 5% (DRY) = 1.5 for water regime across clones.												

SOURCE: CIAT.

Table 2. Activities (μmol/mg chlorophyll per min) of some photosynthetic enzymes in leaf extracts of field-grown cassava as affected by 8 weeks of water stress starting at 92nd day after planting (means ± SD).[a]

Clone	**Unstressed**			**Stressed**		
	PEPC	**Rubisco**	**PEPC/ rubisco**	**PEPC**	**Rubisco**	**PEPC/ rubisco**
CM 4013-1	0.86 ± 0.12	0.28 ± 0.10	3.1	1.18 ± 0.17	0.30 ± 0.01	3.9
CM 4063-6	0.89 ± 0.05	2.30 ± 0.03	0.4	1.42 ± 0.26	0.62 ± 0.02	2.3
SG 536-1	1.46 ± 0.42	0.44 ± 0.12	3.3	1.33 ± 0.22	0.25 ± 0.08	5.3
M Col 1505	1.09 ± 0.10	0.57 ± 0.13	1.9	0.96 ± 0.16	0.89 ± 0.14	1.1
Average	1.08	0.90	2.2	1.22	0.52	3.2
Average changes due to stress (%)				+13	-42	+45

a. PEPC = Phosphoenolpyruvic carboxylase; rubisco = ribulose diphosphate carboxylase (both are enzymes made by cassava during photosynthesis).

SOURCE: CIAT.

Table 3. Area and population of Brazil by region, 1991.

Region	Area		Population (000)	
	km^2 (000)	%	Urban	Rural
North	3,851	45.3	5,931	4,325
North-East	1,556	18.3	25,753	16,716
Central-West	1,604	18.8	7,648	1,763
South-East	924	10.8	55,149	7,511
South	575	6.8	16,392	5,724
Total	8,510		110,873	36,039

SOURCE: IBGE 1992.

Table 4. Rainfall and corresponding surface area of North-East Brazil.

Average annual rainfall (mm)	Area	
	km^2	**%**
>1000	510,000	31.9
750-1000	313,000	19.6
500-750	591,000	36.9
250-500	182,000	11.4
<250	4,000	0.2

SOURCE: SUDENE 1985.

Table 5. Evolution of the cultivated area, production, and yield of cassava in different regions of Brazil, 1970-1990.

Region	**Area (000 ha)**		**Production (000 t)**		**Yield (t/ha)**		**Change (1970-90)**		
	1970	1990	1970	1990	1970	1990	Area	Production	Yield
North	99	332	1,394	4,319	14.1	13.0	233	2,925	-1.1
North-East	995	1,107	12,198	11,833	12.3	10.7	112	-365	-1.6
Central-West	98	67	1,868	1,043	19.1	15.6	-31	-825	-3.5
South-East	314	137	5,260	2,005	16.8	14.6	-177	-3,255	-2.2
South	519	291	8,744	5,085	16.8	17.5	-228	-3,659	0.7

SOURCE: IBGE 1991.

Table 6. Water content, cyanide concentration, protein, and vitamin A content of dried cassava leaves.

Clone	Water content (%)	Cyanide content (mg/100 g)	Protein (%)	Vitamin A (IU/100 g)
Vassourinha	4.85	31	24.6	15,330
IAC-352-7	6.05	25	23.9	11,600
Guaxupé (1-y-old stems)	6.30	20	25.2	11,600
Guaxupé (2-y-old stems)	10.33	21	22.3	14,600
IAC-14-18	6.29	35	22.7	14,600
Mantiqueira	8.03	41	23.8	10,200

SOURCE: Vitti et al. 1972.

Table 7. Performance of elite cassava accessions, local check variety, and means for the trial and selected clones at 9 mo, Petrolina, Brazil, 1992.

Accession	Stand (%)	Reaction to mites[a]	Fresh root yield (t/ha)	Dry matter (%)	Dry matter production (t/ha)	Harvest index	Root cyanide content (ppm)
BGM 706	90	2.4	16.6	25.2	4.18	0.76	87
BGM 648	100	2.7	13.8	29.9	4.12	0.71	89
BGM 814	100	2.8	14.9	27.0	4.03	0.56	85
BGM 1015	90	2.7	14.9	26.9	4.02	0.61	86
BGM 615	100	3.0	11.9	33.2	3.94	0.68	88
BGM 1000	100	2.5	13.9	26.8	3.71	0.68	50
BGM 1217	100	2.5	13.3	27.5	3.64	0.62	72
BGM 652	100	2.7	12.6	28.8	3.63	0.59	85
BGM 876	100	3.7	12.9	27.8	3.58	0.54	100
BGM 611	100	2.7	13.5	25.5	3.43	0.64	86
BGM 1030	100	2.8	13.9	24.6	3.43	0.56	88
Local check	92	2.5	6.4	24.7	1.59	0.46	86
Trial mean	76	2.9	4.3	24.2	1.19	0.40	72
Selected accessions	94	2.8	9.0	26.2	2.43	0.54	75
Elite accessions	98	2.8	13.8	27.6	3.79	0.63	80
SD	0.4	0.28	3.4	1.3	0.87	0.06	12

a. On a scale where 1 = no damage and 5 = highly susceptible.

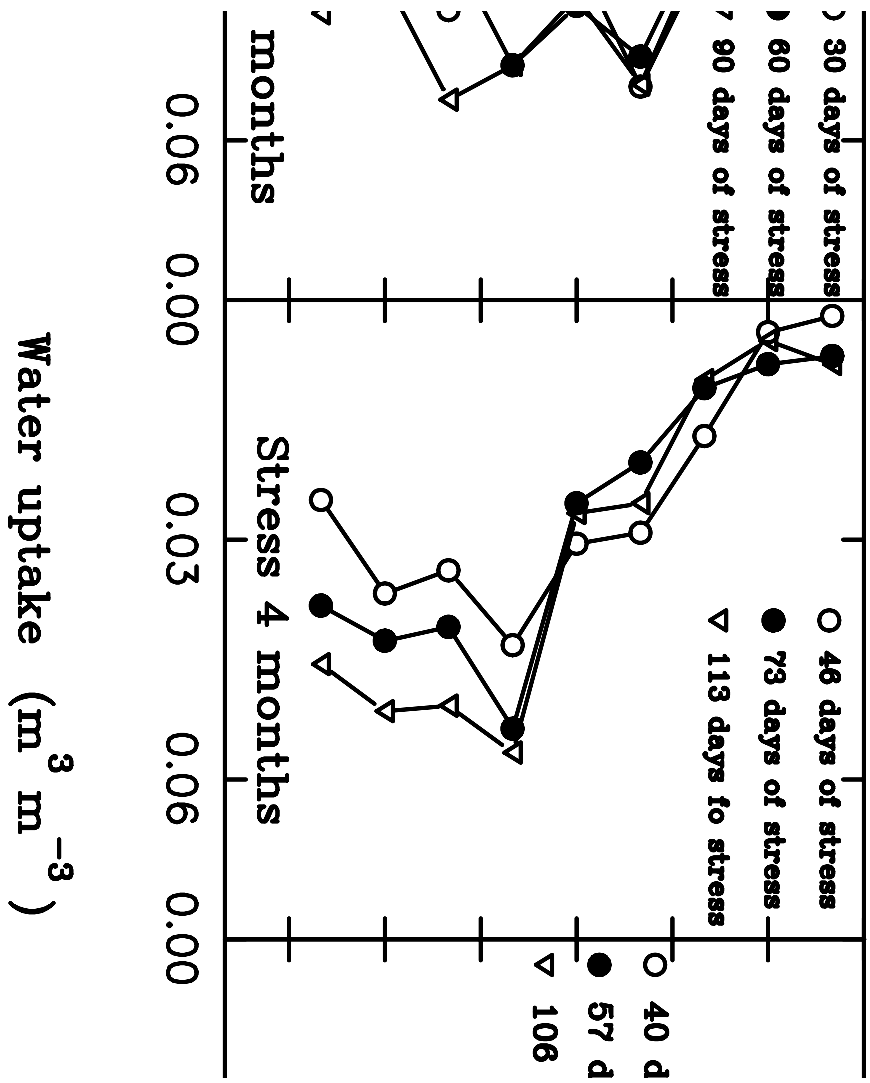

Figure 1. Patterns of water uptake by cassava during extended water deficit at Santander de Quilichao (Cauca, Colombia).

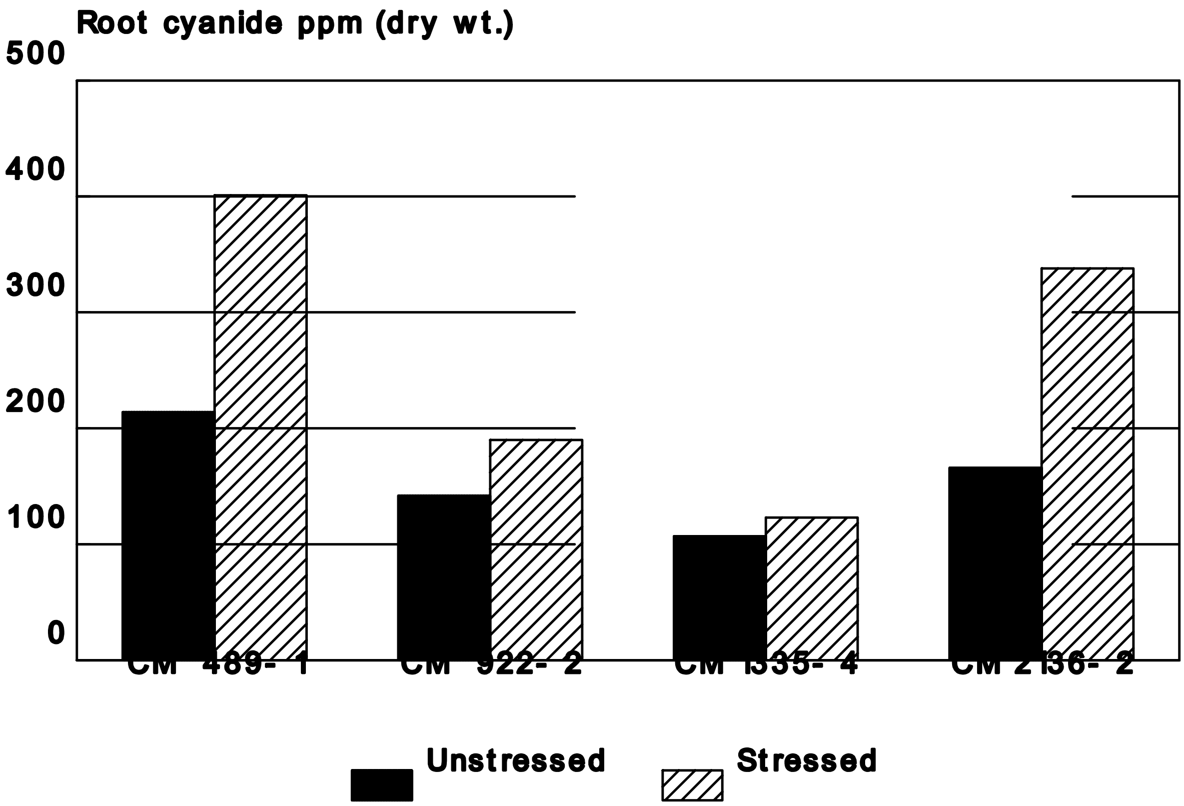

Figure 2. Changes in cassava root cyanide content related to water stress in four genotypes.

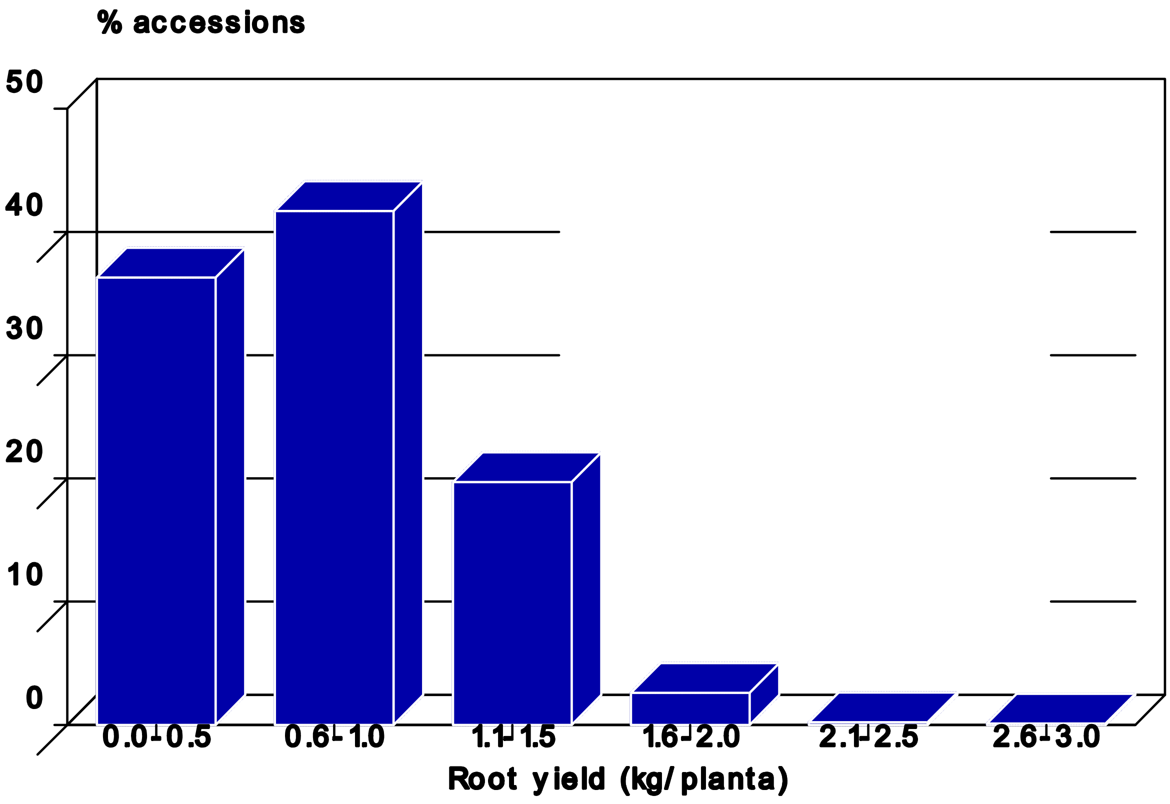

Figure 3. Frequency distribution of root production of 1008 accessions from the CNPMF Cassava Germplasm Collection in semi-arid NE Brazil.

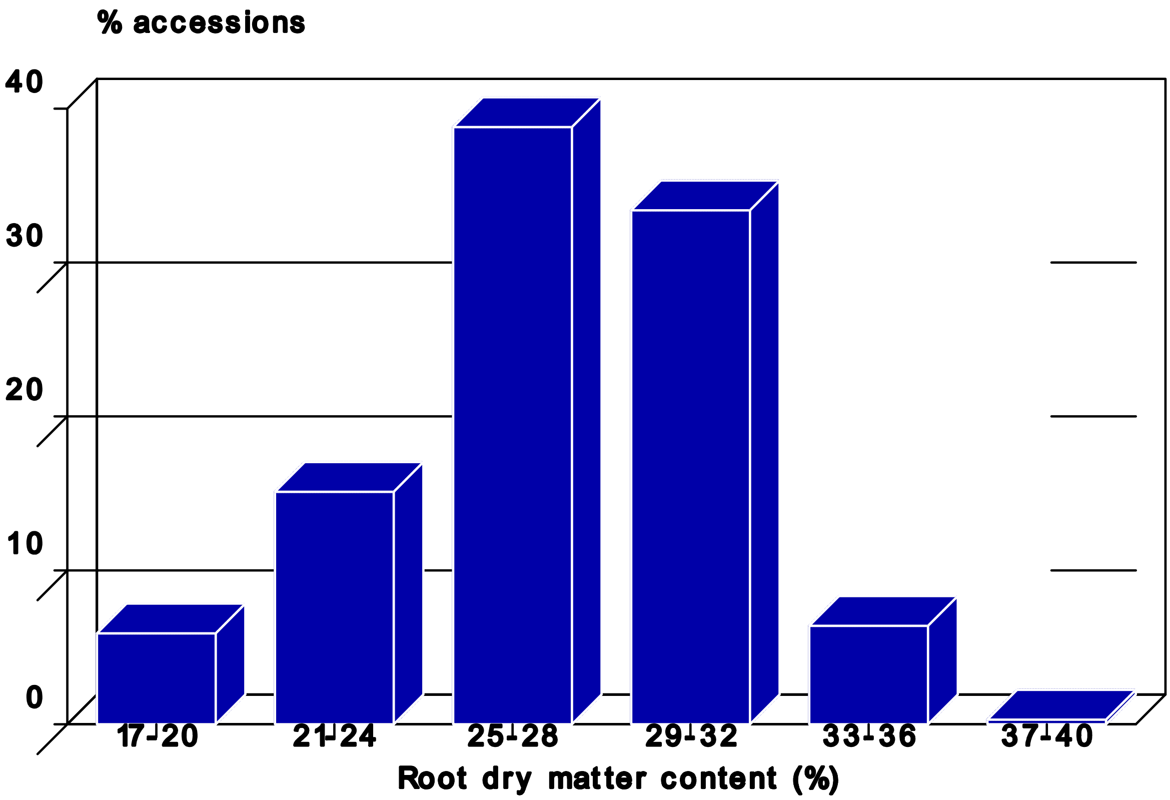

Figure 4. Frequency distribution of root DM content in 1008 accessions from the CNPMF Cassava Germplasm Collection in semi-arid NE Brazil.

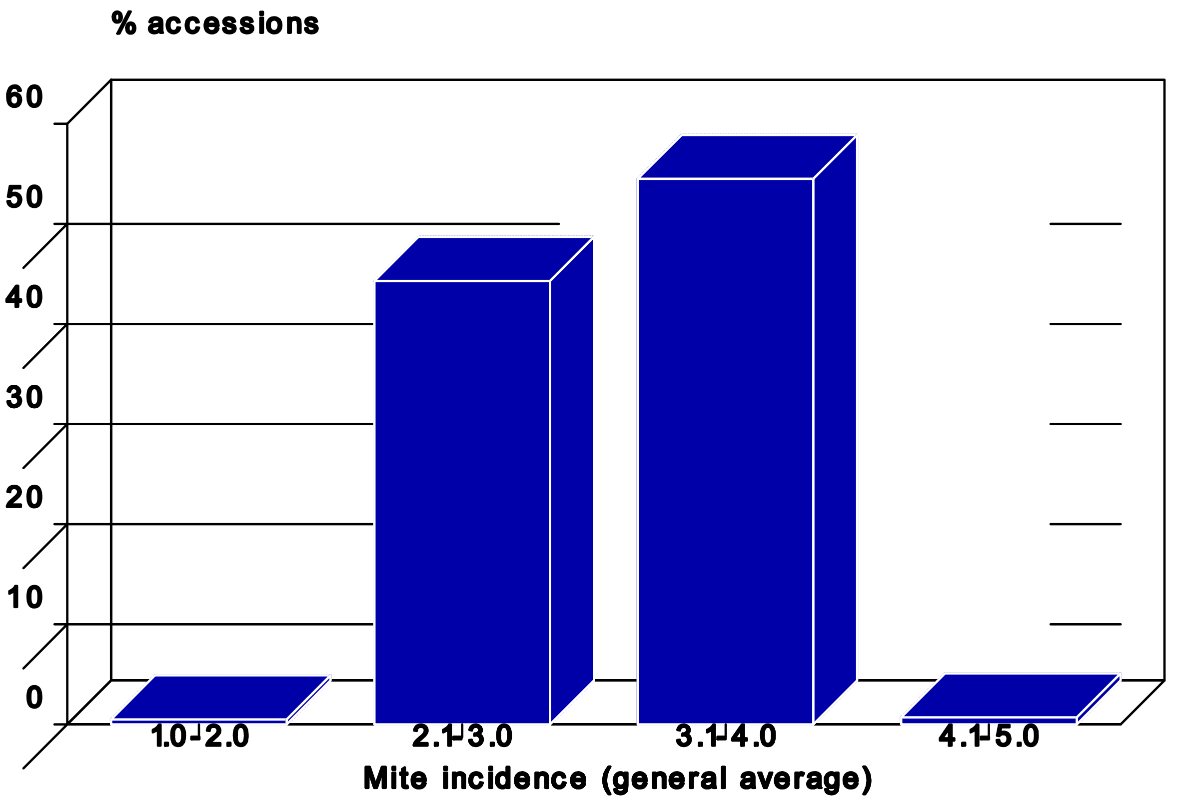

Figure 5. Frequency distribution of avg mite incidence in 1008 accessions from the CNPMF Cassava Germplasm Collection in semi-arid NE Brazil.

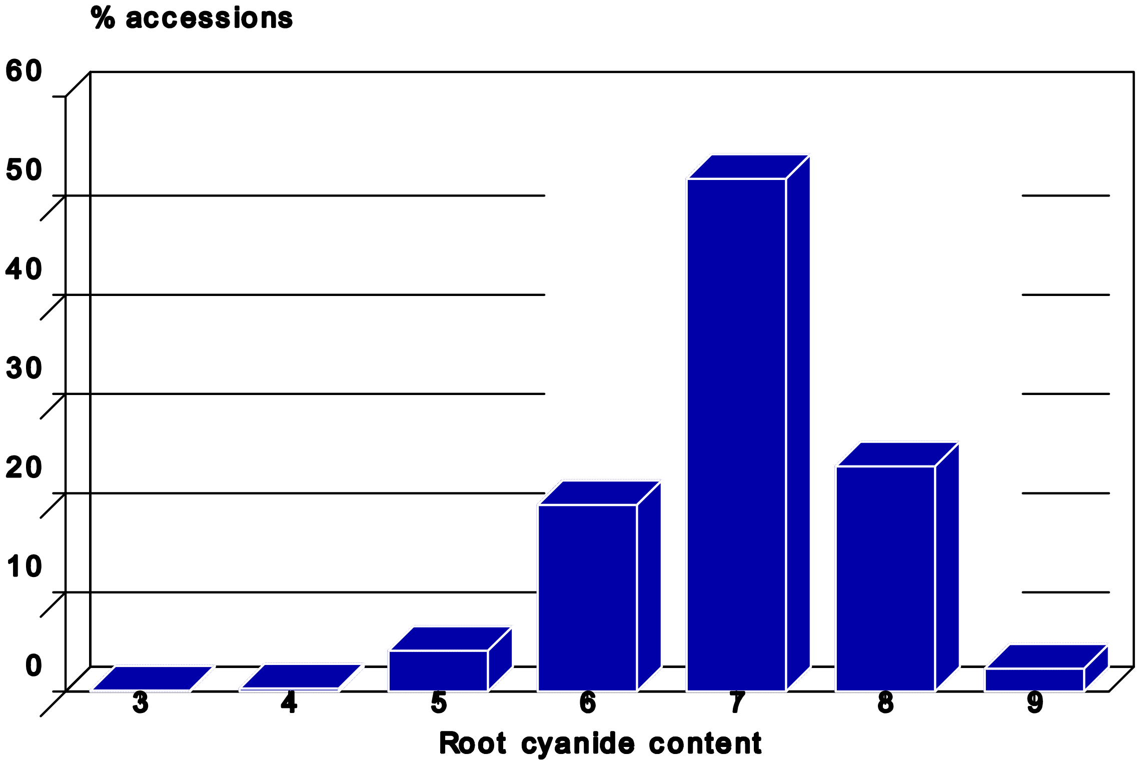

Figure 6. Frequency distribution of root cyanide content in 1008 accessions from the CNPMF Cassava Germplasm Collection in semi-arid NE Brazil (qualitative determination, 1 = <10 ppm; 9 = >150 ppm).