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Genotype × environment interaction and selection for drought adaptation in sweetpotato (*Ipomoea batatas* [L.] Lam.) in Mozambique

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Abstract Sweetpotato is grown throughout the year in Mozambique but drought affects storage root yield and biomass productivity. The objectives of this research were to estimate the impact of genotype × environment interactions (G × E) in sweetpotato and select genotypes based on drought indices such as geometric mean, percent yield reduction, drought sensitivity index and harvest index. A total of 58 clones were evaluated during the dry season of 2006, 2008 and 2009. Two treatments were applied for this multi-year trial: full irrigation and without irrigation at the middle of root initiation growth stage. The field layout was a randomized complete block design with three replications. 'Jonathan', 'Resisto' and 'Tanzania' were the check cultivars in each treatment. Storage root and vine yields were recorded at harvest in the trials. Harvest index was computed from the yield data. The analysis of variance, regression and the additive main effects multiplicative interaction (AMMI) analyses, plus phenotypic coefficient of variation and ecovalence were used for dissecting the G × E and assessing the stability of each clone. Treatment, genotype × treatment and genotype × year (G × Y) interactions had highest contributions to the variation in storage root yield observed among clones. The stability of harvest index was significantly correlated with the absolute AMMI's IPCA1 and IPCA2 values for storage root yield. Cultivar performance varied within treatments. Four clones had significantly higher storage root yield (t ha^{-1}) than 'Tanzania', the best check cultivar under drought. In conclusion, storage root yield (t ha^{-1}) was negatively affected by drought and G × Y interaction. Harvest index stability and the geometric mean may be key to identify clones with storage root yield stability and high storage root yield under both treatments. At least two environments should be used at early breeding stages to consider harvest index in the early breeding cycle.

Keywords Additive main effects multiplicative interaction · Biomass · Drought sensitivity index · Ecovalence · Regression · Stability · Storage root yield · Vine · Water deficit

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Abbreviations

AMMI	Additive main effects and multiplicative interaction
CIP	International Potato Center
G × E	Genotype × environment interaction
HI	Harvest index
IIAM	Instituto de Investigaçao Agrária de Moçambique
RDM	Root dry matter
TYLD	Total storage root yield

Introduction

Sweetpotato provides household food security and is an important source of energy due to its ability to grow throughout the year in some areas of the sub-Saharan Africa, where it ranks among the most widely grown root crops (Andrade et al. 2009). Mozambique grew about 122,000 ha of sweetpotato with a harvest of 890,000 t of storage roots (FAO 2015). The average storage root yield was 7.3 t ha^{-1} in 2013. Sweetpotato production doubled in Mozambique due to promotion and dissemination of orange-fleshed (OFSP) cultivars with the aim of alleviating vitamin A deficiency in the diets, and replacing maize in areas affected by frequent flood (MICOA 2005) and drought. There are two growing seasons in Mozambique: rainy, humid, hot summer (October–March) and dry, cool winter season (May–July) near perennial rivers. The summer cultivation of sweetpotato is affected by the rainfall, which is often uneven, particularly in southern Mozambique that is drier than the north of this country.

Although sweetpotato has been regarded elsewhere as a drought tolerant crop after the storage root formation and towards physiological maturity (Indira and Kabeerathumma 1988; Valenzuela et al. 2000), drought—as a result of uneven rainfall—may cause significant storage root yield loss in Mozambique (FAO 2004; MICOA 2005). There are some sweetpotato cultivars showing some adaptation to drought (Anselmo et al. 1998; Chávez et al. 2000; Ding et al. 1997; Hou et al. 1999; Maquia et al. 2013; Wang et al. 2003; Yang et al. 1999). Their adaptation depends on various mechanisms that are affected by the onset and intensity of drought. These mechanisms include drought escape due to early and rapid root development or early bulking and maturity (Yen et al. 1964; Bouwkamp 1985), drought avoidance resulting from deep rooting (Ekanayake 1990), relative water content and water use efficiency (Kelm 2000; Zhang et al. 2006), and drought tolerance relying on osmotic adjustment due to relative contents of free amino acids and soluble sugars (Zhang et al. 2003, 2004). The sweetpotato cultivar Tanzania is known for its development plasticity that remobilizes assimilates from the shoots to the storage roots under drought, while the cultivar Jonathan avoids drought due to its morphology such as small leaf size that reduces the transpiration surface. The size of the transpiring leaf and stem areas determine the amount of water loss by a plant (Monneveux and Belhassen 1996). Shoot biomass production and vine survival are necessary along with drought escape or avoidance in drought-prone areas. These two traits ensure the availability of sweetpotato planting material for the next growing season. For example, the cultivar Resisto vanished from farmers' fields after severe droughts due to few shoot biomass production and low vine survival despite its ability to escape drought in Mozambique.

The genotype × environment interaction (G × E) significantly affect sweetpotato growth and productivity, as noted when testing bred-germplasm or cultivars under managed drought across sites in Kenya (Kivuva et al. 2014), across locations in Mozambique (Henderson et al. 1997) and Rwanda (Jannsens 1983), varying eco-geography in Perú (Grüneberg et al. 2005), or across sites and over years in South Africa (Tekalign 2007). The G × E causes difficulty to selection of clones with wide adaptation, which may delay the cultivar release (Rukundo et al. 2013). The G × E can be sub-divided within the same location on genotype × growing season (G × S) and genotype × year (G × Y) interactions due to variations of plantings in the rainy summer or in a dry winter, or weather changes over years, respectively.

Knowledge on the G × E structure can assist sweetpotato cultivar development. For example, the adaptability and stability methods were used to select stable or high-yielding sweetpotato cultivars in The Philippines (Nasayao and Saladaga 1998). Likewise, the additive main effects and multiplicative interactions (AMMI) model—which considers additive effects for genotypes and environments and multiplicative terms for G × E– was very useful for analyzing the G × and stability of sweetpotato clones in multi-environment trials in Turkey (Caliskan et al. 2007). The AMMI model also provided means for identifying suitable leafy vegetable bred-germplasm in Malaysia (Thiyagu et al. 2013) that can be further used for a new cycle of crossing and selection.

The aim of this research was to determine G × E patterns—particularly G × S for storage root yield and dry matter content—establish the magnitude of G × E interaction in sweetpotato under irrigation and drought, and assess the usefulness of a drought intensity index to identify suitable clones with storage root and vine yields for drought-prone environments in Mozambique. This research was also the first to study the value of sweetpotato landraces from Mozambique under drought.

Materials and methods

A total of 58 sweetpotato were evaluated at Umbeluzi Research Station over three dry seasons (Table 1). The materials comprised 40 farmer landraces (37 from Mozambique, 1 from Kenya, 1 from Tanzania and 1 from Zimbabwe) and 18 clones coming from seven different breeding programs. Farmer landraces were predominantly spreading except five that had a semi-erect plant type. The check cultivars were Jonathan, Resisto and Tanzania.

The clones were evaluated at Umbeluzi Research Station during the dry seasons of 2006, 2008 and 2009. Umbeluzi Research Station (12 m.a.s.l; latitude: 26°03′S and longitude: 32°23′E) is a representative site for southern African lowlands of the tropical savanna climate at the border of the hot semi-arid climate and the humid subtropical climate zone (Kottek et al. 2006; Fig. 1). Drought is experienced on annual basis in Gaza, Inhambane and Maputo provinces as well as half of Tete province, which translates into 35 % of Mozambique's area suffering from water deficit annually. The soil type at Umbeluzi Research Station is alluvial with a texture ranging from sandy loam in the topsoil to sandy at 1.75 m soil depth. The available water capacity from topsoil to 1.75 m soil depth is about 200 mm. The main weather features and amount of irrigation water applied during growing period and evaluation in 2006, 2008 and 2009 are given in Table 2.

Two irrigation treatments were established: well-watered and water deficit. Trials were established on 7th March 2006, 2nd June 2008 and 8th April 2009. Both treatments received four furrow irrigations of 60 mm each: 1 day before, and 4, 15 and 25 days after planting. The well-watered treatment received additional furrow irrigations of 40 mm of water at 35, 45 and 55 days after planting. Irrigation was resumed 60 days after planting in the water-deficit treatment. The well-watered treatment represented Central and Northern regions of Mozambique that receive adequate rainfall for sweetpotato production. The drought treatment mimics drought as noted in southern Mozambique. Maquia et al. (2013) rated Umbeluzi as a suitable site for screening sweetpotato germplasm under drought.

Each clone was planted in two row plots, replicated three times in each treatment following a randomized complete block design. Each row was planted with 12 plants with a plant-to-plant spacing of 0.3 m, while the distance between rows was 0.9 m. The previous crop to all experiments was maize, which received 92 kg N ha^{-1} from urea. The irrigation treatments were applied to an entire block in particular three blocks received well-watered treatment and three blocks were under water deficit in each season. Hoe weeding was employed to keep weed-freed plots, which did not receive either synthetic fertilizers or pesticides.

Harvesting was done on 10th August 2006, 23rd November 2008 and 17th September 2009. At harvest 10 plants were taken from each plot for recording storage root (t ha^{-1}), vine yields (t ha^{-1}) and harvest index (%). Five roots of medium size were randomly collected from each plot to determine dry matter (DM) content in the laboratory. Each root from each laboratory sample was washed to remove soil particles and rinsed with abundant tap water, peeled and cut longitudinally into four sections. Two opposite sections of each root were used to prepare a 100 g compound sample that was weighed and placed in paper bags and oven dried for 72 h. After the drying period, the samples were reweighed again to determine DM content. Drought stress indices for storage root yield and vine yield were computed (Agili et al. 2012).

The geometric mean productivity is the square root of the product of storage root yield under drought and storage root yield under irrigated condition (GMP) = $\sqrt{\text{storage root yield under drought} \times \text{storage root yield under irrigated condition}}$ (Ramirez-Vallejo and Kelly 1998).

Table 1 Name, code by the International Potato Center (CIP) or Instituto de Investigaçao Agrária de Moçambique (IIAM), cultivar type (CT), country of origin (CO), storage root traits and plant type of sweetpotato landraces and bred-germplasm included in multi-environment testing under irrigation and non-irrigation plots at Umbeluzi (Mozambique) between 2006 and 2009

Name	CIP code	IIAM code	CT[a]	CO[b]	Storage root			
					Skin color[c]	Flesh color[d]	Shape[e]	Plant type[f]
Tacna	187019.1	MZC0001	BL	PE	BO	DY	RE	SE
Chissicuana-2	NA	MZC0002	FV	MZ	BO	LY	RE	S
Nhacutse-5	NA	MZC0003	FV	MZ	BO	DY	LE	S
Nwaracu	NA	MZC0004	FV	MZ	DR	DY	E	S
Nwazambane	NA	MZC0005	FV	MZ	C	LY	E	S
NASPOT5	NA	MZC0006	MV	UG	BO	IO	RE	S
Malawe	NA	MZC0007	FV	MZ	R	LO	O	S
Nhacoongo-1	NA	MZC0008	FV	MZ	C	W	LE	S
Mamphenane	NA	MZC0009	MV	SA	BO	LO	OBL	S
Maphuta	NA	MZC0010	MV	SA	P	DY	E	E
Nwamanhiça	NA	MZC0011	FV	MZ	C	Y	E	S
199062.1	199062.1	MZC0012	BL	PE	BO	IO	RE	S
Nhacutse-3	NA	MZC0013	FV	MZ	C	C	RE	S
ADMARC	NA	MZC0014	FV	MZ	P	C	E	S
Diliva	NA	MZC0015	FV	MZ	P	Y	RE	SE
ST87-030	189001.2	MZC0016	BL	CIP	Y	Y	RE	SE
440203	440203	MZC0017	MV	CIP	BO	W	OBV	S
Thuang-Thuang	NA	MZC0018	FV	MZ	BO	W	RE	S
Atacama	187020.1	MZC0019	MV	PE	DR	Y	RE	S
1998-12-3	NA	MZC0020	BL	PE	LB	DO	E	S
Chissicuana-3	NA	MZC0021	FV	MZ	C	W	RE	S
Nhacutse-1	NA	MZC0022	FV	MZ	C	Y	LO	S
Canassumana	NA	MZC0023	FV	MZ	R	Y	E	S
UNK-Malawe	NA	MZC0024	FV	MZ	R	Y	O	S
Nhacutse-2	NA	MZC0025	FV	MZ	C	W	RE	S
Chitandzana	NA	MZC0026	FV	MZ	R	LY	LE	S
Jogó	NA	MZC0027	FV	MZ	P	LY	R	S
Xiadlaxakau	NA	MZC0028	FV	MZ	R	Y	R	S
Xitsekele	NA	MZC0029	FV	MZ	P	Y	E	S
Chissicuana-1	NA	MZC0030	FV	MZ	DR	DY	RE	S
Nhacutse-4	NA	MZC0031	FV	MZ	BO	W	E	SE
Jogó-2	NA	MZC0032	FV	MZ	BO	W	E	S
Manhissane	NA	MZC0033	FV	MZ	C	W	E	S
Nwamazambe	NA	MZC0034	FV	MZ	BO	Y	E	S
Mafambane	NA	MZC0035	FV	MZ	C	W	OBV	S
Nwamonguane	NA	MZC0036	FV	MZ	C	C	E	S
Chulamete	NA	MZC0037	FV	MZ	C	Y	RE	S
Cinco minutos	NA	MZC0038	FV	MZ	C	Y	RE	S
Xiphone	NA	MZC0039	FV	MZ	C	W	RE	S
Nwaxitsimbwane	NA	MZC0040	FV	MZ	R	W	RE	SE
Cacilda	NA	MZC0041	FV	MZ	C	W	OBV	S

Table 1 continued

Name	CIP code	IIAM code	CT[a]	CO[b]	Storage root			
					Skin color[c]	Flesh color[d]	Shape[e]	Plant type[f]
Nwanaqtsjo	NA	MZC0042	FV	MZ	C	C	E	S
Ligodo	NA	MZC0043	FV	MZ	C	C	RE	SE
Xihetamakote	NA	MZC0044	FV	MZ	C	DY	O	S
TIS 9265	440075	MZC0045	BL	NG	LB	W	OBV	S
Ximitakwatse	NA	MZC0046	FV	MZ	C	Y	O	S
Resisto	440001	MZC0047	MV	US	R	DO	RE	SE
Jonathan	420014	MZC0048	MV	PE	BO	IO	O	E
Japon Tremesino Selecto	420009	MZC0049	MV	PE	BO	IO	O	E
CN-448-49	440181	MZC0050	MV	TW	BO	IO	O	E
Tainung-64	440189	MZC0051	MV	TW	BO	DO	RE	S
Cordner	NA	MZC0052	MV	US	BO	DO	RE	SE
Tanzania	NA	MZC0053		TZ	C	Y	O	SE
TIS-2534	44006	MZC0054	BL	NG	R	W	O	S
MgCl01	NA	MZC0055	FV	MZ	C	DO	RE	S
Moz-White	NA	MZC0056	FV	ZW	R	W	E	S
Lo-323	440185	MZC0057	BL	US	BO	DO	O	E
SPK004	441768	MZC0058	FV	KE	C	IO	RE	SE

[a] *CT* cultivar type, *FV* farmers' landrace, *BL* breeding clone, *MV* modern cultivar

[b] *CO* country of origin, *JP* Japan, *KE* Kenya, *MZ* Mozambique, *NG* Nigeria, *PE* Perú, *SA* South Africa, *TZ* Tanzania, *TW* Taiwan, *US* United States of America, *ZW* Zimbabwe

[c] *C* cream, *LB* light brown, *BO* brown orange, *R* red, *DR* dark red, *P* pink

[d] *W* white, *L* light yellow, *IY* intermediate yellow, *DY* dark yellow, *C* cream, *LO* light orange, *IO* intermediate orange, *DO* dark orange

[e] *RE* round elliptic, *E* elliptic, *LE* long elliptic, *OBV* obovate, *OBL* oblong

[f] *E* erect, *SE* semi-erect, *S* spreading

Drought intensity index (DII) and drought susceptibility index (DSI) were calculated by formula given by Fisher and Maurer (1978) as follows: DII = 1 − mean storage root yield of all clones under drought/mean storage root yield of all clones under irrigated condition, and DSI = (1 − storage root yield under drought/storage root yield under irrigation)/DII. Drought tolerance efficiency (DTE) was calculated by formula given by Fischer and Wood (1981); i.e., DTE % = (yield under drought/yield under irrigation) × 100. Percent reduction (PR) was also computed for storage root yield. PR = [(yield under irrigation − yield under drought)/yield under irrigation] × 100.

Storage root and vine yields (t ha^{-1}), DM (%) and harvest index data were subjected to statistical analyses in Plant Breeding Statistical Program (PLABSTAT; Utz 1997), SAS 6.12 (SAS Institute 1988, 1997) and R (R core team 2015). The data were analyzed in four steps. In the first step phenotypic data were analyzed separately for each treatment in each season using the analysis of variance (ANOVA) for the randomized complete bock design with SAS 6.12 GLM procedure. In the second step phenotypic data were analyzed across treatments and seasons using PLABSTAT and the model statement G + T + S + GT + GS + TS + GTS + R:TS + RGTS, where G corresponds to genotypes, T to treatments and S to seasons. In this model we considered all the main effects (G, T, and S) the interactions among genotypes, treatments, and seasons (GT, GS, TS, and GTS), and the effect of blocks nested into treatments and seasons (R:TS). The term RGTS corresponds to the error term. In the third step, each combination between treatments and seasons was considered an environment (E) for the estimation of stability and adaptability of clones. The dynamic concept of stability was applied for all the

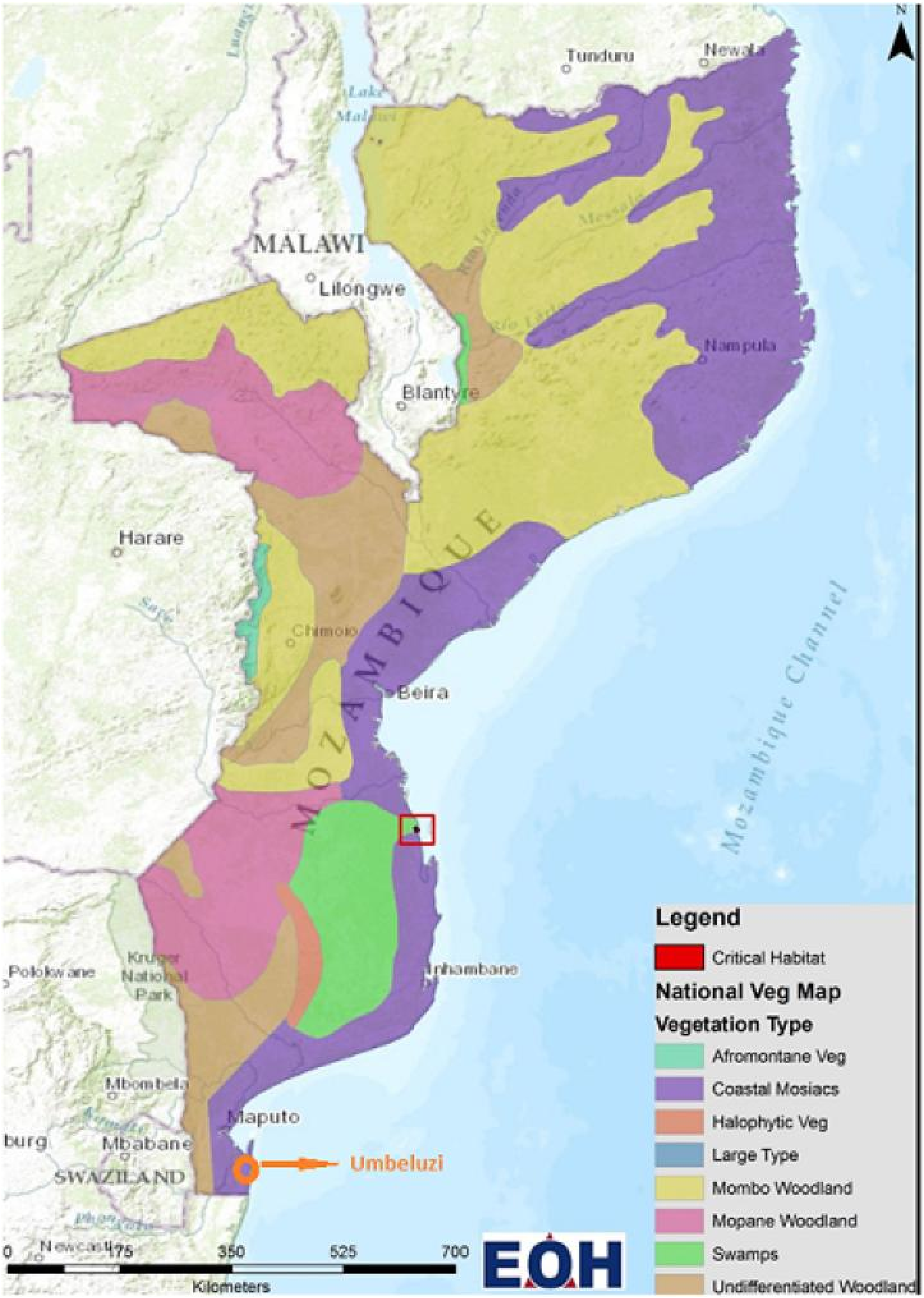

Fig. 1 Position of Umbeluzi Research Station and vegetation distribution in Mozambique

Table 2 Average monthly rainfall (R, mm), temperature (T, °C), evapotranspiration (ET), water applied in irrigated (IRR, mm) and drought (DR, mm) treatments during growing period of multi-environment trials of sweetpotato at Umbeluzi

Year	MP[a]	March	April	May	June	July	August	September	October	November
2006	R	163.7	22.7	1.5	3.6	8.3	18.8	–	–	–
	T	24.9	23.3	20.5	19.2	19.7	20.4			
IRR		–	160	160	160	120	60	–	–	–
DR		–	60	80	80	60	40	–	–	–
	ET	139.1	111.5	126.3	110.4	116.0	156.2	–	–	–
2008	R	–	–	–	14.2	0	0	13.3	0.5	128.7
	T				19.6	20	21.6	22.9	24.2	25.7
IRR		–	–	–	160	160	160	160	120	–
DR		–	–	–	160	60	80	80	120	–
	ET	–	–	–	94.1	125.7	168.6	195.9	200.6	166.0
2009	R	–	5.4	1.7	13.0	5.5	61.9	0	–	–
	T		23.6	22.0	20.5	18.5	20.1	22.5		
IRR		–	160	160	160	160	60	60	–	–
DR		–	160	60	60	60	60	60	–	–
	ET	–	124.4	113.6	109.4	150.0	133.3	130.9	–	–

[a] Meteorological parameter

yield traits where a stable genotype has a varying yield response to the tested genotypes (Becker and Leon 1988). This concept recognizes a specific set of tested genotypes and equals Type II stability with high goodness of fit (Lin et al. 1986). The ecovalence technique was also used to estimate trait stability (Wricke 1962). The phenotypic coefficient of variation across environments (CV) was calculated for each sweetpotato clone (Francis and Kannenberg 1978). In a fourth step the AMMI model (Gollob 1968; Gauch 1992) was fitted using R to decompose the G × E matrix of interaction effects; the first two principal components were presented bi-plots. Finally, correlations among stability parameters the principal component scores of the AMMI analysis were carried out for harvest index (%) and storage root yield (t ha^{-1}) by SAS procedure CORR and the optional statement PEARSON.

Results

There were significant differences for storage root yield, vine yield and total biomass between the two treatments, among genotypes, and due to the G × E (Table 3). The G × E variation was also greater than the environmental or genotypic effects for storage root yield. Both components of the G × E variation, viz. heterogeneity among regression lines and the remainder (deviation) were significant (Table 3). The significant linear G × E indicated the possibility of predicting trait performance of individual genotypes from the linear regression across environments.

Drought affected total biomass, storage root yield and vine across testing years (Table 4). The storage root yields among the landraces, cultivars and other bred-germplasm ranged from 2.24 to 17.38 t ha^{-1} under irrigation and 1.4 to 14.72 t ha^{-1} without irrigation (Table 4). Modern cultivars and other bred-germplasm had higher storage root yields under both treatments than the farmers' landraces. The storage root yields of Chissicuana-2, ADMARC, Thuang-Thuang, Nhacutse-2, Xiadlaxakau, Nwamazambe, Cacilda, Ligodo, Ximitakwatse, Tacna, Mamphenane, 199062.1, ST87-030, Atacama, 1998-12-3, and TIS-2534 were above that of the best cultivar check Resisto under irrigation.

Edible yield is often used to assess adaptation to drought among genotypes (Blum 2005). The storage root yield of ADMARC, Chissicuana-2, Tacna, TIS-2534 and Xiadlaxakau—among the high yielding under irrigation– plus UNK-Malawe, Xitsekele, and Chulamete was above that of Tanzania (=Chingova), which was the best cultivar check under drought

Table 3 Multi-environment analysis of variance including heterogeneity due to regression (Het. R.), deviations from regression lines (Dev. R.), stability variance (σ^2) and relative variance (Rel. σ^2) for storage root yield, vine yield and biomass of sweetpotato landraces and bred-germplasm included in multi-environment testing under irrigation and non-irrigation plots at Umbelezi (Mozambique) between 2006 and 2009

Trait	Source of variation	Degrees of freedom	Mean square	σ^2	Rel. σ^2
Storage root yield	Environment (E)	5	1154.682	5.801**	98.24
	Genotype (G)	57	158.178	5.905**	100
	G × E	285	51.894	12.904**	218.54
	Het. R.	57	72.722	1.446**	11.21[a]
	Dev. R.	228	46.687	11.169**	86.55[a]
	Het. R.	5	240.096	1.101**	8.53[a]
	Dev. R.	280	48.533	11.784**	91.32[a]
	Error	596	13.181	13.181	223.22
Vine yield	E	5	7162.892	36.007**	60.64
	G	57	1257.096	59.375**	100
	G × E	285	188.341	37.732**	63.54
	SUB Het. R.G	57	422.264	16.245**	43.05[a]
	Dev. R.G	228	129.860	18.239**	48.34[a]
	SUB Het. R.E	5	3086.723	16.955**	44.94[a]
	Dev. R.E	280	136.584	20.480**	54.28[a]
	Error	621	75.144	75.144	126.55
Biomass	E	5	8577.841	41.256**	65.74
	G	57	1407.432	62.748**	100
	G × E	285	277.965	59.917**	95.48
	Het. R.	57	423.098	10.079**	16.82[a]
	Dev. R.	228	241.682	47.823**	79.82[a]
	Het. R.	5	3671.485	19.851**	33.13[a]
	Dev. R.	280	217.367	39.718**	66.29[a]
	Error	606	98.214	98.214	156.52

** Indicates and highly significant at $P \leq 0.01$

[a] Relative to $\sigma^2_{\mathrm{G\times E}}$

(Table 4). The storage root yield of the check cultivar Tanzania was higher under drought than under irrigation but the reverse was true for its vine and biomass yield, which were high under irrigation. ADMARC, Tacna and Xiadlaxakau had the best performance without irrigation; their storage root yield was at least 10 t ha^{-1}.

The degree of drought imposed on the trials across the 3 years was moderate (DII = 0.25). Based on the drought stress indices, ADMARC and Tacna were rated as drought tolerant (Table 5) and appeared on one cluster (Fig. 2). Their storage root yields were above 10 t ha^{-1} with or without irrigation, while their DTE was above 75 % and the DSI was below 1. Both cultivars kept a high harvest index, which was above the drought treatment (>40 %). Chissicuana-2 and Xiadlaxakau had also high storage root yield under the two treatments, high geometric mean and good DTE but were highly sensitive to drought. The DSI values for the both landraces were above 1, thus indicating differential yield performance under different treatments. Nonetheless, bred-germplasm and modern cultivars appear to be more sensitive to drought than the farmer landraces. The reduction of storage root yield in bred-germplasm and modern cultivars was 28 % while it was 24 % for landraces. Vine yield was larger under irrigation that under drought (Table 5), which reduced this trait by 36 %. The highest loss was noted in Thuang-Thuang and Nwamonguane.

Table 4 Estimates obtaining using the dynamic concept of genotype × environment interaction (x_i: mean, β: regression coefficient: MS: mean square) and the ecovalence (Eco) for storage root yield, vine yield and biomass for environments and genotypes (Instituto de Investigaçao Agrária de Moçambique [IIAM] code—Table 1) of sweetpotato included in multi-environment testing under irrigation (IR) and non-irrigation (NI) plots at Umbelezi (Mozambique) between 2006 and 2009

	Storage root yield				Vine yield				Biomass			
	x_i	β	MS	Eco	x_i	β	MS	Eco	x_i	β	MS	Eco
Environments												
IR-2006	5.2	1.13	10.9	10.9	26.5	1.49	27.4	43.8	31.7	1.51	48.8	68.1
NI-2006	4.9	1.07	15.3	15.1	21.2	1.55	48.5	68.6	26.0	1.57	82.8	106.8
IR-2008	7.1	0.95	8.6	8.4	23.9	1.33	52.5	59.2	31.0	1.33	62.1	69.6
NI-2008	2.3	0.30	2.3	6.6	10.9	0.53	32.7	47.5	13.2	0.52	41.5	58.8
IR-2009	9.0	1.53	23.8	25.8	17.8	0.64	47.5	55.8	26.4	0.63	82.6	91.8
NI-2009	8.7	1.03	20.1	19.8	11.6	0.46	19.0	39.0	20.2	0.44	44.4	68.2
$LSD_{0..05}$		0.48				0.28				0.35		
β-test			**				+				*	
Genotypes												
MZC0001	15.6	3.20	12.2	41.9	18.2	1.23	43.0	36.5	33.8	1.25	60.9	51.8
MZC0002	11.2	1.51	28.0	24.2	34.6	2.49	134.0	198.9	45.8	2.04	138.1	163.7
MZC0003	6.3	0.97	2.1	1.7	28.3	2.20	13.0	69.2	34.6	1.85	25.8	56.4
MZC0004	3.4	−0.28	8.1	17.3	17.8	1.55	22.3	30.1	21.2	1.49	79.1	75.0
MZC0005	6.8	1.58	13.1	12.9	15.5	0.36	16.8	30.4	22.2	0.15	33.2	62.1
MZC0006	4.5	1.03	10.6	8.5	31.9	2.70	125.9	218.8	36.4	2.00	156.6	174.6
MZC0007	5.0	1.34	6.4	5.8	14.5	−0.40	27.3	102.7	19.4	−0.09	89.3	129.6
MZC0008	3.4	0.21	6.9	9.7	31.1	1.84	4.0	32.5	34.4	1.86	30.4	60.3
MZC0009	7.3	1.26	11.3	9.5	6.4	0.30	32.0	45.8	13.5	0.55	56.4	54.9
MZC0010	4.6	0.64	11.9	10.4	10.3	−0.05	0.9	46.2	14.7	0.00	18.5	64.5
MZC0011	2.6	0.58	3.0	3.6	19.4	1.15	97.4	78.8	22.8	1.08	134.6	108.0
MZC0012	11.5	0.22	51.7	45.4	15.7	1.54	2.5	14.0	27.2	2.03	50.9	92.8
MZC0013	3.9	0.74	4.8	4.3	23.5	1.10	50.5	40.8	27.4	0.99	63.5	50.8
MZC0014	12.0	0.04	42.3	40.0	23.3	2.30	61.2	117.8	35.6	2.61	199.4	286.6
MZC0015	2.4	0.43	2.0	3.7	37.3	1.57	64.2	64.9	39.0	1.19	110.8	90.5
MZC0016	9.1	2.08	8.5	14.6	12.7	0.45	54.9	56.6	22.2	1.02	124.8	99.9
MZC0017	3.1	0.54	0.53	1.9	18.3	1.95	11.8	46.8	21.4	1.75	29.8	51.9
MZC0018	7.2	2.10	17.4	21.9	19.0	1.94	34.9	64.3	26.9	1.93	56.3	87.7
MZC0019	8.6	0.20	24.1	23.6	18.6	−0.20	110.4	147.1	25.8	0.55	134.9	117.7
MZC0020	11.3	−0.61	121.5	114.4	10.0	0.48	7.0	16.7	21.4	1.54	64.5	66.2
MZC0021	5.6	1.06	1.02	0.83	23.5	1.68	45.0	55.1	29.2	1.68	52.8	64.9
MZC0022	3.2	0.58	1.1	2.08	37.5	1.84	114.2	120.5	40.8	1.93	74.3	102.2
MZC0023	6.7	0.32	2.9	5.4	17.9	1.15	40.9	33.6	24.6	0.93	77.3	62.0
MZC0024	7.2	0.92	21.1	17.0	20.3	1.49	56.3	54.8	27.0	1.30	154.6	128.0
MZC0025	5.4	0.59	17.5	15.1	20.9	1.49	36.0	38.8	26.0	1.89	60.6	87.3
MZC0026	4.1	0.51	1.3	2.7	16.9	0.15	26.1	50.5	20.8	0.03	29.0	70.1
MZC0027	2.9	0.15	1.3	5.8	25.3	0.61	55.4	50.5	28.1	0.87	33.9	28.0
MZC0028	12.6	2.19	6.1	14.3	20.8	0.24	12.4	33.5	33.4	0.45	38.2	45.5
MZC0029	6.8	−1.07	67.4	82.3	28.6	1.88	39.6	63.2	35.5	1.70	204.4	187.1
MZC0030	2.9	0.61	0.79	1.7	12.8	0.13	10.1	39.5	15.6	0.26	16.4	39.9
MZC0031	5.2	0.46	3.25	4.5	17.7	1.08	84.2	67.6	22.9	0.83	112.3	91.2

Table 4 continued

	Storage root yield				Vine yield				Biomass			
	x_i	β	MS	Eco	x_i	β	MS	Eco	x_i	β	MS	Eco
MZC0032	5.2	1.61	9.73	10.2	34.9	1.94	4.6	40.1	40.1	1.56	11.7	24.8
MZC0033	6.0	1.38	6.47	6.2	15.3	0.14	1.1	31.6	20.4	0.01	30.6	73.2
MZC0034	7.7	2.18	17.3	23.1	19.3	0.97	114.3	91.5	26.0	1.21	204.9	166.1
MZC0035	2.5	0.29	0.65	3.9	16.9	0.98	3.8	3.1	19.4	0.92	8.20	6.9
MZC0036	4.6	0.64	17.9	15.2	10.8	1.20	20.8	18.3	15.3	1.55	51.8	56.1
MZC0037	7.0	1.12	17.4	14.0	22.7	1.31	4.4	7.6	29.7	1.13	25.2	21.0
MZC0038	6.6	1.14	7.7	6.3	27.1	1.65	43.8	52.5	33.7	1.60	30.8	41.9
MZC0039	5.4	0.23	11.3	13.0	13.4	1.16	59.5	48.7	18.8	1.29	98.0	82.6
MZC0040	3.9	0.73	8.1	7.0	23.3	2.34	133.2	180.5	27.1	1.63	192.6	173.6
MZC0041	6.9	1.82	5.3	8.6	17.4	1.51	23.1	29.0	24.3	1.55	35.6	43.2
MZC0042	7.5	0.13	4.2	8.4	26.0	0.28	71.3	78.7	32.9	−0.16	85.4	134.3
MZC0043	11.9	1.98	60.1	54.4	16.2	1.06	29.5	23.7	28.1	1.53	133.9	121.0
MZC0044	4.1	0.79	2.1	2.0	24.2	0.13	186.3	180.5	29.3	0.12	219.1	213.7
MZC0045	2.5	0.44	1.26	3.1	7.6	0.55	13.3	19.0	10.1	0.66	9.0	13.0
MZC0046	7.5	1.49	19.5	17.2	34.3	2.74	40.0	157.1	41.0	2.61	122.5	226.3
MZC0047	6.2	0.51	10.2	9.7	9.8	0.40	18.1	29.3	16.4	0.63	29.8	30.5
MZC0048	6.8	2.23	15.9	22.7	7.0	0.04	11.8	47.6	14.2	0.17	88.5	104.5
MZC0049	6.0	1.64	10.2	10.9	8.3	−0.02	28.1	65.2	14.6	0.12	86.8	107.6
MZC0050	3.6	1.23	6.7	5.7	7.9	0.47	4.1	14.8	10.4	0.15	32.7	61.2
MZC0051	6.6	2.57	24.3	35.9	8.0	−0.12	21.5	69.0	13.7	−0.34	151.6	210.2
MZC0052	5.1	0.87	1.5	1.3	9.1	0.35	3.0	19.6	14.2	0.52	3.6	14.0
MZC0053	8.3	2.15	28.1	31.3	23.2	1.42	35.2	35.5	30.7	0.66	17.1	19.5
MZC0054	9.5	3.04	59.5	75.1	11.0	0.90	7.5	6.4	20.5	0.56	131.0	114.6
MZC0055	2.5	0.56	3.6	4.1	12.1	0.29	8.3	27.1	14.6	0.44	12.2	25.3
MZC0056	4.3	0.79	14.9	12.2	9.6	0.03	64.3	89.9	13.8	0.07	75.4	102.8
MZC0057	6.5	1.91	9.9	13.3	9.0	0.17	33.9	55.8	15.5	0.34	128.2	123.9
MZC0058	2.1	0.47	3.5	4.7	8.6	−0.11	48.7	90.0	11.0	−0.17	64.2	118.6
$LSD_{0.05}$		1.88				1.23				1.49		
β-test			**				**				+	

**,* and + indicate highly significant at $P \leq 0.01$ and significant at $P \leq 0.05$ or $P \leq 0.10$, respectively

The G × E variation was split due to regression (β) and deviation from the regression lines (MS)—a dynamic concept of stability– and the environmental variance (σ_i^2)—static concept of stability (Tables 4, 6). A stable sweetpotato cultivar or landrace should have a higher trait value than the mean of the population, a β = 1, and a non-significant deviation from the regression (Eberhart and Russell 1966). High storage root yields appear to be associated with either high stability or instability. A β about 1 indicates average responsiveness, but if associated with high mean trait value the genotype will be rated as having general adaptability, while it will be regarded as a sweetpotato having poor adaptability if showing a low mean trait value (Finlay and Wilkinson 1963). A β significantly below 1 indicates a sweetpotato with better adaptation of to low-yielding environments, e.g. ADMARC for total storage root yield (Table 4). The CV is a static stability—i.e., homeostasis—because it measures the dispersion of the data set. Static stability is when a stable genotype tends to maintain constant yield across different environments and shows minimum environmental sensitivity. The smaller the CV, the closer the data of each environment around the

Table 5 Total root yield (TRY, t ha^{-1}) under irrigation (IRRI) and drought (D), its geometric mean (GM), drought sensitivity index (DSI), drought tolerant expression (DTE, %), percent reduction (PR. %) vine yield (VY, t ha^{-1}) total biomass (BIOM t ha^{-1})

Cultivar	TRY		GM	DSI	DTE	PR	VY		PR	BIOM		HI		RDM	
	IRR	D					IRR	D		IRR	D	IRR	D	IRR	D
Farmers' landraces															
Chissicuana-2	13.18	9.26	11.05	1.19	70.26	29.74	38.99	30.24	22.44	52.16	39.50	30.91	24.14	32.31	33.01
Nhacutse-5	7.13	5.54	6.28	0.89	77.70	22.30	36.92	19.64	46.80	44.05	25.17	17.92	25.73	32.64	31.02
Nwaracu	4.13	2.70	3.34	1.38	65.38	34.62	21.52	14.07	34.62	25.54	16.82	12.94	19.56	31.88	32.22
Nwazambane	6.09	7.43	6.73	0.00	0.00	0.00	14.91	16.05	0.00	21.00	23.48	31.31	30.31	31.78	32.70
Malawe	6.47	3.49	4.75	1.84	53.94	46.06	15.45	13.50	12.62	21.92	16.91	28.91	22.74	28.64	33.16
Nhacoongo-1	4.94	1.80	2.98	2.54	36.44	63.56	37.60	24.54	34.73	42.54	26.34	11.21	7.39	36.39	35.24
Nwamanhiça	2.24	2.96	2.57	0.00	0.00	0.00	22.80	15.96	30.00	26.74	18.92	12.26	15.19	33.48	34.88
Nhacutse-3	4.75	3.13	3.86	1.36	65.89	34.11	23.95	23.01	3.92	28.70	26.14	16.61	12.25	32.13	34.95
ADMARC	13.48	10.48	11.89	0.89	77.74	22.26	28.94	17.66	38.98	43.08	28.14	34.57	42.13	32.42	34.96
Diliva	2.89	1.96	2.38	1.29	67.82	32.18	40.56	33.97	16.25	43.00	35.06	7.42	4.72	36.84	36.20
Thuang-Thuang	10.71	3.78	6.36	2.59	35.29	64.71	29.41	8.61	70.72	39.99	13.91	26.58	32.04	33.10	30.89
Chissicuana-3	6.78	4.45	5.49	1.37	65.63	34.37	27.19	19.81	27.14	34.16	24.25	18.67	18.27	32.98	33.44
Nhacutse-1	3.29	3.13	3.21	0.19	95.14	4.86	45.69	29.40	35.65	49.02	32.53	7.24	10.43	32.59	32.24
Canassumana	7.00	6.33	6.66	0.38	90.43	9.57	19.64	16.17	17.67	26.64	22.49	29.65	30.49	34.13	33.51
UNK-Malawe	6.07	8.36	7.12	0.00	0.00	0.00	22.53	18.16	19.40	27.51	26.52	22.73	30.24	32.74	33.93
Nhacutse-2	8.66	2.13	4.29	3.02	24.60	75.40	28.99	12.77	55.95	36.96	14.95	22.90	12.57	35.06	33.05
Chitandzana	4.26	3.89	4.07	0.35	91.31	8.69	17.43	16.31	6.43	21.34	20.16	20.06	18.22	32.44	31.45
Jogó	3.52	2.34	2.87	1.34	66.48	33.52	29.21	21.33	26.98	32.48	23.67	10.28	10.82	33.33	34.66
Xiadlaxakau	15.11	10.10	12.35	1.33	66.84	33.16	21.45	20.12	6.20	36.56	30.26	40.87	33.63	31.91	32.17
Xitsekele	4.89	8.81	6.56	0.00	0.00	0.00	35.98	21.24	40.97	40.87	30.04	10.77	20.06	33.73	32.76
Chissicuana-1	3.83	1.88	2.68	2.04	49.09	50.91	14.83	10.77	27.38	18.52	12.68	20.03	14.39	32.27	31.06
Nhacutse-4	4.54	5.87	5.16	0.00	0.00	0.00	20.29	15.20	25.09	24.87	21.02	21.39	32.41	29.14	30.96
Jogó-2	4.89	5.59	5.23	0.00	0.00	0.00	41.72	28.07	32.72	46.58	33.66	12.63	18.39	33.78	32.67
Manhissane	6.13	5.84	5.98	0.19	95.27	4.73	15.91	14.75	7.29	22.04	18.73	24.82	27.48	31.70	32.97
Nwamazambe	8.50	6.92	7.67	0.74	81.41	18.59	28.95	9.62	66.77	37.45	14.55	19.83	38.38	31.94	31.47
Mafambane	2.72	2.34	2.52	0.56	86.03	13.97	20.55	13.19	35.82	23.27	15.54	12.27	20.92	30.01	33.79
Nwamonguane	7.60	1.52	3.40	3.20	20.00	80.00	17.66	4.02	77.24	25.12	5.55	29.42	22.45	34.40	32.28
Chulamete	5.35	8.74	6.84	0.00	0.00	0.00	27.62	17.79	35.59	32.97	26.53	17.18	30.04	32.93	32.46
Cinco minutos	5.90	7.39	6.60	0.00	0.00	0.00	37.22	16.96	54.43	43.12	24.34	15.91	29.52	33.52	32.73

Table 5 continued

Cultivar	TRY		GM	DSI	DTE	PR	VY		PR	BIOM		HI		RDM	
	IRR	D					IRR	D		IRR	D	IRR	D	IRR	D
Xiphone	7.22	3.63	5.12	1.99	50.28	49.72	13.87	12.93	6.78	21.09	16.55	39.23	27.75	30.75	32.57
Nwaxitsimbwane	2.77	5.06	3.74	0.00	0.00	0.00	26.34	20.16	23.46	28.98	25.15	17.09	27.52	32.21	34.21
Cacilda	8.98	4.78	6.55	1.87	53.23	46.77	25.71	9.18	64.29	34.58	13.96	26.60	28.95	34.77	34.43
Nwanaqtsjo	7.79	7.13	7.45	0.34	91.53	8.47	24.71	27.31	0.00	32.54	33.16	23.86	21.28	31.26	32.73
Ligodo	17.38	6.43	10.57	2.52	37.00	63.00	19.79	12.52	36.74	37.17	18.95	45.55	36.46	32.91	32.60
Xihetamakote	4.03	4.15	4.09	0.00	0.00	0.00	22.23	26.1	0.00	28.36	30.26	23.32	16.51	32.36	34.77
Ximitakwatse	11.96	3.12	6.11	2.96	26.09	73.91	43.31	25.3	41.58	53.58	28.42	27.16	12.14	33.55	36.93
Tanzania = Chingova	7.32	9.28	8.24	0.00	0.00	0.00	28.01	18.37	34.42	33.70	27.66	23.49	32.64	33.88	34.78
MgCl01	3.41	1.63	2.36	2.09	47.80	52.20	13.47	10.68	20.71	16.96	12.30	23.54	20.28	32.60	33.69
Moz-White	3.96	4.68	4.30	0.00	0.00	0.00	13.87	5.33	61.57	17.45	10.06	27.49	34.32	33.62	33.25
SPK004	2.82	1.40	1.99	2.01	49.65	50.35	10.63	6.61	37.82	14.12	7.92	15.83	22.07	32.93	33.86
Average	6.57	4.99					25.65	17.44		32.17	22.31	22.01	23.37	32.78	33.27
Bred-germplasm and modern cultivars															
Tacna	16.40	14.72	15.54	0.41	89.76	10.24	23.56	12.92	45.16	39.96	27.64	43.25	44.88	29.17	32.44
NASPOT5	4.07	4.95	4.49	0.00	0.00	0.00	43.85	19.96	54.48	47.92	24.92	12.62	20.52	36.82	34.74
Mamphenane	8.25	6.30	7.21	0.95	76.36	23.64	9.35	3.54	62.14	17.56	9.53	51.90	53.52	27.10	31.84
Maphuta	3.75	5.55	4.56	0.00	0.00	0.00	9.94	10.76	0.00	13.12	16.31	21.94	30.58	33.15	33.81
199062.1	15.31	7.78	10.91	1.97	50.82	49.18	22.69	8.67	61.79	38.00	16.45	41.95	52.65	28.18	27.06
ST87-030	12.66	5.57	8.40	2.24	44.00	56.00	18.36	7.03	61.71	31.02	13.46	43.36	44.96	35.76	36.08
440203	3.85	2.29	2.97	1.62	59.48	40.52	27.23	9.44	65.33	31.08	11.73	15.72	28.76	33.53	35.26
Atacama	10.07	7.15	8.49	1.16	71.00	29.00	20.4	16.87	17.30	27.62	24.02	45.89	32.35	32.39	31.95
03-12-1998	14.51	8.10	10.84	1.77	55.82	44.18	12.5	7.52	39.84	27.22	15.57	47.07	34.97	28.03	28.45
TIS9265	3.30	1.67	2.35	1.98	50.61	49.39	10.97	4.32	60.62	14.32	5.95	25.24	24.21	28.30	30.13
Resisto	8.13	4.18	5.83	1.94	51.41	48.59	13.75	5.87	57.31	21.88	10.98	38.18	42.9	28.62	30.32
Jonathan	7.38	6.22	6.78	0.63	84.28	15.72	8.80	5.15	41.48	17.06	11.37	41.35	39.15	25.77	29.78
Japon	6.09	5.86	5.97	0.15	96.22	3.78	10.97	5.70	48.04	17.60	11.56	34.42	38.06	24.80	26.88
CN-448-49	3.29	3.87	3.57	0.00	0.00	0.00	10.67	5.21	51.17	11.71	9.07	24.41	34.10	27.84	25.86
Tainung-64	7.40	5.79	6.55	0.87	78.24	21.76	10.00	6.04	39.60	15.6	11.83	39.52	42.86	26.03	27.21
Cordner	6.56	3.57	4.84	1.82	54.42	45.58	11.12	7.17	35.52	17.69	10.74	38.32	31.54	29.25	30.22
TIS-2534	10.24	8.72	9.45	0.59	85.16	14.84	16.23	5.85	63.96	26.46	14.57	30.39	51.21	28.95	27.70
Lo-323	7.67	5.24	6.34	1.27	68.32	31.68	12.62	5.38	57.37	20.30	10.62	32.47	43.89	26.20	25.29

Table 5 continued

Cultivar	TRY		GM	DSI	DTE	PR	VY		PR	BIOM		HI		RDM	
	IRR	D					IRR	D		IRR	D	IRR	D	IRR	D
Average	8.27	5.97					16.29	8.19		24.23	14.24	34.89	38.40	29.44	30.28
Grand mean	7.10	5.29					22.74	14.57		29.70	19.80	26.01	28.03	31.74	32.34
$LSD_{0.05}$	3.34	3.39					8.86	7.11		9.94	8.39	10.92	11.91	3.44	2.16
DII on TRY	0.25														
DII on VY							0.36								

Harvest index (HI), storage root dry matter (RDM) and drought intensity index (DII) of sweetpotato landraces and bred-germplasm included in multi-environment testing under irrigation and non-irrigation plots at Umbeluzi (Mozambique) between 2006 and 2009

mean, and thus the more stable the genotype across the environments tested, e.g. ADMARC, Resisto, ST87-030 and Xiphone for harvest index (Table 6). The ecovalence (Eco) is inversely related to phenotypic stability; i.e., a low Eco indicates high performance stability. However, sweetpotato clones with average to low storage yield had a low Eco, which suggests that genotypes with average to low edible yields lack a response to favorable environments, e.g. Nhacutse-5, 440203, Chissicuana-3 or Cordner. Selection based on low Eco may lead to sweetpotato-bred germplasm with low to average storage root yield. Combining statistic stability and performance may penalize high performance per se, as indicated before by Piepho (1994). Hence, storage root yield and static stability should be treated as two negatively associated traits when using a selection index.

The heterogeneity due to regression was only able to account for 10.9 and 16.8 % the variance component due to G × E for storage root and biomass yield (Table 3), respectively, thus suggesting that AMMI analysis could provide further insights on the multi-environment trial data. In the AMMI bi-plots (Fig. 3) circles (black for irrigated and white for non-irrigated) were the symbols for the environments, while sweetpotato genotypes used black triangles. The first interaction principal component score (IPCA) accounted for 58.1 % of the total treatment variation. The AMMI bi-plot shows the genotype and environment main effects along the abscissa, whereas the IPCA genotype and environment scores are on the ordinate. The vertical dotted line indicates the storage root yield grand mean (μ) whereas the horizontal line indicates a zero IPCA. Displacements along the abscissa and the ordinate show the differences in the main (additive) effects or the interaction effects, respectively. Chissicuana-2, ADMARC, Xiadlaxakau, Tacna and TIS-2534 had higher storage root yield than Resisto under irrigation and than Tanzania without irrigation. Chissicuana-2, ADMARC, Xiadlaxakau along with Tanzania, Nhacutse-5, Nwanaqtsjo, 199062.1, and TIS-2534 had also a storage root harvest above 4 t ha^{-1} even under extreme drought in 2008.

Harvest index and storage root yield were positively associated (Table 7), thus suggesting that selection for the former can be used to select high yielding sweetpotato bred-germplasm. Storage root yield was positively correlated with deviations from

Fig. 2 Cluster analysis of 58 sweetpotato genotypes based on geometric yield (t ha^{-1}), drought sensitivity index (DSI), drought tolerance expression (%), percent reduction, harvest index (HI) and the root dry matter (%)

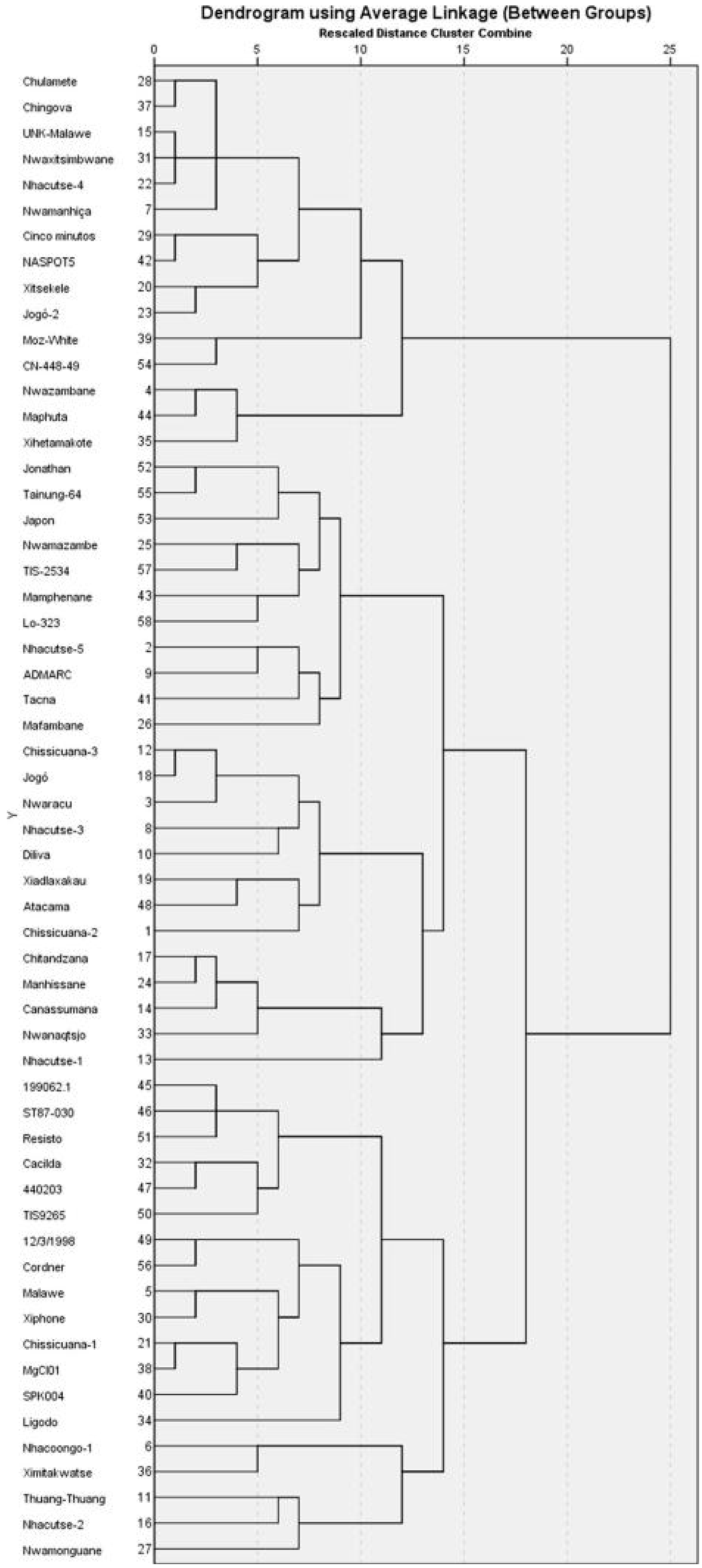

Table 6 Average (x_i) harvest index and storage root dry matter content, their static concept of genotype × environment interaction (stability variance, σ_i^2; coefficient of variation, CV %)

Cultivar	Harvest index			Storage root dry matter content		
	x_i	σ_i^2	CV	x_i	σ_i^2	CV
Tacna	44.1	485.99	49.99	30.8	4.29	6.73
Chissicuana-2	27.5	379.96	70.88	32.7	7.99	8.64
Nhacutse-5	21.8	209.00	66.32	31.8	1.08	3.27
Nwaracu	16.2	63.32	49.12	32.1	2.28	4.70
Nwazambane	30.8	316.81	57.79	32.2	1.16	3.35
NASPOT5	16.6	245.84	94.45	35.8	2.97	4.81
Malawe	25.8	228.87	58.64	30.9	10.72	10.60
Nhacoongo-1	9.3	15.30	42.06	35.8	3.27	5.05
Mamphenane	52.7	699.70	50.19	29.5	8.66	9.98
Maphuta	26.3	233.57	58.11	33.5	8.43	8.67
Nwamanhiça	13.7	73.21	78.30	34.2	7.76	8.15
199062.1	47.3	226.58	31.82	27.6	4.28	7.50
Nhacutse-3	14.4	91.41	66.40	33.5	3.28	5.41
ADMARC	38.3	87.44	24.41	33.7	9.58	9.18
15. Diliva	6.1	15.49	64.52	36.5	11.23	9.18
ST87-030	44.2	82.68	20.57	35.9	2.93	4.77
440203	22.2	246.45	70.71	34.4	2.20	4.31
Thuang–Thuang	29.3	604.97	83.95	32.0	3.75	6.05
Atacama	39.1	574.46	61.30	32.2	0.73	2.65
1998-12-3	41.0	527.39	59.90	28.2	0.82	3.21
Chissicuana-3	18.5	58.17	41.23	33.2	0.15	1.17
Nhacutse-1	8.8	34.11	66.37	32.4	2.63	5.01
Canassumana	30.1	177.07	44.21	33.8	0.89	2.80
UNK-Malawe	26.5	134.94	43.84	33.3	2.05	4.30
25. Nhacutse-2	17.7	39.48	35.50	34.1	8.02	8.31
Chitandzana	19.1	54.95	38.81	31.9	6.43	7.94
Jogó	10.6	12.28	33.06	34.0	4.79	6.44
Xiadlaxakau	37.3	178.45	35.81	32.0	2.72	5.16
Xitsekele	15.4	145.60	78.35	33.2	5.54	7.09
Chissicuana-1	17.2	47.03	39.87	31.7	5.25	7.23
Nhacutse-4	26.9	256.66	59.56	30.1	14.15	12.50
32. Jogó-2	15.5	219.66	95.62	33.2	5.46	7.04
Manhissane	26.2	165.02	49.03	32.3	2.37	4.77
Nwamazambe	29.1	257.25	55.12	31.7	0.45	2.12
Mafambane	16.6	58.11	45.92	31.9	8.41	9.09
Nwamonguane	25.9	89.02	36.43	33.3	12.52	10.62
Chulamete	23.6	178.71	56.65	32.7	2.29	4.63
Cincominutos	22.7	146.63	53.34	33.1	3.27	5.46
Xiphone	33.5	85.49	27.60	31.7	7.76	8.78
Nwaxitsimbwane	22.3	286.29	75.88	33.2	3.91	5.96
Cacilda	27.8	349.62	67.26	34.6	2.85	4.88
Nwanaqtsjo	22.6	67.58	36.38	32.0	2.58	5.02
Ligodo	41.0	202.63	34.71	32.8	1.59	3.84
Xihetamakote	19.9	310.50	88.55	33.6	2.54	4.74

Table 6 continued

Cultivar	Harvest index			Storage root dry matter content		
	x_i	σ_i^2	CV	x_i	σ_i^2	CV
45. TIS9265	24.7	118.15	44.01	29.2	6.09	8.44
Ximitakwatse	19.6	271.81	84.12	35.2	8.32	8.19
Resisto	40.5	87.47	23.09	32.0	2.01	4.83
Jonathan	40.3	455.86	52.98	27.8	12.14	12.53
Japon	36.2	252.51	43.90	25.8	4.04	7.79
CN-448-49	29.3	423.42	70.23	25.7	11.97	13.46
Tainung-64	41.2	557.01	57.28	26.6	17.18	15.58
Cordner	34.9	277.01	47.69	29.7	5.94	8.21
Chingova	28.1	595.41	86.84	34.3	4.48	6.17
TIS-2534	40.8	1057.29	79.70	28.3	1.52	4.36
MgCl01	21.9	112.24	46.39	33.1	4.50	6.41
Moz-White	30.9	384.63	63.47	33.4	2.38	4.62
Lo-323	38.2	193.17	36.39	25.7	14.64	14.89
SPK004	19.0	199.61	74.36	33.4	4.27	6.19

the regression, variances across environments and IPCAs from the AMMI (Table 7), thus indicating that storage root yield and its stability are inversely related among these sweetpotato landraces and modern cultivars. Storage root yield and harvest index also had the same correlation profiles with their trait stability (Table 7); i.e., a low G × E of storage root yield was associated with low G × E for harvest index. The fact that the harvest index was significantly associated to its variances across environments (Fig. 4; Table 7), which can be determined at an early breeding stage when using at least two environments, suggests the possibility on indirect selection for storage root yield and its stability through selecting simultaneously for a high harvest index with low environmental variance. In this way, sweetpotato cultivars with high root yield and stability may be bred, particularly when the heritability of harvest index is higher than that of storage root yield.

Discussion

Drought in these multi-year trials reduced significantly storage root yield by 25 %, which falls within the range (15–39 %), noticed previously after 20 consecutive days under this water deficit during the growing season (Gong and Wang 1990). Water shortage suppresses plant growth—which can be measured as vine yield in sweetpotato– due to loss of turgor in expanded cells (Kirnak et al. 2001). This reduced source strength negatively affected the amount of storage root yield under drought. Sweetpotato is regarded as moderately drought tolerant (Valenzuela et al. 2000) especially when the onset of the drought starts after the root initiation stages. In these multi-year trials, drought began at the middle of the root initiation phase, thereby leading to a moderate water shortage.

In case of irregular rains—as they occur in Mozambique and other countries of southern Africa– there is limited knowledge whether it is possible to breed for sweetpotato clones which are adapted to drought and respond to rains adequately. Knowledge on the G × E structure is therefore important to facilitate recommendations for cultivar releases and to make informed choices regarding selection of cultivars with specific or wide adaptation in sweetpotato breeding programs (Grüneberg et al. 2005). Storage root yield is influenced by various factors. The combined analysis of variance for storage root yield across year environments, genotypes and G × E interaction significantly affected the storage root yield of genotypes. The relative variance component for G × E was highest for storage root yield among the three measured traits. The significant G × E suggests that some of the genotypes were not stable between treatments and from year to year. Ranking of genotypes changed between

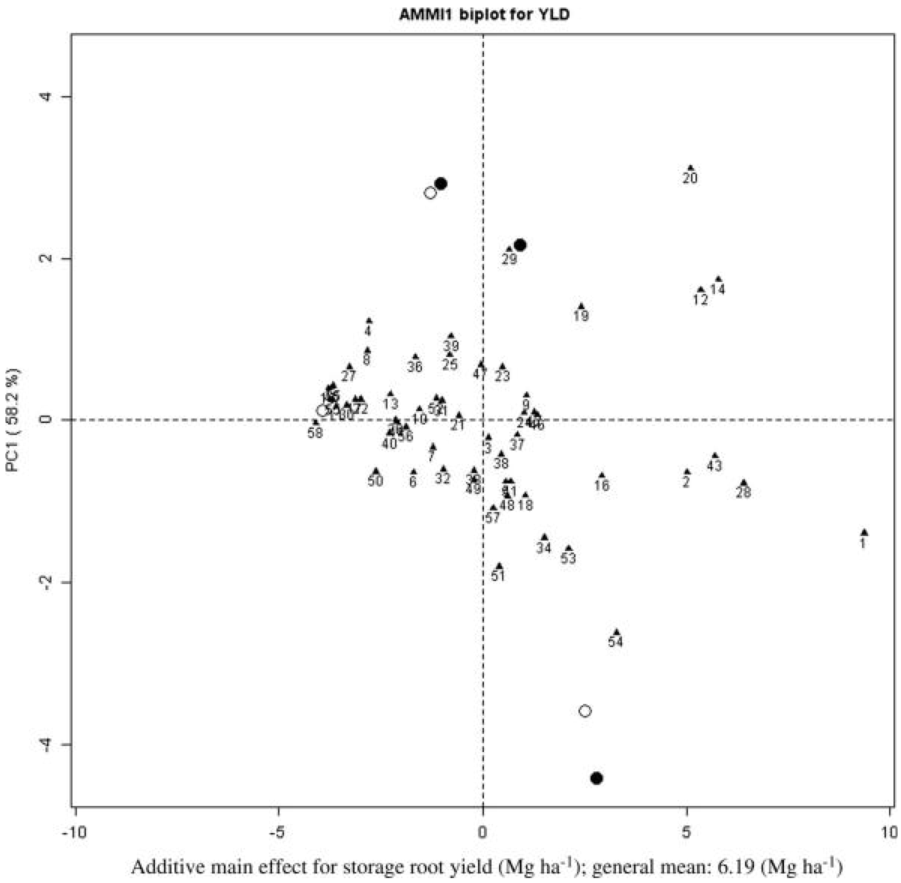

Fig. 3 The additive main effect and multiplicative interaction model 1 (AMMI1) bi-plot of sweetpotato clones(*black triangles*; numbering as per last two digits of IIAM codes given in Table 1) evaluated for storage root yield (YLD) in irrigated (*black circles*) and non-irrigated (*white circles*) environments at Umbeluzi in Mozambique between 2006 and 2009

Table 7 Pearson correlation coefficients among means (x_i), deviations from regression (Ms dev. R.), variances across environments (V_{env}), and interactions principal component 1 (IPCA1) and 2 (PCA2) scores of the additive main effect multiplicative interaction (AMI) model for storage root yield and harvest index of sweetpotato landraces and bred-germplasm included in multi-environment testing under irrigation and non-irrigation plots at Umbeluzi (Mozambique) between 2006 and 2009

	Storage root yield					Harvest index		
	x_i	MS dev. R.	V_{env}	IPCA1	IPCA2	x_i	MS dev. R.	V_{env}	IPCA1
Storage root yield									
MS dev R.	0.569***								
V_{env}	0.741***	0.802***							
IPCA1	0.532***	0.770***	0.785***						
IPCA2	0.364**	0.300*	0.363**	−0.053					
Harvest index									
x_i	0.698***	0.403**	0.576***	0.442**	0.204				
MS dev R.	0.338**	0.558***	0.546***	0.463**	0.118	0.483***			
V_{env}	0.416**	0.428**	0.659***	0.497***	0.195	0.574***	0.754***		
IPCA1	−0.119	0.227	−0.175	0.080	−0.140	−0.127	0.064	−0.356**	
IPCA2	0.248	0.031	0.215	−0.077	0.232	0.356**	0.088	0.268*	−0.000

*****, and * indicate highly significant at $P \leq 0.001$ or $P \leq 0.01$, and significant at $P \leq 0.05$, respectively

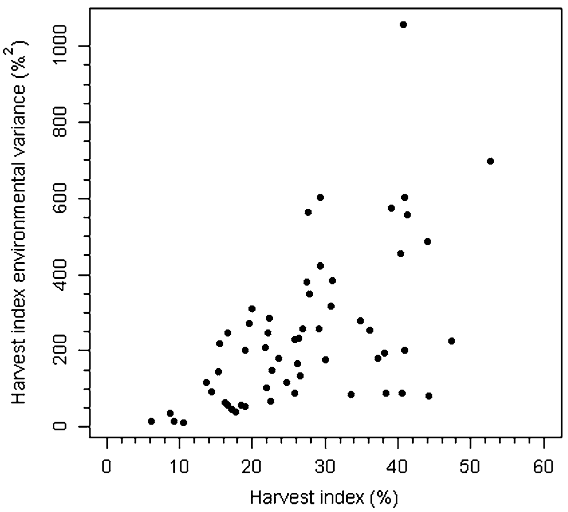

Fig. 4 Harvest index means and variance of harvest index across environments of sweetpotato clones at Umbeluzi in Mozambique between 2006 and 2009

treatments within a year and from year to year. G × E often poses a major challenge for cultivar selection in sweetpotato breeding.

Geometric mean and other drought indices are necessary for selection of sweetpotato genotypes performing well under both drought and optimum environments when the crossover G × E occurs. GMP, DTE and DSI identified ADMARC and Tacna as the two stable high-yielding performers. The harvest index of both—which belong to the same diversity cluster as per a recent analysis based on DNA markers (Maquia et al. 2013)—was high as well. These results indicate therefore that GMP, DTE, DSI and harvest index are useful to select genotypes that are high yielding under drought and optimum environments. Sweetpotato breeding programs have significantly improved storage root yield production of sweetpotato largely due to improved harvest index. The highest harvest index noticed in sweetpotato was 65 % (Evans 1993; Gifford and Evans 1981). In these multi-year trial modern cultivars and other bred-germplasm had significantly higher storage root yield than the farmers' landraces. The former, however, did not show storage root yield stability as noticed by their higher percent reduction under drought than the farmers' landraces. This finding also suggests that sweetpotato breeding for drought adaptation was not a priority elsewhere.

In summary, sweetpotato production environments vary highly and selection on sweetpotato germplasm based on storage root yield alone under optimum environments would bring a disadvantage for farmers growing this crop in poor environments. The use of drought indices and harvest index look promising for selecting bred-germplasm for various production environments and their use would be encouraged to start early in the breeding cycle.

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