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Agronomic and morphological performance of sorghum (*sorghum bicolour* l.) for the dry highlands of Kenya

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ABSTRACT
Objectives: The use of low yielding cultivars has been a major cause of poor sorghum production in the semi arid areas of Kenya. A study was conducted to determine the agronomic and morphological suitability of improved sorghum lines for adaptability to dry highlands of Kenya.
Methodology and Results: An experiment was set up as RCBD with 3 replicates at two sites (Nakuru and Baringo Counties) in the Rift valley Province of Kenya in March/April 2008 and 2009 to determine the plant height, flowering date, grain yield, 100-seed weight and agronomic score of 28 sorghum genotypes. Of the 28 genotypes evaluated, five lines gave significantly higher grain yield than the local check, Ikinyaruka. Mean grain yield was higher at the cooler, wetter Lanet site (3587.5 Kg ha^{-1}) compared to the drier site, Koibatek (2298.5 Kg ha^{-1}). At Koibatek, grain yield was higher in 2008 (2298.8 Kg ha^{-1}) against 715.4 Kg ha^{-1} for 2009. The genotypes were classified into extra early flowering and maturation (BJ 28 and IESV90015 with mean days to flowering of about 80 days; medium maturity (100-107 days to 50% flowering) and late (Koibatek local with 161 days to flower and IS 11909 with 111 days to flower).
Conclusion and application of findings: The late maturity genotypes showed potential for forage by virtue of high biomass through multiple tillering and drought recovery. The IESV series experienced less grain yield reduction compared to other lines under reduced rainfall.
Key Words: Flowering, rainfall, grain yield, agronomic score

INTRODUCTION

Sorghum is adapted to semi arid areas receiving 400 to 800mm of rainfall annually by virtue of its heat and drought tolerance. With improved cultivars, appropriate water and soil management practices this amount of rainfall can support production of sorghum. Only a limited number of sorghum varieties have been developed for the dry highlands of Kenya and are mainly a few forage and dual-purpose types (Ouma *et al*., 1995, Ashiono *et al*., 2005). Seeds developed for the low altitude, high rainfall zones (western Kenya) and for the low altitude, low rainfall zones (mainly eastern Kenya) are not suitable for the low rainfall, high altitude areas (mainly Rift Valley) of Kenya. In the dry highlands, low night temperatures and occasional frost limits growth and seed set of un-adapted cultivars (Arkel, 1979) making seed multiplication of un-adapted varieties unsuccessful. Previous studies have shown that sorghum cultivars adapted to high altitude, low rainfall areas have consistently out yielded maize grown under similar conditions (King and Mukuru, 1992) and would therefore be a suitable alternative crop during years of low rainfall. Sorghum grain yields under low input agriculture (land races, no chemical fertilizers and rain fed) range between 500 to 1000 kg/ha. The potential grain yield of improved varieties in Kenya under high altitude low rainfall conditions is about 3.8tha $^{-1}$ (King and Mukuru, 1992). In the Rift Valley province of Kenya, sorghum is mainly grown in West Pokot, Kericho, Turkana, Marakwet, Baringo and Nandi, but the grain yields are low (Anonymous, 2006). In the dry highlands, low night temperatures <13ºC during the flag leaf stage, can induce male sterility and reduce pollen viability (McLaren, 1997) and possibly stigma receptivity (Osuna- Ortega *et al*., 2000) resulting in partial or complete failure of seed set. Additionally, the plants become susceptible to attacks by sorghum ergot, a non-systemic disease of the ovaries of sorghum resulting in poor seed set and low seed quality.

The variable response of genotypes to low temperature in the dry highlands therefore necessitates evaluation of a broader range of genotypes under different sites in Kenya in order to increase the number of improved varieties adapted to these production areas. The objective was therefore to improve food security among small-scale farmers in sorghum growing areas of the dry highlands of Kenya through evaluating and selecting varieties with high and stable yields.

MATERIALS AND METHODS

The experiment was sited at Lanet, Nakuru County; located on Latitude 0º 30'S and Longitude 36ºE at an altitude of 1920 m a.s.l. The mean maximum temperature during June to August period was 25.3ºC and 28.1 ºC in 2008 and 2009; a minimum of 9.4ºC and 8.7 ºC in 2008 and 2009 respectively. The soils are deep loams to sandy loam with high water holding capacity (Jaetzold *et al*., 2005). Sowing was done on 15th April 2008 and harvested on 28th October 2008 at Lanet. The rainfall received in 2008 and 2009 were 636.7mm and 381.9mm respectively. The second trial site was at Koibatek Agricultural training Centre, Koibatek County. ATC-Koibatek lies at latitude 1º 35' S, and longitude 36º 66' E, altitude 1890 m a.s.l. in agro-ecological zone UM4, with low agricultural potential. Average annual rainfall is 767 mm; mean annual minimum and maximum temperature are 10.9ºC and 28.8ºC respectively. Soils are Vitric Andosols with moderate to high soil fertility, well-drained deep sandy clay loams to sandy loam soil (Jaetzold et. al., 2005).

At Koibatek, sowing was done on 17nd April 2008 and on 22nd April 2009, harvesting carried out on 29th September 2008 and on 8th September 2009 respectively. The plots were laid out as Randomised Complete Block Design with three replicates. Twenty four sorghum lines from International Crops Research Institute for the Semi arid Tropics and 4 local varieties were evaluated, with each variety sown to four rows, 4m long and 0.75m apart, with intra row spacing of 0.20 m. Blocks were separated by a 1m path and plots by 0.5m paths. Total plot size was 1312m2 (0.1312ha), but ¼ ha was prepared to grow large guard row area to limit bird damage. Fertilizer Diammonium Phosphate (18% Nitrogen, 46% Phosphorous) was applied at sowing, in the furrow at a rate of 36 kg N ha $^{-1}$ and 92 kg P_2O_5 ha $^{-1}$. Weed control was done using 2, 4-D amine at a rate of 0.6L/ha at the 4 to 6 leaf stage; thereafter sorghum was manually weeded one month later. The following traits were measured to evaluate varietal behaviour: days to flowering (DF), when at least half the plants in the plot shows exposed anthers at the middle of the panicle, was recorded from date of sowing and plant height at maturity. Agronomic score was determined at maturity visually and rated from 1 to 5, where, 1 is excellent and 5 very poor; grain yield ha $^{-1}$ based on grain dry matter at harvest of ten panicles from the main stems per plot after physiological maturity, as determined by black layer formation, then oven dried at 65ºC. 100 -seed weight was determined after drying seed. Analysis of variance was done using the general linear model (GLM) of SAS (SAS, 2001). Mean separation was performed using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Plant Height: The results of the performance of sorghum lines tested at Lanet and Koibatek are presented (Table 1). There was highly significant interaction between site and genotype (P<0.0001) in 2008. Genotypes BM30, Ikinyaruka and Nyundo were stable in height when moved to Koibatek. Fifteen genotypes had height reduction on being moved from Lanet to Koibatek, and 10 genotypes, i.e. E1291, MB29, BM 27, N2, BJ 28, IESV 91054LT, IESV91069LT, IESV91071LT, IESV91015LT, and IS9203 showed height increments on being moved to Koibatek. Sorghum plants were generally taller at Lanet (mean 165.45cm) compared to Koibatek (mean 147.02 cm). This was probably due to higher temperatures and water stress at Koibatek. At Lanet, the growing season was longer therefore sorghum was able to grow much taller, within the limits of genotype.

Table 1: Sorghum varietal performance in yield, days to flowering, plant height, 100- seed weight and agronomic score mean of two sites in Kenya

Variety	GY kg ha $^{-1}$	DTF	PH (cm)	100- SW	SCORE
IS11909	4477.8	111.67	173.5	2.798	3.667
IS25562	4307.4	107.67	194.31	2.828	3.33
BM16	4187.2	101	202.64	2.82	2.5
S87	3719.5	104.17	143.19	2.898	2.83
BM30	3503.6	101.5	131.25	2.928	2.5
Ikinyaruka **	**3462.4**	**91.5**	**128.38**	**3.00**	**2.83**
E1291	3413.7	94.83	177.5	2.9633	2.00
BM18	3402.0	104.5	120.69	3.093	2.83
NYUNDO	3236.0	98.6	120.69	2.880	3.167
NDAMOGA	3230.9	101.17	141.92	2.890	3.0
MB29	3222.7	105.17	173.33	2.860	3.167
S79	3214.7	105	181.78	2.7217	3.33
MB39	3022.6	100.83	198.45	2.865	3.5
CYTANOMBE	2965.3	105.67	190	3.032	3.50
MB30	2937.5	103.67	205.14	2.9167	2.33
URUKURAZA	2919.4	103.17	177.14	2.938	4.167
IESV91054LT	2903.9	103	119.72	2.728	2.667
IS9201	2866.5	104.33	179.28	2.680	4.33
IS9203	2729.9	98.83	153.75	2.870	2.667
BM27	2713.0	96.83	143.47	2.9617	2.833
ABALESHYA	2609.6	103	135.97	2.8917	2.667
BM32	2401.8	103.5	192.67	3.105	3.00
IESV91069LT	2348.4	96.5	106.53	3.0133	2.500
IESV91071LT	2337.1	93.17	114.72	3.0133	2.667
N2	2091.1	95.75	144.61	3.0233	4.00
KOIBATEK LOCAL	1986.2	161.33	209.86	2.7200	3.667
IESV90015LT	1050.7	80.33	128.33	3.0400	4.33
BJ 28	979.1	81.67	66.81	2.9233	4.83

** Local check

GY Grain yield, DTF days to 50% flowering, PH plant height SW seed weight, SCORE agronomic score

A significant interaction at P<0.046 between year and variety for sorghum plant height was obtained. This was mainly due to the differential response of the sorghum lines to the better rainfall obtained in 2008 compared to 2009 for both trial sites (Fig 1 and 2). The influence of rainfall (Fig.1) and temperature (data not presented) was more evident at Koibatek.

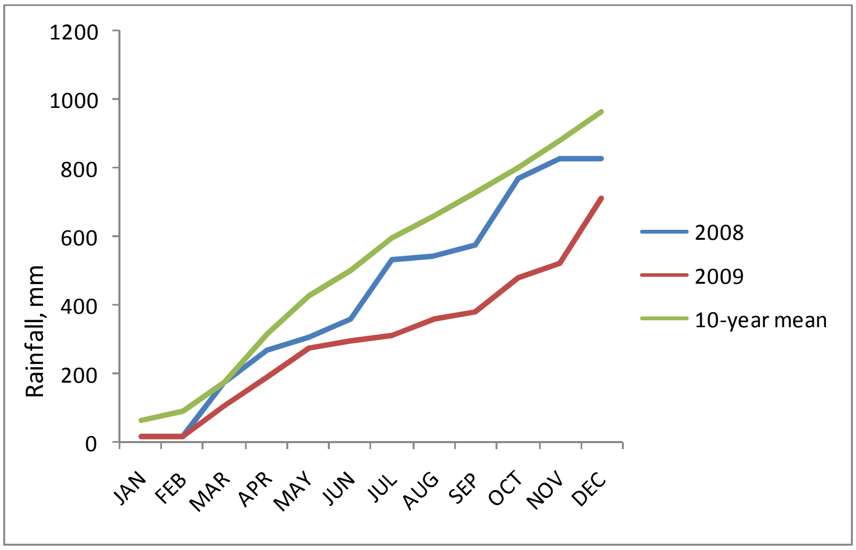

Figure 1: Cumulative rainfall at Koibatek in 2008 and 2009, during Sorghum growing period

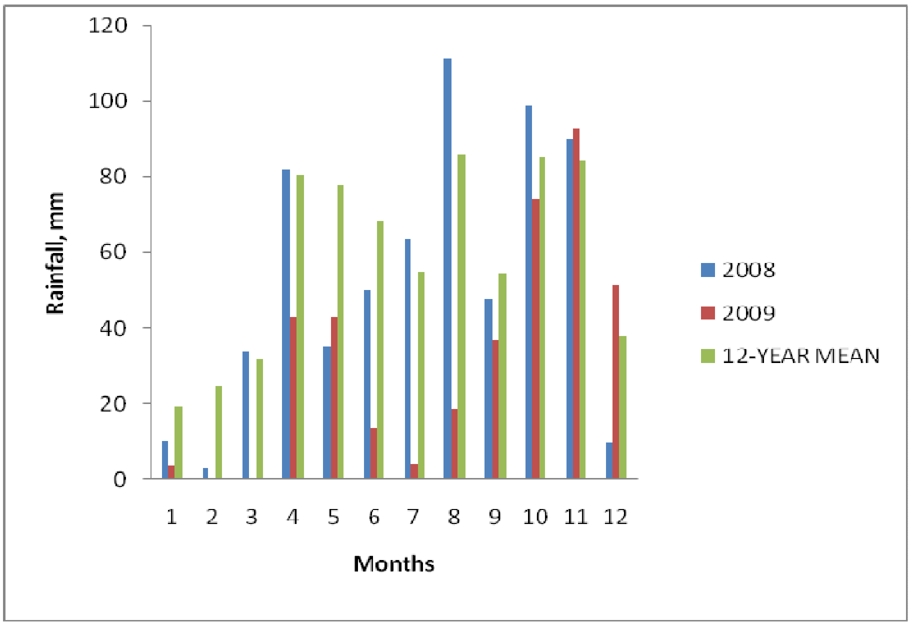

Figure 2: Distribution of rainfall at Lanet, Kenya in 2008 and 2009Days To 50% Flowering

There was a highly significant (P<0.0001) site by variety interaction for days to 50% (Table 1). The number of days to flowering ranged from 83 to 218 d at Lanet and from 78 to 105d at Koibatek. The mean days to flowering at Lanet was 117.4 and at Koibatek 87. The varieties, which flowered earliest at Lanet, also flowered earliest at Koibatek. The rate of flowering was however accelerated at Koibatek, which is at lower altitude and warmer. A comparison of 2008 and 2009 at Koibatek further confirmed the observation that lower rainfall contributed to earlier flowering in the sorghum lines tested. In 2008, the mean number of days to 50% flowering was 93.68 compared to 87.30 in 2009 (Table 2). This response could be due to adaptation of sorghum to water stress, to natural selection or human selection. Haussmann *et al*., 2006 also found that early anthesis in sorghum hybrids was the most important specific adaptation to extreme drought.

Table 2: Sorghum varietal performance in yield, plant height and 100- seed weight at Koibatek, Kenya

Site	**2008**					**2009**				
Genotype	**GY kg ha $^{-1}$**	**DTF**	**PH (cm)**	**100-SW**	**SCORE**	**GY kg ha $^{-1}$**	**DTF**	**PH**	**100 SW**	**SCORE**
IS11909	4142.11	94.3	158.67	2.76	3.3	0	108	113.73	2.61	4.3
IS25562	2481.22	90	149.45	2.65	2.3	462.37	93	173.77	1.65	4.3
BM16	3022.27	85.67	134.44	2.88	2.3	749.26	91	143.33	1.69	3.7
S87	2375.14	87.33	171.11	2.72	2.7	77.96	99.67	168.90	2.18	4.0
BM30	2851.24	86.3	143.65	2.76	2.7	771.0	95	152.1	1.68	2.3
Ikinyaruka **	**2974.82**	**87**	**131.67**	**2.85**	**3.0**	**225.57**	**100.5**	**123.1**	**1.68**	**3.3**
E1291	2573.01	86.33	143.42	2.8	2.0	1241.24	88.67	120.07	1.45	2.0
BM18	2637.64	89	153.17	2.76	3.0	776.52	93	167.63	2.14	3.3
NYUNDO	2504.78	83.33	121.39	2.8	3.0	893.28	93	144.90	1.92	4.0
NDAMOGA	2270.45	86	137.16	2.8	3.3	1254.17	90.67	135.23	1.35	3.0
MB29	3564.38	90.67	190	2.95	3.0	1457.57	91.67	178.17	1.91	2.3
S79	2494.39	86.33	141.89	2.57	3.0	848.61	93.5	147.47	1.81	3.3
MB39	2461.38	85.32	175.22	2.85	3.7	324.94	93	206.47	1.79	4.0
CYTANOMBE	2246.73	89.67	147.50	2.74	3.2	741.98	91.67	189.17	1.65	4 .0
MB30	1616.77	88	153.61	2.94	2.3	595.79	89	145	2.00	3.3
URUKURAZA	1464.01	86	145.11	2.81	4.7	802.49	92.67	199.1	1.78	2.0
IESV91054LT	2310	84.67	146.11	2.5	2.7	151.2	104.33	99.57	1.41	3.3
IS9201	1214.52	86.67	136.89	2.37	4.0	795.74	94.5	187.9	2.08	4.7
IS9203	1942.89	88	160.83	2.73	2.7	553.15	91.3	146.17	1.96	3.3
BM27	2541.51	85	158.61	2.73	2.2	94.47	90.5	125.90	2.02	4.0
ABALESHYA	1910.38	86.3	130.28	2.81	2.0	812.85	93	144.80	1.81	3.0
BM32	1916.77	88	146.17	2.79	3.0	545.89	93.3	195.7	1.83	4.3
IESV91069LT	1919.27	82	121.39	2.73	2.7	1143.73	98.33	109.53	1.53	1.3
IESV91071LT	2068.91	86.67	141.11	2.93	3.3	1693.51	83	112.77	1.52	1.7
N2	1723.07	93.67	155.89	2.88	4.0	608.45	93.3	153.13	1.75	3.3
Koibatek local	**3306.38**	**104.67**	**193.89**	**2.7**	**2.3**	**0**	**110.67**	**130.93**	**-**	**5.0**
IESV90015LT	1049.21	77.32	156.67	2.85	4.3	979.08	74.33	124.8	2.24	3.7
BJ 28	772.82	80	111.94	2.59	4.7	-	-	-	-	-
MEAN	2298.5	93.68	148.45	2.76	3.42	715.40	87.30	148.09	1.84	3.1

GY Grain yield, DTF days to 50% flowering, PH plant height SW seed weight, SCORE agronomic score

Grain Yield: Grain yield varied significantly among varieties and between the two sites. There was no significant site x variety interaction for this parameter (Table 1). Sorghum grain yield reached a mean of 3587.5 kg ha at Lanet compared to 2298.5 kg/ha at Koibatek (Table 3) The grain yield obtained at Lanet compares favourably with previously recorded sorghum yield under research management (King and Mukuru,1992; Ashiono *et al*., 2005) confirming the possibility of obtaining high yield at high altitude tropical areas. For all the genotypes, except Koibatek local at Lanet, there was no significant difference in seed setting of panicles, indicating that they were tolerant to low temperatures at flowering. In 2008 and 2009 the mean minimum temperature was 9.4 and 8.7 ºC during the period of June to August at Lanet.

100-Seed weight: The 100 seed weight did not differ among varieties, but the differences were highly significant between Lanet and Koibatek. The mean seed weight at Lanet was higher than at Koibatek (Table 3). This was probably due to more favourable growing conditions Lanet.

Table 3: Mean performance of sorghum lines by site

Site	GY kg ha $^{-1}$	DTF	PH (cm)	100- SW (g)	SCORE
Lanet, Nakuru County	3587.5	117.4	165.45	3.069	3.28
Koibatek, Eldama Ravine County	2298.5	87.4	147.02	2.757	3.06
Lsd	245.33	1.87	9.32	0.286	0.31

GY Grain yield, DTF days to 50% flowering, PH plant height SW seed weight, SCORE agronomic score

Agronomic Score: The agronomic score is a visual composite score that indicates the relative agronomic suitability of the variety for a specific purpose. It involves the simultaneous selection for grain yield and acceptable levels of other agronomic traits. It is rated from a scale of 1 to 5, with the lower values indicating excellent and higher values poor to very poor. It is rapid and is therefore suitable for screening out those lines under test that are poor performers. The results at both sites indicate that the varieties being evaluated were average in suitability, and no differences were discerned between the sites (Table 3).

DISCUSSION

The variation in the number of days to 50% flowering and 100-seed weight were low within each site. The number of days to flowering was significantly and positively correlated with height and yield but not 100-seed weight. Under severe water stress as experienced in 2009, Days to flowering was significantly and negatively correlated with grain yield and 100 seed weight. Grain yield variation was greatest in 2009 under less rainfall confirming the conclusions that grain yield in sorghum is positively correlated with rainfall amount (Arkel, 1980). However, certain lines showed lower reduction in grain yield loss indication relative stability under limited moisture conditions. The large differences in grain yield between Lanet and Koibatek and between years at Koibatek were mainly due to difference in rainfall received during the crop growing period. This confirms the results of Arkel, 1980 within the same altitude range.

Earlier flowering and maturing lines had relatively low grain yield. Lansac *et al*. (1996) found differences in seed number, and grain yield per panicle among genotypes. Earlier maturing genotypes had lower seed number and yield than medium and late- maturing genotypes, but greater seed size at low temperatures. Genetic studies have shown that phenotypic correlation between plant height and grain yield in sorghum is variable depending on the breeding lines. Mutava *et al*. (2011) found negative correlation between plant height and grain weight, grain numbers and yield in a study involving 300 sorghum genotypes from different races. Significant positive phenotypic correlation between plant height and days to flowering has been observed in several studies with sorghum. Such results were obtained in this study; the early lines were much shorter than late flowering lines.

CONCLUSIONS

Reduction in rainfall caused a significant reduction in grain yield in sorghum grown at two high altitude sites in Kenya. Variation in the number of days to flowering, plant height and grain yield depended on genotype and environment. The genotypes with a combination of medium maturity, short to medium height and stable grain yield were considered suitable for the more drought prone Koibatek site. Very early flowering and maturity genotypes were largely unsuitable due to extensive bird damage.

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