Screening sweetpotato (*Ipomoea batatas* L.) for drought tolerance and high β-carotene content in Mozambique

by

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Republic of South Africa

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DECLARATION

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……

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As the candidate's Supervisor I agree/do not agree to the submission of this thesis

……

Dr Paul E. Shanahan (Supervisor)

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ABSTRACT

Sweetpotato (*Ipomoea batatas,* L.) is one of the important sources of carbohydrates and economic income in Mozambique. As with most of the food crops in Mozambique, it is usually produced by small-scale farmers under dryland conditions. Despite the importance of the crop, the storage root yields are still low and it is difficult to keep planting material (vines) for the next planting season. One of the major challenges to production is drought stress. Drought stress affects sweetpotato by retarding aboveground growth, reducing total root yield, percentage of dry mass, and reducing the quality of the roots as a result of the increase in damage caused by the sweetpotato weevil (*Cylas formicarius*).

The objective of this study was to identify sweetpotato genotypes tolerant to drought particularly amongst the orange fleshed types which can be used in breeding programmes to improve the drought tolerance of genotypes grown in Mozambique. To this end, 48 genotypes were evaluated in both field and greenhouse studies conducted at Umbeluzi Research Station (26º 03' S, 32ºC 23' E; 12 masl) located about 30 km from Maputo city. The field trial was a three replicate, α-design with split-plots. Genotypes were the whole-plot treatment factor and irrigation levels were the sub-plot treatment factor. The three irrigation levels imposed were: nonstressed plants irrigated from planting to 120 DAP; moderately stressed, plants irrigated until 60 DAP; and severely stressed, plants irrigated until 30 DAP. In the greenhouse trial the 48 genotypes were grown in wooden boxes arranged in a two replicate, randomized complete block design. The plants were exposed to water stress from 10 DAP to the end of experiment at 60 DAP.

Genotypes were significantly different for all traits, namely: survival %**,** vine vigour, aboveground biomass, total and commercial root yield, total fresh biomass, harvest index,

β-carotene content, % dry mass, dry mass yield, incidence of sweetpotato virus disease, and incidence of weevil damage. Irrigation levels were significant for the traits: survival %, vine vigour, aboveground biomass, total and commercial root yield, total fresh biomass, harvest index, β-carotene content, % dry mass, and dry mass yield. Irrigation levels were not significant for incidence of sweetpotato virus disease and incidence of weevil damage. The genotypes x irrigation levels interaction was significant for: total and commercial root yield, and incidence of weevil damage; and not significant for: survival %, vine vigour, aboveground biomass, total fresh biomass, harvest index, β-carotene content, % dry mass composition, dry mass yield and incidence of sweetpotato virus disease.

The mean dry mass yields across irrigation levels of the national breeding lines and introduced genotypes were higher than the landrace genotypes. Most of the national breeding lines had higher β-carotene content than the introduced and landrace genotypes. The landrace genotypes had relatively higher % dry mass composition compared to the national breeding lines.

The stress tolerance index (STI) separated the 48 sweetpotato genotypes evaluated in the field trial into three groups: drought tolerant (high STI); moderate drought tolerant (intermediate STI); and drought sensitive (low STI). Under moderate stress, yield potential (Yp) and yield in a stress environment (Ys) were highly significant, positively correlated with Mean productivity (MP), Geometric mean productivity (GMP), Stress tolerance index (STI) and Tolerance index (TOL). Under severe stress the same correlations were reported. Under moderate and severe stress, the correlation between stress tolerance index (STI) and Stress susceptibility index (SSI) was significant and negative.

In the greenhouse trial, differences between genotypes in vine length increment, vine diameter increment, leaf width increment and number of nodes vine^{-1} were significant ($P<0.05$). Vine length, vine diameter, leaf width and length increments either increased or were reduced due to water stress. Less than 10% increment in vine length (between 25 and 50 DAP) was recorded in MGCl01, Atacama, Cordner, Beauregard, and CN1448-49. Higher than 40% vine length increment was recorded in Jonathan and UNK-Malawi, Naspot, MUSG0614-24, Resisto, K566632, Tainung64, Ejumula and MUSG0623-09. Vine diameter decreased in Manhissane and MUSG0616-18. No change in leaf length in Tacna and Jonathan and in leaf width in Xihetamakote and Resisto-Nairobi was recorded.

The longest petiole length at 30 DAP was recorded by Tacna and the shortest by Nhacutse4. The longest internode length was recorded in 199062.1. Similar to petiole length, Nhacuste4 reported the shortest internode length. The highest number of primary vines was recorded by MUSG0608-61 and lowest by Beauregard. Of the 48 genotypes exposed to water stress, 18 survived until the end of the greenhouse experiment at 60 DAP and were therefore considered to be drought tolerant.

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this without you. My thanks go to all my friends and family for their wonderful company and always being there for me.

DEDICATION

I dedicate this work to my mother for her hard work in supporting her family, her unending love, and words of wisdom. To my little girl, Erica Liliana, and little boy, Sidney Christian, I sincerely hope that this work will provide motivation and inspiration in their future lives. Lastly, I dedicate this work to my wife, Helen.

Table of Contents

DECLARATION i
ABSTRACT ii
ACKNOWLEDGEMENTS v
DEDICATION vii
Table of Contents viii
List of Tables x
List of Figures xii
List of symbols and abbreviations xiv
GENERAL INTRODUCTION xvii
Hypotheses and objectives xix
Thesis structure xx

CHAPTER 1 1
Literature review 1
1.1 Introduction 1
1.2 Drought stress 5
1.2.1 Effect of drought on growth and development of sweetpotato 7
1.2.2 Effect of drought on sweetpotato storage root yield 9
1.2.3 Effect of drought on root dry mass content and composition 11
1.2.4 Effect of drought on pests and diseases of sweetpotato 12

CHAPTER 2 13
MATERIALS AND METHODS 14
2.1 Experimental procedure 14
2.2 Multiplication of sweetpotato vines 14
2.3 Screening for drought tolerance in the field 15
2.3.1 Description of the study area 15
2.3.2 Experimental design and treatments 15
2.3.3 Establishment and maintenance of the field trial 16
2.3.4 Data collection 18

2.3.5 Drought tolerance indices of genotypes evaluated under the moderate and severe stress irrigation levels 22
2.4 Screening for drought tolerance in a greenhouse 24
2.4.1 Description of study area 24
2.4.2 Experimental design 24
2.4.3 Establishment and maintenance of the greenhouse trial 25
2.4.4 Data collection 25
2.5 Statistical analyses of field and greenhouse trial data 27

CHAPTER 3 28
RESULTS AND DISCUSSION 28
3.1 Environmental conditions 28
3.2 Screening for drought tolerance in the field 29
3.2.1 Effect of water stress on growth and development 29
3.2.2 Effect of water stress on root yield and other yield traits 36
3.2.3 Effect of water stress on post-harvest traits 47
3.2.4 Effect of water stress on pests and diseases 54
3.2.5 Drought tolerance indices 61
3.3 Screening sweetpotato genotypes in a greenhouse for drought tolerance 69
3.3.1 Vine length increment 69
3.3.2 Vine diameter increment 72
3.3.3 Leaf width and length increments 72
3.3.4: Petiole length, internode length, nodes vine^{-1}, vine plant^{-1} and survival days 73

CHAPTER 4 78
CONCLUSIONS AND RECOMMENDATIONS 78
4.1 Introductions 78
4.2 Recommendations 83
4.3 Further research directions 84
REFERENCES 86
Appendices 102

List of Tables

Table 1.1: Constituents of orange fleshed sweetpotato (source: U.S. Department of Agriculture: Agriculture Research, Service Nutrient Database for Standard Reference, Release 14, 2001) 4
Table 2.1: Genotypes evaluated for drought stress tolerance in the field and greenhouse trials 17
Table 3.1: Environmental data recorded at Umbeluzi research station from June to December 2008..... 28
Table 3.2: F-statistics of genotypes, irrigation levels and genotypes x irrigation levels interaction for three traits of 48 sweetpotato genotypes exposed to three irrigation levels..... 30
Table 3.3: Mean survival % vine vigour and aboveground biomass of 48 sweetpotato genotypes across three irrigation levels…… …. 31
Table 3.4: F-statistics of genotypes, irrigation levels and genotype x irrigation levels interaction for four traits of 48 sweetpotato genotypes exposed to three irrigation levels..... 37
Table 3.5: Total and commercial root yields of 48 sweetpotato genotypes exposed to three irrigation levels..... 38
Table 3.6: Mean total fresh biomass and mean harvest index of 48 sweetpotato genotypes across three irrigation levels..... 43
Table 3.7: F-statistics of genotype, irrigation levels and genotype x irrigation levels interaction for β-carotene content of 48 sweetpotato genotypes exposed to three irrigation levels..... 48
Table 3.8: Mean β-carotene content, dry mass composition and dry mass yield of 48 sweetpotato genotypes across three irrigation levels..... 54
Table 3.9: F-statistics of genotype, irrigation levels and genotype x irrigation levels interaction for incidence of sweetpotato virus disease (SPVD) in 48 sweetpotato genotypes exposed to three irrigation levels..... 55
Table 3.10: Mean scores for incidence of sweetpotato virus (SPVD) in 48 sweetpotato genotypes across three irrigation levels..... 56
Table 3.11: F-statistics of genotype, irrigation levels and genotype x irrigation levels interaction for incidence of sweetpotato weevil damage in 48 sweetpotato genotypes exposed to three irrigation levels..... 57

Table 3.12: Mean scores for incidence of weevil damage in 48 sweetpotato genotypes exposed to three irrigation levels.....59
Table 3.13: Analyses of variance for seven drought tolerance indices of 48 sweetpotato genotypes evaluated under moderate stress 61
Table 3.14: Analyses of variance for seven drought tolerance indices of 48 sweetpotato genotypes evaluated under severe stress.....62
Table 3.15: Correlation coefficients between the mean values of seven drought tolerance indices of 48 sweetpotato genotypes evaluated under moderate and severe water stress 63
Table 3.16: Seven drought stress tolerance indices of 48 sweetpotato genotypes exposed to the moderate stress irrigation level.....64
Table 3.17: Seven drought tolerance indices of 48 sweetpotato genotypes exposed to the severe stress irrigation level.....67
Table 3.18: Mean vine length & diameter, leaf width & length increments of 48 sweetpotato genotypes exposed to water stress from 10 DAP.....70
Table 3.19: Mean petiole length & internode length, nodes vine^{-1}, vine plant^{-1} and survival days of 48 sweetpotato genotypes exposed to water stress from 10 DAP……...74

List of Figures

Figure 2.1: Examples from the Royal Horticultural Society (RHS) Colour Chart for estimating β-carotene content in sweetpotato…….....27
Figure 3.1: Mean survival % of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP. 33
Figure 3.2: mean vine vigour of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP. 34
Figure 3.3: Mean aboveground biomass of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.....36
Figure 3.4: Mean total fresh biomass of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP…….....46
Figure 3.5: Mean harvest index of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP. 47
Figure 3.6: Mean β-carotene content of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.....51
Figure 3.7: Mean dry mass composition of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.....53
Figure 3.8: Mean dry mass yield of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP. 54

Appendices

Appendix 1.1 Field layout of modified split plot design for the evaluation of 48 sweetpotato genotypes subjected to three irrigation levels under field conditions 102
Appendix 1.2 Layout of randomized complete block design for the evaluation of 48 sweetpotato genotypes under for the greenhouse conditions 103
Appendix 1.3: Rainfall and class A pan data for field trial 104
Appendix 2: Analysis of variance (ANOVA) for field trial traits 104
Appendix 2.1*:* ANOVA for survival % 106
Appendix 2.2*:* ANOVA for vine vigour 106
Appendix 2.3*:* ANOVA for aboveground biomass 106
Appendix 2.4: ANOVA for total root yield (t ha^{-1}) 106
Appendix 2.5*:* ANOVA for commercial root yield (t ha^{-1}) 107
Appendix 2.6*:* ANOVA for total fresh biomass 107
Appendix 2.7: ANOVA for harvest index % 107
Appendix 2.8*:* ANOVA for β-carotene content (mg 100 g^{-1}) 107
Appendix 2.9*:* ANOVA for dry mass composition (%) 108
Appendix 2.10*:* ANOVA for dry mass yield (t ha^{-1}) 108
Appendix 2.11*:* ANOVA for incidence of sweetpotato virus disease 108
Appendix 2.12: ANOVA for incidence of weevil damage 108
Appendix 3: ANOVA for greenhouse trial traits 109
Appendix 3.1: ANOVA for vine length increment (%) 109
Appendix 3.2: ANOVA for vine diameter increment (%) 109
Appendix 3.3: ANOVA for leaf length increment (%) 109
Appendix 3.4: ANOVA for leaf width increment (%) 109
Appendix 3.5: ANOVA for petiole length (cm) 109
Appendix 3.6: ANOVA for internode length (cm) 110
Appendix 3.7: ANOVA for nodes $vine^{-1}$ 110
Appendix 3.8: ANOVA for vines $plant^{-1}$ 110
Appendix 3.9: ANOVA for survival days 110

List of symbols and abbreviations

ARC - Agriculture Research Council

AVRDC - Asian Vegetable Research and development Centre

CIP - International Potato Centre

C.V. - Coefficient of variation

CTCRI - Central Tuber Crops Research Institute

DAP - Days after planting

DM - Dry mass

DMY - Dry mass yield

E - East

EARNET - Eastern Africa Root Crops Research Network

EC - Concentrated emulsion

FAO - Food and Agriculture Organization

FW - Fresh mass

GMP - Geometric mean productivity

HI- Harvest index

IIAN - National Institute of Agriculture Research

IIAM - Agrarian Research Institute of Mozambique

ISTRC - International Society for Tropical Root Crops

IU - International unit

Kcal - Kilo calories

KJ - Kilojoules

LSD - Least Significant Differences

µg-RE - micrograms retinol equivalent

MADER - Ministry of Agriculture and Rural Development

MINAG - Ministry of Agriculture

MP - Mean productivity

NPK- Nitrogen, Phosphorous and Potassium

OFSP - Orange-fleshed sweetpotato

PAW - Plant available water

RHS - Royal Horticultural Society

S - South

SA - South Africa

SADC - Southern Africa Development Communities

SARRNET - Southern Africa Root Crops Research Network

SED - Standard error deviation

SI - Stress intensity

SPVD - Sweetpotato virus disease

SSI - Stress susceptibility index

STI - Stress tolerance index

t - Tonnes

TFB - Total fresh biomass

TOL - Tolerance index

UK - United Kingdom

U.S - United States

USA - United States of America

VAD - Vitamin A deficiency

Vit. A - Vitamin A

WP - Wettable powder

WFP - World food Programme

Yp - yield potential of each genotype in a nonstress environment

Ys - yield of each genotype in a stress environment

$\overline{Yp}$ - mean yield of all genotypes in a nonstress environment

$\overline{Ys}$ - mean yield of all genotypes in a stress environment

GENERAL INTRODUCTION

A large percentage of the human population in the tropics depends on different root crops for food security (Woolfe, 1992). Even though the root crops are not cultivated on large scale by commercial farmers and therefore rarely appear on world markets, they are of great importance for smallholder/small-scale farmers. Root crops are part of the daily diet of many developing countries, particularly when cereals are in low supply, as they are an alternate source of starch. Root crops such as sweetpotato (*Ipomoea batatas*, L.) are high yielding and generally require low inputs to produce, with the added advantage in the tropics of being available throughout the year (Gomes, 1996).

In rural areas of Mozambique, sweetpotato is an important source of carbohydrates and economic income (Bias *et al*., 1999). It is normally produced by small-scale farmers under dryland conditions. Despite the importance of the crop, the yields achieved by small-scale farmers remain low relative to the potential of the crop. In Mozambique the average root yields of some local genotypes is about 6 to 13 t ha^{-1} **(**Bias *et al*., 1999; Andrade *et al.,* 2002**)** but can be increased with the use of improved genotypes and appropriate and high inputs. Factors that contribute to such below-potential yields are drought stress, pests and diseases, poor cropping systems and cultural practices, use of traditional (local) genotypes and poor soil fertility.

Drought stress is one of the major constraints limiting sweetpotato production in Mozambique, particularly in the southern region of the country. In this region, agriculture is practiced under climatic conditions characterized by low and erratic rains, often exacerbated by high temperatures as well as short duration and late (starting) rainfall. In

drought affected areas, sweetpotato affords farmers the opportunity to re-establish cropping following a dry season due to its relatively better ability to grow under erratic rainfall. The fact that most Mozambican farmers cannot afford the use of agriculture inputs that are standard practice in commercial agriculture makes sweetpotato an important crop in the local cropping systems. There is considerable reliance on the capacity of sweetpotato to produce economic and/or sustaining yields on marginal lands with very low production costs (Minde and Jumbe, 1997; Bias *et al*., 1999).

Despite its relative tolerance of drought, sweetpotato affected by drought stress will record yield lower than its potential and also reduced root dry mass composition (Ekanayake *et al*., 1988; Mcharo *et al.*, 2001; Saraswati, 2004). Damage caused by weevil and other pests and diseases during a prolonged drought stress also contributes to low marketable roots production (Powell *et al*, 2001). A study carried out in Mozambique recognised that although the production of vines increased when there was excess soil water, the taste of the storage root was negatively affected (Mafalacusser, 1995).

The Agrarian Research Institute of Mozambique (IIAM), and the International Potato Centre (CIP) in Mozambique have been developing orange fleshed sweetpotato (OFSP) genotypes rich in pro-vitamin A content to mitigate Vitamin A deficiency, particularly for children under 5 years old and pregnant women (Low *et al.*, 2006). Despite the high nutritional attributes and high yield, the OFSP genotypes already released are less drought tolerant than existing genotypes (introductions from CIP), which makes the conservation of planting material for the following season difficult to manage. These genotypes are also low in dry mass composition making them less acceptable to farmers than the local

genotypes. Many of the sweetpotato genotypes adapted to the drought conditions in Mozambique are white fleshed with low pro-vitamin A content.

For the reasons presented above, there is a clear need to develop new drought stress tolerant genotypes with acceptable root yield and dry mass composition, and good quality roots. In response to that need a sweetpotato breeding programme in Mozambique was started in 2005 under the auspices of CIP and supported by the Rockefeller Foundation. This programme involved establishing a polycross comprised of local genotypes and introduced genotypes that were reportedly drought tolerant. Screening of progeny from the polycross for drought tolerance was then conducted.

In general, the aim of the study presented in this thesis was to contribute to the sweetpotato breeding programme in Mozambique through the selection of drought tolerant genotypes that are high in β-carotene content. The selected drought-tolerant progeny with high β-carotene content will contribute to an increase in the productivity and quality of sweetpotato produced by smallholder farmers in Mozambique. In particular, the new genotypes will increase the availability of OFSP in the months of September to December where there is a considerable gap in food production.

Hypotheses and objectives

There are many factors which influence crop production, and the importance of each one compared to the others depends on which one is the most limiting. According to Brito (1991), the most limiting factor to production is water. The climatic zones of Mozambique vary from very dry arid to very wet humid zones. The arid zones constitute about 2% of the total area and they are primarily suited to the production of pasture and other non-food

crops (Amane, 2000). The southern areas of Mozambique are characterized by arid to semi-arid zones, and the limited and unpredictable rainfall can cause considerable yield reduction or even crop failure in dryland agriculture (Amane, 2000). The annual rainfall ranges from 400 to 1000 mm and it is concentrated between October and April.

This study tested the hypothesis that there are differences in the response of sweetpotato genotypes to water stress. The null hypothesis is that there are no differences in the response of sweetpotato genotypes to water stress. Additionally, the hypothesis that existing local genotypes are more tolerant than the locally improved and introduced genotypes was tested. The associated null hypothesis is that existing local, locally improved and introduced genotypes are equally tolerant or sensitive to drought.

The overall objective of this study was to identify drought tolerant local and introduced genotypes that also had high root yield, high storage root dry mass composition and high β-carotene content. The specific objective of this study was to identify sweetpotato genotypes tolerant to drought. The genotypes identified as drought tolerant will be used to improve the drought tolerance of OFSP genotypes in Mozambique.

Thesis structure

This thesis comprises four chapters excluding the general introduction. Chapter 1 comprises the literature review covering the importance of sweetpotato as a food crop and the constraints to productivity within the context of the farming systems in Mozambique. Reference was made to drought stress as one of the most important environmental factors affecting the production and productivity of sweetpotato. The different ways in which

drought affects sweetpotato production are also mentioned. Chapter 2 covers the materials and methods in which experimental site, procedure, design, management, data collection and analysis are detailed. In Chapter 3 the response of the tested genotypes to water stress in terms of growth, yield, dry mass composition, β-carotene content, and pest and disease incidence, is discussed. Chapter 4 comprises the final summary discussion and conclusions together with some recommendations and future research objectives.

CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

Sweetpotato is a dicotyledonous root crop, and a member of the Convolvulaceae family. Of the 1000 different species within Convolvulaceae, *I. batatas* is the only one that is a major food crop: some of the others are used locally, but many are actually poisonous (Woolfe, 1992 and Srisuwan et al, 2006). Common names of sweetpotato in Latin America are 'batata', 'camote' and 'boniato' (Spanish), 'batata doce' (Portuguese), 'apichu' and 'kumara' (Woolfe, 1992). The orange-fleshed sweetpotato (OFSP) genotypes are often called yam in some parts of North America, a practice intended to differentiate it from the white genotypes. Sweetpotato is in fact botanically very distinct from yams (*Dioscorea* spp) that are native to Africa and Asia and belong to the monocotyledonous family Dioscoreaceae (Shioyani and Kawase, 1987). Sweetpotato is native to the tropical parts of South America, and was domesticated there nearly 5000 years ago. Sweetpotato is now cultivated throughout the tropical and warm temperate regions wherever there is sufficient water to support its growth.

The sweetpotato (*Ipomoea batatas*, Lam.) is a root crop that is frequently used for food and as a cash crop by millions of people throughout the tropical regions of the world (O'Brien, 1972). The world production of sweetpotato in 2008 was about 127 000 000 t (FAO, 2008). China is the major producer with 80 522 926 t followed by Nigeria with 3 318 000 t. Mozambique is ranked tenth with 890 000 t. About half of China's crop is used for livestock feed. In Mozambique, sweetpotato is ranked as the sixth most important food crop (INIA/SARRNET, 2003; FAO, 2008).

For most of the 3.04 million farm families in Mozambique, agricultural production is based on dryland cultivation and low input management systems (FAO/IBPGR, 2005). Soil productivity is based not only on its quality, but also on the availability and quantity of water; agriculture which is dependent on rainfall cannot become more productive by the application of nutrients alone (Zoë Marriage, 1999).

In general sweetpotato is a perennial crop, but for agricultural purposes it is managed as an annual with a growing period varying from 3 to 8 months depending on the environmental conditions and genotype (CIP, 2007). The edible root is long and covered with a smooth skin which ranges in colour from red, purple, brown to white. Its flesh root colour ranges in gradations from white, yellow, orange to purple.

In Mozambique, sweetpotato is grown for its leaves (the terminal shoots or vines being progressively harvested during the growing season) and for its roots (Gomes *et al*., 2005). Sweetpotato has become well established in eight of the 10 provinces of Mozambique, mainly due to its high yield per unit area and the capacity to grow in relatively poor soils (Bias *et al*, 1999, Andrade and Naico, 2003). Furthermore, sweetpotato can produce more energy (KJ) per day than wheat (*Triticum aestivum L*), rice (*Oryza sativa L*.) or cassava (*Manihot esculenta* Crantz) and is able to grow in arid conditions with limited water supply (FAO/IBPGR, 2005) once it is established. It can grow and produce edible storage roots in marginal environments where other food crops fail, and this makes it a valuable crop for resource poor farmers (CIP, 2007).

The sweetpotato genotypes grown and consumed in Mozambique play an important role, firstly, in contributing towards an adequate caloric intake, and secondly, depending on flesh

colour, improving the Vitamin A nutrition of people, particularly those living in rural areas. White fleshed sweetpotato genotypes lack β-carotene which is a biochemical precursor to Vitamin A (often referred to as pro-vitamin A) and therefore an essential component of all human diets (Woolfe, 1992; Ugwu, 2009). The orange colour of the root flesh of orange-fleshed sweetpotato (OFSP) genotypes is an indicator of β-carotene content (Shloetter, 2006). The OFSP genotypes play an important role combating vitamin A deficiency (VAD) (INIA/SARRNET, 2003). Vitamin A deficiency is widespread in young children in developing countries with an estimated 127 million children affected worldwide. In Mozambique, there is an estimated prevalence of VAD in 71% of children between the ages of 0 and 5 years (Low *et al.*, 2006).

The sweetpotato genotypes grown in eastern and southern Africa are predominantly white-fleshed containing negligible amounts of β-carotene (Agili *et al.,* 2004). As Mozambique is a vast country, with a great diversity of agro-ecological environments, a multiplicity of sweetpotato genotypes is grown mostly white and yellow-fleshed (Andrade *et al.,* 2003), because the OFSP genotypes are more sensitive to drought (Andrade *et al.,* 2007). However, due to the importance of vitamin A in human nutrition (Table 1.1), the production and consumption of OFSP genotypes have steadily been increasing in many areas of Mozambique (CIP, 2007).

Sweetpotato is widely grown in many parts of Mozambique, on a small scale, providing food in months when there is a gap in food availability from other crops (INIA/SARRNET, 2003; Minde and Jumbe, 1997). Sweetpotato is often harvested over a period of several months, with the main harvest period occurring between May and September. In many areas, sweetpotato is ranked among the top six most cultivated food crops after maize (*Zea mays*

L.), cassava, dry bean (*Phaseolus vulgaris*), sorghum (*Sorghum bicolor*) and groundnut (*Arachis hypogea*) (INIA/SARRNET, 2003).

Table 1.1: Constituents of orange fleshed sweetpotato (source: U.S. Department of Agriculture: Agriculture Research, Service Nutrient Database for Standard Reference, Release 14, 2001)

Constituents of 100 g edible root				
	Units	**Raw sweetpotato root**	**Baked in skin**	**Boiled without skin**
Water	g	72.84	72.84	72.84
Energy	kcal	105.00	103.00	105.00
	kj	439.00	431.00	439.00
Protein	g	1.65	1.72	1.65
Total lipid (fat)	g	0.30	0.11	0.30
Carbohydrate by difference	g	24.28	24.27	24.28
Fiber, total dietary	g	3.00	3.00	1.80
Ash	g	0.95	1.06	0.95
Calcium (Ca)	mg	22.00	28.00	21.00
Iron (Fe)	mg	0.59	0.45	0.56
Magnesium (Mg)	mg	10.00	20.00	10.00
Phosphorous (P)	mg	28.00	55.00	27.00
Potassium (K)	mg	204.00	348.00	184.00
Sodium (Na)	mg	13.00	10.10	13.00
Zinc (Zn)	mg	0.28	0.29	0.27
Copper (Cu)	mg	0.17	0.21	0.16
Manganese (Mn)	mg	0.36	0.56	0.34
Selenium (Se)	mg	0.60	0.70	0.70
Vitamin (C)	mg	22.70	24.60	17.10
Thiamin (B_1)	mg	0.07	0.07	0.05
Riboflavin (B_2)	mg	0.15	0.13	0.14
Niacin (B_3)	mg	0.67	0.60	0.64
Pantothenic acid (B_5)	mg	0.59	0.65	0.53
Vitamin (B_6)	mg	0.26	0.24	0.24
Folate, total	mg	14.00	23.00	11.00
Vitamin (B_{12})	mg	0.00	0.00	0.00
Vitamin (A, IU)	IU	20.06	21.82	17.05
Vitamin (A, RE)	µg-RE	2.01	2.18	1.70
Vitamin E	µg--ATE	0.28	0.28	0.28

Despite the importance of sweetpotato relative to the other crop species, yields are still very low in rural areas of Mozambique compared to South Africa where the average yield for a commercial farmer is 40 t ha^{-1} and for a small scale resource poor farmer is estimated at 10 to 20 t ha^{-1} (Agriculture Statistics, 2008). A study conducted by Andrade *et al.* (2002) indicated that sweetpotato yields in Mozambique varied from 6 to 16 t ha^{-1} with an overall mean of 13.7 t ha^{-1}. In spite of cyclical drought in the central and southern regions of Mozambique, the yield, harvested area and total production of sweetpotato have been increasing (FAOSTAT, 2007). This increase is due to the massive multiplication and distribution of improved OFSP genotypes to many households in areas affected by flood and drought (Andrade and Naico, 2003).

Despite research into improving the yield of sweetpotato, drought and floods are still environmental factors limiting production in southern Africa and, in particular, Mozambique. From 2000 to 2004, Mozambique experienced a series of natural disasters, starting with the worst floods in 100 years and culminating in a three year drought (Ismael, 2004). Due to drought and flooding there has been a considerable loss of sweetpotato planting material as a consequence of either the limited or excess soil moisture. As consequence of extended drought, in the 2002/03 season there was a reduction of 43% in cereal production in southern and central Mozambique and in the 2003/04 season the reduction was about 4% of the total cereal production (African Development Bank, 2005).

1.2 Drought stress

Drought stress is one of the most important environmental factors affecting the production and productivity of many crops worldwide (FAO, 2003; Gomes *et al.,* 2005) and has a major

limiting effect on production in many tropical regions where sweetpotato is grown (Anselmo *et al.,* 1991). In Mozambique drought reduces the area and production potential for small farmers who do not have access to supplemental irrigation. Sweetpotato is generally grown on residual soil moisture during the dry months (Demagante *et al.,* 1989).

The limited adaptation of sweetpotato genotypes to drought stress imposes constraints on the current and potential production levels achieved by small-scale farmers (Ekanayake *et al.,* 1988). Sweetpotato can be considered as drought tolerant a crop species as maize and dry bean (Martin, 1988). The productivity of sweetpotato is seriously affected when drought occurs at planting but it can tolerate drought and produce some roots if the drought occurs near the end of the crop's growth cycle (Martin, 1987).

There are several studies indicating that drought affects sweetpotato in different ways, from retarding above-ground growth (Martin, 1988; Demagante *et al*., 1989; Anselmo *et al.,* 1991; Indiramma, 1994; & Nair *et al.,* 1996) to reducing total root yield (Bourke, 1989; Indira, 1990; Anselmo *et al.,* 1991; Naskar *et al.,* 1992; Xu *et al*, 1992; Indiramma, 1994; Nair *et al*., 1996; Valenzuela *et al*., 2000; & Ekanayake *et al.,* 2004). Drought stress reduces total dry matter production (Ekanayake *et al*., 1988; Demagante *et al.,* 1989; Jefferies, 1992; Indiramma, 1994; Mcharo *et al.,* 2001; Ekanayake *et al.,* 2004; & Saraswati *et al.,* 2004) and also affects the quality of roots as a consequence of the higher incidence of the sweetpotato weevil (Villamayor Jr, 1987; Valenzula *et al.,* 2000; Powell *et al.,* 2001; & Mao *et al.,* 2004).

According to Demagante *et al*. (1989) the positive relationship between storage root yield and vine yield suggests that high soil water levels may not suppress vegetative growth if light intensity is also high. Ghuman & Lal (1983) concluded that root yield and distribution of dry

mass composition in sweetpotato were influenced by water table depth. The differences in the performances of sweetpotato genotypes in response to a range of soil water levels reflects the different ways in which the available soil water affects the growth and development of the harvestable components (Riestra-Diaz, 1984).

1.2.1 Effect of drought on growth and development of sweetpotato

Growth and development of sweetpotato is the result of the additive and non-additive interaction of each plant's genes with the environment. The potential amount of growth is determined by the genes but the actual or phenotypic amount of growth is determined by the genes, environment, and the interaction of genes with environment (Ekanayake *et al.,* 1988; Martin; 1988). The components of the environment that affect plant growth and development are biotic (living components such as disease organisms) and abiotic (non-living components such as temperature, light, water, etc.). A combination of biotic and abiotic effects, such as disease and drought, may obviously reduce the potential growth and development to a greater extent than when drought only occurs (Martin, 1988).

When an environment imposes one or more stresses on plants, that environment might be marginal for the growth of some or many species (Martin, 1987). There are effectively three main ways in which drought affects sweetpotato growth: firstly, by reducing the amount of foliage produced; secondly decreasing the rate of photosynthesis per unit of leaf; and lastly shortening the effective root filling period (Loon and Van, 1981).

The final growth attained by sweetpotato genotypes varies in response to the available soil water during the growth cycle (Demagante *et al.*, 1989; Ekanayake *et al*., 2004). Demagante

et al. (1989) found that sweetpotato growth and development were sensitive to water deficit only during early vegetative growth when crop cover was incomplete. Genotypes that grow rapidly may escape water stress by quickly covering the soil and reducing the evaporation from the soil surface (Demagante *et al.,* 1989).

Demagante *et al*. (1989) reported that when irrigation was stopped a week after planting only slight differences in canopy cover between moisture levels for five genotypes was observed during the first 49 days after planting (DAP) due to a reduction in leaf expansion with decreasing soil moisture levels. Indiramma (1994) reported a clear declining trend in leaf area expansion rate with decreasing levels of soil moisture. Anselmo *et al.* (1991) observed that under water stress, genotypes differed in their ability to produce new leaves with some genotypes recording an increased leaf number, others a decreased number, while others had little or no change at all.

Saraswati *et al.* (2004) observed that the reduction in stem length (relative to the control) of 15 genotypes exposed to drought stress varied considerably from 16.1 to 46.0 %. Internode diameter was reduced by 12 to 50 % across the genotypes. Only one of the 15 genotypes was found to be relatively drought tolerant as its growth was less affected by drought as evidenced by delayed wilting and higher leaf water content compared to the other genotypes. Anselmo *et al*. (1998) found that 26 genotypes significantly responded to drought induced 30 DAP by a reduction in internode length and overall plant growth. Nair *et al*. (1996) reported no significant difference between the performance of genotypes under drought imposed from 30 DAP and under irrigated conditions.

1.2.2 Effect of drought on sweetpotato storage root yield

The effect of drought on the yield of sweetpotato and other related crops depends on amount of water supplied at the different stages of plant growth (Demagante *et al*., 1989; Ekanayake *et al*., 2004). Reduction in root yield of sweetpotato due to water deficits exposed from 30 DAP has been reported in various agro-ecological zones (Indira, 1990; Anselmo *et al*., 1991; Naskar *et al*., 1992; Indiramma, 1994; Nair *et al*., 1996; & Valenzuela *et al*., 2000).

The dependence of root yield in sweetpotato on an adequate supply of soil water is well known as evidenced by the strong, positive correlation between rainfall and yield (Ekanayake *et al.*, 1988). The increase of 1.4 t ha^{-1} for each 100 mm increase in rainfall recorded in sweetpotato (Qiwei *et al*, 1991) is similar to the yield response recorded in irrigated potato (*Solanum tuberosum*) (Harris, 1992). Mcharo *et al*. (2001) found that the total root yield of sweetpotato was significantly influenced by seasonal effects. They observed that the drought stress conditions that prevailed during two consecutive seasons depressed the yields of the genotypes under evaluation by 10 and 12.5 %, respectively (Kimoone *et al*., 2005). Although 270.2 mm of rainfall was recorded for the first season, the mean yield recorded of 7.2 t ha^{-1} was the lowest relative to the two subsequent seasons where the rainfall was very limited. Anselmo *et al*. (1991) stated that although sweetpotato can tolerate considerable periods of drought, yields are significantly reduced if water shortage occurs for 50 to 60 DAP, but in general a sweetpotato crop requires 500 mm of rain during the season. Xu *et al.* (1992) classified sweetpotato genotypes in a field experiment with less than 20% root yield reduction as drought tolerant; the highest reduction was 34.1%.

The requirement for water is critical during maximum vine extension, particularly during the first 30 DAP, when the storage roots are just beginning to develop (Demagante *et al.,* 1989;

Anselmo *et al*, 1991). Bourke (1989) detected that the potential number of roots and consequently yield was reduced in sweetpotato plants exposed to dry soil conditions in the period from 3 to 10 weeks after planting (WAP). Bourke (1989) reported that drought had the greatest effect on sweetpotato yield during the root-bulking phase that occurs later in the crop growth cycle. On the other hand, Indira & Kabeerathumma (1988) and Nair *et al*. (1996) reported that the sweetpotato total and commercial root yield were significantly reduced by water stress during the root initiation phase, whereas when stress occurred during the root development (filling) phase there was a slight increase in root yield compared to the control.

Demagante *et al*. (1989) observed that fewer marketable size roots (>3 cm in diameter) were produced when plants were exposed to low levels of available soil water from 30 DAP. A study presented in an AVRDC Progress Report (Anonymous, 1983) suggested that genotypes with smaller, more numerous storage roots tended to maintain relatively higher yields when exposed to water stress from 40 DAP. In Hawaii, yields were increased by 30% with the timeous application of irrigation, particularly at planting to improve stand establishment and during the root development stage from 7 to 9 WAP (Valenzuela *et al*., 2000).

The apparent lack of effect of drought was reported by Indira (1990) where no significant reduction (or increase) in yield was observed when water stress was imposed during the root development phase, and Demagante *et al*. (1989) who found that when water stress was imposed from 30 DAP, the storage root yield at 130 DAP was unaffected by soil moisture levels, but the storage root yields at 90 and 110 DAP were affected.

Anselmo *et al*. (1998) reported that the mean storage root yield of genotypes selected from polycross subjected to water stress conditions was higher (49.89 t ha^{-1}) than under normal

(unstressed) conditions (13.89 t ha^{-1}). Similarly, Shigwedha *et al*. (2004) observed that the drought tolerant genotypes evaluated recorded higher yields under dry land conditions than under conditions of adequate water. In contrast, Demagante *et al.* (1989) stated that the genotypes with high yield potential under favourable conditions would also produce high root yield under drier conditions i.e. exhibited general adaptation. Similarly, based on his research results, Villamayor Jr (1987) expected high yielding cultivars under favourable conditions to be high yielding under dry conditions.

1.2.3 Effect of drought on root dry mass content and composition

Together with quality and root yield, root dry mass composition is a good indicator of drought resistance due to its sensitivity and its high heritability (Ekanayake *et al.,* 2004). Storage root dry mass is positively correlated with vegetative growth (Demagante *et al.,* 1989). Mcharo *et al.* (2001) demonstrated that under water stress conditions the reduction in root dry mass was not as great as the reduction in total root yield. Saraswati (2004) reported that the drought induced reduction in root dry mass ranged from 31 to 46% relative to the control. Ekanayake *et al*. (1988); Indira & Kabeerathumma (1988); Indiramma (1994); and Ekanayake *et al*. (2004) all reported a reduction in root dry mass under water stress conditions.

The primary effect of drought is to alter dry matter partitioning in favour of shoots at the expense of roots (Demagante *et al,* 1989). Drought conditions reduced the root dry mass content by a similar extent in two sweetpotato genotypes (Jefferies, 1993). Experiments conducted on cassava revealed that root dry mass was influenced by environmental conditions, especially water stress which occurred immediately before root harvest (Aina *et al.,* 2009; Bakayoko *et al*., 2009). The root dry mass composition in cassava was

high when water stress does not exceed six months after planting (Bakayoko *et al,* 2009). Demagante *et al.* (1989) reported that the highest soil moisture level (580 mm water) reduced vine dry mass and storage root dry mass in the evaluated sweetpotato genotypes, particularly later in the growing period. The storage root dry mass was highest at soil moisture level of 160 mm.

1.2.4 Effect of drought on pests and diseases of sweetpotato

The sweetpotato weevil (*Cylas formicarius*) is the major insect pest of sweetpotato in the world (Valenzula *et al*., 2000). The impact of drought stress on plants and its direct and indirect effects on herbivorous insects such as the sweetpotato weevil has drawn much attention (Mao *et al*., 2004). Powell *et al*. (2001) found that decreased rainfall resulted in greater damage to marketable roots by sweetpotato weevil. Similarly, Masumba *et al*. (2004) reported that rainfall decreased the severity of weevil damage to sweetpotato genotypes. However, the influence of environmental factors such as drought on pests and diseases are complicated by genotype x environment interactions (Aina *et al.* 2009). The interaction between genotype and drought stress was significant for incidence of weevil damage indicating a differential response to water stress for severity of weevil damage in two genotypes (Mao *et al*., 2004). Encouragingly for the development of sweetpotato cultivars resistant to weevil damage, Villamayor Jr (1987) reported that all seven improved genotypes tested for weevil damage under water stress conditions had superior resistance compared to two check genotypes.

There are no reported effects of drought on the incidence and severity of disease in sweetpotato. Aldahadha *et al* (2010) reported that there were no significant genotypes by

water stress interaction for fungal root diseases in wheat. Green and Ray (2009) stated that diseases increased in incidence in forest trees exposed to a two year long drought in Scotland. The effects of drought stress on plant growth during the early vegetative stage of maize were not affected by the maize dwarf mosaic virus (Oslon *et al*., 1990). Severe water stress during the growing seasons increased the incidence of *Fusarium* spp in maize grain (Váňová *et al*, 2006).

CHAPTER 2

MATERIALS AND METHODS

2.1 Experimental procedure

The first phase of the study began in March 2008 with the multiplication of sweetpotato genotypes that were to be evaluated in the field. The second phase, from June to December 2008, entailed screening 48 genotypes for drought stress tolerance under field conditions. The third and final phase, from September to December 2008, involved screening the same 48 genotypes for drought stress tolerance in a greenhouse.

2.2 Multiplication of sweetpotato vines

Raised beds 5 m long, 1.2 m wide and 20 cm high were prepared in the nursery. Fertilizer was applied at a rate of 10 g m^{-2} of NPK (1:2:1). Vine cuttings 30 cm in length (2 to 5 nodes), were taken from vigorous plants. The cuttings were disinfected with pesticide (Cypermetrin: 25%) and fungicide (Mancozeb: 80%) and planted vertically with one or two nodes below the soil surface at a 20 x 10 cm inter- and intra-row spacing, respectively. The plants were watered once per day in the morning or evening to reduce evaporative losses. Urea (46%) was applied at 13 g m^{-2} WAP (INIA, 1995), followed by irrigation. The nursery beds were weeded as necessary. Any diseased plants were removed. In June, vines were cut for the establishment of the field and greenhouse trials.

2.3 Screening for drought tolerance in the field

2.3.1 Description of the study area

A field trial for screening for tolerance to drought stress was established at the Umbeluzi Research Station in the Boane District of Maputo province, Mozambique on the 16th June 2008. Umbeluzi Research Station is located at 26º 03' S and 32º 15' E with an altitude of 12 meters above sea level. Umbeluzi has a pronounced dry season from May to October and a wet season from November to March. In the wet season temperatures range from 23 to 36ºC and in the dry season from 17 to 23ºC, with 2.8 to 7.2 mm day^{-1} of evaporation in the dry season (Gomes, 1996). The average annual rainfall is 679 mm and the soil type is alluvial with texture ranging from sandy loam in the top soil to sandy at 1.75 m deep; an available water capacity at 1.75 m soil depth is 200 mm.

2.3.2 Experimental design and treatments

The screening for drought stress tolerance in the field was conducted using a three replicate, α-design with split-plots. Twelve genotypes were randomly allocated to plots in each of four blocks per replicate. The **Genotypes** in each plot constituted the whole-plot treatment factor with each whole-plot split for the sub-plot treatment factor of **Irrigation Treatment** at three levels (Appendix 1.1). This allocation of treatment factors at the whole-plot and split-plot strata generally provided for Error a (whole-plot stratum) > Error b (sub-plot stratum) in the ANOVA.

The three levels of Irrigation Treatment were imposed on a non-random basis at three stages of plant growth in relation to storage root development as follows: 1) *severe stress at storage root initiation* where irrigation was provided twice per week (every third day for approximately three hours) up to and including the 30th DAP after which irrigation was stopped; 2) *moderate stress* during storage root development where irrigation was provided twice per week (every third day for approximately three hours) up to and including the 60th DAP after which irrigation was stopped; and 3) *nonstress* where irrigation was provided twice per week (every third day for approximately three hours) up to and including the 30th DAP after which irrigation was provided once per week up to the 120th DAP. From 120 up to 150 DAP irrigation was completely stopped. The trial was harvested at 150 DAP.

Forty eight sweetpotato accessions were used in this study (Table 2.1) of which 12 were landraces locally grown in Mozambique with putative drought tolerance (Andrade *et al.,* 2007), and 23 genotypes were introductions from CIP, Peru with orange fleshed colour and selected for screening through the CIP-Mozambique breeding programme. The remaining 13 genotypes were current national breeding lines and although they had relatively low tolerance to drought they were selected because they had relatively high β-carotene content ranging from 6.12 to 14.37 mg 100 g^{-1} (Andrade, 2007).

2.3.3 Establishment and maintenance of the field trial

The soil was prepared as recommended for sweetpotato cultivation (INIA, 1995). The land was ploughed, harrowed and ridged to 20 cm in height by tractor-drawn implements. Pre- and post-planting fertilizer was applied uniformly to all plots at a rate of 10 g m^{-2} of NPK (1:2:1) according to the general recommendation for Umbeluzi Research Station.

Table 2.1: Genotypes evaluated for drought stress tolerance in the field and greenhouse trials

Genotypes	Origin	Significant attribute
1- Xitsekele	National collection*	High drought tolerance
2- ADMARC	National collection*	High drought tolerance
3- MGCl01	National collection*	High drought tolerance
4- Xiadlaxakau	National collection*	High drought tolerance
5- Manhissane	National collection*	High drought tolerance
6- Canassumana	National collection*	High drought tolerance
7- Tacna	Introduced SA*	High drought tolerance
8- NASPOT	Introduced CIP	Yellow root flesh
9- Resisto	Introduced USA	Orange root flesh
10- Jonathan	Introduced USA	Orange root flesh
11- Carrot-C	Introduced CIP	Orange root flesh
12- K135	Introduced CIP	Cream root flesh
13- Gueri	Introduced CIP	Orange root flesh
14- Zambezi	Introduced CIP	Orange root flesh
15- Ukerewe	Introduced CIP	Orange root flesh
16- Mayai	Introduced CIP	Orange root flesh
17- K566632	Introduced CIP	Orange root flesh
18- K118	Introduced CIP	Orange root flesh
19- Ejumula	Introduced CIP	Orange root flesh
20- Pipi	Introduced CIP	Yellow root flesh
21- 199062.1	Introduced CIP	Orange root flesh
22- MUSG0609-47	National breeding	High yield
23- MUSG0616-18	National breeding	Deep orange /high yield/dry mass
24- CN1448-49	Introduced CIP	Orange root flesh
25- MUSG0623-09	National breeding	High yield/dry mass
26- MUSG0610-45	National breeding	High yield root flesh
27- MUSG0617-10	National breeding	High yield root flesh
28- MUSG0614-24	National breeding	High yield root flesh
29- MUSG0608-61	National breeding	High yield root flesh
30- MUSG0606-02	National breeding	High yield/dry mass
31- Tainung64	Introduced CIP	Orange root flesh
32- MUSG0610-51	National breeding	High dry mass
33- Chulamete	National collection*	Orange root flesh
34- Jonathan-Nairobi	Introduced CIP	Orange root flesh
35- LO323	Introduced CIP	Orange root flesh
36- Resisto-Nairobi	Introduced CIP	Orange root flesh
37- MUSG0615-36	National breeding	High dry mass
38- MUSG0608-33	National breeding	High dry mass
39- MUSG0622-60	National breeding	Deep orange/high dry mass
40- MUSG0614-22	National breeding	Orange root flesh /high dry mass
41- Gabagaba	Introduced CIP	Orange root flesh
42- Ligodo	National collection*	Medium drought tolerant
43- Cordner	Regional genotype	Medium drought tolerant
44- Xihetamakote	National collection*	Medium drought tolerant
45- Nhacutse4	National collection*	Medium drought tolerant
46- Atacama	Introduced SA*	Medium drought tolerant
47- UNK-Malawi	National collection*	Medium drought tolerant
48- Cincominutos	National collection*	Medium drought tolerant

* CIP - Mozambique drought tolerant germplasm, SA - South Africa

Apical-tip vine cuttings (taken from nursery plants) 30 cm in length and disinfected with pesticide (Cypermetrin: 25%) and fungicide (Mancozeb: 80%) were planted. Plots were regularly and uniformly weeded during the course of the trial.

Gross and net plot sizes were 7.2 and 6 m², respectively. The inter- and intra-row spacings were 90 and 30 cm, respectively. Each gross plot therefore consisted of 24 plants grown in two 3.6 m length rows with 20 plants comprising the net plot. The total trial area was approximately 6 500 m².

The irrigation treatments were applied using drip system irrigation. The soil was irrigated to the determined field capacity of 270 mm m^{-1} based on monitoring tensiometers positioned in the irrigated plots in replication 1, the moderate stress plots in replication 2, and the severe stress plots in replication 3. The wilting point was 200 mm m^{-1} and plant available water (PAW) was 70 mm m^{-1} (Gomes *et al.,* 2005). A reading of 0 kPa on the vacuum gauges of the tensiometers indicates a saturated soil at which point plants roots are exposed to poor aeration. A reading of 8 kPa indicated the soil was at field capacity. Readings greater than 30 kPa indicated a dry soil and irrigation was applied to the determined field capacity (Larry, 1992).

2.3.4 Data collection

2.3.4.1 Environmental data

Rainfall, Class A-pan evaporation, temperature, and relative humidity data were recorded weekly from the weather station situated at the Umbeluzi Research Station.

2.3.4.2 Pre-harvest trial data

Data for initial stand (number of established plants) were recorded at 30 DAP and vine vigour was recorded at 120 DAP. Additionally, plants were rated for incidence of the sweetpotato virus disease (SPVD) at 60 DAP. The data of all traits were recorded on a net plot basis after discarding the border rows.

Vine vigour: based on visual appearance using a scale of 1 to 9 where: 1 represents very low vigour (very weak); 3, low vigour (weak); 5, intermediate vigour (good vigour); and 9, high vigour. The data was square-root transformed for statistical analysis.

***Sweetpotato virus disease*:** plants were scored at 60 DAP using a visual rating scale from 1 to 9; where 1 is no apparent symptoms; 3, very low symptoms (5-25 % of total leaves exhibiting symptoms); 5, moderate symptoms (30-50% of total leaves); 7, severe symptoms (55-75% of total leaves); and 9, very severe symptoms (80-100% of total leaves). The data was square-root transformed for statistical analysis.

***Survival %*:** the number of surviving plants in the net plot was recorded one month before harvest i.e 120 DAP.

2.3.4.3 Harvest stage trial data

At 150 DAP all plants were harvested. At harvest, the following data were collected for each net plot:

***Aboveground biomass*:** obtained at harvest by weighing the total vine (stem) and leaf mass on a net plot basis. Aboveground biomass is a partial measurement of whole plant vigour and an indirect measurement of vine vigour.

***Commercial and non-commercial root yield and number*:** based on mass and diameter, roots were graded and counted as commercial (mass >100 g or diameter >3 cm) or non-commercial (mass ≤100 g or diameter ≤3 cm). Roots were also qualitatively graded by neighbouring farmers as commercial if they were well shaped, free of defects and had no weevil damage, or non-commercial roots if they were misshapen, unattractive and had defects.

Total root yield: obtained as the combined fresh mass of commercial and non-commercial roots.

***Total fresh biomass*:** obtained as the combined total fresh root and shoot masses.

***Harvest index*:** defined as the ratio of total fresh root yield to the total above- and belowground fresh biomass at harvest.

***Incidence of weevil damage*:** roots were scored at harvest (150 DAP) using a visual rating scale from 1 to 9; where 1, is no apparent damage to the roots; 3, light (less than 10% of the total number of roots damaged); 5, moderate (10-30% damaged); 7, severe (35-65% damaged); and 9, extremely severe (more than 65% damaged). The data was square-root transformed for statistical analysis.

Dry mass composition **(DM)**: determined from a composite sample of five roots per plot, each root between 300 and 500 g in mass. The roots were washed of soil particles, peeled and each root cut longitudinally into four sections. The two opposite sections of each of the five roots were cut into smaller pieces which were used to prepare a 100 g composite sample. The composite sample was weighed to determine fresh mass and then dried to a constant mass in a forced-draught oven for 72 h at 70°C. The DM composition (DM %) was obtained by expressing DM as a percentage of fresh mass. The total dry mass root yield (DMY (t ha^{-1})) was obtained by multiplying the total fresh root mass (t ha^{-1}) by the DM %.

β-carotene content: estimated using the standard colour chart (Figure 2.1) adapted from CIP (Burgos *et al*., 2009) to score root flesh colour in the range from 0.00 to 14.37 mg 100 g^{-1}, where: 0 to 0.68 mg 100 g^{-1} are white and yellow; 0.69 to 1.76 mg 100 g^{-1} are light orange; 1.77 to 3.02 mg 100 g^{-1} are very light orange, 3.03 to 7.23 mg 100 g^{-1} are intermediate orange; and 7.24 to 14.37 mg 100 g^{-1} are deep orange.

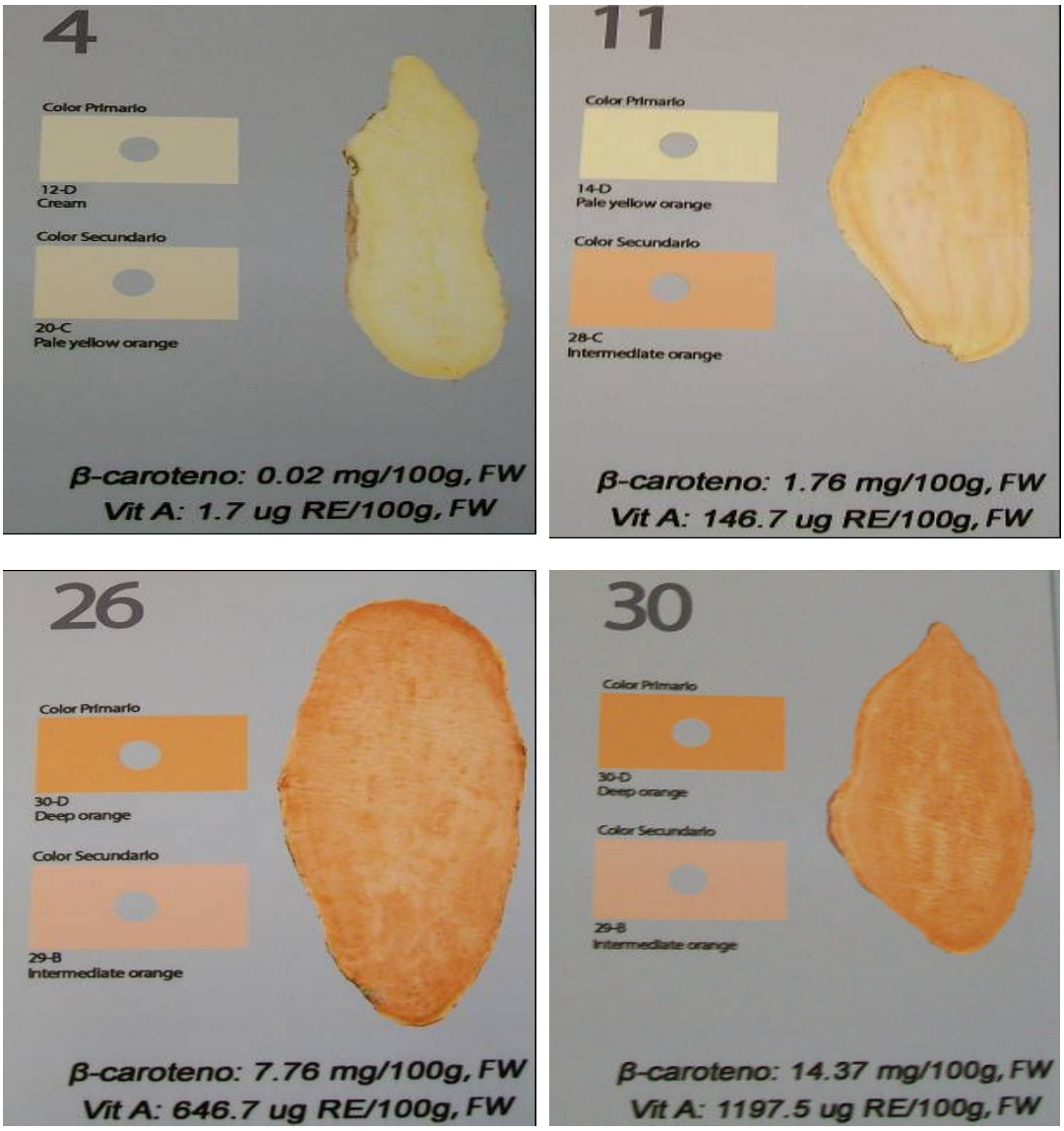

Figure 2.1: Examples from the Royal Horticultural Society (RHS) Colour Chart for estimating β-carotene content in sweetpotato

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2.3.5 Drought tolerance indices of genotypes evaluated under the moderate and severe stress irrigation levels

To identify drought tolerant genotypes the following traits were measured: yield potential of each genotype in a nonstress environment (Yp); yield of each genotype in a stress environment (Ys); mean yield of all genotypes in a nonstress environment ($\overline{Yp}$); mean yield

of all genotypes in a stress environment ($\overline{Ys}$); β-carotene carotene content (mg 100 g^{-1}) and DM % of each genotype. From these measured traits the following indices of drought tolerance were derived (Fernandez, 1992; Farshadfar & Sutka, 2003):

a) **Mean productivity:** MP = $\frac{Yp + Ys}{2}$. Selecting for high MP and low, positive tolerance index would favour genotypes with high yield potential under both nonstress and stress conditions thereby improving overall productivity or stability;

b) **Geometric mean productivity:** GMP = $\sqrt{Yp * Ys}$. The GMP is less sensitive to large, extreme values of Yp and Ys than MP;

c) **Tolerance index:** TOL = Yp - Ys; the larger the value of TOL the greater the sensitivity to stress, thus a smaller value of TOL is favoured. Selection based on a small TOL favours genotypes with similar yield potentials under nonstress and stress conditions. Normally the correlation between TOL and Yp is positive and between TOL and Ys is negative;

d) **Stress intensity:** SI = 1-$\frac{\overline{Ys}}{\overline{Yp}}$. Ranges between 0 and 1 and the larger the value of SI, the more severe is the stress.

***Note**: In this study, SI was used only to estimate SSI.*

e) **Stress susceptibility index**: SSI = (1-$\frac{Ys}{Yp}$) * $\frac{1}{SI}$. The smaller the SSI, the greater is the stress tolerance. Selection based on small SSI favours genotypes with relatively low Yp and

high Ys or genotypes where Ys approaches that of Yp. With SI as the denominator the magnitude of stress tolerance is expressed relative to the intensity of stress in the test environment;

f) **Stress tolerance index**: $STI = \frac{Yp * Ys}{(\overline{Yp})^2}$. Based on GMP, and the higher the stress tolerance or STI for a genotype, the higher its yield under stress conditions, Ys.

For the purposes of convenience, the traits Yp and Ys (for moderate and severe stress conditions) are considered to be drought tolerance indices and therefore reference is made to a total of seven drought tolerance indices (excluding SI) in Chapter 3, Results and Discussion.

2.4 Screening for drought tolerance in a greenhouse

2.4.1 Description of study area

The trial was conducted in a greenhouse located at the Umbeluzi Research Station. The greenhouse was maintained at an average temperature of 25ºC (range: 17-28ºC) by a combination of electric extraction fans at one end of the tunnel and a wet wall at the other end.

2.4.2 Experimental design

The 48 genotypes evaluated in the field trial were evaluated in the greenhouse trial in a two replicate, randomized complete block design (Appendix 1.2).

2.4.3 Establishment and maintenance of the greenhouse trial

Twenty wooden boxes, 150 cm long, 80 cm wide and 20 cm high were used as containers and comprised the experimental plots. The medium was a mixture of 1 clay: 3 sand. The mixture was sterilized as recommended (INIA, 1995). Fertilizer was applied uniformly to all plots at a rate of 10 g m^{-2} NPK (1:2:1) (MINAG, 1984). Apical-tip vine cuttings (taken from nursery plants), 30 cm in length and previously disinfected with pesticide (Cypermetrin: 25% EC) and fungicide (Mancozeb: 80% WP), were planted in two rows of five plants at inter- and intra-row spacing of 20 and 15 cm, respectively on 15th x September 2008. Each cutting (>5 nodes) was planted to a depth of ¾ its own length.

The boxes were watered for 10 DAP up to 100% field capacity; thereafter watering was completely stopped. A few days after water was withheld, water stress started to affect the sweetpotato genotypes in the containers up to the end of the experiment which was at 60 DAP.

2.4.4 Data collection

Vine length, vine diameter, leaf length and width were measured on four randomly sampled plants per plot at 25 and 50 DAP. The increment in each of these traits was determined as the difference between the measurements at 50 DAP and 25 DAP, expressed as a percentage of the measurement at 25 DAP. No root traits were measured because normal root development is inhibited in the wooden boxes in which the plants were grown.

Vine length increment: vine length of the original planted cutting was measured from the point of insertion at the root to the terminal end of the vine (i.e vine tip).

Vine diameter increment: the diameter of the middle section of a main vine was measured using a vernier caliper.

Leaf length and width increment: leaf length was measured from the insertion of the petiole at the leaf base to the tip of the leaf blade, and leaf width was measured across the broadest part of the leaf blade. Four leaves were randomly sampled from each of four randomly sampled plants per plot.

In addition, petiole and internode length, nodes vine^{-1} and vines plant^{-1} were measured at 30 DAP. The number of days that plants survived from planting was expressed as survival days.

Petiole length: obtained by measuring the length of the petiole from the point of its attachment to the vine to the point of its insertion with the leaf. Mean petiole lengths were measured from four randomly sampled leaves from each of four randomly sampled plants per plot.

Internode length: obtained by measuring the mean length of the internode between the nodes of the mid-section of four randomly sampled vines from each of four randomly sampled plants per plot.

Nodes vine^{-1} and vines plant^{-1}: obtained by counting the mean number of nodes per vine of four randomly sampled vines from each of four randomly sampled plants per plot, and the mean number of vines of four randomly sampled plants per plot.

Survival days: number of days after planting that each genotype survived.

2.5 Statistical analyses of field and greenhouse trial data

Statistical analyses of data from the field and greenhouse trials were conducted using PLABSTAT (Plant Breeding Statistical Program) and GENSTAT (8th Edition) statistical software packages. Comparisons of the means for statistically significant main or interaction effects were conducted using Least Significant Differences (LSD) based on the t-distribution at P = 0.05 for all traits.

The seven drought tolerance indices for each of the 48 genotypes grown under the moderate and severe stress irrigation levels in the field trial were subjected to correlation analyses in GENSTAT (8th Edition) to determine the degree of association among the drought stress tolerance indices and genotypes.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Environmental conditions

From June to December 2008 the mean temperature was 22.3°C and the mean minimum and maximum temperature were 15.8 and 28.2°C (Table 3.1). A total of 278.2 mm of rainfall occurred from June to December 2008. During the early stages of plant growth and development very little rainfall occurred with most of the rain falling in September and November (Table 3.1). High evapotranspiration occurred during the growing season with a resultant negative water balance. It was apparent from the rainfall data that the imposition of drought conditions in the field trial was virtually complete due to the low rainfall that occurred for most of the growing season (Table 3.1; Appendix 1.3).

Table 3.1: Environmental data recorded at Umbeluzi research station from June to December 2008

Parameter	June	July	Aug	Sept	Oct	Nov	Dec	Mean or Cumulative
Mean temp °C	19.6	20	21.6	22.9	24.2	25.7	26.4	22.9
Maximum temp °C	26	26.9	28.9	29.9	30.2	30.6	31	29.1
Minimum temp °C	13.4	12.4	14.4	15.6	18.4	20.9	21.8	16.7
Evapotranspiration (mm)	18	94.3	118	137.1	154.5	163.6	32.4	717.9
Monthly water: 30 DAP (mm)	34.9	120	0	13.3	0.5	128.7	0	297.4
Monthly water: 60 DAP (mm)	34.9	124	135	13	0.5	128.7	0	436.1
Water balance: 30 DAP (mm)	16.9	25.7	-118.0	-123.8	-154.0	-34.9	-32.4	-420.5
Water balance: 60 DAP (mm)	16.9	29.7	17.0	-124.1	-154.0	-34.9	-32.4	-281.8

Monthly water = rainfall + irrigated water for: moderate stress treatment, plants irrigated until 60 days after planting (DAP) and severe stress treatment, plants irrigated until 30 DAP; Evapotranspiration = crop evapotranspiration (E class-A pan x crop factor (0.6 from planting until 30 DAP; 0.95 from 30 DAP until harvest))

3.2 Screening for drought tolerance in the field

In the field screening of 48 sweetpotato genotypes for drought tolerance, a number of traits were examined in order to identify drought tolerant genotypes generating a large database. The analysis and interpretation of this database focused on the effects of water stress on: growth and development; root yield and yield components; post-harvest traits; and pests and diseases. The drought tolerance of the 48 genotypes was classified in terms of Yp, Ys and the five drought tolerance indices (excluding SI: see section 2.3.5).

3.2.1 Effect of water stress on growth and development

Analysis of variance was conducted on the traits: survival %**,** vine vigour and aboveground biomass to determine the variation in growth and development of the 48 genotypes in response to the three irrigation levels.

3.2.1.1 Effect of water stress on survival %

From ANOVA, the main effects for Genotypes and Irrigation levels were both highly significant ($P<0.01$) (Table 3.2; Appendix 2.1). The Genotypes x Irrigation levels interaction ($P=0.316$) was not significant meaning that for survival % the response patterns of the 48 Genotypes across Irrigation levels were similar, and *vice versa*.

Table 3.2: F-statistics of genotypes, irrigation levels and genotypes x irrigation levels interaction for three traits of 48 sweetpotato genotypes exposed to three irrigation levels

Treatment factor	Trait		
	Survival %	Vine vigour#	Aboveground biomass (t ha^{-1})
Genotype	2.88**	9.08***	11.29***
Irrigation levels	30.39**	31.01**	6.69 ns
Genotype x Irrigation levels	1.13 ns	1.07 ns	1.23 ns

- data was square-root transformed

* Significant at the 0.05 probability level

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

ns - Not significant

The overall mean survival % was 68.98 % (Table 3.3). Genotypes with a survival % >80% were mostly the national breeding lines (MUSG0623-9, MUSG0609-47, MUSG0616-18, MUSG0608-61 and MUSG0606-2) followed by the local landraces (Xiadlaxakau and Nhacutse4) and one introduced genotype (Lo323). Genotypes with a survival % <80% were seven introduced genotypes (K566632, Resisto, Zambezi, Ukerewe, Mayai, K118 and K135) and one local landrace (Cincominutos) (Table 3.3). Andrade (2007) reported that the national breeding lines and introduced genotypes perform well under both irrigated and non-irrigated conditions as confirmed by the fact that the survival % under non-irrigated conditions was more than 70% compared to the survival % of 83.5% under irrigated conditions.

The survival % for the nonstress Irrigation level of 83.5% was 19.5 and 32.1% greater than that for the moderate and severe stress Irrigation levels, respectively (Figure 3.1). Moderate stress had a higher survival % at 68%, than severe stress at 57%.

Table 3.3: Mean survival %, vine vigour and aboveground biomass of 48 sweetpotato genotypes across three irrigation levels

Genotypes	Survival %	Vine vigour[#]	Aboveground biomass (t ha^{-1})
1- Xitsekele	69.44	2.09	9.72
2- ADMARC	58.33	2.06	9.24
3- MGCl01	66.67	2.08	8.33
4- Xiadlaxakau	83.33	2.64	17.67
5- Manhissane	68.89	1.97	8.06
6- Canassumana	71.11	2.46	18.00
7- Tacna	69.44	2.32	15.43
8- NASPOT	77.78	2.56	18.56
9- Resisto	51.67	1.86	7.04
10- Jonathan	64.44	1.78	5.59
11- Carrot-C	66.67	1.94	7.76
12- K135	57.78	2.07	10.52
13- Gueri	78.89	2.67	20.98
14- Zambezi	56.11	1.86	5.42
15- Ukerewe	56.67	1.96	7.22
16- Mayai	59.44	1.76	6.15
17- K566632	50.56	1.81	6.00
18- K118	57.78	2.06	9.39
19- Ejumula	67.22	1.65	4.57
20- Pipi	72.78	2.40	14.39
21- 199062.1	77.22	2.23	10.09
22- MUSG0609-47	82.78	2.24	11.54
23- MUSG0616-18	81.67	2.36	13.48
24- CN 1448-49	75.56	1.57	4.59
25- MUSG0623-09	85.00	2.24	10.11
26- MUSG0610-45	71.67	2.26	12.02
27- Beauregard	61.11	1.63	4.56

Table 3.3: Mean survival %, vine vigour and aboveground biomass of 48 sweetpotato genotypes across three irrigation levels (Cont.)

Genotypes	Survival %	Vine vigour[#]	Aboveground biomass (t ha^{-1})
28- MUSG0614-24	64.44	1.83	6.30
29- MUSG0608-61	82.78	2.25	10.81
30- MUSG0606-02	82.22	2.69	25.56
31- Tainung64	63.33	1.99	7.22
32- MUSG0610-51	69.44	1.54	3.39
33- Chulamete	77.78	2.09	8.06
34- Jonathan-Nairobi	77.22	1.95	7.67
35- LO323	83.33	2.06	8.33
36- Resisto-Nairobi	60.56	1.81	5.20
37- MUSG0615-36	72.22	2.51	20.96
38- MUSG0608-33	66.11	2.25	10.17
39- MUSG0622-60	75.00	2.05	10.81
40- MUSG0614-22	60.56	1.92	7.43
41- Gabagaba	61.11	2.08	8.41
42- Ligodo	82.22	2.79	32.15
43- Cordner	61.67	1.78	6.02
44- Xihetamakote	73.33	2.67	25.61
45- Nhacutse4	80.56	2.08	8.19
46- Atacama	63.89	2.59	18.76
47- UNK-Malawi	62.22	2.18	10.46
48- Cincominutos	51.11	2.19	10.72
Mean	**68.98**	**2.49**	**10.97**
Min.	**50.56**	**1.54**	**3.39**
Max.	**85.00**	**2.78**	**32.15**
$LSD_{0.05}$	**15.95**	**0.21**	**5.18**
C.V. (%)	**25.49**	**14.21**	**47.26**

Nonstress, plants irrigated from planting; Moderate stress, plants irrigated until 60 DAP;
Severe stress, plants irrigated until 30 DAP
- data was square-root transformed
Vine vigour: 1 - 3 rating (transformed)

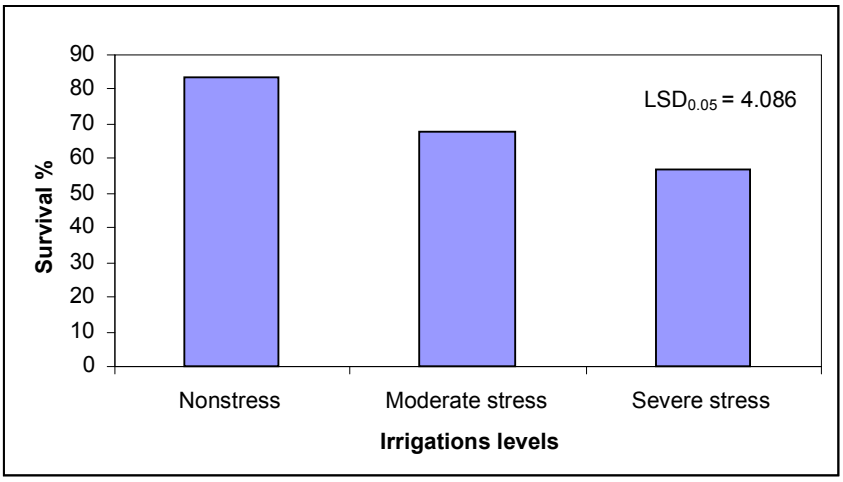

Figure 3.1: Mean survival % of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.

3.2.1.2 Effect of water stress on vine vigour

The main effects for Genotypes and Irrigation levels were both very highly ($P<0.001$) significant (Table 3.2; Appendix 2.2). The non-significant interaction between Genotypes and Irrigation levels ($P=0.3401$) indicated that the Genotypes had similar responses across Irrigation levels for vine vigour. However, Ghuman and Lal (1983) reported significant genotypes by irrigation levels interaction for vine vigour.

High (above average) vine vigour was recorded in local landraces (Ligodo (2.79), Xihetamakote (2.67) and Xiadlaxakau (2.64)), national breeding lines (MUSG0606-2 (2.69), NASPOT (2.56), MUSG0615-36 (2.51), MUSG0616-18 (2.36), MUSG0610-45 (2.26), MUSG0608-33 (2.25), MUSG0609-47 (2.24) and MUSG0623-9 (2.24)) and one introduced

genotype (Gueri (2.67)). On the other hand, low (below average) vine vigour was recorded in introduced genotypes (CN1448-49 (1.57), Beauregard (1.63), Ejumula (1.65), Mayai (1.76), Jonathan (1.78), Cordner (1.78), Resisto-Nairobi (1.81) and K56632 (1.81)) and one national breeding line (MUSG0610-51 (1.54)) (Table 3.3).

Greater vine vigour was recorded for the nonstress and moderate stress Irrigation levels than for the severe stress Irrigation level (Figure 3.2). Based on research reports it was anticipated that the moderately stressed plants would exhibit greater vine vigour than the severely stressed plants (Ekanayake *et al.*, 2004). Demagante *et al.* (1989) reported a significant interaction between water stress and genotypes for vine vigour based on a rating scale.

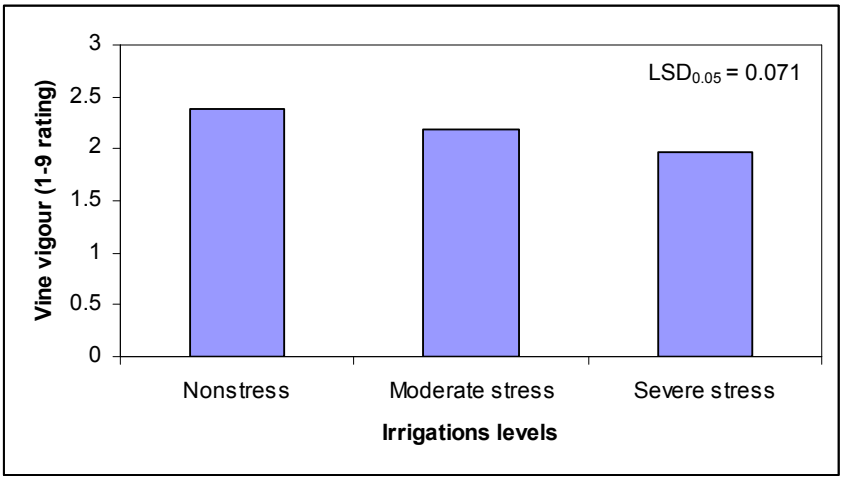

Figure 3.2: Mean vine vigour of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.

3.2.1.3 Effect of water stress on aboveground biomass

The aboveground biomass was obtained from the fresh mass of the leaves and vines. There were very highly significant ($P<0.001$) differences among Genotypes and Irrigation levels (Table 3.2; Appendix 2.3); however, Genotypes x Irrigation levels were not significant ($P=0.0551$). Gomes and Carr (2001) stated that the primary effect of irrigation was to increase canopy size. Qiwei *et al.* (1991) reported significant differences in aboveground biomass between genotypes, indicating that genotypes differed widely in their tolerance to water stress. Carey & Reynoso (1997) and Anselmo *et al*. (1991) reported significant genotypes x irrigation levels interaction for aboveground biomass. In contrast, Nair *et al*. (1996) reported no significant interaction between genotypes and water stress levels for aboveground biomass.

The genotypes differed in their production of aboveground biomass. The aboveground biomass ranged from 3.39 to 32.15 t ha^{-1} with a mean of 11.01 t ha^{-1} (Table 3.3). High (above average) aboveground biomass was produced in four local landraces (Ligodo (32.15 t ha^{-1}), Xihetamakote (25.61 t ha^{-1}), Canassumana (18.00 t ha^{-1}) and Xiadlaxakau (17.67 t ha^{-1})) followed by three national breeding lines (MUSG0606-2 (25.56 t ha^{-1}), MUSG0615-36 (20.96 t ha^{-1}) and MUSG0616-18 (13.48 t ha^{-1})) and five introduced genotypes (Gueri (20.98 t ha^{-1}), Atacama (18.76 t ha^{-1}), Naspot (18.56 t ha^{-1}), Tacna (15.43 t ha^{-1}) and Pipi (14.36 t ha^{-1})) and low (below average) was produced mainly by the introduced genotypes (Beauregard (4.56 t ha^{-1}), Ejumula (4.57 t ha^{-1}), CN1448-49 (4.59 t ha^{-1}), Resisto-Nairobi (5.20 t ha^{-1}), Zambezi (5.42 t ha^{-1}) and Jonathan (5.59 t ha^{-1})) and one national breeding line (MUSG0610-51 (3.39 t ha^{-1})).

The nonstress Irrigation level recorded higher aboveground biomass compared to the other two Irrigation levels with performance under moderate stress better than under severe stress (Figure 3.3).

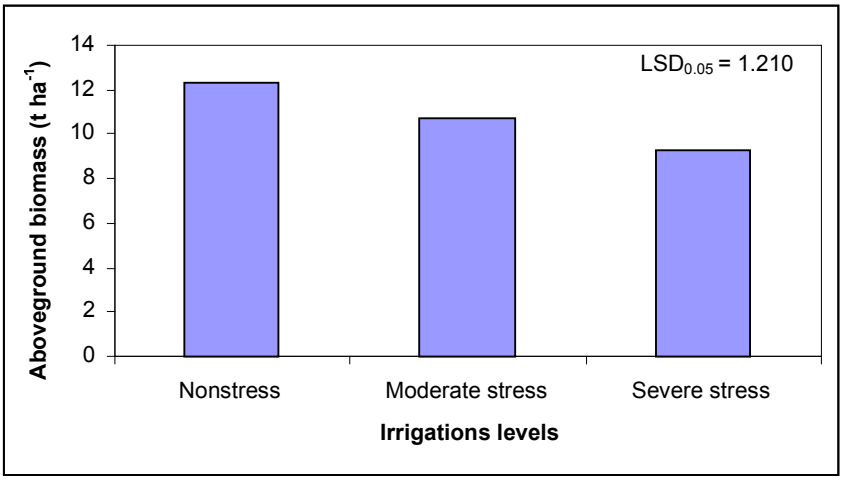

Figure 3.3: Mean aboveground biomass of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.

3.2.2 Effect of water stress on root yield and other yield traits

3.2.2.1 Effect of water stress on total root yield

Genotypes ($P<0.001$), Irrigation levels ($P<0.001$), and Genotypes x Irrigation levels interaction ($P<0.001$) were very highly significant for total root yield (Table 3.4; Appendix 2.4). Demagante *et al.* (1989) reported no significant interaction between genotypes and irrigation treatment for sweetpotato yield. Ekanayake *et al*. (1988), and Gomes and Carr (2001) reported that water stress reduced root yield of sweetpotato genotypes. At Umbeluzi Research Station, Andrade *et al.* (2007) found significant interactions between genotypes and

water stress levels for total root yield. Similar findings were reported by other workers, e.g. Ghuman & Lai (1983), Anselmo *et al.* (1991), Mcharo *et al.* (2001), Ekanayake & Collins (2004), and Saraswati *et al.* (2004). Riestra-Diaz (1984) found that yields for maize, peanut, soybean (*Glycine max* (L.) Merr) and sweetpotato genotypes decreased with increased water stress conditions.

Table 3.4: F-statistics of genotypes, irrigation levels and genotype x irrigation levels interaction for four traits of 48 sweetpotato genotypes exposed to three irrigation levels

Treatment factor	Total root yield (t ha^{-1})	Commercial yield (t ha^{-1})	Total fresh biomass (t ha^{-1})	Harvest index (%)
Genotype	12.04***	9.87***	8.98***	14.85***
Irrigation Levels	18.48***	12.21***	11.09***	32.26***
Genotype x Irrigation Levels	1.57***	1.31***	1.21 ns	1.07 ns

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
ns - Not significant

Total root yield of the 48 Genotypes was generally very low under all Irrigation levels, ranging from: 0.00 (K118) to 8.17 t ha^{-1} (MUSG0608-33) under severe stress; 0.14 (K118) to 13.56 t ha^{-1} (MUSG0608-33) under moderate stress; and 0.24 (K135) to 19.22 t ha^{-1} (MUSG0608-33) under nonstress conditions. It was also apparent that the national breeding lines (MUSG6008-33, MUSG0615-36, MUSG0623-29, MUSG0622-60, MUSG0609-47 and MUSG0616-18) and introduced genotypes (Tainung64, 199062.1, Lo323 and Gabagaba) had higher yields than the landrace genotypes (Xitsekele, ADMARC, MGCL01, Xiadlaxakau, Manhissane, Canassumana, Xihetamakote, Nhacutse4, UNK-Malawi and Cincominutos) (Table 3.5).

Table 3.5: Total and commercial root yields of 48 sweetpotato genotypes exposed to three irrigation levels

Genotypes	Total root yield (t ha^{-1})			Commercial root yield (t ha^{-1})		
	Severe stress	Moderate stress	Nonstress	Severe stress	Moderate stress	Nonstress
1- Xitsekele	0.06	0.72	1.06	0.00	0.50	0.28
2- ADMARC	1.17	2.00	3.17	1.06	1.89	1.89
3- MGCl01	0.33	1.28	2.56	0.11	1.03	2.22
4- Xiadlaxakau	0.78	3.39	5.94	0.39	2.56	4.44
5- Manhissane	1.72	2.06	4.23	1.61	1.56	2.78
6- Canassumana	3.94	2.61	5.11	3.44	2.33	4.33
7- Tacna	0.11	1.94	2.17	0.11	1.83	1.89
8- NASPOT	0.78	2.83	7.56	0.61	2.67	7.22
9- Resisto	0.33	1.94	3.11	0.22	1.50	2.78
10- Jonathan	0.11	1.78	3.00	0.11	1.43	1.67
11- Carrot-C	0.22	0.45	1.56	0.17	0.37	0.78
12- K135	0.06	0.17	0.24	0.00	0.17	0.22
13- Gueri	0.22	0.40	2.40	0.22	0.33	1.77
14- Zambezi	0.39	0.39	2.06	0.28	0.33	1.44
15- Ukerewe	0.22	4.06	7.28	0.00	3.56	6.56
16- Mayai	0.22	0.72	2.50	0.11	0.33	2.22
17- K566632	0.22	1.06	1.17	0.00	0.88	1.00
18- K118	0.00	0.14	0.33	0.00	0.00	0.28
19- Ejumula	0.50	1.16	2.11	0.28	0.78	1.78
20- Pipi	0.33	2.83	5.11	0.17	2.56	4.67
21- 199062.1	6.39	9.50	12.94	5.39	4.77	11.44
22- MUSG0609-47	4.28	9.11	14.89	3.89	7.22	12.89
23- MUSG0616-18	4.61	10.22	13.61	3.11	8.33	11.67
24- CN 1448-49	0.28	2.39	2.67	0.11	1.82	1.22
25- MUSG0623-09	4.50	10.44	16.89	4.28	9.24	14.44
26- MUSG0610-45	1.17	3.67	4.33	1.06	3.06	3.78
27- Beauregard	4.33	4.50	10.22	3.67	3.17	9.50

Table 3.5: Total and commercial root yields of 48 sweetpotato genotypes exposed to three irrigation levels (Cont.)

Genotypes	Total root yield (t ha^{-1})			Commercial root yield (t ha^{-1})		
	Severe stress	Moderate stress	Nonstress	Severe stress	Moderate stress	Nonstress
28- MUSG0614-24	0.89	3.11	3.67	0.33	2.67	3.28
29- MUSG0608-61	1.44	2.39	7.50	1.17	2.06	6.17
30- MUSG0606-02	0.72	5.00	10.94	0.56	3.83	9.72
31- Tainung64	6.33	7.67	17.28	6.11	6.81	16.11
32- MUSG0610-51	1.17	2.17	3.94	0.83	2.11	3.06
33- Chulamete	2.17	2.10	3.06	0.78	1.44	1.22
34- Jonathan-Nairobi	6.67	6.50	7.67	6.11	5.17	4.56
35- LO323	6.78	3.49	9.89	5.06	3.06	9.06
36- Resisto-Nairobi	1.06	3.28	6.94	0.72	2.11	5.44
37- MUSG0615-36	1.89	7.72	17.33	1.56	7.22	10.00
38- MUSG0608-33	8.17	13.56	19.22	7.83	13.11	18.28
39- MUSG0622-60	0.94	9.22	14.72	0.78	8.33	13.78
40- MUSG0614-22	3.61	4.78	9.67	3.17	4.00	7.44
41- Gabagaba	1.56	6.06	8.33	0.94	5.06	7.22
42- Ligodo	0.11	1.72	5.00	0.06	1.83	4.50
43- Cordner	2.06	4.10	11.44	1.67	3.26	9.78
44- Xihetamakote	0.11	0.65	0.94	0.00	0.10	0.78
45- Nhacutse4	1.67	1.39	2.18	1.39	1.21	1.76
46- Atacama	3.06	2.33	6.22	2.78	2.06	4.44
47- UNK-Malawi	0.11	0.44	1.78	0.06	0.28	1.50
48- Cincominutos	0.56	1.35	2.50	0.39	0.83	1.78
Mean	**1.84**	**3.56**	**6.43**	**1.51**	**2.93**	**5.31**
Min.	**0.00**	**0.14**	**0.24**	**0.00**	**0.00**	**0.22**
Max.	**8.17**	**13.56**	**19.22**	**7.83**	**13.11**	**18.28**
$LSD_{0.05}$	**4.33**	**4.02**	**5.99**	**3.50**	**3.89**	**5.89**
C.V. (%)	**62.53**	**76.01**	**75.76**	**57.45**	**69.61**	**66.34**

Commercial root yield: root with mass >100 grams or diameter >3 cm; Nonstress, plants irrigated from planting; Moderate stress, plants irrigated until 60 DAP; Severe stress, plants irrigated until 30 DAP

MUSG0608-33 (19.22, 13.56, 8.17 t ha^{-1}), MUSG0623-9 (16.89, 10.44, 4.50 t ha^{-1}), MUSG0609-47 (14.89, 9.11, 4.28 t ha^{-1}), MUSG0616-18 (13.61, 10.22, 4.61 t ha^{-1}) and 199062.1 (12.91, 9.50, 6.39 t ha^{-1}) recorded the highest yields under nonstress, moderate and severe stress Irrigation levels, respectively. Villamayor Jr (1987) reported that high yielding genotypes under nonstress conditions also produced high yields under stress conditions.

The yields of K118, Tainung64, Chulamete, Jonathan-Nairobi, Xihetamakote and Nhacutse4 were only slightly higher under nonstress conditions compared to moderate and severe stress conditions indicating a limited response to available water by these Genotypes (Table 3.5). Demagante *et al*. (1989) also found that root yield in some genotypes did not increase in response to increased irrigation. In contrast, NASPOT, Ukerewe, Canassumana, MUSG0606-2, MUSG0615-36, MUSG0622-60, Gabagaba and Cordner recorded higher yields with increasing Irrigation levels (Table 3.5).

MUSG0608-33 (8.17 t ha^{-1}), Lo323 (6.78 t ha^{-1}), Jonathan-Nairobi (6.67 t ha^{-1}), 199062.1 (6.39 t ha^{-1}), Tainung64 (6.33 t ha^{-1}), MUSG0616-18 (4.61 t ha^{-1}), MUSG0623-9 (4.50 t ha^{-1}), MUSG0609-47 (4.28 t ha^{-1}) and Atacama (3.06 t ha^{-1}) had their highest yield under severe stress. Conversely, under moderate stress, Lo323 (3.49 t ha^{-1}) and Jonathan-Nairobi (6.5 t ha^{-1}) recorded their lowest yield.

The nonstress Irrigation level had the highest mean yield (6.43 t ha^{-1}) followed by the moderate stress (3.56 t ha^{-1}) and severe stress (1.85 t ha^{-1}) Irrigation levels. Relative to the nonstress Irrigation level, total root yield was considerably reduced (69.2 %,) by water stress which occurred from early root initiation and development onwards i.e. severe stress Irrigation level, whereas water stress from mid-root development onwards i.e. moderate stress

Irrigation level only moderately reduced (34.4 %) root yield. Ekanayake *et al* (1988) reported a reduction of 70% in total yield of water stressed genotypes exposed at 4 weeks relative to nonstressed genotypes. Indira and Kabeerathuma (1998) reported a decrease in the storage root yield of genotypes due to water stress conditions during the root initiation stage i.e. at 30 DAP.

3.2.2.2 Effect of water stress on commercial root yield

Genotypes ($P<0.001$) and Irrigation levels ($P<0.001$) were very highly significant, and Genotypes x Irrigation levels interaction ($P=0.004$) was highly significant (Table 3.4; Appendix 2.5). The significant interaction indicated that, in terms of commercial yield, the response patterns of the Genotypes to the Irrigation levels were different. Nair *et al.* (1969) reported a significant reduction of commercial root yield as a consequence of severe water stress. Ekanayake *et al.* (1988) reported that the sweetpotato commercial root yield was affected by severe water stress. Riestra-Diaz (1984) reported that the interaction of genotypes with irrigation levels was significant for marketable root yield.

The commercial root yield under the nonstress Irrigation level ranged from 0.22 to 18.28 t ha^{-1} with a mean of 5.31 t ha^{-1} (Table 3.5). The highest commercial root yield under nonstress was recorded mainly by national breeding lines (MUSG0608-33 (18.28 t ha^{-1}), MUSG0623-9 (14.44 t ha^{-1}), MUSG0622-60 (13.78 t ha^{-1}), MUSG0609-47 (12.89 t ha^{-1}) and MUSG0616-18 (11.67 t ha^{-1})) and introduced genotypes (Tainung64 (16.11 t ha^{-1}) and 199062.1 (11.44 t ha^{-1})). Under severe stress the highest commercial root yield was recorded by national breeding lines (MUSG0608-33 (7.83 t ha^{-1}), MUSG0623-09 (4.28 t ha^{-1}) and MUSG0609-47 (3.89 t ha^{-1})) and introduced genotypes (Jonathan-Nairobi (6.11 t ha^{-1}),

Tainung64 (6.11 t ha^{-1}), 199062.1 (5.39 t ha^{-1}), Lo323 (5.06 t ha^{-1}), and Beauregard (3.6 t ha^{-1})). Five introduced genotypes (199062.1, Jonathan-Nairobi, Lo323, Beauregard and Atacama) and one local landrace (Canassumana) had higher commercial yield under severe stress compared to moderate stress, and under moderate stress two introduced genotypes (CN1448-49 and Jonathan-Nairobi) and two local landraces (Xitsekele and Chulamete) had higher commercial root yield than under nonstress conditions (Table 3.5).

Generally, the mean commercial root yield was highest under nonstress conditions followed by that under moderate stress and that under severe stress conditions (Table 3.5). The mean reduction in commercial root yield was 70.1% under severe stress, and 36.6% under moderate stress relative to nonstress conditions. Riestra-Diaz (1984) and Nair *et al*. (1996) reported that water stress induced during the root initiation phase resulted in significant reduction (53%) in the number of marketable grade roots thereby resulting in lower yield.

3.2.2.3 Effect of water stress on total fresh biomass

Genotypes ($P<0.001$) and Irrigations levels ($P<0.001$) were very highly significant (Table 3.4; Appendix 2.6) for total fresh biomass (TFB). There was no significant Genotypes x Irrigation levels ($P=0.132$) interaction in contrast to Nair *et al*. (1996) who reported a significant interaction between genotypes and irrigation level for total fresh biomass.

Table 3.6: Mean total fresh biomass and mean harvest index of 48 sweetpotato genotypes across three irrigation levels

Genotypes	Total fresh biomass (t ha^{-1})	Harvest index (%)
1- Xitsekele	10.47	5.97
2- ADMARC	11.56	13.33
3- MGCl01	10.04	12.80
4- Xiadlaxakau	21.04	14.63
5- Manhissane	10.81	19.03
6- Canassumana	21.81	17.98
7- Tacna	17.20	9.30
8- NASPOT	22.39	13.99
9- Resisto	8.98	18.90
10- Jonathan	7.61	20.53
11- Carrot-C	8.97	9.76
12- K135	10.93	3.76
13- Gueri	22.19	4.69
14- Zambezi	5.22	17.52
15- Ukerewe	11.12	28.43
16- Mayai	7.46	16.52
17- K566632	7.33	12.68
18- K118	9.46	4.19
19- Ejumula	5.85	20.97
20- Pipi	17.50	16.01
21- 199062.1	19.98	48.46
22- MUSG0609-47	20.81	39.91
23- MUSG0616-18	23.33	38.71
24- CN 1448-49	6.87	25.67
25- MUSG0623-09	20.17	42.19
26- MUSG0610-45	15.11	18.52
27- Beauregard	11.46	59.82

Table 3.6: Mean total fresh biomass and mean harvest index of 48 sweetpotato genotypes across three irrigation levels (Cont.)

Genotypes	Total fresh biomass (t ha^{-1})	Harvest index (%)
28- MUSG0614-24	8.37	31.34
29- MUSG0608-61	14.78	22.09
30- MUSG0606-02	31.11	14.70
31- Tainung64	18.33	58.47
32- MUSG0610-51	5.78	36.48
33- Chulamete	9.96	18.88
34- Jonathan-Nairobi	14.11	46.06
35- LO323	15.37	44.19
36- Resisto-Nairobi	9.20	40.57
37- MUSG0615-36	27.72	28.43
38- MUSG0608-33	23.96	53.21
39- MUSG0622-60	19.28	36.68
40- MUSG0614-22	13.33	38.41
41- Gabagaba	13.72	36.84
42- Ligodo	34.76	6.38
43- Cordner	12.09	42.33
44- Xihetamakote	26.19	1.92
45- Nhacutse4	9.61	16.21
46- Atacama	22.59	15.43
47- UNK-Malawi	11.30	5.76
48- Cincominutos	12.11	12.28
Mean	**14.99**	**24.21**
Min.	**5.22**	**1.92**
Max.	**34.76**	**59.82**
$LSD_{0.05}$	**6.57**	**11.20**
C.V. (%)	**46.80**	**46.13**

Nonstress, plants irrigated from planting; Moderate stress, plants irrigated until 60 DAP; Severe stress, plants irrigated until 30 DAP

In descending order of performance: local landraces (Ligodo (34.76 t ha^{-1}), Xihetamakote (26.19 t ha^{-1}), Xiadlaxakau (21.04 t ha^{-1})); national breeding lines (MUSG0606-2 (31.11 t ha^{-1}), MUSG0615-36 (27.72 t ha^{-1}), MUSG0808-33 (23.96 t ha^{-1}), MUSG0616-18 (23.33 t ha^{-1}), MUSG0609-47 (20.81 t ha^{-1}) and MUSG0623-9 (20.17 t ha^{-1})); and introduced genotypes (Atacama (22.59 t ha^{-1}), Naspot (22.39 t ha^{-1}), Gueri (22.19 t ha^{-1}) and 199062.1 (19.98 t ha^{-1})), had the highest (above average) mean TFB across Irrigation levels (Table 3.6).

In increasing order of performance, the lowest (below average) mean TFB was recorded by six introduced genotypes (Zambezi (5.22 t ha^{-1}), Ejumula (5.85 t ha^{-1}), CN1448-49 (6.87 t ha^{-1}), K566632 (7.33 t ha^{-1}), Mayai (7.46 t ha^{-1}), and Jonathan (7.61 t ha^{-1})); and one national breeding line (MUSG0610-51 (5.78 t ha^{-1})) (Table 3.6).

The TFB ranged from 5.22 to 34.76 t ha^{-1} across the three Irrigation levels, with a mean of 14.99 t ha^{-1}. The highest TFB was recorded under nonstress conditions (18.2 t ha^{-1}) followed by that under moderate stress (15.3 t ha^{-1}) and severe stress (11.2 t ha^{-1}) conditions (Figure 3.4). The TFB under the nonstress Irrigation level was 19.93 and 39.13 % greater than that under the moderate stress and the severe stress Irrigation levels, respectively.

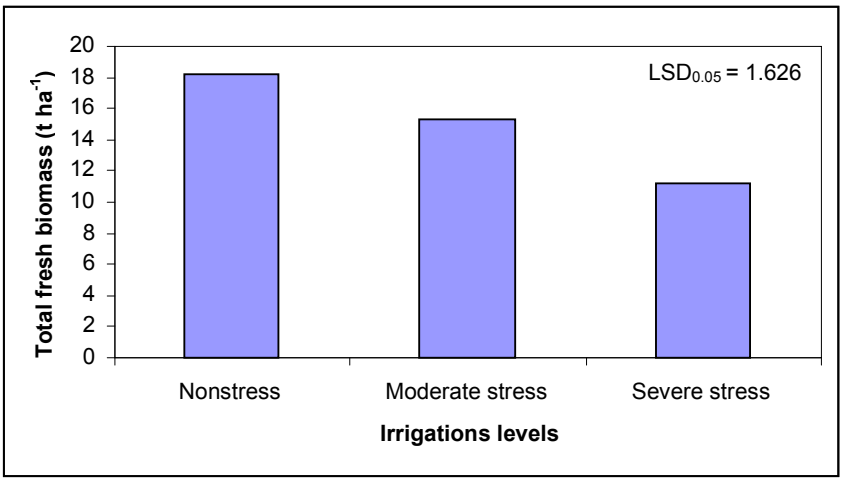

Figure 3.4: Mean total fresh biomass of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.

3.1.2.4 Effect of water stress on harvest index

Genotypes and Irrigations levels were very highly significant ($P<0.001$) while the non-significant Genotypes x Irrigation levels interaction ($P=0.095$) indicated that the response patterns of the 48 Genotypes across Irrigation levels were similar (Table 3.4; Appendix 2.7). In contrast, Villamayor Jr (1987) and Anselmo *et al.* (1991) reported a significant interaction between genotypes and irrigation levels for HI %.

The highest mean HI % (Table 3.6) was recorded in five introduced genotypes (Beauregard (59.82%), Tainung64 (58.47%), 199062.1 (48.46%), Jonathan-Nairobi (46.06%) and Lo332 (44.19%)) and one national breeding line (MUSG0608-33 (53.21%)). The lowest HI % was recorded in four local landraces (Xihetamakote (1.92%), UNK-Malawi (5.76%), Xitsekele (5.97%) and Ligodo (5.10%)), and two introduced genotypes (K135 (3.76%) and K135 (4.19%)).

The mean HI % decreased with decreasing levels of irrigation from 32.28% under nonstress conditions to 26.44% under moderate stress, and to 13.91% under severe stress (Figure 3.5).

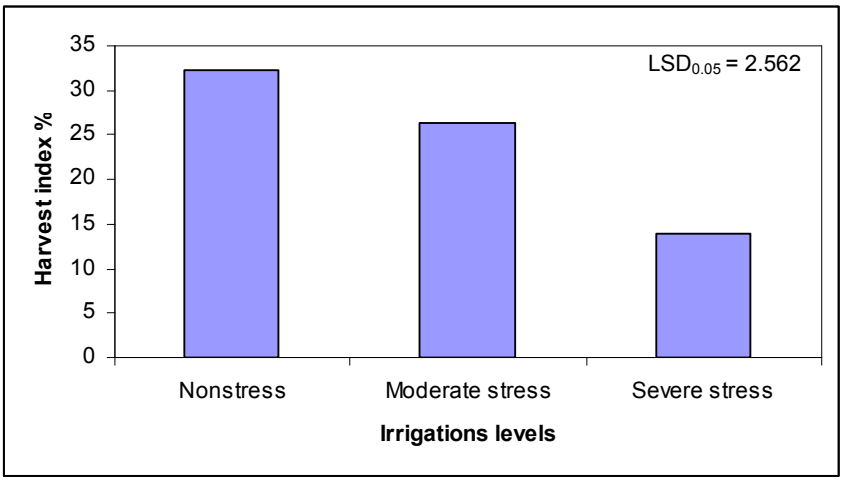

Figure 3.5: Mean harvest index of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.

3.2.3 Effect of water stress on post-harvest traits

3.2.31 Effect of water stress on β-carotene content

Genotypes ($P<0.001$) was very highly significant and Irrigation levels ($P=0.035$) was significant; however, the Genotypes x Irrigation levels interaction ($P=0.612$) was not significant (Table 3.7; Appendix 2.8).

Table 3.7: F-statistics of genotype, irrigation levels and genotype x irrigation levels interaction for β-carotene content of 48 sweetpotato genotypes exposed to three irrigation levels

Treatment factor	β-carotene (mg 100 g^{-1})	Dry mass composition (%)	Dry mass yield (t ha^{-1})
Genotypes	27.47***	2.06 ***	8.33***
Irrigation levels	10.75*	0.29 ***	20.59***
Genotype x Irrigation levels	0.92 ns	1.07 ns	1.24 ns

* Significant at the 0.05 probability level,
** Significant at the 0.01 probability level,
*** Significant at the 0.001 probability level,
ns - not significant

The β-carotene content for the 48 Genotypes meaned across Irrigation levels ranged from 0.00 to 10.41 mg 100 g^{-1} (Table 3.8). The highest (above the average) β-carotene content was recorded by MUSG0614-24, MUSG0602-02 and Resisto-Naroibi at 10.41 mg 100 g^{-1} followed by MUSG0608-33, MUSG0609-47, and MUSG0616-18 at 10.30 mg 100 g^{-1}, MUSG0614-22 at 10.17 mg 100 g^{-1}, MUSG0615-36 at 9.80 mg 100 g^{-1}, Resisto at 8.71 mg 100 g^{-1} and Carrot-C at 8.45 mg 100 g^{-1} (Table 3.8).

The lowest (below average) β-carotene content was recorded in**:** Tacna and Nhacutse4 at 0.0 mg 100 g^{-1}; Xitsekele, Ukerewe, K135, and Cincominutos at 0.01 mg 100 g^{-1}; UNK-Malawi, Manhissane, Canassumana at 0.02 mg 100 g^{-1}; Naspot at 0.12 mg 100 g^{-1}, ADMARC at 0.13 mg 100 g^{-1} and Xiadlaxakau at 0.16 mg 100 g^{-1} (Table 3.8).

Table 3.8: Mean β-carotene content, dry mass composition and dry mass yield of 48 sweetpotato genotypes across three irrigation levels

Genotypes	β-carotene (mg 100 g^{-1})	Dry mass composition (%)	Dry matter yield (t ha^{-1})
1- Xitsekele	0.01	33.04	0.24
2- ADMARC	0.13	31.27	0.56
3- MGCl01	5.15	34.13	0.54
4- Xiadlaxakau	0.16	30.48	1.04
5- Manhissane	0.02	31.61	0.75
6- Canassumana	0.02	32.40	1.26
7- Tacna	0.00	32.28	0.52
8- NASPOT	0.12	33.79	1.25
9- Resisto	8.71	30.76	0.58
10- Jonathan	4.54	5.65	0.48
11- Carrot-C	8.45	25.68	0.31
12- K135	0.01	31.85	0.12
13- Gueri	2.80	31.72	0.36
14- Zambezi	5.43	31.49	0.29
15- Ukerewe	0.01	35.75	1.42
16- Mayai	5.04	31.88	0.40
17- K566632	5.31	33.88	0.39
18- K118	1.86	29.04	0.02
19- Ejumula	4.81	32.63	0.42
20- Pipi	0.64	33.36	1.04
21- 199062.1	4.81	26.63	2.63
22- MUSG0609-47	10.17	22.26	2.12
23- MUSG0616-18	10.17	26.05	2.55
24- CN1448-49	3.97	22.99	0.54
25- MUSG0623-09	5.77	23.24	2.26
26- MUSG0610-45	7.12	26.66	0.85
27- Beauregard	7.84	21.99	1.54

Table 3.8: Mean β-carotene content, dry mass composition and dry mass yield of 48 sweetpotato genotypes across three irrigation levels (Cont.)

Genotypes	β-carotene (mg 100 g^{-1})	Dry mass composition (%)	Dry mass yield (t ha^{-1})
28- MUSG0614-24	10.41	24.52	0.69
29- MUSG0608-61	4.58	28.48	1.08
30- MUSG0606-02	10.41	24.32	1.40
31- Tainung64	6.49	25.34	2.90
32- MUSG0610-51	5.54	29.79	0.74
33- Chulamete	1.85	30.36	0.58
34- Jonathan-Nairobi	5.27	27.72	1.80
35- LO323	5.04	23.14	1.64
36- Resisto-Nairobi	10.41	26.92	1.03
37- MUSG0615-36	9.80	25.17	1.72
38- MUSG0608-33	10.30	22.62	3.15
39- MUSG0622-60	5.26	26.45	2.17
40- MUSG0614-22	10.17	24.39	1.49
41- Gabagaba	7.22	26.79	1.46
42- Ligodo	1.00	33.23	0.86
43- Cordner	6.11	23.29	1.41
44- Xihetamakote	1.77	30.10	0.17
45- Nhacutse4	0.00	32.02	0.33
46- Atacama	0.00	29.25	0.96
47- UNK-Malawi	0.02	32.62	0.26
48- Cincominutos	0.01	31.57	0.42
Mean	**4.47**	**29.37**	**1.06**
Min.	**0.00**	**21.99**	**0.02**
Max.	**10.41**	**35.75**	**3.15**
$LSD_{0.05}$	**1.97**	**11.72**	**0.76**
C.V. (%)	**46.11**	**7.28**	**75.33**

Nonstress, plants irrigated from planting; Moderate stress, plants irrigated until 60 DAP;
Severe stress, plants irrigated until 30 DAP

Not surprisingly, the national breeding genotypes which are mostly orange-fleshed, tended to have higher β-carotene content while the local genotypes which are mostly white- and yellow-fleshed, tended to have lower β-carotene content. Ssebuliba et al. (2001) reported that the β-carotene content of orange-fleshed genotypes was higher than that of yellow-fleshed genotypes which concurs with the results of this study.

Nonstressed plants had the highest β-carotene content (4.70 mg 100 g^{-1}) compared to moderate (4.10 mg 100 g^{-1}) and severe (4.51 mg 100 g^{-1}) stressed plants with the lowest mean β-carotene content recorded by the moderate stress Irrigation level (Figure 3.6).

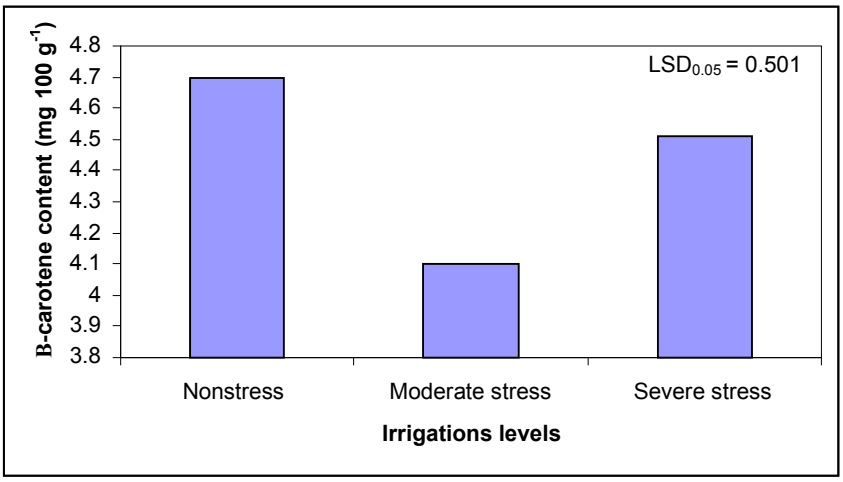

Figure 3.6: Mean β-carotene content of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.

3.2.3.2. Effect of water stress on dry mass composition

Genotypes and Irrigation levels ($P<0.001$) were very highly significant, while Genotypes x Irrigation levels interaction ($P=0.0637$) were not significant for DM % (Table 3.7; Appendix

2.9). In contrast, Ekanayake and Collins (2004) reported highly significant genotypes, irrigation levels, and genotypes x irrigation levels interaction for DM %. Ekanayake *et al*. (1988) observed that water stressed genotypes had relatively higher DM % than the nonstress genotypes. Similarly, Demagante *et al.* (1989) reported that the highest soil moisture levels reduced the DM %. In contrast, Indira & Kabeerathumma (1988) reported a reduction in DM % due to water stress. Bakayoko *et al.* (2009) reported that DM % was markedly influenced by environmental conditions, especially water stress immediately before root harvest which reduced DM %.

The mean DM % across Irrigation levels ranged from 21.99% (Beauregard) to 35.75% (Ukerewe) (Table 3.8). Ukerewe (37.75%), MGCL01 (34.13%), K566632 (33.88%), Naspot (33.79%), Pipi (33.36%) and Xitsekele (33.04%) had above average mean DM % while below average DM % was recorded in Beauregard (21.99%), MUSG0609-47 (22.26%), CN1448-49 (22.99%), Lo323 (23.14%), MUSG0623-9 (23.24%), Cordner (23.29%) and; (Table 3.8).

The local landraces (MGCL01, Ligodo, Xitsekele, UNK-Malawi, Canassumana, Nhacutse4, Manhissane, Cincominutos, ADMARC, Xiadlaxakau, Chulamente and Xihetamakote) had relatively high (above average) DM % compared to the relatively low (below average) DM % of the national improved genotypes (MUSG0609-47, MUSG0608-33, MUSG0623-9, MUSG0606-02, MUSG0614-24, MUSG0615-36, MUSG06016-18, MUSG0622-60, MUSG0610-45 and MUSG0608-61). Andrade *et al.* (2007) also reported high DM % for the local landraces compared to the national breeding lines.

The mean DM % for each Irrigation level was 29.76% for nonstress, 28.76% for moderate stress and 29.58% for severe stress (Figure 3.7).

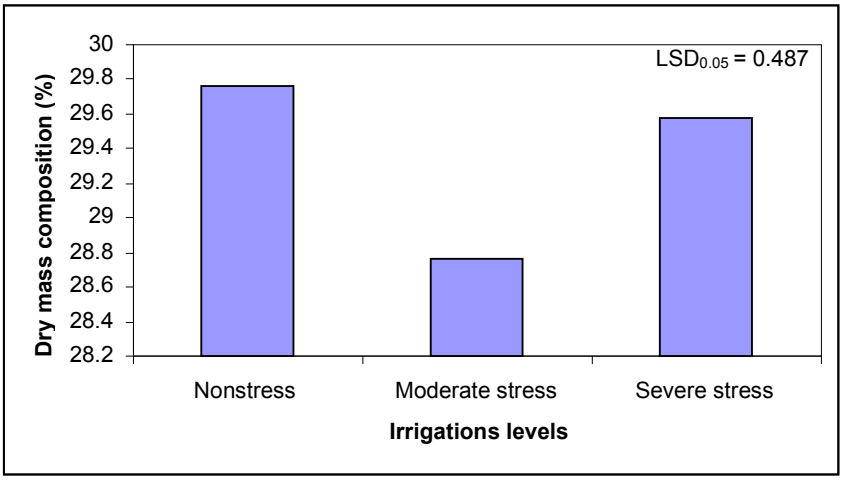

Figure 3.7: Mean dry mass composition of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.

3.2.3.3 Effect of water stress on dry mass yield

Genotypes ($P<0.001$) and Irrigation levels ($P<0.001$) were very highly significant while the Genotypes x Irrigation levels interaction ($P=0.072$) was not significant for DMY (Table 3.7; Appendix 2.10).

The mean DMY ranged from 0.02 to 3.15 t ha^{-1} with an overall mean of 1.06 t ha^{-1} (Table 3.8). Below average performance was recorded in three introduced genotypes (K118 (0.02 t ha^{-1}), K135 (0.12 t ha^{-1}), Zambezi (0.29 t ha^{-1})); two local landraces (Xitsekele (0.24 t ha^{-1}) and UNK-Malawi (0.26 t ha^{-1})); and above average performance in five national breeding lines (MUSG0608-33 (3.15 t ha^{-1}), MUSG0616-18 (2.55 t ha^{-1}), MUSG0623-9

(2.26 t ha^{-1}), MUSG0622-60 (2.17 t ha^{-1}) and MUSG0609-47 (2.12 t ha^{-1})); and two introduced genotypes (Tainung64 (2.90 t ha^{-1}) and 199062.1 (2.63 t ha^{-1})).

Mean DMY for the nonstress Irrigation level was higher (1.72 t ha^{-1}) than for the other two Irrigation levels, with moderate stress (1.15 t ha^{-1}) higher than severe stress (0.46 t ha^{-1}) (Figure 3.8).

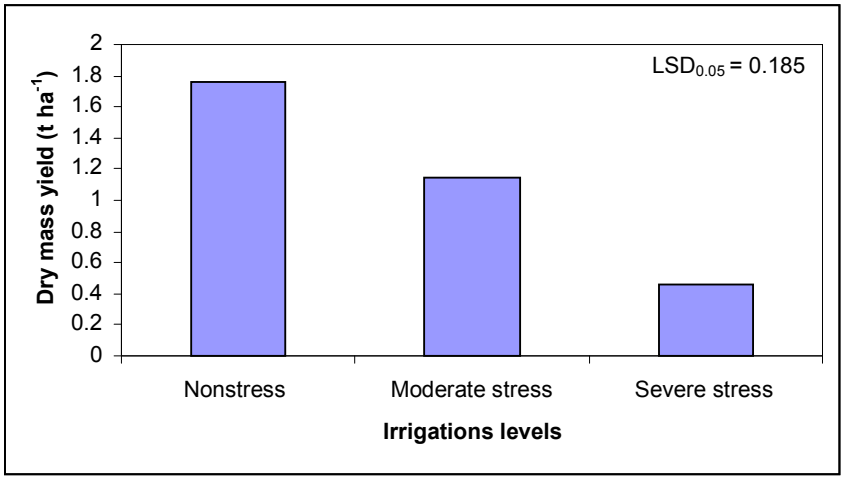

Figure 3.8: Mean dry mass yield of 48 sweetpotato genotypes exposed to three irrigation levels: nonstress, plants irrigated from planting; moderate stress, plants irrigated until 60 DAP; severe stress, plants irrigated until 30 DAP.

3.2.4 Effect of water stress on pests and diseases

During the field trial little presence and effect of pests and diseases were recorded. Of the various pests and diseases of sweetpotato, those that cause significant damage are sweetpotato weevil and SPVD. Plants were rated for incidence of SPVD and sweetpotato weevil damage.

3.2.4.1 Effect of water stress on incidence of sweetpotato virus disease

Genotypes were significant (P<0.001) while Irrigation levels were not significant (P=0.245); however, trend-wise the nonstress and severe stress Irrigation levels had higher incidence of SPVD compared to the moderate stress Irrigation level (Table 3.9; Appendix 2.11). The Genotypes x Irrigation levels interaction (P=0.827) was not significant which indicated that the Genotypes had similar trends for incidence of SPVD across Irrigation levels.

Table 3.9: F-statistics of genotype, irrigation levels and genotype x irrigation levels interaction for incidence of sweetpotato virus disease (SPVD) in 48 sweetpotato genotypes exposed to three irrigation levels

Treatment factor	SPVD incidence (1 to 3 rating)[#]
Genotypes	7.36***
Irrigation levels	2.41 ns
Genotypes x Irrigation levels	0.82 ns

- Data was square-root transformed
*** Significant at the 0.001 probability level.
ns - not significant

Mean scores for SPVD incidence varied from 1 to 5 out of a maximum of 9 and 1 to 2.24 out of a maximum of 3 (transformed data), implying that the Genotypes generally had low to moderate virus infection (Table 3.10).

No SPVD symptoms were observed in Xitsekele, Xiadlaxakau, Manhissane, MUSG0616-18, CN1448-49, MUSG0610-45, MUSG0608-61, Chulamete, Resisto-Nairobi, MUSG0608-33 and Cincominutos. Mayai, K566632, Ejumula, 199062.1, Jonathan-Nairobi and Atacama recorded higher SPVD incidence scores relative to the other Genotypes.

Table 3.10: Mean scores for incidence of sweetpotato virus disease (SPVD) in 48 sweetpotato genotypes across three irrigation levels

Genotypes	SPVD scores[#]	Genotypes	SPVD scores[#]
1- Xitsekele	1.00	25- MUSG0623-09	1.32
2- ADMARC	1.57	26- MUSG0610-45	1.00
3- MGCl01	1.08	27- Beauregard	1.24
4- Xiadlaxakau	1.00	28- MUSG0614-24	1.59
5- Manhissane	1.00	29- MUSG0608-61	1.00
6- Canassumana	1.09	30- MUSG0606-02	1.09
7- Tacna	1.30	31- Tainung64	1.65
8- NASPOT	1.42	32- MUSG0610-51	1.93
9- Resisto	1.32	33- Chulamete	1.00
10- Jonathan	1.00	34- Jonathan-Nairobi	2.02
11- Carrot-C	1.84	35- LO323	1.08
12- K135	1.50	36- Resisto-Nairobi	1.00
13- Gueri	1.09	37- MUSG0615-36	1.33
14- Zambezi	1.46	38- MUSG0608-33	1.00
15- Ukerewe	1.68	39- MUSG0622-60	1.44
16- Mayai	2.01	40- MUSG0614-22	1.16
17- K566632	2.23	41- Gabagaba	1.68
18- K118	1.65	42- Ligodo	1.32
19- Ejumula	1.99	43- Cordner	1.90
20- Pipi	1.49	44- Xihetamakote	1.32
21- 199062.1	2.12	45- Nhacutse4	1.16
22- MUSG0609-47	1.09	46- Atacama	2.09
23- MUSG0616-18	1.00	47- UNK-Malawi	1.24
24- CN1448-49	1.00	48- Cincominutos	1.00
Mean	**1.39**	**C.V. (%)**	**19.09**
Min.	**1.00**	**SED**	**0.07**
Max.	**2.23**	**$LSD_{0.05}$**	**0.38**

SPVD incidence: 1-3 rating (transformed) where 1 = no apparent symptoms, and 3 = very severe symptoms; Nonstress, plants irrigated from planting; Moderate stress, plants irrigated until 60 DAP; Severe stress, plants irrigated until 30 DAP;
- Data was square-root transformed

3.2.4.2 Effect of water stress on incidence of weevil damage

Genotypes (P=0.043) and Genotypes x Irrigation levels interaction (P=0.05) were significant while Irrigation levels (P<0.001) were highly significant (Table 3.11; Appendix 2.12). Mao *et al*. (2004) reported significant interaction between genotypes and irrigation levels which indicated that, in terms of incidence of weevil damage, the patterns of response of the genotypes to irrigation levels varied. Powell *et al*. (2001) reported that the interaction between water stress and genotypes was significant for incidence of weevil damage.

Table 3.11: F-statistics of genotype, irrigation levels and genotype x irrigation levels interaction for incidence of sweetpotato weevil damage in 48 sweetpotato genotypes exposed to three irrigation levels

Treatment factor	Incidence of weevil damage
Genotypes	1.37*
Irrigation levels	5.03***
Genotypes x irrigation levels	1.43*

Data was square-root transformed
* Significant at the 0.05 probability level.
*** Significant at the 0.001 probability level.

A high incidence of weevil damage under severe stress was recorded in eight local landraces (ADMARC, Manhissane, Chulamete, Resisto-Nairobi, Ligodo, Xihetamakote, UNK-Malawi and Cincominutos); nine introduced genotypes (NASPOT, Resisto, K135, Gueri, Zambezi, Ukerewe, K566632, K118 and Gabagaba); and three national breeding lines (MUSG0616-18, MUSG0610-45 and MUSG0614-22), all scoring a rating of 2 on a scale of 1 to 3, while under nonstress the same Genotypes had very low to no incidence of weevil damage (Table 3.12). One national breeding line (MUSG0623-09 (1.24, 1.27)); three introduced genotypes

(Beauregard (1.38, 1.00), K566632 (1.38, 1.41), Zambezi (1.38, 1.00)); and one local landrace (Manhissane (1.38, 1.34)), behaved contrarily by exhibiting reduced incidence under moderate stress relative to nonstress. Powell *et al*. (2001) reported that the individual characteristics of genotypes influenced the incidence of weevil damage.

The nonstress Irrigation level had very low incidence of weevil damage followed by moderate stress and severe stress with mean scores of 1.11, 1.54 and 1.91, respectively (Table 3.12). It is apparent that providing optimal irrigation under field conditions reduced the incidence of weevil damage. Mao *et al*. (2004) reported significantly increased levels of weevil damage on sweetpotato genotypes due to water stress.

Table 3.12: Mean scores for incidence of weevil damage[#] in 48 sweetpotato genotypes exposed to three irrigation levels

Genotypes	Severe stress	Moderate stress	Nonstress
1- Xitsekele	1.91	1.52	1.00
2- ADMARC	2.00	1.62	1.24
3- MGCl 01	1.73	1.62	1.00
4- Xiadlaxakau	1.91	1.49	1.00
5- Manhissane	2.00	1.38	1.34
6- Canassumana	1.91	1.62	1.75
7- Tacna	1.73	1.62	1.00
8- NASPOT	2.00	1.52	1.00
9- Resisto	2.00	1.62	1.38
10- Jonathan	1.73	1.52	1.27
11- Carrot-C	1.91	1.73	1.27
12- K135	2.00	1.73	1.00
13- Gueri	2.00	1.00	1.00
14- Zambezi	2.00	1.38	1.00
15- Ukerewe	2.00	1.73	1.14
16- Mayai	1.49	1.49	1.00
17- K566632	2.00	1.38	1.41
18- K118	2.00	1.73	1.00
19- Ejumula	1.91	1.52	1.00
20- Pipi	1.80	1.62	1.62
21- 199062.1	1.73	1.52	1.14
22- MUSG0609-47	1.71	1.62	1.14
23- MUSG0616-18	2.00	1.62	1.00
24- CN1448-49	1.82	1.41	1.00
25- MUSG0623-09	1.82	1.24	1.27
26- MUSG0610-45	2.00	1.52	1.00
27- Beauregard	1.82	1.38	1.00

Table 3.12: Mean scores for incidence of weevil damage[#] in 48 sweetpotato genotypes exposed to three irrigation levels (Cont.)

Genotypes	Severe stress	Moderate stress	Nonstress
28- MUSG0614-24	1.91	1.62	1.00
29- MUSG0608-61	1.91	1.52	1.14
30- MUSG0606-02	1.82	1.51	1.00
31- Tainung64	1.91	1.73	1.00
32- MUSG0610-51	1.91	1.52	1.38
33- Chulamete	2.00	1.70	1.14
34- Jonathan-Nairobi	1.82	1.62	1.00
35- LO323	1.91	1.52	1.14
36- Resisto- Nairobi	2.00	1.73	1.00
37- MUSG0615-36	1.91	1.51	1.00
38- MUSG0608-33	1.91	1.52	1.00
39- MUSG0622-60	1.91	1.52	1.00
40- MUSG0614-22	2.00	1.52	1.13
41- Gabagaba	2.00	1.27	1.41
42- Ligodo	2.00	1.73	1.14
43- Cordner	1.91	1.62	1.14
44- Xihetamakote	2.00	1.73	1.00
45- Nhacutse4	1.91	1.62	1.00
46- Atacama	1.82	1.52	1.00
47- UNK-Malawi	2.00	1.52	1.00
48- Cincominutos	2.00	1.57	1.00
Mean	**1.91**	**1.54**	**1.11**
Min.	**1.00**	**1.00**	**1.00**
Max.	**2.00**	**1.73**	**1.74**
$LSD_{0.05}$	**0.21**	**0.40**	**0.48**
C.V. (%)	**6.90**	**12.93**	**28.49**

Nonstress, plants irrigated from planting; Moderate stress, plants irrigated until 60 DAP;
Severe stress, plants irrigated until 30 DAP
- Data was square-root transformed

3.2.5 Drought tolerance indices

3.2.5.1 Analyses of variance and correlation for seven drought tolerance indices

The ANOVA (Tables 3.13 & 3.14) revealed highly significant differences among the Genotypes for Yp, Ys, MP, GMP, TOL and STI; indicative of genetic variation between Genotypes for these indices when subjected to moderate and severe water stress. These results concur with those reported by Ekanayake *et al.* (1988), Demagante *et al.* (1989), and Anselmo *et al*. (1991).

Table 3.13: Analyses of variance for mean values of seven drought tolerance indices of 48 sweetpotato genotypes evaluated under moderate stress

Source of Variation	Mean squares of drought tolerance indices						
	Yp	Ys	MP	GMP	TOL	SSI	STI
Replication	133.83	28.49	64.95	47.97	64.84	0.72	6.37
Genotypes	80.83**	30.92**	51.21**	46.84**	18.66**	0.13 ns	7.05**
Error	13.64	6.14	7.03	6.76	11.42	0.22	1.99

** Significant at the 0.01 probability level;
Ns - not significant.
Yp = Yield potential under nonstress;
Ys =Yield under stress environment;
TOL = Tolerance index; MP =Mean productivity;
GMP = Geometric mean productivity; SSI=Stress susceptibility index;
STI = Stress tolerance index
Derivation of indices in section 2.2.5 of Chapter 2
Moderate stress, plants irrigated until 60 DAP

Table 3.14: Analyses of variance for mean values of seven drought tolerance indices of 48 sweetpotato genotypes evaluated under severe stress

Source of Variation	Mean squares of drought tolerance indices						
	Yp	Ys	MP	GMP	TOL	SSI	STI
Replication	19.46	133.83	35.85	20.43	163.18	1.31	2.234
Genotypes	14.35**	80.83**	36.14**	25.65**	45.81**	0.28 ns	2.005**
Error	5.13	13.64	4.57	4.94	19.25	0.19	0.760

** Significant at the 0.01 probability level,
ns - not significant
Yp = Yield potential under nonstress;
Ys = Yield under stress environment;
TOL = Tolerance index;
MP = Mean productivity;
GMP = Geometric mean productivity;
SSI = Stress susceptibility index;
STI = Stress tolerance index
Derivation of indices in section 2.2.5 of Chapter 2
Severe stress, plants irrigated until 30 DAP

To determine the degree of association between the drought tolerance indices, the correlations between the indices averaged across the 48 genotypes were calculated (Table 3.15). Under moderate stress, Yp and Ys stress yield were positively (P=0.01) correlated with MP, GMP, TOL and STI. The same correlations were obtained under severe stress. Significant, negative correlations between Ys and SSI under both moderate (P=0.01) and severe (P=0.05) stress were obtained. Under moderate and severe stress, STI was positively (P=0.10) correlated with TOL. Farshadfar and Sutka (2003) also reported significant, positive correlations of Yp and Ys with MP, GMP and STI; thus the indices Yp and Ys could be considered as useful in screening for drought tolerant genotypes. Fernandez (1992), reported significant, positive correlations of Yp with MP, TOL, STI and SSI under moderate stress conditions, and under severe stress conditions a significant, negative correlation between Ys and SSI. Also in this study, only under severe stress was the correlation between STI and SSI negative and significant (P=0.01).

Table 3.15: Correlation coefficients between the mean values of seven drought tolerance indices of 48 sweetpotato genotypes evaluated under moderate and severe water stress

	Moderate stress					
	Yp	**Ys**	**MP**	**GMP**	**TOL**	**SSI**
Ys	0.925**	1				
MP	0.990**	0.969**	1			
GMP	0.973**	0.986**	0.995**	1		
TOL	0.888**	0.699**	0.831**	0.785**	1	
SSI	-0.222 ns	-0.292*	-0.265 ns	-0.268 ns	0.018 ns	1
STI	0.901**	0.954**	0.935**	0.950**	0.714**	-0.149 ns
	Severe stress					
	Yp	**Ys**	**MP**	**GMP**	**TOL**	**SSI**
Ys	0.719**	1				
MP	0.976**	0.848**	1			
GMP	0.855**	0.964**	0.942**	1		
TOL	0.901**	0.407**	0.804**	0.579**	1	
SSI	-0.234 ns	-0.679**	-0.394**	-0.570**	0.124 ns	1
STI	0.799**	0.918**	0.890**	0.957**	0.511**	0.521**

** significant at the 0.01 probability level,

* significant at the 0.01 probability level ,

ns - not significant

According to Fernandez (1992), STI is expected to distinguish Group A from Group B and Group C genotypes. Group A genotypes are defined as those with high STI and associated high yields under nonstress and stress conditions; Group B genotypes are those with intermediate STI and associated intermediate yields under nonstress and stress conditions; and Group C genotypes are those with low STI and associated low yields under nonstress and stress conditions.

Table 3.16: Seven drought stress tolerance indices of 48 sweetpotato genotypes exposed to the moderate stress irrigation level

Genotypes	Yp	Ys	MP	GMP	TOL	SSI	STI
1- Xitsekele	1.06	0.83	0.95	0.94	0.23	0.304	0.0213
2- ADMARC	3.17	2.00	2.59	2.52	1.17	0.517	0.1538
3- MGCl01	2.56	1.28	1.92	1.81	1.28	0.701	0.0795
4- Xiadlaxakau	5.94	3.39	4.67	4.49	2.55	0.602	0.4885
5- Manhissane	4.23	2.06	3.15	2.95	2.17	0.719	0.2114
6- Canassumana	5.11	2.61	3.86	3.65	2.50	0.686	0.3236
7- Tacna	2.17	1.94	2.06	2.05	0.23	0.149	0.1021
8- NASPOT	7.56	2.83	5.20	4.63	4.73	0.877	0.5190
9- Resisto	3.11	1.94	2.53	2.46	1.17	0.527	0.1464
10- Jonathan	3.00	1.78	2.39	2.31	1.22	0.570	0.1295
11- Carrot-C	1.56	0.45	1.01	0.84	1.11	0.997	0.0170
12- K135	0.24	0.17	0.21	0.20	0.07	0.409	0.0010
13- Gueri	2.40	0.40	1.40	0.98	2.00	1.168	0.0233
14- Zambezi	2.06	0.39	1.23	0.90	1.67	1.136	0.0195
15- Ukerewe	7.28	4.06	5.67	5.44	3.22	0.620	0.7170
16- Mayai	2.50	0.72	1.61	1.34	1.78	0.998	0.0437
17- K566632	1.17	1.06	1.12	1.11	0.11	0.132	0.0301
18- K118	0.33	0.14	0.24	0.21	0.19	0.807	0.0011
19- Ejumula	2.11	1.16	1.64	1.56	0.95	0.631	0.0594
20- Pipi	5.11	2.83	3.97	3.80	2.28	0.625	0.3508
21- 199062.1	12.94	9.50	11.22	11.09	3.44	0.373	2.9823
22- MUSG0609-47	14.89	9.11	12.00	11.65	5.78	0.544	3.2908
23- MUSG0616-18	13.61	10.22	11.92	11.79	3.39	0.349	3.3744
24- CN1448-49	2.67	2.39	2.53	2.53	0.28	0.147	0.1548
25- MUSG0623-09	16.89	10.44	13.67	13.28	6.45	0.535	4.2778
26- MUSG0610-45	4.33	3.67	4.00	3.99	0.66	0.214	0.3855
27- Beauregard	10.22	4.50	7.36	6.78	5.72	0.785	1.1157

Table 3.16: Seven drought stress tolerance indices of 48 sweetpotato genotypes exposed to the moderate stress irrigation level (Cont.)

Genotypes	Yp	Ys	MP	GMP	TOL	SSI	STI
28- MUSG0614-24	3.67	3.11	3.39	3.38	0.56	0.214	0.2769
29- MUSG0608-61	7.50	2.39	4.95	4.23	5.11	0.955	0.4349
30- MUSG0606-02	10.94	5.00	7.97	7.40	5.94	0.761	1.3270
31- Tainung64	17.28	7.67	12.48	11.51	9.61	0.780	3.2154
32- MUSG0610-51	3.94	2.17	3.06	2.92	1.77	0.630	0.2074
33- Chulamete	3.06	2.10	2.58	2.53	0.96	0.440	0.1559
34- Jonathan-Nairobi	7.67	6.50	7.09	7.06	1.17	0.214	1.2095
35- LO323	9.89	3.49	6.69	5.88	6.40	0.907	0.8374
36- Resisto-Nairobi	6.94	3.28	5.11	4.77	3.66	0.739	0.5522
37- MUSG0615-36	17.33	7.72	12.53	11.57	9.61	0.777	3.2457
38- MUSG0608-33	19.22	13.56	16.39	16.14	5.66	0.413	6.3227
39- MUSG0622-60	14.72	9.22	11.97	11.65	5.50	0.524	3.2925
40- MUSG0614-22	9.67	4.78	7.23	6.80	4.89	0.709	1.1214
41- Gabagaba	8.33	6.06	7.20	7.10	2.27	0.382	1.2246
42- Ligodo	5.00	1.72	3.36	2.93	3.28	0.920	0.2086
43- Cordner	11.44	4.10	7.77	6.85	7.34	0.899	1.1379
44- Xihetamakote	0.94	0.65	0.80	0.78	0.29	0.432	0.0148
45- Nhacutse4	2.18	1.39	1.79	1.74	0.79	0.508	0.0735
46- Atacama	6.22	2.33	4.28	3.81	3.89	0.877	0.3516
47- UNK-Malawi	1.78	0.44	1.11	0.88	1.34	1.055	0.0190
48- Cincominutos	2.50	1.35	1.93	1.84	1.15	0.645	0.0819
Mean	6.43	3.56	4.99	4.59	2.87	0.545	1.01
$LSD_{0.05}$	5.99	4.02	4.29	4.22	5.48	0.77	2.29

Yp = Yield potential under nonstress; Ys = Yield under stress environment; TOL = Tolerance index;
MP = Mean productivity; GMP = Geometric mean productivity; SSI = Stress susceptibility index;
STI = Stress tolerance index
Derivation of stress indices provided in section 2.2.5 of Chapter 2
Moderate stress, plants irrigated until 60 DAP

Under moderate stress, MUSG0608-33 (6.32), MUSG0623-09 (4.27), MUSG0622-60 (3.29), MUSG0616-18 (3.37), MUSG0609-47 (3.29), MUSG0615-36 (3.25), Tainung64 (3.22) and

199062.1 (2.98), had high STI (Table 3.16) and were therefore classified in Group A. These genotypes maintained their relatively high Yp achieved under nonstress conditions when exposed to moderate stress. According to Farshadfar and Sutka (2003) the higher the STI for a genotype, the higher its stress tolerance and yield potential. MUSG0606-2 (1.32), Gabagaba (1.22), Cordner (1.13), MUSG0614-22 (1.12), Jonathan-Nairobi (1.21) and Beauregard (1.12) had intermediate STI and were therefore classified in Group B. The rest of the Genotypes were assigned to Group C due to their low value of STI and poor Ys performance under moderate stress conditions (Table 3.16).

Under severe stress, MUSG0608-33 (3.81), Tainung64 (2.65), 199062.1 (2.01), MUSG0623-09 (1.84), LO323 (1.63), Jonathan-Nairobi (1.63), MUSG0609-47 (1.55) and MUSG0616-18 (1.52), had high STI and were therefore classified in Group A (Table 3.17). Beauregard (1.07), MUSG0614-22 (0.85), MUSG0615-36 (0.79), Canassumana (0.49) and Atacama (0.46), had intermediate STI and were assigned to Group B. The rest of the Genotypes were allocated to Group C due to their low (below average) STI and low Ys under severe stress conditions.

Table 3.17: Seven drought tolerance indices of 48 sweetpotato genotypes exposed to the severe stress irrigation level

Genotypes	Yp	Ys	Mp	GMP	TOL	SSI	STI
1- Xitsekele	1.06	0.06	0.56	0.25	1.00	1.322	0.0015
2- ADMARC	3.17	1.17	2.17	1.93	2.00	0.884	0.0900
3- MGCl01	2.56	0.33	1.45	0.92	2.23	1.221	0.0205
4- Xiadlaxakau	5.94	0.78	3.36	2.15	5.16	1.218	0.1124
5- Manhissane	4.23	1.72	2.98	2.70	2.51	0.832	0.1765
6- Canassumana	5.11	3.94	4.53	4.49	1.17	0.321	0.4884
7- Tacna	2.17	0.11	1.14	0.49	2.06	1.331	0.0058
8- NASPOT	7.56	0.78	4.17	2.43	6.78	1.257	0.1431
9- Resisto	3.11	0.33	1.72	1.01	2.78	1.253	0.0249
10- Jonathan	3.00	0.11	1.56	0.57	2.89	1.350	0.0080
11- Carrot-C	1.56	0.22	0.89	0.59	1.34	1.204	0.0083
12- K135	0.24	0.06	0.15	0.12	0.18	1.051	0.0003
13- Gueri	2.40	0.22	1.31	0.73	2.18	1.273	0.0128
14- Zambezi	2.06	0.39	1.23	0.90	1.67	1.136	0.0195
15- Ukerewe	7.28	0.22	3.75	1.27	7.06	1.359	0.0389
16- Mayai	2.50	0.22	1.36	0.74	2.28	1.278	0.0133
17- K566632	1.17	0.22	0.70	0.51	0.95	1.138	0.0062
18- K118	0.33	0.00	0.17	0.00	0.33	1.402	0.0000
19- Ejumula	2.11	0.50	1.31	1.03	1.61	1.070	0.0256
20- Pipi	5.11	0.33	2.72	1.30	4.78	1.311	0.0409
21- 199062.1	12.94	6.39	9.67	9.09	6.55	0.710	2.0060
22- MUSG0609-47	14.89	4.28	9.59	7.98	10.61	0.999	1.5461
23- MUSG0616-18	13.61	4.61	9.11	7.92	9.00	0.927	1.5221
24- CN1448-49	2.67	0.28	1.48	0.86	2.39	1.255	0.0181
25- MUSG0623-09	16.89	4.50	10.70	8.72	12.39	1.028	1.8439
26- MUSG0610-45	4.33	1.17	2.75	2.25	3.16	1.023	0.1229
27- Beauregard	10.22	4.33	7.28	6.65	5.89	0.808	1.0736
28- MUSG0614-24	3.67	0.89	2.28	1.81	2.78	1.062	0.0792

Table 3.17: Seven drought tolerance indices of 48 sweetpotato genotypes exposed to the severe stress irrigation level (Cont.)

Genotypes	Yp	Ys	Mp	GMP	TOL	SSI	STI
29- MUSG0608-61	7.50	1.44	4.47	3.29	6.06	1.133	0.2620
30- MUSG0606-02	10.94	0.72	5.83	2.81	10.22	1.309	0.1911
31- Tainung64	17.28	6.33	11.81	10.46	10.95	0.888	2.6536
32- MUSG0610-51	3.94	1.17	2.56	2.15	2.77	0.985	0.1118
33- Chulamete	3.06	2.17	2.62	2.58	0.89	0.408	0.1611
34- Jonathan-Nairobi	7.67	6.67	7.17	7.15	1.00	0.183	1.2411
35- LO323	9.89	6.78	8.34	8.19	3.11	0.441	1.6267
36- Resisto-Nairobi	6.94	1.06	4.00	2.71	5.88	1.188	0.1785
37- MUSG0615-36	17.33	1.89	9.61	5.72	15.44	1.249	0.7946
38- MUSG0608-33	19.22	8.17	13.70	12.53	11.05	0.806	3.8095
39- MUSG0622-60	14.72	0.94	7.83	3.72	13.78	1.312	0.3357
40- MUSG0614-22	9.67	3.61	6.64	5.91	6.06	0.878	0.8469
41- Gabagaba	8.33	1.56	4.95	3.60	6.77	1.139	0.3153
42- Ligodo	5.00	0.11	2.56	0.74	4.89	1.371	0.0133
43- Cordner	11.44	2.06	6.75	4.85	9.38	1.149	0.5717
44- Xihetamakote	0.94	0.11	0.53	0.32	0.83	1.238	0.0025
45- Nhacutse4	2.18	1.67	1.93	1.91	0.51	0.328	0.0883
46- Atacama	6.22	3.06	4.64	4.36	3.16	0.712	0.4617
47- UNK-Malawi	1.78	0.11	0.95	0.44	1.67	1.315	0.0048
48- Cincominutos	2.50	0.56	1.53	1.18	1.94	1.088	0.0340
Mean	6.43	1.84	4.13	2.79	4.59	0.99	0.48
$LSD_{0.05}$	5.98	3.67	3.46	3.60	7.11	0.72	1.41

Yp = Yield potential under nonstress; Ys = Yield under stress environment; TOL = Tolerance index; MP = Mean productivity; GMP = Geometric mean productivity; SSI = Stress susceptibility index; STI = Stress tolerance index

Derivation of stress indices provided in section 2.2.5 of Chapter 2

Severe stress, plants irrigated until 30 DAP

3.3 Screening sweetpotato genotypes in a greenhouse for drought tolerance

In order to identify drought tolerant genotypes in the greenhouse the following aboveground traits were evaluated: vine length increment; vine diameter increment (%); leaf width and length increment, petiole length, internode length, nodes vines^{-1}, vines plant^{-1} and survival days**.**

3.3.1 Vine length increment

From ANOVA, Genotypes was significant (P=0.0378), (Appendix 3.1). The increment in vine length of the Genotypes ranged from 0 to 42.75% with a mean of 12.23% during the duration of the trial under stress conditions. As expected, the response of the vine length increment to water stress varied among Genotypes, where some were less affected than others (Table 3.18). This is in agreement with the results of Saraswati *et al*. (2004) who reported a reduction in vine length due to decreased irrigation. On the other hand, Demagante *et al*. (1989) reported that vine length was insignificantly reduced with decreased irrigation.

Very little vine length increment occurred in MGCL01, Atacama, Cordner, Beauregard, CN1448-49, MUSG0616-18 and Manhissane. The highest vine length increment was recorded by six introduced genotypes (Jonathan (42.75%) followed by Naspot (33.19%), Resisto (29.66%), K566632 (29.41%), Tainung64 (24.46%), Ejumula (20.99%)); two national breeding lines (MUSG0614-24 (29.80%) and MUSG0623-09 (20.16%)); and one local landrace (UNK-Malawi (41.39%)) (Table 3.18). Anselmo *et al.* (1991) reported genotype differences in vine length increment in response to water stress.

Table 3.18: Mean vine length & diameter, leaf width & length increments of 48 sweetpotato genotypes exposed to water stress from 10 DAP

Genotype	Vine length increment (%)	Vine diameter increment (%)	Leaf length increment (%)	Leaf width increment (%)
1- Xitsekele	18.09	12.28	16.28	14.95
2- ADMARC	2.86	12.66	9.46	9.23
3- MGCl 01	0.00	13.82	40.26	35.45
4- Xiadlaxakau	1.15	2.5	14.96	32.09
5- Manhissane	0.72	-8.20	2.40	22.13
6- Canassumana	1.36	4.17	10.25	30.71
7- Tacna	14.47	-14.67	0.00	13.79
8- NASPOT	33.19	-6.35	12.15	4.55
9- Resisto	29.66	4.76	12.01	43.85
10- Jonathan	42.75	8.67	3.26	9.26
11- Carrot-C	14.75	9.60	34.39	17.21
12- K135	13.99	11.11	18.27	20.53
13- Gueri	5.50	6.67	8.40	1.62
14- Zambezi	7.37	3.69	10.36	12.87
15- Ukerewe	19.42	4.01	5.79	44.27
16- Mayai	17.21	2.78	10.43	13.33
17- K566632	29.41	0.00	4.84	9.19
18- K118	13.15	2.38	12.87	13.79
19- Ejumula	20.99	10.00	2.46	15.95
20- Pipi	13.37	4.55	9.61	2.00
21- 199062.1	19.17	19.64	2.73	17.12
22- MUSG0609-47	17.61	1.72	8.62	1.39
23- MUSG0616-18	0.52	-15.36	15.70	7.81
24- CN1448-49	0.49	6.67	3.33	20.00
25- MUSG0623-09	20.16	30.36	8.04	13.27
26- MUSG0610-45	5.36	17.03	30.67	11.19

Table 3.18: Mean vine diameter & length, leaf width & length increments of 48 sweetpotato genotypes exposed to water stress from 10 DAP (Cont.)

Genotype	Vine length increment (%)	Vine diameter increment (%)	Leaf length increment (%)	Leaf width increment (%)
27- Beauregard	0.33	3.13	6.97	14.10
28- MUSG0614-24	29.80	22.73	6.25	13.21
29- MUSG0608-61	12.73	12.89	5.77	4.55
30- MUSG0606-02	3.81	8.69	7.10	8.28
31- Tainung64	24.46	11.07	7.43	25.09
32- MUSG0610-51	9.95	-16.67	8.93	23.75
33- Chulamete	4.83	10.07	11.83	3.70
34- Jonathan-Nairobi	1.47	14.76	0.00	51.03
35- LO323	13.92	13.64	8.09	15.00
36- Resisto- Nairobi	1.12	14.21	11.70	0.00
37- MUSG0615-36	11.80	17.59	3.47	26.89
38- MUSG0608-33	8.21	9.02	6.03	15.71
39- MUSG0622-60	17.44	19.58	1.45	2.09
40- MUSG0614-22	9.92	-8.89	11.86	13.33
41- Gabagaba	12.17	16.67	2.39	26.04
42- Ligodo	9.44	4.51	22.59	37.27
43- Cordner	0.28	13.64	0.95	8.91
44- Xihetamakote	5.24	20.45	11.27	0.00
45- Nhacutse4	1.36	27.27	19.99	1.62
46- Atacama	0.27	0.48	2.40	24.31
47- UNK-Malawi	41.39	10.63	6.47	13.18
48- Cincominutos	15.12	7.48	5.32	12.06
Mean	**12.23**	**7.84**	**10.07**	**16.59**
Min.	**0.00**	**-16.67**	**0.00**	**0.00**
Max.	**42.75**	**30.36**	**40.26**	**51.03**
$LSD_{0.05}$	**25.62**	**23.58**	**27.04**	**31.85**
C.V. (%)	**23.07**	**71.13**	**55.49**	**48.03**

3.3.2 Vine diameter increment

Under water stress Genotypes was significant (P=0.0468) (Appendix 3.12). A wide range in vine diameter increment was recorded from -16.67 to 30.36% under water stress conditions (Table 3.18). The negative vine diameter increment recorded in response to water stress was also reported by Saraswati *et al*. (2004). Of the 48 Genotypes, 6 (12.5% of the total), namely: Manhissane, Tacna, Naspot, MUSG0616-18, MUSG0610-51 and MUSG0614-22, recorded a decrease in vine diameter, while 9 (18.75% of the total), namely: 199062.1, MUSG0623-9, MUSG0610-45, MUSG0614-24, MUSG0615-36, MUSG0622-60, Gabagaba, Xihetamakote and Nhacutse4 had a high vine diameter increment in response to water stress relative to the rest of the Genotypes (Table 3.18).

3.3.3 Leaf width and length increments

Under water stress Genotypes was not significant (P=0.3829) for leaf width increment (Appendix 3.3), while Genotypes was significant (P=0.049) for leaf length increment (Appendix 3.4): In this study, some genotypes had relatively low leaf width and/or length increments while others recorded relatively high increments (Table 3.19). Saraswati *et al*. (2004) reported that the reduction of leaf area and mass was strongly correlated with a reduction in leaf water potential under water stress environment.

Leaf length increment ranged from 0 to 40.16% with a mean of 10.07% (Table 3.19). No change in leaf length was observed in Tacna and Jonathan-Nairobi. It appears that the growth of the leaves of these two Genotypes was not affected by water stress. The lowest (below average) increments in leaf length were recorded in Cordner (0.95%), MUSG0622-60 (1.45%), Gabagaba (2.39 %), Atacama (2.40%), and Manhissane (2.40%), Ejumula (2.46%),

199062.1 (2.73%); the highest (above average) increments in MGCL01 (40.26%) followed by Carrot-C (34.39%), MUSG0610-45 (30.67%), Ligodo (22.50%), Nhacutse4 (19.99 %) and K135 (12.87%).

Leaf width increment ranged from 0 to 51.03% with a mean of 16.59%. No increment in leaf width was observed in Xihetamakote and Resisto-Nairobi (Table 3.18). The lowest (below average) leaf width increments were recorded by two national breeding lines (MUSG0609-47 (1.39%) and MUSG0622-60 (2.09%)); two local landraces (Nhacutse4 (1.62%) and Chulamete (3.70%)); and two introduced genotypes (Gueri (1.62%) and Pipi (2.00%)). The highest (above average) increments were recorded by four introduced genotypes (Jonathan-Nairobi (51.03%), Ukerewe (44.27%), Resisto (43.85%) and Tainung64 (25.09%)) and two local landraces (Ligodo (37.27%) and MGCL01 (34.45%)); and one national breeding line (MUSG0615-36 (26.89%)).

3.3.4: Petiole length, internode length, nodes vine^{-1}, vine plant^{-1} and survival days

From ANOVA, Genotypes were not significant for petiole length (P=0.414), internode length (P=0.522), vine plant^{-1} and survival days (P=0.564) (Appendixes 3.5; 3.6; 3.8 and 3.9), while Genotypes were significant (P=0.05) for nodes vine^{-1} (Appendix 3.7).

Petiole length at 30 DAP ranged from 2.00 to 6.05 cm with a mean of 3.91 cm. The longest (above average) petiole length was observed in Atacama (6.05 cm), K135 (5.95 cm), NASPOT (5.75 cm), Tacna (5.70 cm), MUSG0608-61 (5.45 cm) and Ukerewe (5.40 cm). The shortest (below average) petiole length was observed in Nhacutse4 (2.00 cm), Carrot-C (2.20 cm), 199062.1 (2.50 cm) and Ligodo (2.65 cm); (Table 3.19).

Table 3.19: Mean petiole & internode length, nodes vine^{-1}, vines plant^{-1} and survival days of 48 sweetpotato genotypes exposed to water stress from 10 DAP

Genotype	Petiole length (cm)	Internode length (cm)	Nodes vine^{-1}	Vines plant^{-1}	Survival days (DAP)
1- Xitsekele	3.50	3.00	7.55	1.90	44
2- ADMARC	3.65	2.95	5.20	1.65	55
3- MGCl01	3.85	2.25	14.35	2.00	60
4- Xiadlaxakau	2.90	3.05	10.35	1.5	60
5- Manhissane	3.25	2.15	5.85	1.60	28
6- Canassumana	4.90	2.55	14.50	1.50	55
7- Tacna	5.70	2.30	11.25	5.85	60
8- NASPOT	5.75	2.50	10.85	2.10	44
9- Resisto	3.20	2.55	10.55	1.00	50
10- Jonathan	4.55	2.60	7.20	2.50	55
11- Carrot-C	2.20	2.05	9.95	1.36	60
12- K135	5.95	2.45	12.65	1.75	44
13- Gueri	4.85	2.20	11.85	1.65	60
14- Zambezi	3.35	3.30	6.84	1.25	39
15- Ukerewe	5.40	2.40	11.20	2.65	60
16- Mayai	3.70	2.15	14.60	2.90	55
17- K566632	3.15	2.65	6.65	1.85	60
18- K118	4.40	2.25	13.95	1.55	60
19- Ejumula	4.15	2.25	14.50	2.16	39
20- Pipi	4.75	2.15	11.15	1.15	55
21- 199062.1	2.50	5.90	3.35	1.65	55
22- MUSG0609-47	4.00	1.75	10.35	1.85	60
23- MUSG0616-18	3.55	2.60	7.60	1.25	55
24- CN 1448-49	4.80	1.80	13.60	1.75	55
25- MUSG0623-09	4.75	2.15	10.85	1.10	55
26- MUSG0610-45	3.55	3.15	7.75	1.65	60
27- Beauregard	2.95	2.10	1.34	1.66	39

Table 3.19: Mean petiole & internode length, nodes vine^{-1}, vines plant^{-1} and survival days of 48 sweetpotato genotypes exposed to water stress from 10 DAP (Cont.)

Genotype	Petiole length (cm)	Internode length (cm)	Nodes vine^{-1}	Vines plant^{-1}	Survival days (DAP)
28- MUSG0614-24	4.45	2.30	9.50	1.5	60
29- MUSG0608-61	5.45	2.10	18.70	1.00	60
30- MUSG0606-02	3.50	2.40	8.25	1.60	60
31- Tainung64	3.95	3.55	11.00	1.00	60
32- MUSG0610-51	3.05	2.10	9.90	1.75	39
33- Chulamete	3.20	2.15	9.54	2.35	44
34- Jonathan-Nairobi	4.60	2.00	6.95	5.60	28
35- LO323	3.20	1.85	7.60	1.00	28
36- Resisto-Nairobi	3.55	3.30	6.75	1.00	55
37- MUSG0615-36	2.95	2.75	7.85	1.90	39
38- MUSG0608-33	3.90	2.50	6.35	1.30	60
39- MUSG0622-60	2.95	2.65	6.50	1.00	60
40- MUSG0614-22	4.05	2.90	8.04	1.85	44
41- Gabagaba	4.70	2.85	9.34	1.30	39
42- Ligodo	2.65	2.45	5.10	1.20	60
43- Cordner	4.75	2.35	15.85	1.20	28
44- Xihetamakote	3.00	2.20	12.50	1.16	50
45- Nhacutse4	2.00	1.55	12.10	1.30	60
46- Atacama	6.05	3.00	12.10	1.25	55
47- UNK-Malawi	3.45	2.10	14.35	1.55	60
48- Cincominutos	3.15	2.35	10.30	1.10	55
Mean	**3.91**	**2.51**	**10.19**	**1.75**	**51.38**
Min.	**2.00**	**1.55**	**1.34**	**1.00**	**28.00**
Max.	**6.05**	**5.90**	**18.70**	**5.85**	**60.00**
$LSD_{0.05}$	**1.874**	**1.776**	**7.843**	**2.596**	**8.39**
C.V. (%)	**27.94**	**36.46**	**30.83**	**50.45**	**23.93**

Internode length at 30 DAP ranged from 1.55 to 5.90 cm with a mean of 2.51 cm. Although the genotypes mostly had similar internode lengths, 199062.1 recorded the longest internode length (5.91 cm), followed by Tainung64 (3.55 cm), Resisto-Nairobi (3.30 cm), Zambezi (3.30 cm), MUSG0610-45 (3.15 cm), Xiadlaxakau (3.05 cm), Xitsekele (3.00 cm) and Atacama (3.00 cm); while Lo323 (1.85 cm), CN1448-49 (1.80 cm), MUSG0609-47 (1.75 cm) and Nhacutse (1.55 cm) had the shortest internode lengths (Table 3.19).

Number of nodes of the primary vines at 30 DAP varied from 1.34 to 18.7 nodes vine^{-1} with a mean of 10.19 nodes vine^{-1}. The lowest (below average) nodes vine^{-1} were recorded in Beauregard, (1.34) 199062.1 (3.35), ADMARC (5.20) and Manhissane (5.85) and the highest (above average) nodes vine^{-1} in MUSG0608-61 (18.70), Cordner (15.85), Mayai (14.60), Canassumana (14.50), Ejumula (14.50), UNK-Malawi (14.35), MGCl01 (14.35), K118 (13.60) and CN1448-49 (13.60); (Table 3.19).

The mean number of vines per plant at 30 DAP varied from 1 to 5.85 vines plant^{-1} with an overall mean of 1.75 vines plant^{-1}. The highest mean of vines plant^{-1} (Table 3.19) was recorded in Tacna (5.85) followed by Jonathan-Nairobi (5.60), Mayai (2.9), Ukerewe (2.65), Jonathan (2.50), Chulamete (2.35), Ejumula (2.16) and MGCL01 (2.0).

The survival days varied from 28 to 60 DAP. The genotypes that survived from the beginning up to the end of the experiment (60 DAP), namely: MGCL01, Xiadlaxakau, Tacna, Carrot-C, Gueri, Ukerewe, K566632, K118, MUSG0609-47, MUSG0610-45, MUSG0614-24, MUSG0608-61, MUSG0606-2, Tainung64, MUSG0608-33, MUSG0622-60, Ligodo and UNK-Malawi, were considered to be drought tolerant. In contrast, Cordner, Lo323, Joanthan-

Nairobi, and Manhissane survived from the beginning of the experiment until only 28 DAP and were considered to be susceptible to drought (Table 3.19).

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Introduction

The key objectives of this study were to identify sweetpotato genotypes tolerant to drought and to identify high yield, high storage root dry mass composition and high β-carotene content in local landrace genotypes and existing introductions in Mozambique. The hypotheses tested were that there are differences in the response of the selected group of sweetpotato genotypes to water stress, and local landrace genotypes are more tolerant than the locally improved and introduced genotypes. To this end, a field trial and a greenhouse trial were conducted to evaluate the response of 48 local, improved and introduced sweetpotato genotypes to imposed water stress.

4.1.1 Field trial

In the field trial, under the nonstress, moderate and severe stress Irrigation levels there were differences among the Genotypes in survival % with above 80% survival recorded in MUSG0623-9, MUSG0609-47, MUSG0616-18, MUSG0608-61 and MUSG0606-2 for the national breeding lines, Xiadlaxakau and Nhacutse4 for the local landraces and Lo323 for the introduced genotypes. The variation in survival % was indicative of the genetic variation in drought tolerance among the 48 genotypes. As expected, the survival % under the nonstress Irrigation level was 19.5 and 32.1% higher compared to the moderate stress and severe stress Irrigation levels, respectively. The survival % was not affected by an interaction between Genotype and Irrigation levels.

High vine vigour under nonstress, moderate and severe stress Irrigation levels were recorded in Xiadlaxakau, Ligodo, Xihetamakote, Gueri, MUSG0609-47, MUSG0608-33, MUSG0615-36, MUSG0606-2, MUSG0623-9, NASPOT, MUSG0616-18 and MUSG0610-45. Higher vine vigour was recorded for the nonstress and moderate stress Irrigation levels than for the severe stress Irrigation levels. Vine vigour was not affected by an interaction between Genotypes and Irrigation level. The imposition of water stress at 60 DAP (moderate stress Irrigation level) under field conditions demonstrated that once the genotypes had established full canopy, they could withstand periods of water stress.

Above average aboveground biomass was produced by Ligodo, MUSG0606-2, MUSG0615-36, Xiadlaxakau, Xihetamakote, Gueri, Canassumana, Atacama, Naspot, Tacna, Pipi and MUSG0616-18 under nonstress, moderate and severe stress Irrigation levels. The higher aboveground biomass recorded under the nonstress Irrigation level relative to that recorded under the stress Irrigation levels demonstrated the unexploited yield potential of the crop when it is grown without supplemental irrigation under the typically less favourable environmental conditions encountered by farmers in Mozambique. The Genotypes had similar patterns of response to Irrigation levels for aboveground biomass.

The effect of drought stress on sweetpotato total root yield depended on both the degree of stress and on the stage of growth at which the stress occurred. Genotypes differed significantly in their response to Irrigation levels for total root yield. The highest yields under nonstress and stress conditions were obtained by MUSG0608-33, MUSG0623-9, MUSG0609-47, MUSG0616-18 and 199062.1; these Genotypes could be used to increase yield under both irrigated and non-irrigated conditions. The highest yielding Genotypes under nonstress conditions were MUSG0615-36, Tainung64 and MUSG0622-60; these Genotypes

could be used to improve yield under nonstress or irrigated conditions. Under severe stress Lo323, Jonathan-Nairobi, and Atacama were the highest yielding genotypes; these genotypes could be used to improve yield under stress or non-irrigated conditions.

The total root yield decreased considerably with a reduction in irrigation. As expected, the nonstress Irrigation level had the highest total root yield followed by the moderate stress and severe stress Irrigation levels. Obviously, in a dry season irrigation has to be applied to obtain higher yield.

There were differences between the Genotypes in total fresh biomass recorded across Irrigation levels. The highest mean total fresh biomass were obtained by Ligodo, MUSG0606-2, MUSG0615-36, MUSG0808-33, Xihetamakote, Atacama, Xiadlaxakau, Naspot, Gueri, 199062.1, MUSG0609-47, MUSG0616-18 and MUSG0623-9 under nonstress, moderate and severe stress Irrigation levels. Increased water stress decreased the total fresh biomass with the highest total fresh biomass recorded under nonstress conditions followed by that under moderate stress and severe stress conditions. Total fresh biomass was unaffected by an interaction between Genotypes and Irrigation levels.

The harvest index increased with increased irrigation. The harvest index for sweetpotato is a very dynamic index which varies considerably from genotype to genotype and from environment to environment. Additionally, genotypes with high root yield may record either high or low harvest index depending on the production of total fresh biomass. Consequently, harvest index is not the best index on which to base selection of genotypes in a breeding programme. As expected, the highest harvest index was recorded under the nonstress Irrigation level followed by the moderate stress and severe stress Irrigation levels.

Genotypes differed in β-carotene content. The highest β-carotene content was recorded mostly by the national breeding lines, while the lowest β-carotene content was recorded by the local genotypes. The highest β-carotene content was recorded by MUSG0614-24, MUSG0602-02 and Resisto-Naroibi followed by MUSG0608-33, MUSG0609-47, MUSG0616-18 and MUSG0614-22, MUSG0615-36, Resisto and Carrot-C. However, the relatively low dry mass composition recorded for these orange-fleshed genotypes will have to be improved to ensure that they are consumed to a greater extent. The β-carotene content was unaffected by an interaction between Genotypes and Irrigation levels indicating that in terms of β-carotene content the Genotypes had similar response patterns across Irrigation levels.

Of the sweetpotato traits considered in this study, dry mass composition is arguably the most valued by farmers in Mozambique and consumers. The local landraces genotypes recorded higher dry mass composition compared to the national improved genotypes. The highest dry mass compositions were recorded in Ukerewe, MGCl01, K566632, Naspot, Pipi and Xitsekele; however, these genotypes tended to have low β-carotene content. The lowest dry mass compositions were recorded in Beauregard, MUSG0609-47, CN1448-49, MUSG0608-33, MUSG0623-9, Cordner and Lo323. Dry mass composition was not affected by an interaction between Genotypes and Irrigation levels.

Decreased irrigation increased the incidence of weevil damage. Very low incidence of weevil damage was recorded under the nonstress and moderate stress Irrigation levels. Clearly, for breeding purposes, screening for resistance or tolerance to weevils must be conducted under conditions equivalent to that under the severe stress irrigation level. The genotypes recorded different incidences of weevil damage in response to the three Irrigation levels. Under severe stress high incidence of weevil damage was recorded in ADMARC, Manhissane, NASPOT,

Resisto, K135, Gueri, Zambezi, Ukerewe, K566632, K118, MUSG0616-18, MUSG0610-45, Chulamete, Resisto-Nairobi, MUSG0614-22, Gabagaba, Ligodo, Xihetamakote, UNK-Malawi and Cincominutos. Under nonstress the same Genotypes had very low to no incidence of weevil damage.

The drought tolerant indices classified the genotypes into three groups based on the level of drought tolerance as quantified by the STI index:

1) Group A comprises genotypes with high STI and associated high yield potential under nonstress and stress conditions. This group is considered to be highly drought tolerant, namely: MUSG0608-33, MUSG0623-9, Tainung64, MUSG0616-18, MUSG0609-47, and 199062.1.

2) Group B comprises genotypes with intermediate STI and associated intermediate yield potential under nonstress and stress conditions. This group is considered to be moderately drought tolerant, namely: Beauregard, MUSG0614-22 and Jonathan-Nairobi.

3) Group C comprises genotypes with low STI and associated low yield potential under nonstress and stress conditions. This group is considered to be drought sensitive and the remainder of the genotypes were classified in this group. Generally the yield performances of these genotypes were low under nonstress and severe stress conditions.

Under moderate stress, Yp and Ys were highly significantly, positively correlated with MP, GMP, TOL and STI. Under severe stress the same correlations were obtained. Under moderate and severe stress, Ys and SSI were significantly, negatively correlated with one

another. Under moderate and severe stress, the correlations between STI and TOL were significant and positive.

4.1.2 Greenhouse trial

In the greenhouse trial, MGCL01, Atacama, Cordner, Beauregard, CN1448-49, MUSG0616-18 and Manhissane recorded vine length increments less than 10% and were classified as highly susceptible to drought. Underscoring this classification, Manhissane and MUSG0616-18 recorded a decrease in vine diameter. Naspot, MUSG0614-24, Resisto, K566632, Tainung64, Ejumula and MUSG0623-09 were classified as moderately drought tolerant with vine length increments ranging from 21 to 40%. MUSG0623-9, MUSG0614-24 were confirmed as moderately tolerant with a vine diameter increment between 18.75 and 40%. Drought tolerant genotypes with more than 40% vine length increment were Jonathan and UNK-Malawi.

The genotypes that survived up to the end of the greenhouse experiment at 60 DAP, namely: MGCL01, Xiadlaxakau, Tacna, Carrot-C, Gueri, Ukerewe, K566632, K118, MUSG0609-47, MUSG0610-45, MUSG0614-24, MUSG0608-61, MUSG0606-2, Tainung64, MUSG0608-33, MUSG0622-60, Ligodo and UNK-Malawi, were considered to be drought tolerant.

4.2 Recommendations

The following recommendations are suggested to improve the productivity of sweetpotato in the southern areas of Mozambique:

- Firstly, it is important for breeders to continue to improve the dry mass composition of orange fleshed sweetpotato genotypes because consumers in Mozambique (and many other countries) prefer moderate to high dry mass composition genotypes.

- Secondly, it is important that the selection for improved resistance to sweetpotato weevil is undertaken in different agro-ecological locations, which will obviously influence the incidence of weevil and the severity of the damage they cause.

- Thirdly, some of the genotypes that had promising performance under severe stress conditions in the field trial could be promoted among low-input farmers that are without the means to provide supplemental irrigation. In most of the production areas of Mozambique it should be possible to produce two crops of these genotypes in a year.

- Fourthly, based on the experience gained from the field trial it is recommended that in future studies of a similar nature, fewer genotypes be evaluated in order to accommodate the basic statistical requirements for implementing a split-plot design.

4.3 Further research directions

In order to increase the knowledge of the sweetpotato performance in different environments, the following research directions are identified:

- Extend the experimentation to different genotypes and more irrigation levels.

- Extend the study on the statistical and genetic relationship between dry mass composition and β-carotene content.

- Evaluate the effects of water stress on sweetpotato in mixed cropping systems. On-farm experimentation is important to properly evaluate performance under the intercropping conditions commonly implemented by farmers in Mozambique and elsewhere.

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Appendices

Appendix 1.1 Field layout of modified split plot design for the evaluation of 48 sweetpotato genotypes subjected to three irrigation levels under field conditions

Irrigation applied until harvest   Irrigation withheld from 60 DAP   Irrigation withheld from 30 DAP

REP 1

6	15	33	17
11	40	27	19
32	13	31	35
39	30	18	42
46	48	43	45
28	23	5	29
14	7	2	41
47	16	36	3
44	25	38	20
12	4	1	21
22	9	10	34
26	37	24	8

<6 m>

REP 1

6	15	33	17
11	40	27	19
32	13	31	35
39	30	18	42
46	48	43	45
28	23	5	29
14	7	2	41
47	16	36	3
44	25	38	20
12	4	1	21
22	9	10	34
26	37	24	8

6 m

<6 m>

REP 1

6	15	33	17
11	40	27	19
32	13	31	35
39	30	18	42
46	48	43	45
28	23	5	29
14	7	2	41
47	16	36	3
44	25	38	20
12	4	1	21
22	9	10	34
26	37	24	8

REP2

18	38	2	27
23	6	22	24
14	32	25	21
33	13	35	39
4	3	34	11
36	16	15	10
20	48	7	17
9	29	42	5
41	31	12	26
44	46	43	45
47	8	37	28
19	30	1	40

REP 2

18	38	2	27
23	6	22	24
14	32	25	21
33	13	35	39
4	3	34	11
36	16	15	10
20	48	7	17
9	29	42	5
41	31	12	26
44	46	43	45
47	8	37	28
19	30	1	40

REP 2

18	38	2	27
23	6	22	24
14	32	25	21
33	13	35	39
4	3	34	11
36	16	15	10
20	48	7	17
9	29	42	5
41	31	12	26
44	46	43	45
47	8	37	28
19	30	1	40

REP 3

11	48	45	6
31	19	40	41
32	43	27	37
30	1	34	25
33	44	38	18
35	12	14	4
42	8	22	26
10	7	20	24
39	21	2	17
3	13	23	28
16	15	29	47
46	36	9	5

REP 3

11	48	45	6
31	19	40	41
32	43	27	37
30	1	34	25
33	44	38	18
35	12	14	4
42	8	22	26
10	7	20	24
39	21	2	17
3	13	23	28
16	15	29	47
46	36	9	5

REP 3

11	48	45	6
31	19	40	41
32	43	27	37
30	1	34	25
33	44	38	18
35	12	14	4
42	8	22	26
10	7	20	24
39	21	2	17
3	13	23	28
16	15	29	47
46	36	9	5

Appendix 1.2 Layout of randomized complete block design for the evaluation of 48 sweetpotato genotypes in greenhouse

Rep 1

36	41	15	12	37	9	5	1	39	29	17	11	27	30	44	28	22	23	26	16	8	31	43	6
33	14	20	48	25	2	4	46	13	24	38	19	35	32	34	7	47	45	18	42	21	3	10	40

Rep 2

2	42	25	28	17	26	22	6	4	27	41	43	8	35	5	11	47	40	46	34	39	32	21	38
23	16	1	13	19	3	9	18	29	20	45	10	7	48	33	31	36	30	15	14	44	24	37	12

Appendix 1.3: Rainfall and evaporation based on class-A pan data for field trial

June			July			Aug			Sept			Oct			Nov			Dec		
Day	Rain	Evap	**Day**	Rain	Evap	**Day**	Rain	Evap	**Day**	Rain	Evap	**Day**	Rain	Evap	**Day**	Rain	Evap	**Day**	Rain	Evap
1			1	0.0	3.3	1	0.0	7.1	1	0.0	10.9	1	0.0	11.8	1	0.0	3.4	1	0.0	5.0
2			2	0.0	7.3	2	0.0	13.8	2	0.0	18.4	2	0.0	17.9	2	0.0	11.4	2	0.0	3.6
3			3	0.0	11.5	3	0.0	17.8	3	0.0	25.6	3	0.0	32.3	3	0.0	24.0	3	0.0	10.2
4			4	0.0	14.1	4	0.0	21.3	4	0.0	31.3	4	0.0	38.6	4	6.1	32.6	4	**H**	
5			5	0.0	22.4	5	0.0	25.1	5	0.0	37.4	5	0.0	45.0	5	6.1	35.8			
6			6	0.0	26.3	6	0.0	30.1	6	0.0	49.1	6	0.0	47.4	6	6.1	37.9			
7			7	0.0	30.6	7	0.0	34.8	7	0.0	55.4	7	0.0	47.5	7	6.1	42.0			
8			8	0.0	35.6	8	0.0	41.0	8	0.0	60.1	8	0.0	54.1	8	18.5	55.8			
9			9	0.0	42.6	9	0.0	45.6	9	0.0	67.9	9	0.0	61.2	9	22.5	57.5			
10			10	0.0	46.8	10	0.0	50.6	10	0.0	72.4	10	0.0	69.9	10	22.5	60.3			
11			11	0.0	52.1	11	0.0	55.9	11	0.0	80.6	11	0.0	77.3	11	22.5	67.0			
12			12	0.0	54.6	12	0.0	60.8	12	0.0	82.6	12	0.0	80.1	12	37.3	73.6			
13			13	0.0	58.6	13	0.0	65.7	13	0.0	83.6	13	0.0	89.7	13	42.4	79.8			
14			14	0.0	63.3	14	0.0	73.8	14	0.0	90.5	14	0.0	98.3	14	109.4	86.2			
15			15	0.0	66.8	15	0.0	78.7	15	0.0	98.9	15	0.0	101.8	15	112.1	91.4			
16			16	0.0	73.1	16	0.0	84.4	16	0.0	107.8	16	0.0	116.3	16	112.1	98.6			
17			17	0.0	77.9	17	0.0	90.7	17	0.0	115.8	17	0.0	122.3	17	112.1	101.2			
18			18	0.0	81.8	18	0.0	94.1	18	0.0	120.3	18	0.5	125.9	18	122.9	101.3			
19			19	0.0	82.9	19	0.0	95.7	19	0.0	130.1	19	0.5	131.4	19	128.7	105.2			
20			20	0.0	87.3	20	0.0	101.8	20	0.0	136.3	20	0.5	136.7	20	128.7	106.5			
21			21	0.0	90.8	21	0.0	107.2	21	7.0	139.2	21	0.5	144.6	21	128.7	113.5			
22			22	0.0	93.6	22	0.0	111.7	22	7.0	146.4	22	0.5	151.2	22	128.7	116.6			
23			23	0.0	96.7	23	0.0	117.0	23	7.0	152.6	23	0.5	153.7	23	128.7	125.0			
24			24	0.0	100.0	24	0.0	123.3	24	7.0	164.4	24	0.5	157.0	24	128.7	131.1			
25			25	0.0	101.0	**60DAP**	0.0	128.9	25	7.0	173.3	25	0.5	166.7	25	128.7	137.9			
P- 26	4.9	4.3	**30DAP**	0.0	103.9	26	0.0	137.8	26	7.0	175.6	26	0.5	168.3	26	128.7	144.8			
27	4.9	5.8	27	0.0	108.9	27	0.0	139.0	27	13.3	185.4	27	0.5	173.4	27	128.7	152.8			
28	4.9	9.6	28	0.0	112.5	28	0.0	142.4	28	13.3	187.7	28	0.5	182.9	28	128.7	161.1			

Appendix 1.3: Rainfall and evaporation based on class-A pan data for field trial (Cont)

June			July			Aug			Sept			Oct			Nov			Dec		
Day	Rain	Evap	Day	Rain	Evap	Day	Rain	Evap	Day	Rain	Evap	Day	Rain	Evap	Day	Rain	Evap	Day	Rain	Evap
29	4.9	11.4	29	0.0	116.6	29	0.0	156.0	29	13.3	189.4	29	0.5	188.7	29	128.7	167.2			
30	4.9	14.0	30	0.0	120.1	30	0.0	161.1	30	13.3	195.9	30	0.5	191.8	30	128.7	172.2			
31			31	0.0	125.7	31	0.0	168.6				31	0.5	200.6						
Total	4.9	14.0		0.0	125.7		0.0	168.6			195.9		0.5	2006.0		128.7	172.2		0.0	18.8

P = Date of planting; 30 DAP = Irrigation stopped at 30 DAP; 60 DAP = Irrigation stopped at 60 DAP; H = Date of harvest

Appendix 2: Analysis of variance (ANOVA) for field trial traits

Appendix 2.1*:* ANOVA for survival %

Source	DF	SS	MS	F	P
Rep	2	8038	4019.2		
Var	47	39930	849.6	2.91	0.0000
Error Rep*Var	94	27417	291.7		
Trt	2	52408	26203.9	84.78	0.0000
Var*Trt	94	31514	335.3	1.08	0.3163
Error Rep*Var*Trt	192	59344	309.1		
Total	431	218652			

CV(Rep*Var) 24.76, CV(Rep*Var*Trt) 25.49

Note: Var- Genotypes, Trt- Irrigation levels

Appendix 2.2*:* ANOVA for vine vigour

Source	DF	SS	MS	F	P
Rep	2	3.9949	1.9975		
Var	47	41.4298	0.8815	9.08	0.0000
Error Rep*Var	94	9.1271	0.0971		
Trt	2	5.6439	2.8219	31.01	0.000
Var*Trt	94	9.1728	0.0975	1.07	0.3401
Error Rep*Var*Trt	191	67.444	0.3531		
Total	430				

CV(Rep*Var) 17.06, CV(Rep*Var*Trt) 9.44

Appendix 2.3*:* ANOVA for aboveground biomass

Source	DF	SS	MS	F	P
Rep	2	1001.4	500.714		
Var	47	16363.2	348.152	8.55	0.0000
Error Rep*Var	94	3826.9	40.712		
Trt	2	675.3	337.671	12.47	0.0000
Var*Trt	94	3576.8	38.051	1.41	0.0551
Error Rep*Var*Trt	190	5144.0	27.074		
Total	429	30587.6			

CV(Rep*Var) 57.96, CV(Rep*Var*Trt) 47.26

Appendix 2.4: ANOVA for total root yield (t ha^{-1})

Source	DF	SS	MS	F	P
Rep	2	196.4	98.203		
Var	47	4697.4	99.946	8.74	0.0000
Error Rep*Var	94	1074.3	11.429		
Trt	2	1545.6	772.792	103.43	0.0000
Var*Trt	94	1229.3	13.077	1.75	0.0060
Error Rep*Var*Trt	192	1434.6	7.472		
Total	431	10177.6			

CV(Rep*Var) 85.76, CV(Rep*Var*Trt) 69.34

Appendix 2.5*:* ANOVA for commercial root yield (t ha^{-1})

Source	DF	SS	MS	F	P
Rep	2	141.17	70.583		
Var	47	3818.40	81.242	8.60	0.0000
Error Rep*Var	94	887.88	9.446		
Trt	2	1232.07	616.033	90.45	0.0000
Var*Trt	94	1013.21	10.779	1.58	0.0040
Error Rep*Var*Trt	192	1307.65	6.811		
Total	431	8400.37			

CV(Rep*Var) 92.62, CV(Rep*Var*Trt) 78.65

Appendix 2.6*:* ANOVA for total fresh biomass (t ha^{-1})

Source	DF	SS	MS	F	P
Rep	2	1904.6	952.29		
Var	47	20796.3	442.47	7.54	0.0000
Error Rep*Var	94	5518.7	58.71		
Trt	2	3658.6	1829.29	37.41	0.0000
Var*Trt	94	5578.8	59.35	1.21	0.1323
Error Rep*Var*Trt	190	9290.4	48.90		
Total	429	46747.4			

CV(Rep*Var) 51.28, CV(Rep*Var*Trt) 46.80

Appendix 2.7: ANOVA for harvest index %

Source	DF	SS	MS	F	P
Rep	2	740	369.82		
Var	47	104443	2222.20	17.51	0.0000
Error Rep*Var	94	11928	126.89		
Trt	2	19896	9947.79	83.26	0.0000
Var*Trt	94	14114	150.15	1.26	0.0948
Error Rep*Var*Trt	188	22461	119.47		
Total	427	173582			

CV(Rep*Var) 47.54, CV(Rep*Var*Trt) 46.13

Appendix 2.8*:* ANOVA for β-carotene content (mg 100 g^{-1})

Source	DF	SS	MS	F	P
Rep	2	5.06	2.530		
Var	47	5398.77	114.867	25.60	0.0000
Error Rep*Var	94	421.81	4.487		
Trt	2	30.23	15.113	3.40	0.0356
Var*Trt	94	395.93	4.212	0.95	0.6123
Error Rep*Var*Trt	182	809.89	4.450		
Total	421	7061.69			

CV(Rep*Var) 46.30, CV(Rep*Var*Trt) 46.11

Appendix 2.9*:* ANOVA for dry mass composition (%)

Source	DF	SS	MS	F	P
Rep	2	13.14	6.570		
Var	47	6275.89	133.530	31.09	0.0000
Error Rep*Var	94	403.69	4.295		
Trt	2	280.59	140.296	32.02	0.0000
Var*Trt	94	688.73	7.327	1.67	0.0598
Error Rep*Var*Trt	191	836.89	4.382		
Total	430	8498.93			

CV(Rep*Var) 7.20, CV(Rep*Var*Trt) 7.28

Appendix 2.10*:* ANOVA for dry mass yield (t ha^{-1})

Source	DF	SS	MS	F	P
Rep	2	13.096	6.5482		
Var	47	258.667	5.5036	6.90	0.0000
Error Rep*Var	94	75.004	0.7979		
Trt	2	100.341	50.1706	79.17	0.0000
Var*Trt	94	76.817	0.8172	1.29	0.0716
Error Rep*Var*Trt	191	121.031	0.6337		
Total	430	644.956			

CV(Rep*Var) 84.53, CV(Rep*Var*Trt) 75.33

Appendix 2.11*:* ANOVA for incidence of sweetpotato virus disease

Source	DF	SS	MS	F	P
Rep	2	0.1891	0.0945		
Var	47	57.879	1.2314	7.3.6	0.0000
Error Rep*Var	94	15.721	0.1672		
Trt	2	0.3381	0.1690	2.41	0.0921
Var*Trt	94	5.4194	0.0577	0.82	0.8540
Error Rep*Var*Trt	190	5.4194	0.0700		
Total	429	84.966			

CV (Rep*Var) 60.80, CV (Rep*Var*Trt) 39.49

Appendix 2.12: ANOVA for incidence of weevil damage

Source	DF	SS	MS	F	P
Rep	2	0.2524	0.1262		
Var	47	3.1023	0.0660	1.37	0.041
Error Rep*Var	94	4.5266	0.0482		
Trt	2	8.4663	4.2332	1.68	0.0000
Var*Trt	94	5.8402	0.0621	1.43	0.0197
Error Rep*Var*Trt	182	8.0193	0.0433		
Total	421	30.207			

CV(Rep*Var) 11.62, CV(Rep*Var*Trt) 11.89

Appendix 3: ANOVA for greenhouse trial traits

Appendix 3.1: ANOVA for vine length increment (%)

Source	DF	SS	MS	F	P
Rep	1	2.1356	2.1356		
Trt	47	93.2879	1.9848	2.16	0.0378
Error	47	6459.2	137.43		
Total	95	18207.8			

CV 23.07

Note: Trt- Genotypes

Appendix 3.2: ANOVA for vine diameter increment (%)

Source	DF	SS	MS	F	P
Rep	1	908.72	908.72		
Trt	47	5639.8	120.00	3.86	0.0468
Error	47	1459.2	31.05		
Total	95	8007.8			

CV 71.73

Appendix 3.3: ANOVA for leaf length increment (%)

Source	DF	SS	MS	F	P
Rep	1	322.6	322.593		
Trt	47	6297.3	133.985	1.09	0.3829
Error	47	2770.6	58.948		
Total	95	92390.5			

CV 55.49

Appendix 3.4: ANOVA for leaf width increment (%)

Source	DF	SS	MS	F	P
Rep	1	94.9	94.943		
Trt	47	9271.3	197.261	2.114	0.04809
Error	47	4387.3	93.346		
Total	95	13753.6			

CV 58.03

Appendix 3.5: ANOVA for petiole length (cm)

Source	DF	SS	MS	F	P
Rep	1	0.010	0.01042		
Trt	47	59.850	1.27340	1.07	0.4146
Error	47	56.180	1.19531		
Total	95	116.040			

CV 27.94

Appendix 3.6: ANOVA for internode length (cm)

Source	DF	SS	MS	F	P
Rep	1	2.6667	2.66667		
Trt	47	37.9550	0.80755	0.96	0.5522
Error	47	39.4433	0.83922		
Total	95	80.0650			

CV 36.46

Appendix 3.7: ANOVA for nodes vine^{-1}

Source	DF	SS	MS	F	P
Rep	1	111.16	111.155		
Trt	47	741.38	15.774	1.60	0.05
Error	47	463.99	9.872		
Total	95	1316.52			

CV 30.83

Appendix 3.8: ANOVA for vines plant^{-1}

Source	DF	SS	MS	F	P
Rep	1	1.815	1.81500		
Trt	47	72.910	1.55127	0.95	0.5643
Error	47	36.66	0.7845		
Total	95	111.40			

CV 50.45

Appendix 3.9: ANOVA for survival days

Source	DF	SS	MS	F	P
Rep	1	416.7	416.667		
Trt	47	6994.5	148.819	0.98	0.5210
Error	47	7103.3	151.135		
Total	95	14514.5			

CV 23.93