academicJournals

Vol. 8(2), pp. 13-22, February, 2016
DOI: 10.5897/JPBCS2015.0529
Article Number: A75A57057175
ISSN 2006-9758

http://www.academicjournals.org/JPBCS

Journal of Plant Breeding and Crop Science

Full Length Research Paper

Genotype × environment interaction on sugar and biomass production in sweet sorghum (*Sorghum bicolor (*L). Moench) in western Kenya

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Received 4 August, 2015; Accepted 3 December, 2015

Genotype x environment interaction was determined from field experiments conducted to evaluate sweet sorghum genotypes in Western Kenya during the 2011, 2012 and 2013 rainy season from April to July at Alupe, Kibos, Homa Bay and Spectre International farm. The materials used in the study consisted of sixteen sweet sorghum genotypes and two sorghum genotypes sourced from ICRISAT and KARI. The treatments were laid out in a Randomized Complete Block Design (RCBD) and replicated three times. Data were collected on sorghum traits in accordance with the procedure outlined in the ICRISAT sorghum descriptor. The study revealed that genotype by environment interaction had significant influence on most of the traits. This indicates that selection for plant height, girth, brix juice, juice volume and stalks weigh cannot be carried out across the four environments, suggesting that selection for these traits have to be carried separately in each of the four environments.

Key words: Biomass, brix, environment, genotype, sweet sorghum.

INTRODUCTION

Genotype x Environment interaction can be defined as the differential response of varying genotypes under change(s) in the environment (Mather and Caligari, 1976). It refers to instances where the joint effects of genotype and environment are significantly greater or significantly reduced, than would be predicted from the sum of the separate effects (Andrew et al., 1998). In order to exploit the existing variability and develop new high yielding cultivars, sorghum improvement efforts under diverse environmental conditions are needed (Faisal and Aisha, 2011). There are many reports on G × E and stability studies in sorghum (Majisu and Dogget, 1972; Chapman et al., 2000; Haussmann et al., 2000; Kenga et al., 2004). Studying G × E for yield using 12 sorghum genotypes of diverse origin across 25 environments, Alagarswamy and Chandra (1998) found that 12% of the variation was due

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to genotypes, 61% due to environment while G × E accounted for 27%. Chapman et al. (2000) reported that most of the G × E in sorghum was a result of the genotype by location by year, but suggested breeders to deal with the genotype by location type over a fixed number of seasons.

The prevalence of environmental causes of variation over the genetic effects does not suggest that the importance of genotype should be minimized (Faisal and Aisha, 2011). However, global warming and climatic changes will reduce the productivity of many crops around the world. So that a considerable attention should be given to the effect of genotype x environment interaction in the plant breeding programs especially in the developed countries (Ghazy et al., 2012). Developing high yielding cultivars is mainly depending upon existing genetic variation among the germplasm under existing breeding programs. The relative performance of cultivars for quantitative traits such as yield and other characters, which influence yield, vary from an environment to another. Consequently, to develop a variety with high yielding ability and consistency, attention should be given to the importance of stability performance for the genotypes under different environments and their interactions (Ghazy et al., 2012). The interaction between genotype and environment has an important bearing on breeding for better varieties (Allard and Bradshaw, 1964). It is therefore important to conduct multi-location testing, quantify G × E and conduct stability analyses to select superior materials in sorghum.

The objective of the study was to investigate the influence of genotype by environment interaction on sugar and biomass yield of sweet sorghum in Western Kenya.

MATERIALS AND METHODS

Test materials

A total of sixteen varieties and two checks from ICRISAT (IESV 92038/2-SH, NTJ 2, IESV 92008 DL, IESV 93042-SH, IS 2331, IESV 91-018 LT, IESV 91104 DL, IESV 93046, Kenya Agricultural Research Institute (KARI) (KARI Mtama 2, GADAM,) Argentina (Malon, Paisano, Argensor 151 DP, Argensor 165 BIO) and United States of America (NK 5989-29005, NK 7829-29006, NK 8416-19075, NK 8830-29007) were evaluated in Randomized Complete Block Design with three replications during 2011, 2012 and 2013 for the 1^{st}, 2^{nd} and 3^{rd} seasons respectively.

Each entry was raised in four rows of 3 m length with a spacing of 70 cm × 20 cm. Sowing was done manually by placing 3 seeds in holes spaced 20 cm apart. Data were obtained from plants harvested from the two inner rows of each plot. Care was taken to reduce border effects due to unequal competition of cultivars by the appropriate use of sorghum buffer rows. Nitrogen fertilizer was added at a rate of 70 kg N/ha. All the package of practices were followed to raise a good and healthy crop.

Study sites

Four study sites were used; Kibos, CYMMIT farm; altitude 1190 m above the sea level (masl), average daily temperature is 24°C, rainfall per annum is 1441 mm and the soils are planosol. Alupe; altitude is 1165 masl, average daily temperature is 22.2°C, rainfall per annum is 1550 mm and the soils are acrisol. Spectre International farm-Kisumu**,** The soil type is chromic vertisol described as poorly drained, very deep, very dark grey to black, very firm, cracking clay. The average daily temperature is 23.1°C. The annual average rainfall per annum is 1353 mm. The altitude is 1164 masl. Homa Bay; soil types are black cotton, cracking and swelling montmorillonite. The altitude is 1190 masl. The mean daily temperatures are 25.8°C. The annual rainfall per annum ranges from 900 to 1200 mm. The materials were evaluated for three seasons. Data collected included days to 50% flowering, plant height (cm), stem thickness (cm), cane weight (g), juice volume (ml), brix % at 90 and 120 days after planting, pol % juice, purity % juice, panicle height at harvest (cm), panicle diameter (cm) and 100-grain weight (g).

Sampling was done in the following manner: Flowering date was recorded when 50% of the plot had flowered. The length of the plant from the ground to the panicle tip was measured to estimate plant height. Stem diameter was measured 20 cm above ground. The juice volume measured by using measuring cylinder. The fresh main stalk was pressed and 2 to 3 droplets of juice were collected on a sucrose- sensitive refractometer to measure the brix. Pol analysis was done using polarimetric method. Six gram of basic lead acetate was added to 300 ml of juice in clarification process. The juice was filtered through a Whatman filter paper No. 91. The pol reading was then fitted in the formula below to obtain Pol at 20°C; POL20 = PT {1+ 0.000185(T-20) - 0.000003 (T-20)2}.

Data analyses

The data obtained on all the characters over four environments and three seasons was subjected to GenStat 14th edition to perform the analysis of variance (ANOVA). The analysis used the Linear Model for randomized completely block design.

$$Y_{ij} = \mu + r_i + g_j + e_{ij}$$

Where: Y_{ij}= Observed effect for i^{th} replication and j^{th} genotypes, μ = grand mean of the experiment, r_i= effect due to the ith replication, g_j= effect due to jth genotype, e_{ij} = effects due to the residual or random error of the experiment.

Other analysis done included additive main effect and multiplicative interaction (AMMI) and Interaction Principle Component Axes (IPCA).

RESULTS

Performance of genotypes based on brix and biomass

Higher brix value during the 1^{st} season in 2011 (Table 1) was obtained from sweet sorghum cultivated in Kibos (13.9). Among the genotypes subjected to evaluation, IS 2331 recorded highest brix in Kibos (17.19). Pol percentage (Table 1) which is an indicator of sucrose percent varied from 5. 83 to 6.65 percent (environmental mean) across the two environments. Genotype IS 2331 showed the highest pol percent (10.8) while the lowest pol percentage was recorded by IESV 91018 LT (3.4%).

Table 1. Performance of genotypes for sugar and biomass related traits across two environments during the 1st season in 2011.

Location	Brix juice %		Girth (mm)		Height (cm)		Purity %		Pol % juice	
	Alupe	Kibos	Alupe	Kibos	Alupe	Kibos	Alupe	Kibos	Alupe	Kibos
GADAM	9.34	11.23	14.6	16.6	105.33	110.33	27.23	44.43	2.74	4.82
IESV 91018 LT	9.66	10.84	15.5	16.5	210.67	212.67	28.35	32.13	3.49	3.60
IESV 91104 DL	12.9	13.75	14.53	17.73	190.33	181.33	42.2	61.11	5.73	11.07
IESV 92008 DL	15.27	15.07	14.5	17.15	167.33	188.33	59.06	23.42	9.10	4.10
IESV 92038/2 SH	13.4	12.93	14.5	18.37	165..67	173.67	42.67	48.2	5.78	6.17
IESV 93042 SH	11.93	12.56	15.6	16.6	163.67	175.67	47.04	43.7	6.49	5.86
IESV 93046	13.06	14.43	13.87	17.87	270.00	278.20	51.07	57.99	6.78	8.34
IS 2331	15.86	17.19	15.47	17.47	261.00	272.33	62.56	61.97	9.91	10.84
KARI MTAMA 2	11.24	13.35	14.63	15.63	171.50	181.00	34.05	52.2	3.92	7.03
NTJ 2	11.44	14.21	13.97	16.97	200.24	237.67	38.18	30.47	4.41	4.63
Mean	12.41	13.956	14.717	17.08	193.34	201.12	43.24	45.56	5.83	6.65
LSD	4.707	2.356	1.728	1.604	15.75	14.65	29.2	31.03	5.03	5.30
CV%	22.11	9.84	6.84	5.76	11.35	11.15	39.36	39.71	50.23	46.53

The high coefficient of variation for purity percent and pol percent of 39 and 46% respectively in Kibos can be attributed to large variation among the genotypes with respect to the two attributes. For instance, the top performing genotype IS 2331 recorded purity percent of 61.9 and pol percent of 10.8 while the lowest performing genotype IESV 92008 DL registered purity percent and pol percent of 23.4 and 4.1 respectively under the same environment.

IESV 93046 and IS 2331 were the tallest varieties across the four locations (Table 2) registering mean height of 269.64 and 252.76 cm respectively. IESV 93046 was the best performing genotype in terms of juice volume (1199 ml) and brix % (14.2). Environment wise, Homa Bay was best performing registering highest genotypic mean of brix percent and pol percent of 14.8 and 8.8 respectively (Table 3).

Purity is important when sugar is to be produced from the juice. Alupe, Kibos, Homa Bay and Spectre environments varied for purity percent (Table 3) as evident from the varying environment mean (21 to 58.6%). Purity percent was at the maximum in Homa Bay (58.6) and the least was observed in Kibos (21). Among the genotypic means for purity IESV 93046 exhibited the highest value of 73.6% in Homa Bay.

From Table 3 Spectre environment registered the maximum environmental mean (590.2 ml) in terms of juice yield, whereas Alupe environment was the least favored (384 ml). Among the test genotypes, maximum juice yield was recorded by IESV 93046 (1550 ml) at Spectre International farm.

Analysis of variance

Across location and seasons analysis of variance (Table 4) showed that genotypes and seasons were significantly different (P<0.001) for all the major traits evaluated. Locations x seasons interactions were significantly different (P<0.001) for brix juice percent, juice volume and purity percent. Location x variety interactions were significantly different (P<0.001) for girth, stalk weight and juice volume. Higher interactions of location by season by variety was significant (P<0.05) for brix percent. For brix juice percent, genotypes, environments and interactions accounted for 8.9, 31 and 5.5% of the sum of squares treatment respectively (Table 4).

Analysis of variance for Additive Main Effect and Multiplicative Interaction (AMMI) model showed significant differences amongst treatments, genotypes, environments and interactions between genotypes and environments (P>0.001) (Table 5). For girth, genotypes, environments and interactions accounted for 60.8, 28.1 and 10.9% of the sum of squares treatment respectively. For brix juice percent, genotypes, environments and interactions accounted for 14.4, 69.6 and 16.0% of the sum of squares treatment respectively. For purity juice percent, genotypes, environments and interactions accounted for 19.1, 60.1 and 20.7% of the sum of squares treatment respectively. When the analysis was split into Interaction Principle Component Axes (IPCA), IPCA-1 and IPCA-2 showed significant different mean purity percent (P<0.01) and captured 58.5 and 37.3% of the sum of squares for interaction (Table 5).

Figure 1 presents AMMI biplot providing a visual expression of the relationships between the second interaction principal component axis (IPCA2) and means of genotypes and environments based on brix percent juice.

The AMMI biplot (Figure 1) showed four groupings of genotypes; IESV 91018 LT, generally low brix and stable; NK 7829-29006 and KS 5989-29005, low brix and

Table 2. Mean of agronomic and quality parameters of sweet sorghum genotypes across locations in 2012 season two at 120 days after planting.

Variety	Height (cm)	Girth (mm)	Brix (%)	Pol (%)	Juice volume (mm)	Purity (%)	Grain weight (g)	Stalk dry weight (g)
ARGENSOR 151 DP	139.49	18.3	9.45	4.01	452	37.68	203.6	346.9
ARGENSOR 165 BIO	217.49	19.5	11.11	4.78	796	39.44	302.4	659.4
GADAM	107.01	18.3	9.43	4.32	215	40.87	146	300.6
ICSV 91018 LT	220.53	22.5	7.56	2.34	1161	26.41	250	567.7
ICSV 9104 DL	196.71	20.3	12.7	6.74	607	46.76	269.6	402.3
ICSV 92008 DL	178.85	19.2	12.56	6.44	698	45.52	313.4	456.4
ICSV 92038/2 SH	166.55	20.5	11.56	5.72	536	43.38	286	532.8
ICSV 93042 SH	167.6	20	11.08	5.52	532	44.45	237.8	414.5
ICSV 93046	269.64	20.4	14.24	9.47	1199	57.30	290.7	448.2
IS 2331	252.76	19.2	13.32	7.72	694	53.00	251.7	587.8
KARI MTAMA 2	167.88	18.7	11.11	6.05	190	45.68	183.7	404.1
KS 5989-29005	120.18	21.2	9.77	4.73	232	43.64	219.1	420.6
MALON	117.06	20.5	8.91	3.87	279	37.33	220.6	417.4
NK 7829-29006	95.59	22	8.94	5.48	168	47.63	202.9	383.3
NK 8416-19075	114.9	18.3	9.04	4.64	111	44.91	192.3	295.6
NK 8830-29007	100.86	21.3	8.84	4.13	178	42.07	203.2	384.0
NTJ 2	202.47	20	10.12	4.07	731	36.09	273	453.4
PAISANO	115.18	21.3	9	4.22	411	42.51	252	555.4
P-values	0.016	<.001	<.001	<.001	0.035	<.001	<.001	<.001
Lsd	21.194	2.20	2.307	2.432	317.8	13.59	134.20	159.61
Sed	10.721	1.11	1.167	1.229	160.8	6.87	67.89	80.74
CV %	8.0	6.8	13.6	28.8	38.6	19.6	34.8	26.3

Lsd=Least significance difference, Sed= Standard error of difference, CV=Coefficient of variation.

unstable. The other two groups included NK 8830-29700 and NTJ 2 that had moderate brix yield and stable and IESV 93046 that had high brix yield but unstable. Homa Bay showed high brix yields and high stability while Kibos was low yielding and very unstable environment. However, Spectre was more stable than Alupe. Figure 2 presents AMMI biplot providing a visual expression of the relationships between the second interaction principal component axis (IPCA2) and means of genotypes and environments based on girth.

The AMMI biplot (Figure 2) showed four groupings of genotypes; NK 8416-19075 thin and unstable; ARGENSOR.151 DP thin and stable. The other two groups included IESV 93046 and NTJ 2 that had moderate girth and stable and NK 7829-29006 and KS 5989-29005 that were thick but unstable. Homa Bay and Alupe showed high stem girth and high stability while Spectre and Kibos were low girth and unstable environments.

Figure 3 presents AMMI biplot providing a visual expression of the relationships between the second interaction principal component axis (IPCA2) and means of genotypes and environments based on purity juice percent.

The AMMI biplot (Figure 3) showed three groupings of genotypes; IESV 91018 LT low purity percent and unstable; IS 2331 moderate purity percent and stable; IESV 93046 high purity and unstable. Homa Bay environment registered high purity percent but was unstable while Kibos recorded low purity percent and was equally unstable.

Results from AMMI analysis (Table 6) revealed that the best environment was Homa Bay recording the best overall mean for girth, brix juice percent and purity percent. The best four genotypes in terms of brix were IESV 93046, IESV 92008 DL, IS 2331 and IESV 91104 DL. IESV 93046 can be considered stable and adaptable to wider environments in terms of sugar quality. Kibos consistently registered the lowest genotypes means on the parameters evaluated.

DISCUSSION

High brix was recorded by some genotypes (Table 3), IESV 93046 registered brix of 17.2% in Alupe and IESV 92008 DL registered brix of 17.2% in Homa Bay. The results are closer to what was observed by Reddy et al., (2005) of 16 to 23% brix and slightly higher than that observed by Woods (2000) of 11.0 to 18.5% brix among

Table 3. Mean of quality parameters of sweet sorghum genotypes by locations in 2012 season two at 120 days after planting.

Variety	Brix (%)				Pol (%)				Juice Volume(ml)				Purity %			
	AL	HB	KB	SP	AL	HB	KB	SP	AL	HB	KB	SP	AL	HB	KB	SP
ARGENSOR 151 DP	7.37	14.21	8.97	7.24	2.57	8.46	2.84	2.15	147	372	867	422	35.1	59.5	27	29.5
ARGENSOR 165 BIO	10.02	14.77	10.13	9.52	3.97	8.24	3.49	3.43	537	923	843	880	32.3	55.1	34	36.1
GADAM	11.14	12.25	5.17	9.17	5.41	7.18	0.50	4.18	143	212	328	178	46.5	57.5	14	45.5
IESV 91018 LT	10.57	9.17	3.90	6.60	4.09	2.96	0.44	1.85	890	1293	1103	1357	38.4	31.1	8.9	27.2
IESV 9104 DL	17.11	16.35	6.11	11.24	11.52	9.34	1.23	4.89	718	680	390	640	67.1	57.1	20	43.4
IESV 92008 DL	13.10	17.25	7.45	12.45	6.91	10.91	1.52	6.42	555	688	640	908	52.4	62.3	16	51.6
IESV 92038/2 SH	13.99	16.22	6.06	9.97	7.78	9.86	1.01	4.23	463	635	468	577	55.7	60.7	15	42
IESV 93042 SH	14.37	14.23	5.43	10.27	8.83	7.59	1.10	4.54	463	650	299	717	59.6	53	21	44.1
IESV 93046	17.26	18.51	5.34	15.83	12.07	13.63	0.84	11.34	933	1423	890	1550	69.4	73.6	15	71.2
IS 2331	16.83	16.83	8.04	11.57	11.70	11.12	2.31	5.77	612	885	493	787	68.6	66	28	49.9
KARI MTAMA 2	11.46	18.56	5.62	8.78	6.71	12.50	1.46	3.51	90	157	228	283	51.6	67.4	24	39.4
KS 5989-29005	9.13	15.14	5.88	8.95	4.51	9.52	1.53	3.37	137	188	303	300	49	62.9	25	37.5
MALON	6.57	14.21	5.96	8.89	3.12	8.29	0.87	3.19	133	317	279	385	42.1	57.8	14	35.3
NK 7829-29006	5.44	14.46	6.32	9.52	6.48	9.14	1.89	4.39	85	183	193	210	54.6	63.2	28	44.7
NK 8416-19075	7.46	13.58	6.61	8.52	5.64	7.37	1.80	3.72	52	98	215	78	51.9	55.9	28	44.2
NK 8830-29007	6.91	14.13	5.72	8.61	3.03	8.45	1.38	3.64	103	227	200	183	43.2	59.4	23	42.3
NTJ 2	11.74	12.94	6.21	9.61	5.67	6.25	0.79	3.57	540	943	607	833	47.7	48.1	12	36.5
PAISANO	6.58	13.66	7.34	8.42	2.37	8.81	2.08	3.63	320	452	538	335	35.3	64.4	28	42
Location Means	**10.95**	**14.80**	**6.46**	**9.73**	**6.24**	**8.87**	**1.50**	**4.32**	**384.0**	**573.7**	**493.6**	**590.2**	**50.0**	**58.6**	**21**	**42.36**
P-values	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	0.004	<.001	<.001
Lsd	2.674	2.746	3.492	1.960	3.009	2.645	3.406	1.828	147.9	195.5	218.5	210.8	15.03	20.59	11.35	13.63
Sed	1.314	1.350	1.718	0.9645	1.467	1.454	1.674	0.8995	72.77	96.11	107.5	103.7	7.314	10.02	5.655	6.708
CV %	14.47	17.18	17.25	13.06	26.81	31.89	27.25	26.24	23.18	17.05	21.95	21.01	16.80	23.36	11.92	19.38

AL=Alupe, HB=Homa Bay, KB=Kibos and SP=Spectre International Farm, Lsd=Least significance difference, CV=Coefficient of variation.

genotypes evaluated. This variation could be attributed to stalk variety, different soils and climatic conditions.

Purity is important when sugar is to be produced from the juice. Alupe, Kibos, Homa Bay and Spectre environments varied for purity percent (Table 3) as evident from the varying environment mean (21 to 58.6). Mean purity percent was at the maximum in Homa Bay (58.6) and the least was observed in Kibos (21). Among the genotypic means for purity IESV 93046 exhibited the highest value of 73.6% in Homa Bay. Similar report was given earlier by Woods (2000) where the apparent purity for the sweet sorghum varieties considered varied from 48.2 to 69.7% whereas that of sugarcane juice was 83.6%. Sucrose purity is used to calculate the ease with which sucrose can be extracted and crystallized and 75% is required as the minimum (Woods, 2001). Among the genotypes evaluated IESV 93056 has potential of being exploited for sucrose extraction and crystallization.

Superior performance of genotypes in Homa Bay (Table 3) can be attributed to montmorillonite soils in this environment which are very efficient in nutrient uptake. Genotypes performed better in Spectre International farm than Kibos despite the fact that these environments have similar average

Table 4. General ANOVA for sugar and biomass traits across location and seasons.

Source of variation	d.f.	Girth	Explained percentage	Stalk weight	Explained percentage	Brix juice %	Explained percentage	Juice volume	Explained percentage	Purity juice %	Explained percentage
Location	3	2308.77***	19.59	1.29**	1.65	817.70***	31.02	310314.00*	1.92	4101.40*	4.62
Season	1	16494.31***	46.65	27.40***	11.67	495.85**	6.27	7617835.00***	15.72	7617.20**	2.86
Location x Season	3	7.89ns	0.07	3.06ns	3.91	104.58***	3.97	607658.00***	3.76	12516.30***	14.10
Location/season/rep	16	4.02**	0.18	0.17ns	1.16	42.26***	8.55	42435.94ns	1.40	622.97*	3.74
Variety	17	19.00***	0.91	5.48**	39.67	41.61***	8.94	992040***	34.80	2120.90***	13.53
Location x Variety	51	2.01***	0.29	0.23ns	4.99	8.53ns	5.50	47190ns	4.97	451.70ns	8.65
Season x Variety	17	4.85***	0.23	1.72***	12.45	12.36ns	2.66	396022***	13.89	776.60ns	4.96
Location x Season x Variety	51	0.45ns	0.06	0.30***	6.51	10.54*	6.80	55770***	5.87	482.20	9.23
Residual	284	1.80	1.45	0.14	16.93	7.32	26.29	27732	16.25	358.50	38.22
Total	427	82.81		0.55		18.52		113491		623.88	

ns=not significant *Significant at 0.05, ** significant at 0.01, *** significant at 0.001.

Table 5. AMMI ANOVA for sugar and biomass traits across locations.

Source of variation	df	Girth	Explained percentage	Brix Juice %	Explained percentage	Purity juice %	Explained percentage
Treatments	71	9.99***		40.59***		1011***	
Genotypes	17	25.41***	60.88	24.40***	14.40	809***	19.16
Environments	3	66.66***	28.19	668.50***	69.60	14382***	60.11
Block	8	4.19ns		59.36***		1288***	
Interactions	51	1.52ns	10.92	9.05**	16.00	292***	20.73
IPCA I	19	3.28ns	80.39	15.09***	62.26	458***	58.50
IPCA II	17	0.80ns	17.55	6.81ns	25.16	327**	37.36
Residuals	15	0.11ns	2.19	3.93ns	12.80	41ns	4.13
Error	136	2.24		5.23		139	
Total	215	4.87		18.92		470	

ns=not significant *Significant at 0.05, ** significant at 0.01, *** significant at 0.001.

daily temperatures and rainfall per annum. Very deep and firm clay soils at Spectre International farm might have contributed to better performance under this environment. Woods (2000) reported that sweet sorghum performance variation could be attributed to different soil conditions.

Combined analysis of variance (Table 4) revealed highly significant (P≤0.001) variations among environments, genotypes, seasons, genotype x

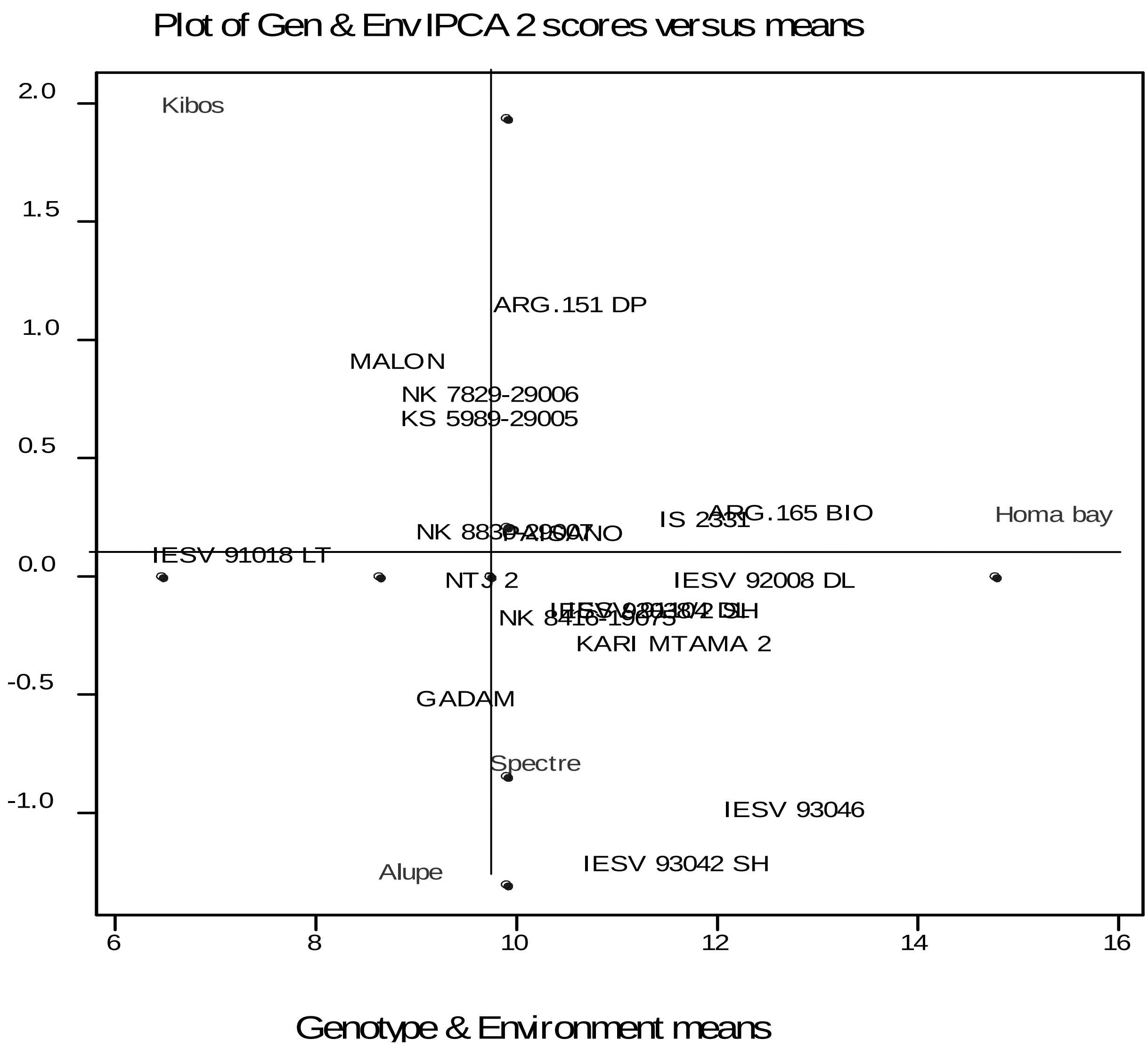

Figure 1. AMMI biplot of interaction principal component axis-2 (IPCA-2) against mean brix % juice of 18 genotypes and four environments.

environment and environment x variety x season interaction.

This result revealed that there was a differential yield performance among the sweet sorghum genotypes across testing environments and seasons. Maarouf and Moataz (2009) reported variation between sorghum genotypes with respect to fodder production. This indicate that, simultaneous selection for girth, brix% , stalk weight and purity percent is not possible across the four environments and that selection for each location have to be carried out separately. This limit their wider utilization, as reported by Pham and Kang (1988) who stated that, significant G x E for a quantitative trait is known to reduce the usefulness of the genotype means over all locations or environments for selecting and advancing superior genotypes to the next stage of selection.

Across location and seasons analysis of variance (Table 4) showed that genotypes and seasons were significantly different (P<0.001) for all sugar related traits. Seasons x variety interactions were significantly different (P<0.001) for girth, stalk weight and juice volume. Chapman et al., (2000) reported that most of the G × E in sorghum was a result of the genotype by location by year, but suggested breeders to deal with the genotype by location type over a fixed number of seasons. This difference among seasons can be attributed to heavy rains received in 2012.

When the interaction between environments and genotypes was significant further analysis was done using Additive Main Effects and Multiplicative Interaction (AMMI) model to determine adaptive response of specific

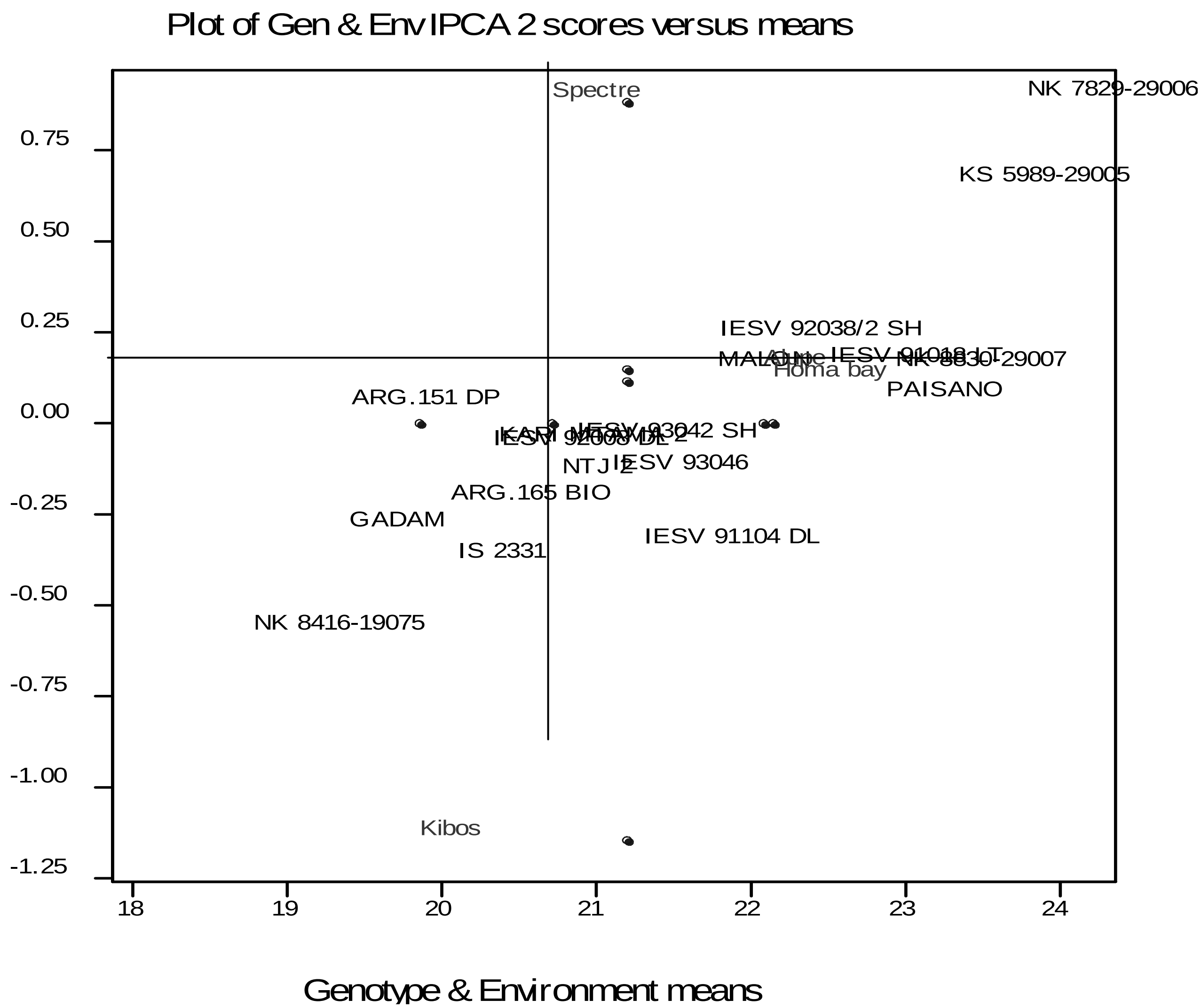

Figure 2. AMMI biplot of interaction principal component axis-1 (IPCA-1) against mean girth of 18 genotypes and four environments.

genotypes to specific locations (Annicchiarico, 2002; Egesi and Asiedu, 2002).

Analysis of variance for Additive Main Effect and Multiplicative Interaction (AMMI) model showed significant differences amongst treatments, genotypes, environments and interactions between genotypes and environments (P<0.001) (Table 5). For brix percent, genotypes, environments and interactions accounted for 14.4, 69.6 and 16.0% of the sum of squares treatment respectively. These variations are closer to the ones reported by Alagarswamy and Chandra (1998) while studying G × E for yield using 12 sorghum genotypes of diverse origin across 25 environments. He found that 12% of the variation was due to genotypes, 61% due to environment while G × E accounted for 27%.

Interaction principal component axis (IPCA1) based on brix percent was significant (P<0.001) while Interaction principal component axis (IPCAII) on the same parameter was not significant (Table 5). Van Euwijik (1995) noted that the first axis represents the hypothetical environmental variable which describes interaction as much as possible and therefore is best suited to discriminate between genotypes.

Conclusions

High performance demonstrated by genotypes IESV 93046 and IS 2331 for stem brix and stem biomass shows their potential for exploitation for ethanol production. Homa Bay is the best environment for sweet sorghum production. The study indicated that selection for girth, brix percent juice, purity percent and stalks weigh cannot be carried out across the four environments, suggesting that selection for these traits have to be carried separately in each of the four environments.

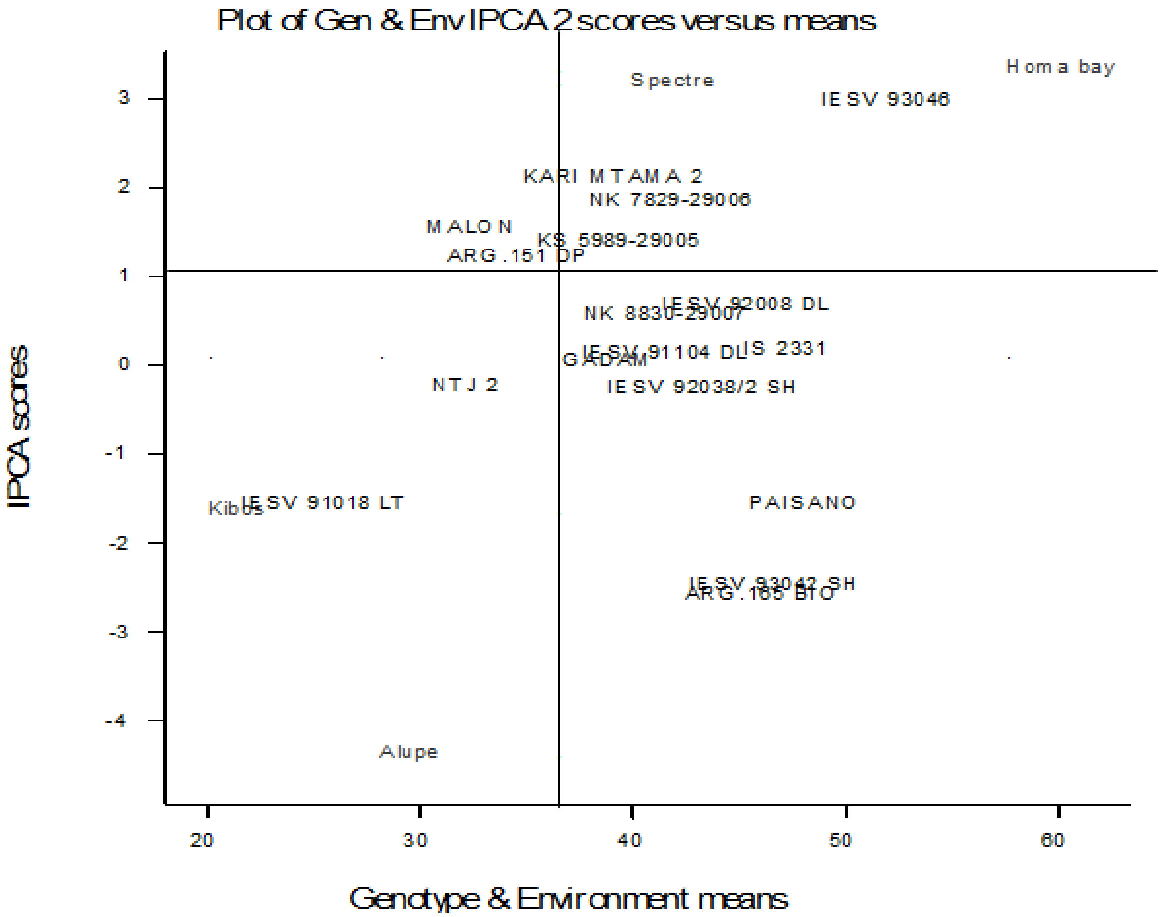

Figure 3. AMMI biplot of interaction principal component axis-1 (IPCA-1) against mean purity % of 18 genotypes and four environments.

Table 6. First four AMMI selections per environment on the basis of girth, brix % and purity %.

S/N	Girth (mm)					
	Environment	**Mean**	**1**	**2**	**3**	**4**
1	Homa bay	22.14	NK 8830-29007	PAISANO	KS 5989-29005	MALON
2	Alupe	22.08	NK 8830-29007	PAISANO	KS 5989-29005	MALON
3	Spectre	20.71	NK 7829-29006	KS 5989-29005	PAISANO	NK 8830-29007
4	Kibos	19.86	NK 7829-29006	KS 5989-29005	PAISANO	NK 8830-29007
				Brix%		
1	Homa bay	14.763	IESV 93046	IESV 92008 DL	IS 2331	IESV 91104 DL
2	Spectre	9.731	IESV 93046	IESV 92008 DL	IS 2331	IESV 91104 DL
3	Alupe	8.626	ARG.165 BIO	IESV 93042 SH	NK 8416-19075	PAISANO
4	Kibos	6.46	ARG.165 BIO	ARG.151 DP	IS 2331	IESV 92008 DL
				Purity %		
1	Homa bay	57.6	IESV 93046	NK 7829-29006	IS 2331	KARI MTAMA 2
2	Spectre	39.9	IESV 93046	IESV 92008 DL	IS 2331	GADAM
3	Alupe	28.12	IESV 93042 SH	PAISANO	ARG.165 BIO	GADAM
4	Kibos	20.01	ARG.165 BIO	PAISANO	NK 8416-19075	IS 2331

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

Funding from Kenya Sugar Research Foundation and logistical support from Kenya Agricultural Research Institute, ICRISAT and Mark Consulting Services Limited are greatly appreciated.

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