DROUGHT TOLERANCE ASSESSMENT OF CASSAVA GENOTYPES IN A SEMI-ARID ENVIRONMENT IN CENTRAL TANZANIA

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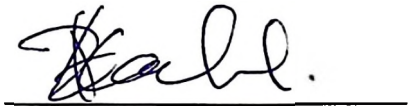
ABSTRACT

Drought tolerance is an increasingly important trait in cassava due to globally dwindling water resources, a shift in production areas and increasing input costs. This study was conducted to evaluate eighteen cassava genotypes for drought tolerance to counteract frequent shortages of rainfall. An experiment was set in Dodoma, Tanzania which is a drought-stricken environment where cassava genotypes were grown under watered and water stressed conditions. Identification of drought tolerant genotypes that also had good yield potential was facilitated by the stress treatments used on farm. Morphological (leaf length, leaf width, plant height), physiological (leaf retention, chlorophyll content), biochemical (Catalase and Peroxidase enzymes activities) and yield (number of roots per plant, yield in tons per hectare, above ground biomass, percentage dry matter content and harvest index) attributes were used to assess tolerance of the tested genotypes to drought stress. During harvesting, on farm farmers participatory evaluation and organoleptic test were also conducted to enable farmers select best genotypes based on consumers criteria. It was found during the study that water stress had profound effect on growth, physio-chemical and yield performance of cassava genotypes. All attributes measured were significantly influenced by drought except leaf length at180 DAP, plant height at 120 and 150 DAP, number of roots per plant, weight of above ground biomass and harvest index ($P \leq 0.05$). Generally water stress suppressed both growth and yield of the crop. Through the study, superior drought promising cassava genotypes identified were 92B/00073, KBH 2006/363, KBH 2006/12 and KBH 2006/18. These genotypes performed well under stress and well watered conditions and thus may serve as parents for drought stress improvement and genetic analysis.

DECLARATION

I, Andrew Zebedayo Kachiwile, do hereby declare to the Senate of Sokoine University of Agriculture that this is my own, original work done within the period of registration and that it has neither been nor being concurrently submitted in any other institution.



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20/11/2014

Date

The above declaration is confirmed by

Prof. D. G. Msuya

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20.11.2014

Date

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DEDICATION

This work is dedicated to my Almighty God who allowed me to accomplish this work, without Him this work could not be possible. I dedicate also to my parents Zebedayo and Dolorosa Kachiwile, my wife Atupele Mbalase and our daughter Aila Kachiwile for their support throughout my study period.

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LIST OF ABBREVIATIONS AND SYMBOLS

µl	Microlitre
µmol	Micromole
AGB	Above Ground Biomass
ANOVA	Analysis of Variance
CAT	Catalase
CBSD	Cassava Brown Steak Disease
ChC	Chlorophyll Content
CMD	Cassava Mosaic Diseases
COSTECH	Commission of Science and Technology
DAP	Days After Planting
DM	Dry Matter Content
DNA	Deoxyribonucleic Acid
FAO	Food and Agriculture Organization
H_2O_2	Peroxide
HI	Harvest Index
IITA	International Institute of Tropical Agriculture
KBH	Kibaha
LL	Leaf Length
LSD	Least Square Difference
LW	Leaf Width
M	Mole
MAFC	Ministry of Agriculture, Food security and Cooperatives
MARI	Mikocheni Agriculture Research Institute

Mg	Milligram
Mls	Milliliters
NDL	Naliendele
NGO	Non Government Organizations
Nm	Nanometers
NS	Numbers
PH	Plant Height
pH	Negative logarithm of hydrogen ion concentration
POD	Peroxidase
PVS	Participatory Variety Selection
RH	Relative Humidity
ROS	Reactive oxygen species.
RT	Leaf Retention
WS	Water Stressed
WW	Well Watered

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Cassava (*Manihot esculenta* Crantz) is an essential tropical root crop that belongs to Euphorbiaceae family and is a major source of carbohydrate for millions of people in the tropics (FAO, 2006). Cassava is mostly produced by small scale farmers often on marginal land. The crop is efficient in carbohydrate production, thrives well on infertile soils and tolerates adverse climatic conditions and low input management (FAO, 2006). The broad agro-ecological adaptability of cassava and its ability to produce reasonable yields where most crops cannot makes it the basis for food security at the household level and an important source of dietary energy. The crop is an essential part of the diet of more than half a billion people and provides livelihood for millions of farmers, and many processors and traders worldwide. Cassava gives about 40 percent of carbohydrate production per hectare which is higher than rice and 25 percent more than maize. As a result cassava is considered the cheapest source of calories for both human nutrition and animal feeding. In some cases the root tubers are used for making chips and flour. Both in developed and developing countries the crop is also utilized for industrial purposes, in preparing starch flakes and pearls and in animal feed formulation. Currently the role of cassava in Tanzania, Nigeria and many parts of Asia and Latin America has been changed from traditional human food to an efficient industrial crop (FAO, 2002).

In Tanzania the crop has gained economic importance through transforming it from a rural subsistence staple to a cash crop. This situation has led to rapid increase in production and marketing and as a result it has been given a second priority in national ranking of important crops in Tanzania (FAO, 2006).

1.1.1 Cassava production in Africa

Global cassava output in 2011 was expected to rise by over 6 percent from the previous year and to surpass 250 million tons for the first time. The expansion was being driven by increasing industrial applications of cassava in Southeast Asia, especially ethanol, in parallel with rising food demand in Africa, which adhere the importance of the crop to the food security of many countries in the continent. These trends underscore a growing geographical divide between the contrasting roles of cassava in the agricultural economy.

Table 1: The major cassava producing countries worldwide

NS	Country	Production (tons)
1	Nigeria	37 504 100
2	Indonesia	23 918 100
3	Thailand	22 005 700
4	Congo	15 049 500
5	Angola	13 858 700
6	Ghana	13 504 100
7	Brazil	24 524 300
8	Viet Nam	8 521 670
9	India	8 059 800
10	Mozambique	5 700 000
11	Uganda	5 282 000
12	Cambodia	4 247 420
13	China	4 684 000
14	Tanzania	4 392 170
15	Malawi	4 000 990

Source: FAO (2010)

1.1.2 Cassava production in Tanzania

Tanzania is the seventh largest producer of cassava in Africa after Nigeria, DR Congo, Angola, Ghana, Mozambique, and Uganda with an estimated total root production of about

4.4 million tonnes (FAO, 2010). Cassava is widely grown in all farming systems in Tanzania due to its adaptability to various soils and agro-ecological conditions. The main cassava producing areas in Tanzania are the Lake Victoria zone (Mwanza, Mara, Kagera and Shinyanga regions), the Southern zone (Lindi and Mtwara regions and Tunduru district in Ruvuma region), the Eastern zone (Morogoro, Tanga, Coast, Dar es Salaam) and Zanzibar (Pemba and Unguja islands). Fig. 1 show the cassava production in Tanzania by zones and regions, respectively.

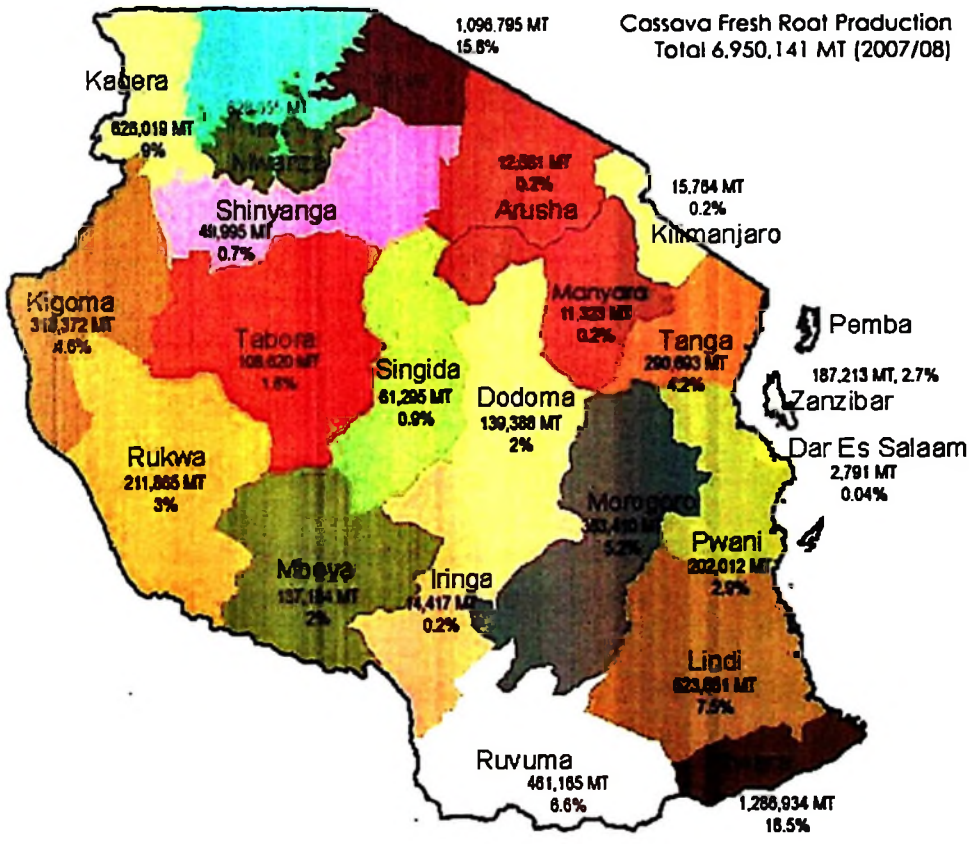

Figure 1: Regional production of fresh cassava (mt) and percentage of national production of Tanzania in 2007/2008

Source: Natural Resource Institute, University of Greenwich (May, 2012)

1.1.3 Production constraints of cassava in Tanzania

The production of cassava is dependent on a supply of good quality stem cuttings. The multiplication rate of these vegetative planting materials is very low compared to grain crops, which are propagated by true seeds. In addition, cassava stem cuttings are bulky and highly perishable as they dry up within a week.

In Tanzania, the low average yields of about 4.4 million tones is caused by many factors including susceptibility of commonly grown varieties to major diseases and pests (Muhana and Mtunda, 2002), drought, shortage of planting materials and continuous use of low genetic potential cassava varieties.

1.1.4 Breeding challenges in cassava

The time required to develop an improved cassava genotype by conventional breeding can be up to 10 years before it gets to the national variety release process, which can take at least six additional years (Okechukwu and Dixon, 2008). The cassava plant generated from stem cutting takes a minimum of 12 months to complete its cycle. The inability of some of the breeding materials to flower and the high rate of abortion subsequent to pollination are additional hurdles to developing breeding populations by hybridization. Being an alogamous species, cassava is characterized by a high level of heterozygosity, which limits the options for genetic and genomic analysis (Ceballos *et al.*, 2004). The low multiplication ratio of vegetative plant propagules influences the design of variety trials in terms of plot size and replicated multi-environment evaluations (Ojulong *et al.*, 2008).

1.2 Justification

Climate change nowadays poses a major threat to crop production and food security. Drought, heat, floods and changes in disease and pest epidemics greatly impact on

sustained food production. In Tanzania according to Ministry of Agriculture we have droughts roughly every four years which affect 3 629 239 people. The most frequently hit are central areas of Dodoma and Singida; Shinyanga, Mwanza, Mara and some parts of Coast. Parts of these regions receive approximately 200 –600mm of annual rainfall.

Fortunately, well-adapted cultivars coupled with improved crop management practices could serve as mitigation measures to climate change. Due to its resilience in marginal environments, its plasticity to environmental stresses and high yield potential, cassava is one of the best crops for food and nutrition security in the face of climate change. The crop can be grown in drought prone locations, or in acid soils, which explain the role of this crop in stabilizing farming, especially among the resource poor.

Designing appropriate mitigation measures requires understanding of the behavior of major stresses affecting crops under changing climatic patterns. In Tanzania research on drought tolerance has been conducted in other crops like maize, not equivalent research in cassava despite its importance as drought tolerant crop. Elsewhere research has shown variability in the magnitude to which varieties of cassava can tolerate drought. There is a need to identify cassava varieties in Tanzania that are more resilient to drought and determine their characteristics in order to make available materials that can increase productivity especially under different agro-ecological zones of the country.

1.3 Objectives

1.3.1 Overall objective

To improve yield of cassava by exploiting genetic variability in drought tolerance.

1.3.2 Specific objectives

i. To determine the effect of drought on growth and yield of different cassava genotypes

ii. To determine the influence of drought on physiology and biochemical reactions of cassava genotypes

iii. To establish farmers preference of improved cassava genotypes

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cassava Origin

Cassava is originally from South America, probably domesticated in the Amazon region (Olsen and Schaal, 2001; Olsen, 2004). The process of cassava domestication involved selection for root size, growth habit, number of stems and the ability of clonal propagation through stem cuttings. About 98 species of Manihot are known of which 28 wild species evolved through inter specific hybridization. Sexual barriers within the genus appear to be weak, indicating a recent evolution of the genus (Roa *et al.*, 1997).

2.2 Introduction and Spread of Cassava in Africa (Tanzania)

Cassava was first taken to Africa from Latin America in early 15th century by European traders as a potentially useful food crop. From there, cassava spread through Africa by a number of mechanisms. The most important appear to have been initial contacts with the Portuguese-Brazilian culture at the African coasts where the crop infiltrated the inland through revering trade routes. Cassava arrived and diffused first along the West African coast, while it arrived at the East African coast during the 18^{th} century (Fregene *et al.*, 2001). In Tanzania cassava first reached the shores of Lake Tanganyika from West Africa through Congolese farmers. From there, cassava moved to the inland Tanganyika through farmers to farmer's diffusion (Cartel *et al.*, 1992). Both bitter and sweet varieties were grown at an early state after cassava was introduced to Africa. Distinction between early maturing and late-maturing varieties was important and the latter were used in areas where famine was a frequent threat.

2.3 Drought Stress

Drought, one of the environmental stresses, is the most significant factor restricting plant growth and crop productivity in the majority of agricultural fields of the world (Tas and Tas, 2007). Drought impacts include on growth, yield, membrane integrity, pigment content, osmotic adjustment, water relations, and photosynthetic activity (Benjamin and Nielsen, 2006; Praba *et al.*, 2009). Drought stress is determined by climatic, edaphic and agronomic factors. The susceptibility of plants to drought stress varies in dependence on degree of stress, different accompanying stress factors, plant species, and their developmental stages (Demirevska *et al.*, 2009). Acclimation of plants to water deficit is the result of different events, which lead to adaptive changes in plant growth and physio-biochemical processes, such as changes in plant structure, growth rate, tissue osmotic potential and antioxidant defenses (Duan *et al.*, 2007). It has become imperative to elucidate the responses and adaptation of crops to water deficit, and take actions to improve the drought resistance ability of crop plants and to ensure higher crop yields against unfavorable environmental stresses.

2.4 Cassava Breeding and Drought

Currently breeding programs emphasize on increase of cassava production to serve as the main food security in sub- Saharan countries. One of the best methods to achieve that is through the development of better varieties that are resistant to diseases, insect pests, drought, as well as high yielding varieties (Moyib *et al.*, 2007).

Cassava breeding endeavors in the last few decades have helped elevate the status of cassava from a subsistence (poor man's) crop to a modern food, feed, and industrial crop. Tanzania under the Ministry of Agriculture Food Security and Co-operatives (MAFC) research department has the roots and tubers program where roots crops research and

development activities are being conducted through, with the objectives of having drought and disease resistant high yielding cassava varieties.

Despite its importance to world agriculture, cassava has received relatively little breeding attention until recently (Ceballios *et al.*, 2004). In part, this is due to its long breeding cycle (18–24 months), the difficulties in production of recombinant seed, and its highly heterozygous nature. Given the difficulties of conventional breeding in cassava, there is considerable interest in augmenting breeding with molecular marker approaches (Fregene *et al.*, 2001). Studies in a wide range of crops have shown that when water deficit closes stomata and limits photosynthesis, an important adaptation strategy is mobilization of storage carbohydrates to provide a source of carbohydrate substrate for metabolism and osmolyte synthesis (Blum, 1998).

It is plausible that cassava with its thick woody tissues may accumulate abundant starch reserves in its stem, leaves, and roots (including roots pre-tuberisation) that could be mobilized during stress and contribute to drought tolerance. As in other plant species, the full benefit of such capability requires proper regulation of storage and remobilization activities. Thus, genetic variation in the regulation of these activities among different varieties could be an important factor that determines genotypic differences in drought tolerance.

2.5 Screening for Drought Tolerance

Drought stress of cassava is a complex physiological trait and the selection for drought tolerance is often hampered by the lack of appropriate screening techniques in the field. Laurie *et al.* (2009) observed that the measurement of morphological characters like leaf longevity, leaf area, number of the branching levels, stem length, number and length of

storage roots, together with physiological and biochemical response of stomata conductance, leaf retention and increase in enzymatic antioxidant levels are suitable methods to screen varieties for adaptability to drought stress.

2.6 Morphological Effects on Drought

Leaf longevity is one of the main traits associated with high yields in cassava (El-Sharkawy *et al.*, 1992). Drought tends to alter storage root number and length in cassava. Plant height and leaf area growth is decreased in response to water stress and is rapidly reversed following the release from stress. This response limits the development of plant transpiration surface area during water deficit and keeps sink demand well balanced with plant assimilatory capacity. In cassava a positive correlation between the leaf area and yield of storage roots has been reported, indicating that leaf area is crucial in determining crop growth rate and the storage bulking rate of cassava. Furthermore, leaf retention during water deficit is positively correlated with high drought tolerance, productivity, and root quality.

2.7 Biochemical Response to Drought

Water stress is inevitably associated with increased oxidative stress due to enhanced accumulation of reactive oxygen species (ROS), particularly oxide ion and peroxide in chloroplasts, mitochondria, and peroxisomes. ROS especially peroxide can act as second messengers involved in the stress signal transduction pathway (Chamnongpol *et al.*, 1998). However excessive ROS production can cause oxidative stress, which damages plants by oxidizing photosynthetic pigments, membrane lipids, proteins and nucleic acids (Yordanov *et al.*, 2000). To keep the levels of active oxygen species under control, plants have enzymatic antioxidant systems to protect cells from oxidative damage (Mittler, 2002). Enzymes normally used include Superoxide Dismutase (SOD), Guaiacol

Peroxidase (POD), Ascorbate Peroxidase (APX), Catalase (CAT), Polyphenol Oxidase (PPO) and Glutathione Reductase (GR) (Xu *et al.*, 2008). Responses of antioxidant enzyme activities and their isozyme patterns in different cassava varieties under drought stress can suggest the ability of a variety to resist drought environment and result to good production. The results can be used as practical biochemical parameters for selection of drought tolerant cassava genotypes which can be used for breeding in arid regions.

2.8 Farmer's Participatory Evaluation

One way of increasing the speed of adoption of new varieties is for farmers to be given a wide range of improved varieties to test for themselves in their own field (Baidu-Forson *et al.*, 1997). Participatory Variety Selection (PVS) is becoming a more widely adopted method of making improved varieties available to farmers. It is a relatively simple, low-cost technique that can be used to overcome constraints that cause farmers to grow obsolete varieties. The main players in this process are farmers, researchers, extension agents, and NGOs. On-farm pilot programs provide farmers with first hand information on the advantages of improved varieties and agronomic practices. These programs need to be replicated in other target areas in collaboration with partners who have established links with farming communities (Baidu-Forson *et al.*, 1997).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location

Agronomic, morphological and farmer's participatory evaluations were conducted in an experimental field at Hombolo Agriculture Research Institute in Dodoma. The institute is located at 05° 58' S; and 35° 57' E, at an altitude of 1070 m above sea level. Since February when we started our experiments the area received a total of 95.7 mm of rainfall that was recorded only once in early April. The period when such amount of rainfall is observed has been named by Gupta and O'toole (1986) as dry mass period.

The experimental field was characterized by sandy clay loam soil. The average monthly rainfall, relative humidity and temperature from January, 2012 to December 2012 are as shown in Fig. 2 below.

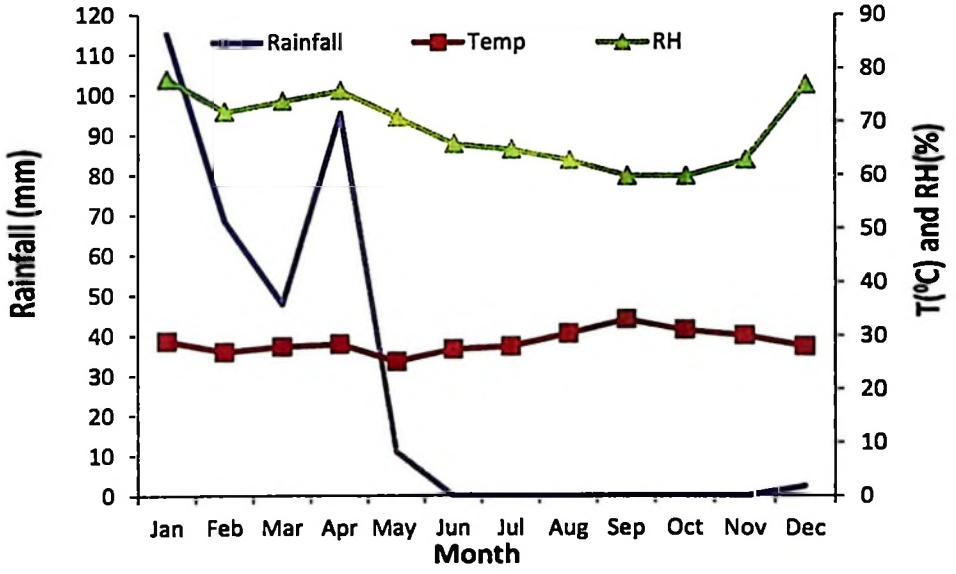

Figure 2: Climate at Hombolo research station showing monthly rainfall, temperature and relative humidity in 2012

3.2 Treatments and Experimental Design

A two factor factorial experimental design was used. Treatments involved 18 cassava genotypes and two watering regimes: well watered (WW) and water stressed (WS). For the WW regime, the genotypes were fully irrigated throughout the experiment in interval of two days; whereas the WS regime involved irrigating the genotypes up to three months after planting (90 DAP). 15 cm long cassava genotypes cuttings were planted in 12 m^2 plots at a spacing of 1m x 1m. Drought tolerance was evaluated at 120, 150 and 180 days after planting using agronomic and physiological parameters as described by Fukuda *et al.* (2010). Final yield and farmers participatory evaluation was performed during harvest (270 DAP) in order to identify some traits that are most contrasting and can be useful to select genotypes for drought tolerant attributes.

3.3 Planting Materials

Out of eighteen genotypes selected for this study, Mfaransa was a landrace and Kiroba was the improved check for its adaptability. Others were genotypes from Agriculture Research Institute Kibaha known to be tolerant to Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD). The selected genotypes are shown in Table 2.

Table 2: Cassava genotype used in drought tolerance evaluation

NS	Genotypes	Status
1	92B/00073	BL
2	KBH 2002/066	BL
3	KBH 2002/135	BL
4	KBH 2002/363	BL
5	KBH 2002/482	BL
6	KBH 2006/109	BL
7	KBH 2006/12	BL
8	KBH 2006/18	BL
9	KBH 2006/24	BL
10	KBH 2006/26	BL
11	KBH 2006/29	BL
12	KBH 2006/74	BL
13	KBH 2006/94	BL
14	KBH 2006/98	BL
15	KIROBA	IC
16	LML 2000/1833	BL
17	MFARANSA	LR
18	NDL 2006/74	BL

BL = Breeding Line, IC = Improved check and LR = Land race

3.4 Data Collected

Data were collected as explained below and summarized in (Table 3).

3.4.1 Leaf length, width and plant height

Leaf length (LL), leaf width (LW) and plant height (PH) of cassava genotypes were measured in centimeters using a meter rule. It was measured starting from the basal lobe to the tip of the leaf. Leaf width was determined by measuring the widest part of middle lobe of

the leaf. Plant height was measured from the soil level to the highest tip of the plant, excluding side branches.

3.4.2 Leaf retention

Leaf retention was determined by visual estimation of retained leaves in terms of 25, 50, 75 and 100 percent. All plants in the plots were involved in the observation.

3.4.3 Leaf chlorophyll content

The portable Minolta chlorophyll meter SPAD-502 (Spectrum Technologies, Inc., Plainfield, IL, U.S.) was used in measurement. Three leaves per plant were measured and their average was recorded.

3.4.4 Number of roots/plant, weight of roots/plot and weight of above ground biomass/plot

Number of roots/plant was determined after harvesting by counting roots in five plants per plot after 270 days from planting. Roots from a single plot were weighed using a weighing balance to obtain weight of roots per plot. Above ground biomass from a single plot was weighed using weighing balance to obtain weight of above ground biomass per plot.

3.4.5 Yield per hectare

This was determined by converting weight harvested/plot to tones per hectare as follows:-

$$Yield\left({}^{t}/_{ha}\right) = \frac{\left(Weight\ of\ roots/_{plot}\,(Kg)\right)10{,}000}{(Plot\ size)1000kg} \qquad (1)$$

3.4.6 Dry matter content

Five hundred grams (500 gm) of fresh roots for each genotype was taken for dry matter (DM) determination. The cassava roots were chopped into slices of about 2 mm using a

vegetable slicer. The slices were carefully collected into paper bags and oven-dried at a temperature of 110^0C for 48 hours until when they attained constant weight. Percentage DM was calculated as;

$$\%DM = \frac{(Weight\ after\ drying)100}{500\ gm} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

3.4.7 Harvest index

For each genotype, weight of the roots and the above ground biomass (stems, branches and leaves) were determined separately. HI was computed as a ratio of weight of the harvestable roots to total biomass (root and above ground biomass).

$$HI = \frac{Wr}{(Wr+Wab)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: - Wr = Weight of roots, Wab = Weight of above ground biomass

Table 3: Summary of morphological, physiological, biochemical and harvest traits evaluated for drought tolerant and susceptible cassava genotypes

	Abbreviation	Unit	Remark
Morphological traits			
Leaf length	LL	cm	Central leaf lobe was measured
Leaf width	LW	cm	Widest part of middle lobe was measured
Plant height	PH	cm	Side branches were not recorded
Physiological traits			
Leaf retention	LR	%	Recorded as either 25, 50, 75, 100 based on visual estimation
Chlorophyll content	ChC	Spad reading	Central leaf lobe was measured
Biochemical traits			
Catalase	CAT	unit/mg Protein	Determined from leaf samples collected
Peroxidase	POD	unit/mg Protein	Determined from leaf samples collected
Harvest traits			
Number of roots/plant	NRP	N	Determined from 5 plants combined
Weight of roots/plot	WRP	Kg	Determined from 5 plants combined
Above ground biomass	AGB	Kg	Determined from 5 plants combined
Harvest Index	HI	%	Determined as ration of WRP to the sum of WRP and AGB from 5 plants combined
Dry matter	DM	%	Determined by oven dying at 110°C

3.5 Determination of Antioxidant Enzymes

This study used two antioxidant enzymes, Catalase and Peroxidase to determine drought tolerance from selected cassava genotypes.

3.5.1 Enzymes extraction

One gram cassava samples were ground with liquid nitrogen then mixed with 3 mls phosphate buffer (pH 7.2) then centrifuged at 10,000 rpm for 15 minutes at 4°C. Supernatant was removed for assay and stored on ice.

3.5.2 Determination of Catalase enzymes activity

Catalase (CAT) activity was assayed by measuring the rate of peroxide (H_2O_2) disappearance at the wavelength of 240 nm as described by (Aebi, 1984). The final volume of reaction mixture contained 1 M potassium phosphate buffer (pH 7.2) and 5% H_2O_2. The reaction was started by adding 25 µL leaf crude extract to this solution, CAT activity was estimated by a decrease of H_2O_2 absorbance at 240 nm and one unit of CAT was defined as the amount of enzyme dismounting 1 mM of H_2O_2 per min. The absorbance of the reaction mixture was recorded using a spectrophotometer (WPA, Biowave II V.1.7.0).

3.5.3 Determination of Peroxidase enzymes activity

Peroxidase (POD) activity was assayed using guaiacol test according to the method of Polle *et al.* (1994), where the final volume of reaction mixture contained 1 M potassium phosphate buffer (pH 6.0) and 5% H_2O_2. The reaction was started by adding 25 µL leaf crude extract to this solution, POD activity was estimated by a increase of H_2O_2 absorbance at 420 nm and one unit of POD was defined as the amount of enzyme protein required for the formation of 1 µmol tetraguaicol per min. The absorbance of the reaction mixture was recorded using a spectrophotometer (WPA, Biowave II V.1.7.0).

3.6 Participatory Evaluation

Participatory selection with Farmers' was done at harvest where pair-wise ranking approach was used. Thirty knowledgeable farmers experienced in cassava production and

utilization from different nearby villages were involved to evaluate cassava clones based on their performance in the field using farmer's preferred criteria. A purposive sampling was undertaken to target specific people in the villages (men and women) who were believed to possess more indigenous knowledge about cassava, and also to ensure gender and age representation for men and women. These criteria were met with the help of field officers who were more familiar with farmers in the study area. The farmers were then asked to rank the eighteen genotypes based on those criteria. The farmers set the following criteria in the order of significance; drought tolerances, disease tolerance, yields, pests, taste, dry matter content and appearance. Those criteria were scored as very good, good, moderate, poor and very poor. Farmers were provided with questionnaires which helped them in evaluation of cassava genotypes before harvest, after harvest and taste after they were cooked.

3.7 Harvesting

Cassava plants were harvested manually by digging and pulling out the tubers after a growing period of 270 DAP for each plot. Yield was determined by measuring weight of harvested cassava roots in every plot for both watered and water stressed conditions. Farmers participatory yield evaluation was then conducted based on harvested cassava.

3.8 Statistical Analysis

Analysis of variance (ANOVA) for different morphological, yield and harvest parameters was conducted using GenStat version 14 at 0.05 level of probability using the statistical model shown in Appendix 1. SPSS statistical software version 16 was used to analyze farmer's field participatory evaluation data. Means for the ANOVA results were separated by Turkey's test.

CHAPTER FOUR

4.0 RESULTS

4.1 General Description

Results of characteristics of the different genotypes as well as their comparative resilience under drought conditions are presented in Tables 4 - 20 and Figures 3 - 6. Data have also been collected on participatory evaluation of the genotypes by farmers and results of these are presented in Tables 21 and 22.

Characteristics and response of the different genotypes have been categorized into morphological, physiological, biochemical (enzyme reaction) and yield measurements. There were significant differences in various attributes between irrigation regimes and within genotypes. Combined analysis of variance results are shown in Tables 4 and 5. According to the results moisture regimes significantly influenced all field parameters measured ($P \leq 0.05$) except plant height at 120 DAP and leaf retention at 150 DAP. The effect of genotypes was significant on all field parameters except leaf length at 180 DAP, plant height at 120 and 150 DAP, number of roots per plant, weight of above ground biomass and harvest index. The interaction between moisture regimes and genotypes was not significant on whatever the field parameter measured.

Tables 6 and 7 generally show effects of moisture regimes (variation pattern) while the detailed effects of genotypes are presented after each data attribute described below.

Table 4: Combined analysis of variance (ANOVA) of cassava genotypes under stressed and watered regimes at Hombolo research station, Dodoma

Source of variation	DF	Leaf length			Leaf width			Plant height			Leaf retention		Chlorophyll content		
		120 DAP	150 DAP	180 DAP	120 DAP	150 DAP	180 DAP	120 DAP	150 DAP	180 DAP	150 DAP	180 DAP	120 DAP	150 DAP	180 DAP
Moisture regimes	1	36.750^{***}	56.045^{***}	126.577^{***}	5.7778^{***}	2.7012^{***}	3.0133^{**}	206.7^{NS}	1955.9^{**}	10684.3^{***}	61.96^{NS}	31552.9^{***}	210.23^{***}	70.50^{*}	1823.69^{***}
Genotypes	17	8.652^{***}	9.393^{*}	7.763^{NS}	1.4516^{***}	2.8382^{***}	1.5083^{***}	137.4^{NS}	233.9^{NS}	579.3^{**}	318.24^{***}	927.4^{***}	80.83^{***}	91.34^{***}	68.84^{*}
Moisture vs Genotype	17	1.061^{NS}	3.897^{NS}	6.002^{NS}	0.2539^{NS}	0.1029^{NS}	0.2107^{NS}	202.5^{NS}	264.2^{NS}	247.2^{NS}	47.85^{NS}	172.3^{NS}	10.65^{NS}	10.73^{NS}	52.64^{NS}
Residual	72	1.072	4.669	4.508	0.1461	0.1707	0.3206	207	264.6	228	82.36	232.5	13.82	14.9	35.4
Total	107														

NS = Not significant at ($P \leq 0.05$), * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$

Table 5: Combined analysis of variance (ANOVA) of harvest parameters of cassava genotypes under stressed and watered regimes

Source of variation	DF	Number of roots/plant	Weight of roots/plot	% Dry matter	Weight of above biomass	Harvest index
		270 DAP	270 DAP	270 DAP	270 DAP	270 DAP
Moisture regime	1	348.031^{***}	2773.87^{***}	342.39^{**}	1753.48^{***}	3421.82^{***}
Genotype	17	5.245^{NS}	38.34^{*}	61.82^{**}	17.78^{NS}	0.79^{NS}
Moisture vs Genotype	17	3.356^{NS}	21.18^{NS}	18.11^{NS}	15.97^{NS}	0.55^{NS}
Residual	72	3.208	18.34	22.7	12.07	0.61
Total	107					

NS = Not significant at ($P \leq 0.05$), * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$

Table 6: Influence of water stress on various growth parameters in cassava at various growth durations in cassava genotypes

	Leaf length			Leaf width			Plant height			Leaf retention		Chlorophyll content		
Treatment	120 DAP	150 DAP	180 DAP	120 DAP	150 DAP	180 DAP	120 DAP	150 DAP	180 DAP	150 DAP	180 DAP	120 DAP	150 DAP	180 DAP
WW	12.35	14.15	11.62	3.31	3.69	2.89	53.1	71.5	92.1	88.18	82	45.05	44.43	39.92
WS	11.18	12.71	9.46	2.85	3.38	2.55	50.3	63	72.2	86.67	47.9	47.84	46.04	31.7
Mean	11.765	13.43	10.54	3.08	3.535	2.72	51.7	67.25	82.15	87.425	64.95	46.445	45.235	35.81
S.E(±)	1.0352	2.161	2.123	0.3822	0.4131	0.5663	14.39	16.27	15.1	9.075	15.25	2.146	3.86	5.95
CV	8.8	16.1	20.1	12.4	11.7	20.8	27.8	24.2	18.4	20.4	23.5	8	8.5	16.6
Fpr	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	NS	0.008	<0.001	NS	<0.001	<0.001	0.033	<0.001

NS = Not significant at (P≤0.05), * P ≤ 0.05; ** P ≤ 0.01; *** P ≤ 0.001

Table 7: Influence of water stress in cassava parameters with different irrigation regimes during harvest

Treatment	Number of roots/plant	Weight of roots/plot	%Dry matter content	Weight of above biomass	Harvest index
WW	4.98	9.93	37.81	10.55	0.52
WS	1.16	0.76	9.72	2.49	0.29
Mean	3.07	5.345	23.765	6.52	0.405
S.E (±)	1.789	4.282	0.91	0.922	0.11
CV	33.8	20	18.3	14.2	28.8
Fpr	<0.001	<0.001	0.008	<0.001	<0.001

NS = Not significant at (P≤0.05), * P ≤ 0.05; ** P ≤ 0.01; *** P ≤ 0.001

4.2 Field Parameters

4.2.1 Leaf Length

Based on the results of this study, leaf length was significantly greater in watered than in water stressed treatments at all time (DAP) as shown in (Table 6). Generally, leaf lengths increased from 120 to 150 DAP but was lower at 180 DAP.

Leaf length of genotypes differed significantly at ($P \leq 0.05$) at all stages of measurement except at 180 DAP. Leaf lengths at 120 DAP ranged from highest value of 14.07 to lowest value of 10.51 (Table 8). The highest values were scored by genotypes KBH 2006/18, 92B/00073 and KBH 2006/24 whose leaves were significantly longer ($P \leq 0.05$) than all the other genotypes. The lowest leaf lengths were observed in genotypes KBH 2002/066, KBH 2006/94, KBH 2002/363 and NDL 2006/74 which were also significantly shorter than all the other genotypes except KBH 2002/482, LML 2000/1833, KBH 2006/98, KBH 2006/26, Mfaransa and KBH 2006/12. Leaf lengths at 150 DAP ranged from highest value of 16.24 to lowest value of 11.78. The highest value was scored by genotype KBH 2006/18 and was significantly longer ($P \leq 0.05$) than all the other genotypes except KBH 2006/24, KBH 2002/482 and 92B/00073. The lowest values were observed in genotypes LML 2000/1833, KBH 2002/066, KBH 2006/94 and KBH 2002/363 which were significantly shorter than all the remaining genotypes except KBH 2006/24, NDL 2006/74, Mfaransa, KBH 2006/12, KBH 2006/98, KBH 2006/29, KBH 2006/109, KBH 2002/135, KBH 2006/74 and Kiroba.

Table 8: Combined mean for leaf length of cassava genotypes evaluated for drought tolerance

Genotypes	120 DAP	150 DAP	180 DAP
92B/00073	13.97 e	15.01 bcdc	11.13
KBH 2002/066	10.51 a	12.11 a	9.88
KBH 2002/135	12.28 d	13.52 abcd	10.69
KBH 2002/363	10.62 a	12.52 a	10.74
KBH 2002/482	10.68 ab	15.22 cde	9.83
KBH 2006/109	11.83 bcd	13.29 abcd	11.31
KBH 2006/12	11.65 abcd	12.83 abc	11.60
KBH 2006/18	14.07 e	16.24 e	11.32
KBH 2006/24	13.95 e	15.47 de	11.65
KBH 2006/26	11.47 abcd	12.70 ab	10.95
KBH 2006/29	12.03 d	13.13 abcd	10.01
KBH 2006/74	12.00 cd	13.59 abcd	10.97
KBH 2006/94	10.60 a	12.33 a	12.59
KBH 2006/98	10.83 abc	12.75 abc	10.34
KIROBA	12.32 d	13.61 abcd	7.54
LML 2000/1833	10.75 ab	11.78 a	8.87
MFARANSA	11.64 abcd	12.90 abc	10.41
NDL 2006/74	10.57 a	12.70 ab	9.91
Mean	11.76	13.43	10.54
SE (±)	1.0352	2.161	2.123
CV	8.8	16.1	20.1
Fpr	<0.001	0.021	NS

NS = Not significant at ($P \leq 0.05$). Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.2.2 Leaf width

Differences on the influence of water regimes to leaf width of genotypes different DAP were significant ($P \leq 0.05$).The leaf width at 120 DAP ranged from highest value of 3.98 for Mfaransa to lowest value of 1.65 for KBH 2006/18 (Table 9).Genotype Mfaransa was significantly wider ($P \leq 0.05$) than all the other, genotypes KBH 2006/18 was significantly

thinner than all the other genotypes at all times. Leaf widths at 150 DAP ranged from the highest value of 4.40 to lowest value of 1.42. The highest value was scored by genotypes KBH 2006/94 and Mfaransa which were significantly wider ($P \leq 0.05$) than all the other genotypes except NDL 2006/74 and KBH 2002/135. The lowest value was observed in genotype KBH 2006/18 which was significantly thinner than all the other genotypes. Widths at 180 DAP ranged from highest value of 3.78 for Mfaransa to lowest value of 1.43 for KBH 2006/18. Mfaransa was significantly wider ($P \leq 0.05$) than all the other genotypes except KBH 2006/94 where as genotype KBH 2006/18 was significantly thinner than all the other genotypes.

Table 9: Combined mean for leaf width of cassava genotypes evaluated for drought tolerance

Genotypes	120 DAP		150 DAP		180 DAP	
92B/00073	3.34	e	3.59	def	3.09	de
KBH 2002/066	3.40	e	3.74	efg	2.88	bcde
KBH 2002/135	3.23	de	3.98	fgh	2.88	bcde
KBH 2002/363	2.88	bcd	3.45	cde	2.69	bcd
KBH 2002/482	3.25	de	3.68	def	2.65	bcd
KBH 2006/109	2.51	b	2.88	b	2.62	bcd
KBH 2006/12	2.62	bc	2.82	b	2.26	b
KBH 2006/18	1.65	a	1.42	a	1.43	a
KBH 2006/24	3.19	de	3.26	bcd	2.38	bc
KBH 2006/26	3.33	e	3.80	efg	2.93	cde
KBH 2006/29	3.36	e	3.72	def	2.75	bcde
KBH 2006/74	3.22	de	3.71	def	2.92	cde
KBH 2006/94	3.01	cde	4.40	h	3.39	ef
KBH 2006/98	2.68	bc	3.10	bc	2.56	bcd
KIROBA	3.22	de	3.66	def	2.25	b
LML 2000/1833	3.29	de	3.80	efg	2.46	bcd
MFARANSA	3.98	f	4.37	h	3.78	f
NDL 2006/74	3.33	e	4.20	gh	3.03	cde
Mean	3.08		3.53		2.72	
SE (±)	0.3822		0.4131		0.5663	
CV	12.4		11.7		20.8	
Fpr	<0.001		<0.001		0.027	

NS = Not significant at ($P \leq 0.05$). Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.2.3 Plant height

Significant influence of water regimes on plant height of the genotypes was observed at 150 and 180 DAP (Table 6). At 120 DAP the influence was not significant ($P \leq 0.05$) however the plant height was consistently greater in watered than in stressed treatment and increased with period of stay in the field (DAP).

Genotypes differences in terms of measured plant height are as shown in (Table 10). From the table there were no significant differences among genotypes in their response to water regimes in plant height at 120 and 150 DAP. Plant height at 180 DAP ranged from the highest value of 96.2 to the lowest value of 62.7. The highest value was scored by genotypes KBH 2006/24 and KBH 2002/135 which were significantly taller ($P \leq 0.05$) than all the other genotypes except KBH 2006/26, 92B/00073, KBH 2006/94, KBH 2006/74, KBH 2006/109, KBH 2006/12, KBH 2002/066 and KBH 2002/363. The lowest height was observed in genotype KBH 2006/29 which was significantly shorter than all the other genotypes except KBH 2006/18, KBH 2006/98, Mfaransa, KBH 2002/482, LML 2000/1833 and Kiroba.

Table 10: Combined mean for plant height of cassava genotypes evaluated for drought tolerance

Genotypes	120 DAP	150 DAP	180 DAP	
92B/00073	54.40	71.60	92.90	def
KBH 2002/066	50.90	68.30	82.90	bcdef
KBH 2002/135	58.90	74.10	94.80	f
KBH 2002/363	51.70	66.50	80.20	bcdef
KBH 2002/482	50.00	63.70	75.80	abcd
KBH 2006/109	46.00	63.10	85.40	cdef
KBH 2006/12	54.20	66.70	83.30	bcdef
KBH 2006/18	47.20	61.10	67.80	ab
KBH 2006/24	59.70	76.00	96.20	f
KBH 2006/26	55.70	71.00	94.30	ef
KBH 2006/29	45.00	53.90	62.70	a
KBH 2006/74	51.70	71.90	87.90	cdef
KBH 2006/94	54.00	77.30	90.50	def
KBH 2006/98	42.00	57.60	70.90	abc
KIROBA	56.30	69.10	77.20	abcde
LML 2000/1833	50.80	67.80	76.90	abcde
MFARANSA	47.80	61.40	72.90	abc
NDL 2006/74	54.50	69.30	85.80	cdef
Mean	51.70	67.20	82.10	
SE (±)	14.39	16.27	15.1	
CV	27.8	24.2	18.4	
Fpr	NS	NS	0.027	

NS = Not significant at ($P \leq 0.05$). Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.3 Physiological Parameters

4.3.1 Leaf retention

Based on results of this study, leaf retention was significantly different ($P<0.05$) between water regimes at 180 DAP and there was no significant difference observed at 150 DAP (Table 6). Leaf retention was higher in watered treatments than in water stressed treatments throughout the period of observation, however decreased as number of days the genotypes were exposed to stress increased from 150 DAP to 180 DAP.

Genotypes differences in leaf retention are as shown in (Table 11). At 120 DAP all genotypes retained 100% of their leaves. However at 150 DAP leaf retention ranged from highest value of 96.67 for KBH 2002/066 to the lowest value of 69 for KBH 2006/29 and Kiroba. Genotype KBH 2002/066 was significantly higher ($P \leq 0.05$) than the other genotypes except KBH 2002/135, KBH 2002/482, KBH 2006/18, KBH 2006/26, Kiroba and LML 2000/1833. KBH 2006/29 and Kiroba were significantly lower than all the other genotypes except LML 2000/1833. Leaf retentions at 180 DAP ranged from highest value of 82.50 to lowest value of 36.67. The highest value was scored by genotypes KBH 2002/006 and KBH 2006/109 which were significantly higher ($P \leq 0.05$) than the others except 92B/00073, KBH 2006/94, KBH 2006/98, KBH 2006/74, KBH 2006/26, KBH 2002/363 and KBH 2006/18. The lowest leaf retention was observed in Kiroba which was significantly lower than all the others except KBH 2006/29 and Mfaransa. Leaf retention tends to decrease with time in all genotypes, with 92B/00073 and KBH 2006/109 having minimum decrease while Mfaransa and KBH 2002/482 showed maximum decrease.

Table 11: Combined mean for leaf retention of cassava genotypes evaluated for drought tolerance

Genotypes	150 DAP		180 DAP	
92B/00073	86.67	bcdc	80.83	gh
KBH 2002/066	96.67	e	82.50	h
KBH 2002/135	84.97	bc	59.00	bcde
KBH 2002/363	87.50	bcde	67.50	cdefgh
KBH 2002/482	85.00	bc	49.17	ab
KBH 2006/109	91.67	cde	82.50	h
KBH 2006/12	88.33	bcde	61.67	bcdef
KBH 2006/18	85.67	bcd	66.67	bcdefgh
KBH 2006/24	87.50	bcde	64.17	bcdefg
KBH 2006/26	94.17	cde	70.00	defgh
KBH 2006/29	74.17	a	50.83	abc
KBH 2006/74	92.50	cde	70.00	defgh
KBH 2006/94	92.50	cde	79.17	fgh
KBH 2006/98	95.83	de	70.83	efgh
KIROBA	69.00	a	36.67	a
LML 2000/1833	79.17	ab	62.50	bcdef
MFARANSA	90.00	cde	52.50	abcd
NDL 2006/74	92.33	cde	62.50	bcdef
Mean	87.42		64.90	
SE (±)	9.075		15.25	
CV	20.4		23.5	
Fpr	<0.001		<0.001	

Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.3.2 Chlorophyll content (ChC)

Chlorophyll content was significantly different ($P<0.05$) between water regimes at 120, 150 and 180 DAP (Table 6). Chlorophyll was higher in water stressed treatments at all time except at 180 DAP. Generally, chlorophyll content was decreasing throughout the stages of measurement.

Genotypes differences in leaf chlorophyll content are shown in (Table 12). From the table the chlorophyll content at 120 DAP ranged from highest value of 53.9 for KBH 2006/29 to

lowest value of 38.5 for KBH 2006/26. KBH 2006/29 was significantly higher ($P \leq 0.05$) than all the other genotypes. KBH 2006/26 was also significantly lower than all the other genotypes except Mfaransa. Leaf chlorophyll contents at 150 DAP ranged from highest value of 52.3 to lowest value of 36.5. The highest value was scored by genotype KBH 2006/29 and was significantly higher ($P \leq 0.05$) than all the other genotypes except KBH 2006/98, KBH 2006/109, KBH 2006/12 and KBH 2006/24. The lowest chlorophyll content was observed in genotype KBH 2006/26 which was also significantly lower than all the other genotypes except Mfaransa. Chlorophyll content at 180 DAP ranged from highest value of 41.9 for KBH 2006/109 to lowest value of 29.9 for Mfaransa. KBH 2006/109 was significantly ($P \leq 0.05$) higher than Mfaransa, KBH 2006/26, Kiroba, LML 2000/1833, NDL 2006/74 and 92B/00073. Mfaransa was significantly lower than KBH 2002/135, KBH 2002/363, KBH 2006/109, KBH 2006/29, KBH 2006/74, KBH 2006/94 and KBH 2006/98.

Table 12: Combined mean for chlorophyll content of cassava genotypes evaluated for drought tolerance

Genotypes	120 DAP		150 DAP		180 DAP	
92B/00073	45.45	cdef	43.07	bcde	33.64	abcdef
KBH 2002/066	42.81	bc	41.05	bc	35.36	abcdefg
KBH 2002/135	49.37	f	45.96	efg	36.96	bcdefg
KBH 2002/363	45.53	cdef	44.38	cdef	38.13	defg
KBH 2002/482	49.44	f	46.59	efg	35.63	abcdefg
KBH 2006/109	47.73	def	48.92	gh	41.86	g
KBH 2006/12	48.47	def	48.75	fgh	36.36	abcdefg
KBH 2006/18	44.98	cde	47.15	efg	35.47	abcdefg
KBH 2006/24	48.25	def	48.28	fgh	36.44	abcdefg
KBH 2006/26	38.52	a	36.46	a	30.88	ab
KBH 2006/29	53.89	g	52.31	h	40.31	fg
KBH 2006/74	46.91	cdef	45.59	defg	37.91	cdefg
KBH 2006/94	44.51	cd	41.49	bcd	38.66	defg
KBH 2006/98	49.63	f	48.98	gh	39.95	efg
KIROBA	49.24	ef	46.51	efg	31.11	abc
LML 2000/1833	44.99	cde	44.95	cdefg	32.91	abcd
MFARANSA	39.86	ab	39.12	ab	29.88	a
NDL 2006/74	46.42	cdef	44.65	cdefg	33.25	abcde
Mean	46.44		45.23		35.81	
SE (±)	2.146		3.86		5.95	
CV	8		8.5		16.6	
Fpr	<0.001		<0.001		0.027	

Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.4 Yield and Harvest Parameters

The influence of water regimes on field yield parameters at harvest are shown in (Table 7). Results on yield components showed that there was significant difference ($P \leq 0.05$) in number of roots per plant, weight of roots per plot, percentage dry matter, weight of above ground biomass and harvest index under well watered and water stressed treatments. Well watered treatment led to higher values compared to water stressed.

Genotypes difference in terms of number of roots per plant, weight of roots per plot, percentage dry matter content, weight of above ground biomass and harvest index are shown in (Table 13). There was no significant difference ($P \leq 0.05$) in number of roots per plant, weight of above ground biomass and harvest index between genotypes. However, there were significant differences ($P \leq 0.05$) among genotypes in weight of roots per plot and percentage dry matter content.

4.4.1 Weight of roots per plot (tons/ha)

Results from Table 13 indicate that weight of roots per plot ranged from highest value of 13 tons/ha to lowest value of 2 tons/ha. The highest value was scored by genotype KBH 2002/363 and was significantly higher ($P \leq 0.05$) than all the other genotypes. The lowest value was observed in genotype KBH 2002/135 which was also significantly lower than all the other genotypes.

Figure 3: Cassava genotype KBH 2002/363 roots after harvest

4.4.2 Percentage dry matter content (%DM)

The percentage dry matter content ranged from highest value of 20 to lowest value of 5 (Table 13). The highest value was scored by 92B/00073 and was significantly different ($P \leq 0.05$) from all the other genotypes. The lowest value was observed by genotypes KBH 2006/29 and KBH 2006/94 which were also significantly lower than all the other genotypes except KBH 2002/135.

Table 13: Yield components of cassava genotypes evaluated for drought tolerance at harvest (270 MAP)

Genotype	Number of roots / plant	Weight of roots / plot (Tons/ha)	Dry matter content (%)	Weight of above ground biomass (Kg)	Harvest index (%)
92B/00073	3.00	11h	20k	3.85	0.14
KBH 2002/066	5.00	10gh	12gh	4.36	0.24
KBH 2002/135	2.00	2a	6ab	4.94	0.30
KBH 2002/363	5.00	13i	13hi	5.00	0.34
KBH 2002/482	5.00	7de	14i	5.22	0.35
KBH 2006/109	4.00	6cd	9de	5.37	0.36
KBH 2006/12	4.00	8ef	8cd	5.59	0.36
KBH 2006/18	3.00	5bc	10ef	6.21	0.37
KBH 2006/24	3.00	7de	17j	6.50	0.38
KBH 2006/26	3.00	6cd	7bc	6.65	0.39
KBH 2006/29	4.00	8ef	5a	6.74	0.43
KBH 2006/74	2.00	4b	9de	6.83	0.43
KBH 2006/94	4.00	9fg	5a	7.00	0.44
KBH 2006/98	4.00	9fg	10ef	7.10	0.52
KIROBA	2.00	4b	13hi	7.49	0.54
LML 2000/1833	2.00	6cd	9de	8.56	0.58
MFARANSA	2.00	5bc	10ef	9.58	0.58
NDL 2006/74	4.00	7de	11fg	10.34	0.61
Mean	3.27	7.11	23.76	6.52	0.41
SE (±)	1.789	4.282	0.91	0.922	0.11
CV	33.8	20	18.3	14.2	28.8
Fpr	NS	0.019	0.004	NS	NS

NS = Not significant at ($P \leq 0.05$). Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.5 Performance of Genotypes under Drought Condition Alone (Non irrigated)

There was no significant interaction ($P \leq 0.05$) observed between genotypes and irrigation regimes, but under water stress alone it was possible to observe genotype differences in relation to drought in a more conclusive way.

According to the results, water stress significantly ($P \leq 0.05$) influenced the performance of genotypes in some field parameters 120, 150 and 180 DAP except yield and harvest parameters. Water stress influenced the performance of genotypes in all field parameters except leaf length at 150 and 180 DAP, leaf width at 180 DAP, plant height at 120 and 150 DAP, chlorophyll content at 150 and 180 DAP. Further, water stress influenced the performance of genotypes in yield and harvest components that is; number of roots per plant, weight of roots per plot, percentage dry matter, weight of above ground biomass and harvest index.

Table 14: Mean squares from analysis of variance (ANOVA) of cassava genotypes in water stressed treatment at Hombolo research station, Dodoma

Source of variation	DF	Leaf length			Leaf width			Plant Height			Leaf retention		Chlorophyll content		
		120 DAP	150 DAP	180 DAP	120 DAP	150 DAP	180 DAP	120 DAP	150 DAP	180 DAP	150 DAP	180 DAP	120 DAP	150 DAP	180 DAP
Replications	2	0.392	1.696	8.09	0.0802	0.06	0.07	134.2	76.8	108.2	12.5	220	171.65	43.08	39.40
Genotypes	17	3.763*	5.339^{NS}	10.873^{NS}	0.3703**	1.334***	0.8343^{NS}	224.9^{NS}	330.9^{NS}	503.7*	237.3*	832.5*	49.48***	48.82^{NS}	84.32^{NS}
Residual	34	1.484	3.407	7.811	0.1129	0.191	0.5535	194.9	264.6	254.1	110	400.4	12.06	25.33	66.63
Total	53														

NS = Not significant at (P≤0.05), * P ≤ 0.05; ** P ≤ 0.01; *** P ≤ 0.001

Table 15: Mean squares from analysis of variance (ANOVA) of cassava genotypes in water stressed treatment during harvest

Source of variation	DF	Number of roots/plant	Weight of roots/plot	%Dry matter content	Weight of above biomass	Harvest index
		270 DAP	270 DAP	270 DAP	270 DAP	270 DAP
Replications	2	0.4481	0.394	32.39	0.707	0.9912
Genotype	17	1.4567^{NS}	2.639^{NS}	41.64^{NS}	3.993^{NS}	0.4592^{NS}
Residual	34	0.9985	2.203	29.4	2.831	0.7367
Total	53					

NS = Not significant at (P≤0.05), * P ≤ 0.05; ** P ≤ 0.01; *** P ≤ 0.001

4.5.1 Leaf length

Leaf length of stressed genotypes differed significantly ($P \leq 0.05$) at 120 DAP. However, significant difference among genotypes was not observed at 150 and 180 DAP (Table 14). At 120 DAP, leaves were longest (Table 16) in genotype 92B/00073 and difference were significant ($P \leq 0.05$) than all the other genotypes. On the other hand, the shortest leaves at 120 DAP were obtained from genotype KBH 2002/066 and the differences were significant from all the other genotypes.

Table 16: Leaf length of cassava genotypes evaluated under stressed condition

Genotypes	120 DAP		150 DAP	180 DAP
92B/00073	13.4	b	14.07	9.12
KBH 2002/066	9.6	a	11.29	8.75
KBH 2002/135	11.73	ab	12.99	10.01
KBH 2002/363	10.27	ab	11.64	10.07
KBH 2002/482	10.53	ab	12.07	8.6
KBH 2006/109	10.93	ab	12.63	10.44
KBH 2006/12	11.33	ab	13.22	10.71
KBH 2006/18	12.93	ab	15.45	9.37
KBH 2006/24	13.07	ab	15.25	9.52
KBH 2006/26	10.33	ab	11.98	10.01
KBH 2006/29	11.53	ab	13.09	8.28
KBH 2006/74	11.8	ab	13.71	10.9
KBH 2006/94	10.73	ab	11.06	14.11
KBH 2006/98	9.73	ab	11.25	10.15
KIROBA	11.93	ab	13.31	4.4
LML 2000/1833	10.47	ab	11.19	7.12
MFARANSA	10.4	ab	11.61	9.47
NDL 2006/74	10.53	ab	12.93	9.2
Overall Mean	11.18		12.71	9.46
SE (±)	1.218		1.846	2.795
CV	10.9		14.6	29.5
Fpr	0.01		NS	NS

NS = Not significant at ($P \leq 0.05$). Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.5.2 Leaf width

Stressed genotypes differed significantly in leaf width ($P \leq 0.05$) at 120 and 150 DAP, but not at 180 DAP (Table 14). Elaborated further in (Table 17), leaf width at 120 DAP was highest in genotype KBH 2006/74 however, differences were only significant ($P \leq 0.05$) when compared with KBH 2006/18 only. The lowest leaf width was observed in genotype KBH 2006/18 and differences were significant than all the other genotypes except KBH 2002/363, KBH 2006/94, KBH 2006/98, KBH 2006/12 and KBH 2006/109. The leaves at 150 were widest in genotype NDL 2006/74 significantly ($P \leq 0.05$) than all the other genotypes. There was a consistent increase in width of leaves from 120 DAP to 150 DAP within genotypes, declining at 180 DAP except genotype KBH 2006/18 in which there was an increase.

Table 17: Leaf width of cassava genotypes evaluated under stressed condition

Genotypes	120 DAP		150 DAP		180 DAP
92B/00073	3.067	b	3.28	bcd	3.09
KBH 2002/066	2.933	b	3.42	bcde	2.64
KBH 2002/135	2.933	b	3.82	def	2.9
KBH 2002/363	2.8	ab	3.193	bcd	2.47
KBH 2002/482	3.033	b	3.54	cdef	2.35
KBH 2006/109	2.4	ab	2.74	b	2.51
KBH 2006/12	2.467	ab	2.867	bc	2.17
KBH 2006/18	1.833	a	1.313	a	1.56
KBH 2006/24	3.133	b	3.247	bcd	2.22
KBH 2006/26	3	b	3.547	cdef	2.67
KBH 2006/29	3.067	b	3.673	def	2.63
KBH 2006/74	3.2	b	3.767	def	2.93
KBH 2006/94	2.733	ab	4.06	ef	3.23
KBH 2006/98	2.5	ab	2.813	b	2.53
KIROBA	2.933	b	3.587	cdef	1.51
LML 2000/1833	3	b	3.573	cdef	2.13
MFARANSA	3.167	b	4.1	ef	3.58
NDL 2006/74	3.133	b	4.207	f	2.82
Overall Mean	2.852		3.375		2.55
SE (±)	0.3361		0.437		0.744
CV	11.8		13		29.1
Fpr	0.002		<0.001		NS

NS = Not significant at ($P \leq 0.05$). Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.5.3 Plant height

The plant height of stressed genotypes didn't differ significantly ($P \leq 0.05$) at 120 and 150 DAP. At 180 DAP, the tallest plants were from genotype KBH 2006/24 differences were significant ($P \leq 0.05$) than all the other genotypes except KBH 2006/26, 92B/00073, KBH 2002/135, KBH 2002/482, KBH 2006/94, KBH 2006/74, KBH 2006/109, KBH 2006/12, LML 2000/1833, NDL 2006/74 and KBH 2002/363. The shortest plants were observed in Mfaransa, which was also significantly shorter than all the other genotypes except KBH 2002/006, KBH 2002/363, KBH 2002/482, KBH 2006/18, KBH 2006/98, KBH 2006/29, KBH 2006/98, LML 2000/1833 and Kiroba.

Table 18: Plant height of cassava genotypes evaluated under stressed condition

Genotypes	120 DAP	150 DAP	180 DAP	
92B/00073	51.7	64.4	80.67	cde
KBH 2002/066	39	52.6	61.33	abcd
KBH 2002/135	61	69.8	85.87	de
KBH 2002/363	47.7	61.1	68.67	abcde
KBH 2002/482	50.7	62.2	69.73	abcde
KBH 2006/109	43	57.4	76.2	bcde
KBH 2006/12	61.1	70.3	83.87	de
KBH 2006/18	44	54.1	55.33	abc
KBH 2006/24	68	82.2	92.67	e
KBH 2006/26	47	59.8	81	cde
KBH 2006/29	50	54.3	56.33	abc
KBH 2006/74	56.7	76.9	87.73	de
KBH 2006/94	53.3	78.2	81	cde
KBH 2006/98	37.7	47.1	53.73	ab
KIROBA	59.3	68.7	67.33	abcde
LML 2000/1833	47.5	62.5	69.33	abcde
MFARANSA	36.3	43.9	49.13	a
NDL 2006/74	51.7	67.9	79.33	bcde
Overall Mean	50.3	63	72.2	
SE (±)	13.96	16.27	15.94	
CV	27.7	25.8	22.1	
Fpr	NS	NS	0.044	

NS = Not significant at ($P \leq 0.05$). Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.5.4 Leaf retention

The response of genotypes to stress in leaf retention is shown in Table 19. At 120 DAP, all the genotypes retained 100% of their leaves. However, at 150 DAP leaf retention ranged from the highest value of 98.33 to the lowest value of 63.33. The highest value was scored by genotype KBH 2002/066 however, was significantly higher ($P \leq 0.05$) than KBH 2006/29, Kiroba and LML 2000/1833 only. The lowest leaf retention was observed in Kiroba which was significantly lower than all the other genotypes except LML 2000/1833 and KBH 2006/29. Leaf retentions at 180 DAP ranged from highest value of 73.33 to lowest value of 13.33. The highest value was scored by genotypes KBH 2002/066 and KBH 2006/109 which were significantly higher ($P \leq 0.05$) than other genotypes except 92B/00073, KBH 2006/24, KBH 2006/98, KBH 2006/74, KBH 2006/26, KBH 2002/363, KBH 2006/18 and LML 2000/1833. The lowest leaf retention was observed in Kiroba which was significantly lower than all the other genotypes except KBH 2002/135, KBH 2002/482, KBH 2006/12, KBH 2006/24, KBH 2006/29, Mfaransa and NDL 2006/74. As expected, leaf retention within genotypes tended to decrease with time under stressed conditions.

Table 19: Leaf retention of cassava genotypes evaluated under stressed condition

Genotypes	150 DAP		180 DAP	
92B/00073	85	bcd	65	de
KBH 2002/066	98.33	d	73.33	e
KBH 2002/135	86.67	bcd	36.33	abcd
KBH 2002/363	88.33	cd	53.33	bcde
KBH 2002/482	86.67	bcd	31.67	abc
KBH 2006/109	86.67	bcd	73.33	e
KBH 2006/12	86.67	bcd	40	abcd
KBH 2006/18	86.67	bcd	53.33	bcde
KBH 2006/24	85	bcd	45	abcde
KBH 2006/26	96.67	d	60	cde
KBH 2006/29	70	ab	30	abc
KBH 2006/74	93.33	cd	56.67	bcde
KBH 2006/94	95	cd	66.67	de
KBH 2006/98	91.67	cd	48.33	bcde
KIROBA	63.33	a	13.33	a
LML 2000/1833	78.33	abc	48.33	bcde
MFARANSA	86.67	bcd	26.67	ab
NDL 2006/74	95	cd	40	abcd
Mean	86.7		49.9	
SE (±)	10.49		20.01	
CV	12.1		41.8	
Fpr	0.028		0.034	

Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.5.5 Chlorophyll content

Genotypes differences in leaf chlorophyll content for stressed treatment are shown in Table 20. There was no significant difference ($P \leq 0.05$) observed at 150 and 180 but at 120 DAP. The chlorophyll content at 120 DAP ranged from the highest value of 56.54 in genotype KBH 2006/29 which was significantly higher ($P \leq 0.05$) than KBH 2006/26, KBH 2002/066, KBH 2006/94 and Mfaransa. The lowest chlorophyll content was 38.49 observed in genotype KBH 2006/26 which was also significantly lower than KBH 2002/135, KBH 2002/482, KBH 2006/109, KBH 2006/98, Kiroba, Mfaransa and NDL 2006/74.

Table 20: Chlorophyll content of cassava genotypes evaluated under stressed condition

Genotypes	120 DAP		150 DAP	180 DAP
92B/00073	48.63	abc	42.25	28.6
KBH 2002/066	43.29	ab	42.03	34.3
KBH 2002/135	52.36	bc	44.99	33
KBH 2002/363	46.27	abc	44.32	34.1
KBH 2002/482	50.45	bc	47	29.4
KBH 2006/109	49.19	bc	50.29	40.7
KBH 2006/12	48.01	abc	49.04	34.8
KBH 2006/18	48.4	abc	48.3	28.6
KBH 2006/24	47.83	abc	48.51	32.9
KBH 2006/26	38.49	a	39.15	29.8
KBH 2006/29	56.54	c	54.92	36.1
KBH 2006/74	48.26	abc	49.25	35.9
KBH 2006/94	43.93	ab	40.78	36.3
KBH 2006/98	50.46	bc	47.9	37.4
KIROBA	50.23	bc	47.63	18.1
LML 2000/1833	48.23	abc	45.36	27.2
MFARANSA	42.15	ab	40.4	27.3
NDL 2006/74	49.73	bc	46.62	26.3
Overall Mean	47.91		46.04	31.7
SE (±)	3.473		5.033	8.16
CV	7.2		10.9	25.7
Fpr	<0.001		NS	NS

NS = Not significant at ($P \leq 0.05$). Means followed by a common letter within a column are not significantly different. Mean separation by Turkey at 5% level

4.5.6 Yield and harvest parameters

As pointed out in section 4.5, there were no significant difference among genotypes ($P \leq 0.05$) in all yield and harvest parameters (number of roots per plant, weight of roots per plot, percentage dry matter, weight of above ground biomass and harvest index) under water stressed conditions.

4.6 Biochemical Parameters

The activities of antioxidant enzymes participating in scavenging Reactive Oxygen Species (ROS) in extracts of different cassava genotypes under moisture stress conditions

are presented in Fig. 4 and 5. Different cassava genotypes clearly responded differently to water deficiency in terms of the activities of Catalase (CAT) and Peroxidase (POD). CAT and POD enzyme activities, has been considered as an important anti-drought mechanism to cope with oxidative stress during water deficit conditions (McKersie *et al.* 1999). Results revealed more activities of Catalase and Peroxidase in water stressed leaves compared to well watered leaves of cassava genotypes.

Maximum decrease of absorbance for CAT was observed in genotypes KBH 2006/18, KBH 2006/12, 92B/00073, KBH 2002/363, KBH 2002/482 and KBH 2006/24 which suggest having good mechanism of overcoming oxidative stress compared to genotypes KBH 2006/26, KBH 2006/98, KBH 2006/29, KBH 2002/135 and Mfaransa under water stress condition (Fig. 4). Most genotypes under well watered condition had no pronounced decrease of absorbance for CAT activities observed with exception of LML 2000/1833 and Mfaransa.

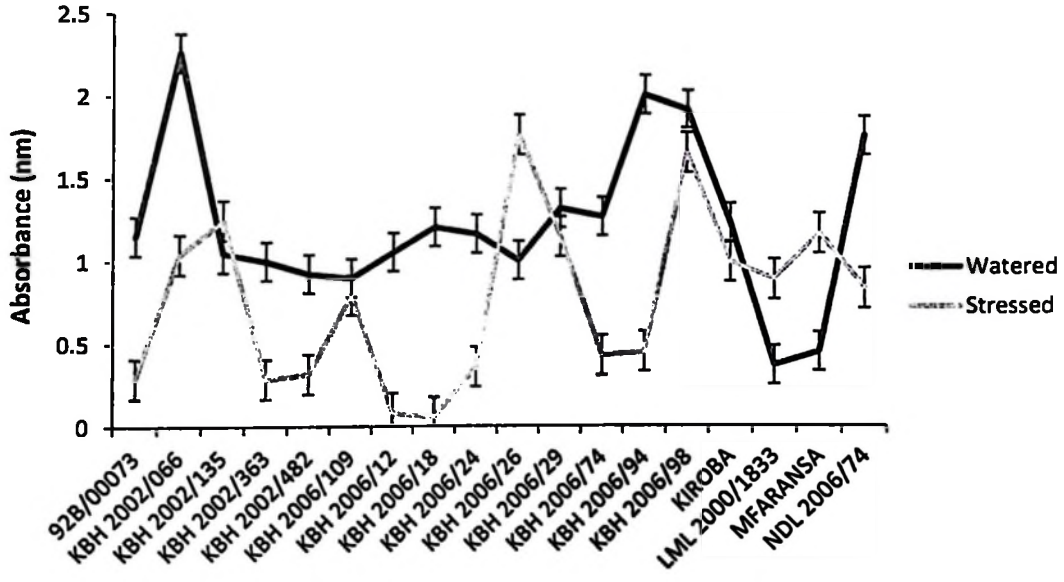

Figure 4: Catalase activities from leaves of eighteen cassava genotypes subjected to drought treatments (watered and stressed) at 180 DAP

Maximum increase in POD absorbance was observed in genotypes 92B/00073, KBH 2006/12, KBH 2002/363, KBH 2002/482 and KBH 2006/74 which suggest having good mechanism of overcoming oxidative stress compared to Mfaransa, KBH 2006/109 and KBH 2006/94 under water stress condition (Fig. 5). Most genotypes under well watered treatment did not give pronounced increase in absorbance due to Peroxidase activity with exception of KBH 2006/109 and KBH 2006/94.

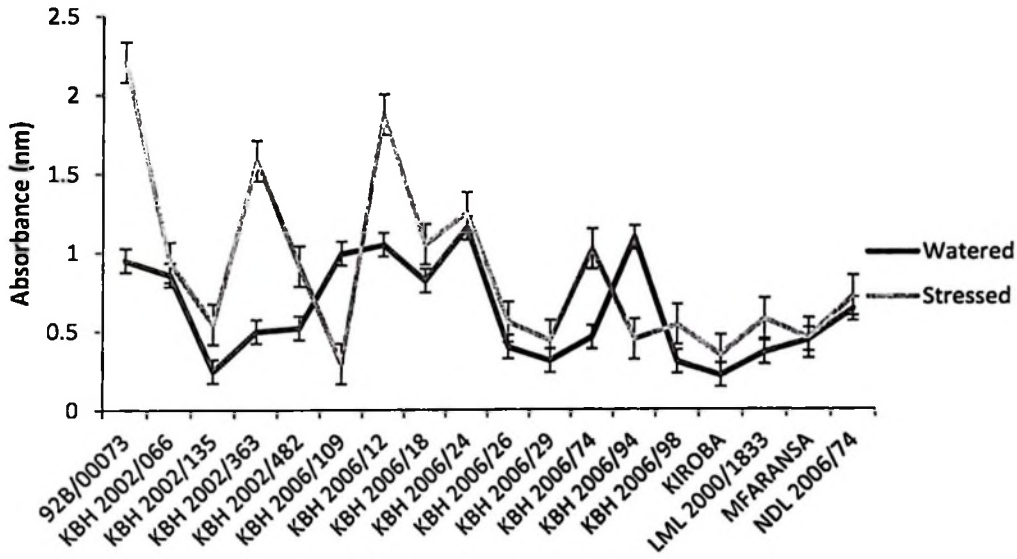

Figure 5: Peroxidase activities from leaves of eighteen cassava genotypes subjected to drought treatments (watered and stressed) at 180 DAP

4.7 Farmer's Participatory Evaluation

4.7.1 Root size

Evaluation of the genotypes by farmers after harvesting (uprooting) showed that genotypes KBH 2002/363 and 92B/00073 were most preferred for good root size, followed by KBH 2006/12, KBH 2006/18, KBH 2006/98 and KBH 2002/482 which were rated good (Table 14). NDL 2006/74 was rated bad meaning it had smallest roots.

4.7.2 Root inner and outer part

As shown in Table 21, genotypes 92B/00073, LML 2000/1833, KBH 2002/363, KBH 2002/482, KBH 2006/18, KBH 2006/98 and KBH 2006/12 had good root skin outer cover selection rate while root flesh inner part had eleven genotypes with the good preference. There was no genotype with the highest bad rated ranks which suggest that all genotypes inner parts were satisfying.

4.7.3 Fresh root yield

Field participatory genotypes evaluation by farmers for yield had genotype 92B/00073 and KBH 2002/363 highly preferred by farmers. Genotypes KBH 2002/482, KBH 2006/12, KBH 2006/24, KBH 2002/006, KBH 2006/18 and KBH 2006/109 also showed good performance in terms of yield preference rank (Table 21). Genotypes KBH 2002/135 and KBH 2006/74 were rated to have bad yield.

Table 21: Farmer's evaluation scores for water stressed genotypes after uprooting

	Frequency of farmer's rating (n=30)											
	Root Size			Root Outer cover			Root Inner Part			Yield		
Genotype	Good	Moderate	Bad	Good	Moderate	Bad	Good	Moderate	Bad	Good	Moderate	Bad
KBH 2002/363	19	7	4	15	12	3	14	11	5	19	11	0
MFARANSA	5	16	9	10	11	9	13	14	3	11	11	8
KBH 2002/006	10	11	9	11	11	8	13	12	5	13	12	5
KBH 2006/98	14	10	6	12	9	9	12	11	7	11	10	9
NDL 2006/74	9	9	12	6	12	12	7	13	10	11	13	6
KBH 2006/26	9	13	8	9	11	10	11	10	9	8	16	6
KBH 2002/482	13	10	7	14	12	4	12	12	6	17	12	1
LML 2000/1833	10	11	9	15	11	4	9	11	10	1	15	14
KBH 2002/135	10	11	9	11	12	7	12	13	5	0	14	16
92B/00073	18	9	3	16	11	3	14	13	3	20	10	0
KBH 2006/12	15	11	4	13	12	5	15	9	6	17	13	0
KBH 2006/74	9	12	9	10	10	10	15	13	2	8	10	12
KBH 2006/29	9	13	8	9	11	10	14	7	9	9	11	10
KBH 2006/18	15	10	5	14	9	7	14	13	3	13	12	5
KBH 2006/109	10	11	9	10	12	8	12	10	8	12	11	7
KBH 2006/24	10	13	7	11	12	7	11	11	8	15	14	1
KIROBA	10	13	7	10	14	6	17	12	1	6	16	8
KBH 2006/94	9	12	9	11	12	7	10	11	9	11	10	9

4.7.4 Organoleptic test

All eighteen genotypes where cooked and tasted for organoleptic characteristics in pair wise matrix (Table 22). Eight genotypes were selected and further compared. From matrix ranking, six genotypes were subsequently selected by farmers' as the most preferred genotypes on the basis of good taste. In order of preferences, most liked genotypes were KBH 2006/12, KBH 2002/363, KBH2006/29, KIROBA, KBH 2006/26 and KBH 2006/109.

Figure 6: Organoleptic testing of 18 cassava genotypes by farmers in Hombolo, Dodoma

Table 22: Pair wise Organoleptic ranking of cassava genotypes during farmers participatory testing of cooked traits

NS	Genotypes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Score	Rank
1	92B/00073		2	3	4	5	6	7	8	9	1	11	12	13	14	15	16	17	18	1	13
2	KBH 2002/066			2	4	5	6	2	8	2	2	11	12	2	2	15	16	17	18	7	9
3	KBH 2006/74				4	5	6	3	8	3	3	11	12	3	14	15	16	17	18	5	10
4	KBH 2002/135					5	6	4	8	4	4	11	12	4	4	15	16	17	18	8	8
5	MFARANSA						6	5	8	5	5	11	5	5	5	5	16	17	18	11	6*
6	KIROBA							6	6	6	6	11	6	6	6	6	6	17	18	14	3*
7	KBH 2006/18								8	9	7	11	12	7	7	15	16	17	18	4	11
8	NDL 2006/74									8	8	11	8	8	8	15	16	17	18	11	6*
9	KBH 2006/24										9	11	12	9	9	15	16	17	18	5	10
10	KBH 2002/482											11	12	13	14	15	16	17	18	0	14
11	KBH 2006/26												11	11	11	15	11	17	18	13	4
12	LML 2000/1833													12	12	15	16	17	18	9	7
13	KBH 2006/98														13	15	16	17	18	3	12*
14	KBH 2006/94															15	16	17	18	3	12*
15	KBH 2006/109																16	17	18	12	5
16	KBH 2006/29																	17	18	14	3*
17	KBH 2002/363																		18	16	2
18	KBH 2006/12																			17	1

*= Genotypes with equal score

4.8 Correlation between Different Traits Evaluated for Genotypes Tolerance to Drought

The relationship between traits determined by Spearman's correlation analysis is presented in Table 23. There was no significant correlation between leaf length and harvest index, leaf width and number of roots per plant, above ground biomass, percentage dry matter content and harvest index. Also, no significant correlation was observed between harvest index and leaf length, harvest index and above ground biomass.

Plant height, percentage leaf retention, chlorophyll content and root weight per plot had significant positive correlation with all other parameters involved. It was found that number of roots per plant had significant correlation with leaf length (r=0.24*), plant height (r=0.49***), percentage leaf retention (r=0.54***), chlorophyll content (r=0.35***), weight of storage roots (r=0.90***), above ground biomass (r=0.61***), percentage dry matter (r=0.96***) and harvest index (r=0.58***). Therefore selection of any one of these parameters will increase root yield production. Positive correlation between leaf retention and weight of storage roots (r = 0.60***) indicates that leaf retention is crucial in determining crop growth rate and the storage bulking rate of cassava genotypes.

Table 23: Spearman's rank correlation coefficient between traits assessed for 18 cassava genotypes evaluated at Hombolo, Dodoma

Traits	Leaf length	Leaf width	Plant height	Leaf retention	Chlorophyll content	Number of roots/plant	Root weight/plot	Above ground biomass	Dry matter content	Harvest index
Leaf length	-									
Leaf width	0.39***	-								
Plant height	0.26**	0.23*	-							
Leaf retention	0.54***	0.36***	0.34***	-						
Chlorophyll content	0.59***	0.27**	0.22*	0.66***	-					
Number of roots/plant	0.24*	0.15^{NS}	0.49***	0.54***	0.35***	-				
Root weight per plot	0.28**	0.20*	0.48***	0.60***	0.41***	0.90***	-			
Above ground biomass	0.25*	0.14^{NS}	0.43***	0.53***	0.41***	0.61***	0.61***	-		
Dry matter content	0.26*	0.17^{NS}	0.46***	0.55***	0.38***	0.96***	0.93***	0.63***	-	
Harvest index	0.18^{NS}	0.15^{NS}	0.32**	0.32**	0.21*	0.58***	0.64***	0.06^{NS}	0.60**	-

* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$ n = 108

CHAPTER FIVE

5.0 DISCUSSION

The results have shown that genotypes differed significantly in all the traits studied under both well watered and water stressed conditions, which implies that, the genotypes constitute a pool of germplasm with adequate genetic variability. Selection of desirable characters among these genotypes may lead into significant progress in cassava improvement. According to Aina *et al.* (2007), germplasm introduction provides a unique source of variability to genetic base, selection should be geared towards drought tolerant tall plants with closer inter node spacing since more cuttings can be obtained and hence a higher multiplication rate. This is because cassava multiplication in farmer's fields is commonly through stem cuttings.

Drought is one of the environmental factors affecting leaf development in cassava. Lenis *et al.* (2006) reported that cassava accessions with greater leaf longevity can produce more total fresh biomass and a 33% higher root DM compared to drought susceptible cultivars. From our study, we found genotypes KBH 2006/18, 92B/00073 and KBH 2006/24 being not influenced by water stress for leaf length trait; also Mfaransa and KBH 2006/94 showed less sensitivity to water stress for leaf width trait. Genotype KBH 2006/18 had the smallest leaf width which means it had less evaporation from its leaves surface compared to other genotypes. Genotypes with these characters are potentially drought tolerant and can be used for food security in semi-arid areas.

Mean plant height for all genotypes didn't differ significantly at 120 and 150 DAP. A stunted growth of cassava shoots of water stressed genotypes was observed at 180 DAP

where magnitude of suppression of plant height were not similar among different genotypes, with KBH 2006/29 being the highly suppressed. Genotypes KBH 2006/24 and KBH 2002/135 were taller but also had low yield which suggest that, tallness is not desired in selection of tolerance genotypes, as it would use most of its resources to grow up and less to the roots. Height of a mature cassava plant usually ranges from 1 to 2 meters, although some cultivars reach 4 meters. Height is determined by genetic and environmental factors (IITA, 1997).

Leaf retention was the same in both well watered and water stressed treatments, until at 150 DAP after which significant decrease was observed. These results suggest that leaf retention during drought can be affected from fifth month of cassava growth. This is due to dynamics of cassava development that control and favor partitioning of photosynthetic assimilates towards the most important economic plant part (roots) as compared to leaf formation. Also at this stage lower canopy leaves senesce and abscise due to aging and shed at accelerating rates (Pellet and El-shakary, 2001). Out of the 18 genotypes, Kiroba and KBH 2006/29 were most sensitive to water stress as the two varieties had highest percentage of leaf loss. Leaf retention has been reported as one of the desired traits in achieving high yields in crops under limited moisture (Lenis *et al.*, 2006). Genotypes KBH 2002/066 and KBH 2006/109 were less sensitive to water stress in terms of percentage leaf loss. Percentage leaf retention was positively correlated with all yield parameters, thus it is advantageous to breed and select for longer leaf life and hence, better leaf retention when developing varieties adapted to dry areas.

Water deficit can destroy the chlorophyll and its synthesis (Lessani and Mojtahedi, 2002). Some other researchers have reported damage to leaf pigments as a result of water deficit

(Montagu and Woo, 1999; Nilsen and Orcutt, 1996). In this study at 120 and 150 DAP most of the stressed genotypes had higher leaf chlorophyll content compared to well water genotypes. Genotypes with the highest chlorophyll content values were KBH 2006/29 and KBH 2006/109. Mensah *et al.* (2006) found that subjecting Sesame to drought stress caused leaf chlorophyll to increase and then remained unchanged. During the study it was observed as water stress progressed to 180 DAP leaf chlorophyll content of all stressed genotypes decreased significantly, with genotypes KBH 2006/26 and Mfaransa having the lowest values. The findings correspond to those of Martínez-Ferri *et al.*, 2004; Jaleel *et al.*, 2009; Anjum *et al.*, 2011, which suggest that under severe drought stress leaf chlorophyll contents often decline due to chlorophyll degradation. There was highly significance differences observed between water regimes and between genotypes for chlorophyll content.

Good yield stability will require genotypes that can produce well under prolonged stressed conditions as water continues to become a rare commodity especially in semi-arid tropics. El-sharkawy (1993) showed that cassava yields of 8-16 t/ha of fresh roots are normally attained with local, traditional varieties on marginal soils without application of agrochemicals. Out of 18 genotypes evaluated in this study, 3 showed good performance with fresh weight root yield of $\geq$ 10 tons/ha, which were genotypes KBH 2002/363, 92B/00073 and KBH 2002/066 which suggest high level of resilience to water stress.

Dry matter of cassava genotypes was also evaluated known to be a major component of the crop yield. Cassava roots have mean dry matter of about 35 percent, which is high compared to many roots and tubers. Starch and sugar comprise about 90 percent of this dry matter. The study shows drought to have significantly influenced root dry matter.

Variation in dry matter content ranged from 5 to 20 percent. Genotype 92B/00073 had the highest value which differed significantly with all other genotypes. This agrees with the findings of Westby (2002), who showed that dry matter in cassava can vary from 20 to 45 percent depending on the variety, growing conditions (especially temperature and soil moisture), and health of the plants. Genotype KBH 2006/94 had the lowest dry matter content which suggests being more susceptible under water stress environment.

Harvest index, as the ability to convert biomass into economic yield (Mutegi 2009), is a valuable trait in cassava breeding, in that selections based on this trait are stable across evaluation stages. Under prolonged water stress, cassava produces less total biomass but an increased harvest index (El-Sharkary and Cadad, 2002). This means that nutrient use efficiency for root production is greater in stress environment than in well watered conditions. This study shows there was no significant difference between genotypes for harvest index, number of roots per plant and weight of above ground biomass.

In this study, analysis of variance (ANOVA) which included morphological, physiological and yield parameters at different levels of stress and at harvest for both well watered and water stressed genotypes did not give any interaction between genotypes and irrigation regimes. This means the effect of one variable is essentially the same regardless of the level of the other. We analyzed water stressed genotypes alone in effort to find outstanding drought tolerant cassava genotypes.

Ability of plants to overcome oxidative stress relies on induction of SOD, CAT activities and subsequently on the up regulation of other downstream antioxidant enzymes (Alscher *et al.,* 2002). Removal of peroxide produced in the peroxisomes is catalyzed by CAT

(Noctor and Foyer 2000). Similar to Willekens *et al.*, 1995 and Dat *et al.*, 1998, in this study, absorbance was decreasing with time for stressed genotypes compared to watered condition for the same genotypes. Although CAT activity was significantly decreased in all genotypes exposed to water stress condition but higher decrease was observed in four genotypes which include KBH 2006/12, KBH 2002/363, 92B/00073 and KBH 2006/24. The decline in CAT activity is regarded as a general response to many stresses (Herbinger *et al.* 2002; Bakalova *et al.* 2004; Jung 2004; Guo *et al.* 2006; Pan *et al.* 2006; Gunes *et al.* 2008; Liu *et al.* 2008). The reduction of CAT activity is supposedly due to the inhibition of enzyme synthesis or change in the assembly of enzyme subunits under stress conditions.

The study indicates a significant increase in POD absorbance in cassava genotypes under drought stress. Some previous studies, report the increased POD absorbance under drought stress conditions in various plants, like sunflower (Gunes *et al.*, 2008), poplar (Xiao *et al.*, 2008), liquorice (Pan *et al.*, 2006), brassica species (Das and Uprety, 2006) and wheat (Csiszar *et al.*, 2005). POD activities were significantly increased in most stressed genotypes but higher increase was observed in five genotypes which include 92B/00073, KBH 2006/12, KBH 2002/363, KBH 2002/482 and KBH 2006/74. This reflects high ROS scavenging capacity and decreased damage to stressed cassava genotypes. Water stress is inevitably associated with increased oxidative stress due to enhanced accumulation of ROS, particularly oxide and peroxide in chloroplasts, mitochondria, and peroxisomes. As a result, the induction of antioxidant enzyme activities is a general adaptation strategy which plants use to overcome oxidative stresses (Foyer and Noctor 2003). So above mentioned genotypes, have shown notable stress tolerance capacity in terms of enzymes reaction.

Participatory plant breeding reduces chances of developing varieties which, for reasons unknown or overlooked by the breeder, are not acceptable to farmers. During this study through participatory variety selection (PVS), farmers gained skills, information and knowledge about drought evaluation of varieties. Farmer's selections showed that in overall KBH 2002/363 was the only genotype that scored highly than others in all criteria's used, with 92B/00073, KBH 2006/12 and KBH 2002/482 also scoring high according to farmers. Genotype 92B/00073 with high yield and percentage dry matter was selected as the second best by farmer's preference on farm evaluation but was not among the best 5 in farmers organoleptic testing, while genotype KBH 2002/363 was selected for both higher on-farm and organoleptic test. This suggests that farmers have their own ways of choosing technologies.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study observed that water stress negatively affects almost all aspects of plant growth by inducing a number of changes in morphological, physiological and metabolic levels. Ability of few selected genotypes to adapt well to stress depends a lot on their performances in these different mechanisms in combination.

Hypothesis tested in this study was whether there are cassava genotypes that can tolerate and be adapted to drought prone areas of Tanzania. Findings showed potential genotypes and suggest leaf length, width, retention, yield parameters, antioxidant assays and participatory variety selection by farmers to be important in evaluating cassava genotypes under well watered and stressed conditions.

Production of drought tolerant crops able to grow under restricted water without reduction of yield will minimize drought related losses and ensure food production in water limited lands. In this study, significant differences were observed among the genotypes which suggest good genetic basis for the phenotypic variation. Variation was also observed in water stress and well watered environments for most traits evaluated. This was due to water applied to watered plots since during the experiment, there was hardly any rainfall. Although drought tolerant genotypes could be identified from morphological and physiological parameters evaluated, the yield that is primary concern to farmers, did not show any significant difference for water stressed genotypes. Selection of outstanding genotypes in a water limited environment from yield parameters was not achieved in this

study. Five promising drought tolerant genotypes namely; 92B/00073, KBH 2006/363, KBH 2006/12, KBH 2006/18 and KBH 2002/066 were identified based on their best performance in morphological expression, had higher enzymes activities and they were among those selected by farmers. Out of those, KBH 2002/066 was identified as a stay green genotype and this may serve as a parent for drought stress improvement and genetic analysis.

6.2 Recommendations

(i) Further experiment is suggested to repeat the few promising genotypes in a controlled environment during the normal growing season of the crop, so as to verify the results obtained in this study.

(ii) Analysis of food nutrients composition in these genotypes should be included in the next experiment which will involve more semi-arid locations and several growing seasons to determine genotypes by environment interactions.

(iii) There is a need for molecular study for selected tolerant genotypes so as to determine the genetic basis of their drought tolerance.

REFERENCES

Aebi, H. (1984). Catalase in vitro. *Methods in Enzymology* 105: 121–126.

Aina, O., Dixon, A. and Akinrinde, E. (2007). Effect of soil moisture stress on growth and yield of cassava in Nigeria. *Pakistan Journal of Biological Sciences* 10: 3085-3090.

Alscher, R. G., Erturk, N. and Heath, L. S. (2002). Role of superoxide dismutases (SODs) in controlling oxidative stress. *Journal of Experimental Botany* 53: 1331–1341.

Anjum, S. A., Xie, X., Wang, L. C., Saleem, M. F., Man, C. and Lei, W. (2011). Morphological, physiological and biochemical responses of plants to drought stress. *African Journal of Agricultural Research* 6: 2026–2032.

Baidu-Forson, J. B., Ntare, R. and Waliyar, F. (1997). Utilizing conjoint utility analysis to design modern crop varieties: empirical example for groundnut in Niger. *Agricultural Economics* 16: 219-226.

Bakalova, S., Nikolova, A. and Wedera, D. (2004). Isoenzyme profiles of peroxidase catalase and superoxide dismutase as affected by dehydration stress and ABA during germination of wheat seeds. *Journal of Plant Physiology* 30: 64–77.

Benjamin, J. G. and Nielsen, D.C. (2006). Water deficit effects on root distribution of soybean, field pea and chickpea. *Field Crops Res* 97: 248-253.

Blum, A. (1998). Improving wheat grain filling under stress by stem reserve mobilization. *Euphytica* 100: 77-83.

Borell, A., Hammer, G. and Henzell, R. (2000). Does maintaining green leaf area in sorghum improve yield under drought? II Dry matter production and yield. *Crop science* 40: 1037-1048.

Ceballos, H., Iglesias, C. A., Perez, J. C. and Dixon, A. G. O. (2004). Cassava breeding: Opportunities and challenges. *Plant Molecular Biology* 56: 503–516.

Chamnongpol, S., Willekens, H., Moeder, W., Langebartels, C., Sandermann, H., Van M. M., Inze, D. and Van, C.W. (1998). Defense activation and enhanced pathogen tolerance induced by H_2O_2 in transgenic tobacco. *Proceedings of the National Academy of Science of the United States of America* 95: 5818–5823.

Csiszar,, J., Feher-Juhasz, E., Kotai, E., Ivankovits-Kiss, O., Horvath, G. V., Mai, A., Galle, A., Tari, I., Pauk, J., Dudits, D. and Erdei, L. (2005). Effect of osmotic stress on antioxidant enzyme activities in transgenic wheat calli bearing *MsALR* gene. *Acta Biologica Szegediensis* 49: 49–50.

Das R., Uprety D.C. (2006): Interactive effect of moisture stress and elevated CO2 on the oxidative stress in *Brassica* species. *Journal of Food Agriculture and Environment* 4: 298–305.

Dat, J.F., C.H. Foyer and I.M. Scott. (1998). *Plant Physiol* 118: 1455-1461.

Demirevska, K., Zasheva, D., Dimitrov, R., Simova-Stoilova, L., Stamenova, M. and Feller, U. (2009). Drought stress effects on Rubisco in wheat:changes in the Rubisco large subunit. *Acta Physiol. Plant* 31: 1129-1138.

Duan, B., Yang, Y., Lu, Y., Korpelainen, H., Berninger, F. and Li, C. (2007). Interactions between drought stress, ABA and genotypes in Picea oasperata. *J. Exp. Bot* 58: 3025-3036.

El-Sharkarwy, M. and Cadavid, L. (2002). Response of cassava to prolonged water stress imposed at different stages of growth. *Experimental agriculture* 38: 333 – 350.

El-Sharkawy, M. (1993). Drought tolerant cassava for Africa, Asia and Latin America. *Bioscience* 43: 441-451.

El-Sharkawy, M. A., Hernandez, A. D. P. and Hershey, C. (1992). Yield stability of cassava during prolonged midseason water stress. *Experimental Agriculture* 28: 165-174.

FAO (2002). Partnership formed to improve cassava, staple food of 600 million people [http://www.fao.org/english/newsroom/news/2002/10541en.html] site visited on 17/07/2010.

FAO (2006). Cassava production efficiency [http://www.fao.org] sited visited on 27/07/2010.

FAO (2010). The major cassava producing countries worldwide [http://www.fao.org] sited visited on 27/04/2011.

Foyer CH and Noctor G. (2003). Redox sensing and signalling associated with reactive oxygen in chloroplasts, peroxisomes and mitochondria. *Physiol Plant* 119: 355–364.

Foyer, C. H., Lelandais, M. and Kunert, K. J. (1994). Photo oxidative stress in plants. *Physiologia Plantarum* 92: 696–717.

Fregene, M., Okogbenin, E., Mba, C., Angel, F., Suarez, M. C., Janneth, G., Chavarriaga, P., Roca, W., Bonierbale, M. and Tohme, J., (2001). Genome mapping in cassava improvement: Challenges, achievements and opportunities, *Euphytica* 120:159–165.

Fukuda, W. M. G., Guevara, C. L., Kawuki, R. and Ferguson, M. E. (2010). Selected morphological and agronomic descriptors for the characterization of cassava. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. 19 pp.

Gunes, A., Pilbeam, D., Inal, A. and Coban, S. (2008). Influence of silicon on sunflower cultivars under drought stress, I: Growth, antioxidant mechanisms and lipid peroxidation. Commun. *Soil Science and Plant Nutrition* 39: 1885–1903.

Gupta, P. C, and O'toole, J. C. (1986). Upland rice: A global perspective. International Rice research Institute Manila, Philippines 360pp.

Guo, Z., Ou, W., Lu, S. and Zhong, Q. (2006). Differential responses of antioxidative system to chilling and drought in four rice cultivars differing in sensitivity. *Plant Physiology and Biochemistry* 44: 828–836.

Herbinger, K., Tausz, M., Wonisch, A., Soja, G., Sorger, A. and Grill, D. (2002). Complex interactive effects of drought and ozone stress on the antioxidant defence systems of two wheat cultivars. *Plant Physiology and Biochemistry* 40: 691–696.

IITA (1997). Cassava in Africa: past, present and future. Report prepared for IITA by Spencer and associates. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Jaleel, C. A., Manivannan, P., Wahid, A., Farooq, M., Somasundaram, R., Panneerselvam, R., (2009). Drought stress in plants: a review on morphological characteristics and pigments composition. *International Journal of Agriculture and Biology* 11: 100–105.

Jung, S. (2004). Variation in antioxidant metabolism of young and mature leaves of *Arabidopsis thaliana* subjected to drought. *Plant Science* 166: 459–466.

Laurie, R. N., Du ploy, C. P. and Laurie, S. M. (2009). Effect of moisture stress on growth and performance of orange fleshed sweet potato varieties, African *Crop Science Society* Vol. 9: 235 – 239.

Lenis, J., Calle, F., Jaramilo, G., Perez, J., Ceballos, H. and Cock, J. (2006). Leaf retention and cassava productivity. *Field Crops Research* 95: 126-134.

Lessani, H. and Mojtahedi, M. (2002). Introduction to Plant Physiology (Translation). 6th Edn., Tehran University press, Iran, ISBN: 964-03-3568-1. pp 726.

Liu, J., Xie, X., Du, J., Sun, J. and Bai, X. (2008). Effects of simultaneous drought and heat stress on Kentucky bluegrass. *Journal of Horticultural Science* 115: 190–195.

Martínez-Ferri, E., Manrique, E., Valladares, F. and Balaguer, L., (2004). Winter photoinhibition in the field involves different processes in four co-occurring Mediterranean tree species. *Tree Physiology* 24: 981–990.

McKersie B.D., Bowley S.R., Jones K.S. (1999): Winter survival of transgenic alfalfa overexpressing superoxide dismutase. *Plant Physiology* 119: 839–848.

Mensah, J. K., Obadoni, B. O. Eroutor, P. G. and Onome-Irieguna, F. (2006). Simulated flooding and drought effects on germination, growth, and yield parameters of Sesame (*Sesamum indicum* L.). *Afr. J. Biotechnol* 5:1249-1253.

Mittler, R. (2002). Oxidative stress, antioxidants and stress tolerance. *Trends in Plant Science* 7: 405–410.

Montagu, K. D. and Woo, K. C. (1999). Recovery of tree photosynthetic capacity from seasonal drought in the wet-dry tropics: The role of phyllode and canopy processes in Acacia auriculiformis. *Aust. J. Plant Physiol* 26: 135-145.

Moyib, O. K., Odunola, O. K. and Dixon, A. G. O. (2007). SSR Markers reveal genetic variation between improved cultivar and landraces within a collection of Nigeria cassava germplasm. *African Journal of Biotechnology* 6(23):2666-2674.

Muhana, M. and Mtunda, K. J. (2002). The effect of cassava brown streak virus disease yield and quality of cassava. *Journal of phytopathology* 149:389-394.

Nilsen, E. T. and Orcutt, D. M. (1996). Physiology of Plants Under Stress, Abiotic Factors. 2nd Edn, John Wiley and Sons Inc, New York, ISBN: 0471170089, pp 689.

Noctor G and Foyer C. (2000). Oxygen processing in photosynthesis: regulation and signaling. *New Phytol* 146: 359-388.

Ojulong H, Labuschagne MT, Fregene M, Herselman L (2008). A cassava clonal evaluation trial based on a new cassava breeding scheme. *Euphytica* 160: 119-129.

Okechukwu, R. U. and Dixon, A. G. O. (2008). Cassava variety release system in Nigeria: a successful fast-track approach. Global Cassava Partnership-First Scientific Meeting: Cassava Meeting the challenges of the New Millennium, 21–25 July 2008, Ghent University, Ghent, Belgium. 102pp.

Olsen, K. and Sachaal, B. (2001). Microsatellite variation in cassava *Manihot esculenta, Euphorbiaceae* and its wild relatives: evidence for a southern Amazonian origin of domestication. *American journal of botany* 131 - 142.

Olsen, K. M. (2004). SNPs, SSRs and inferences on cassava's origin. *Plant Molecular Biology* 56: 517 - 526.

Pan, Y., Wu, L. J. and Yu, Z. L. (2006). Effect of salt and drought stress on antioxidant enzymes activities and SOD isoenzymes of liquorice (*Glycorhiza uralensis* Fisch). *Journal of Plant Growth Regulation* 49: 157–165.

Pellet, D. and El-Sharkary, M. (2001). Cassav varietal response to fertilization: Growth dynamics and Implications for cropping sustainability. *Experimental Agriculture* 33: 353-365.

Polle, A., Otter, T. and Seifert, F. (1994). Apoplastic peroxidases and lignification in needles of Norway spruce (Picea abies L.). *Plant Physiology* 106: 53–60.

Praba, M. L., Cairns, J. E., Babu, R. C. and Lafitte, H.R. (2009). Identification of physiological traits underlying cultivar differences in drought tolerance in rice and wheat. *J. Agron. Crop Sci* 195: 30-46.

Roa, A. C., Maya, M. M., Duque, M. M., Tohme, J., Allen, A. C. and Bonierbale, M. W. (1997). AFLP analysis of relationships among cassava and other Manihot species. *Theor. appl. Genet* 95: 741–750.

Tas, S. and Tas, B. (2007). Some physiological responses of drought stress in wheat genotypes with different ploidity in Turkiye. *World Journal of Agricultural Sciences* 3: 178–183.

Westby, A. (2002). Cassava utilization, storage and small-scale processing. In: Hillocks, R. J. Thresh, J. M. and Belloti, A. (eds.) Cassava: Biology, production and utilization. CABI publishing, Wallingford, NY, pp 281-300.

Willekens H, Langebartels C, Tire C, Van MM, Inze' D, Van CW (1994). Differential expression of catalase genes in *Nicotiana plumbaginifolia. Proc. Natl. Acad. Sci. U.S.A* 91: 10450-10454.

Xiao, X., Xu, X. and Yang, F. (2008). Adaptive responses to progressive drought stress in two *Populus cathayana* populations. *Silva Fennica* 42: 705–719.

Xu, P. L., Guo, Y. K., Bai, J. G., Shang, L. and Wang, X. J. (2008). Effects of long-term chilling on ultrastructure and antioxidant activity in leaves of two cucumber cultivars under low light. *Physiologia Plantarum* 132: 467–478.

Yordanov, I., Velikova, V. and Tsonev, T. (2000). Plant responses to drought, acclimation, and stress tolerance. *Photosynthetica* 38: 171–186.

APPENDICES

Appendix 1: Statistical model

Statistical model was: $Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$

Where:

- Y_{ijk} = is the k^{th} replicate observation from the combination of the i^{th} level of factor A and the j^{th} level of factor B.
- μ = is the overall (constant) population mean of the response variable.
- α_i = is effect of i^{th} level of factor A, pooling the levels of factor B.
- β_j = is effect of j^{th} level of factor B, pooling the levels of factor A.
- $(\alpha\beta)_{ij}$ = is the effect of the interaction of the i^{th} level of A and the j^{th} level of B.
- ε_{ijk} = is random or unexplained error associated with the k^{th} replicate observation from the combination of the i^{th} level of A and the j^{th} level of B.

Appendix 2: On farm cassava evaluation sheet

Evaluator name: Sex:
Date: Village:

Character	Cassava genotypes																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Drought tolerance																		
General opinion																		
Root size																		
Root outer cover																		
Root inner part																		
Yield																		

Where:-
A = Very good; B = Good; C = Moderate; D = poor; E = Very poor

Appendix 3: Cooked cassava evaluation sheet

Evaluator name: Sex:
Date: Village:

Character	Cassava genotypes																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Color appearance																		
Taste																		
Flour																		
Non fibers																		
Acceptance/ General opinion																		

Where:-
A = Very good; B = Good; C = Moderate; D = poor; E = Very poor

Appendix 4: Pair wise ranking table

Genotypes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Score	Rank
1																				
2																				
3																				
4																				
5																				
6																				
7																				
8																				
9																				
10																				
11																				
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