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Screening and Evaluation of Forage Sorghum Cultivars for Forage production using multi-criterion decision analysis

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ABSTRACT

Studies were carried out to estimate the extent of variability in forage sorghum (Sorghum bicolor L. Moench) genotypes developed by individual plant selection among the land race cultivar " Abu Sab'in " . Five exotic cytoplasm male sterile lines and four fertile local inbred lines of forage sorghum were evaluated during seasons 2002 and 2003. across three environments (locations : Shambat 1, Shambat 2 and Omdoum), to obtain information on genetic and morphological diversity. The experiment was laid out in a randomized complete block design with three replications. Fourteen different agronomic and quality traits were measured including yield, quality and growth traits. The results obtained indicated that significant differences ($P \leq 0.05$) were observed between genotypes and genotypes × location interaction for most of the combined traits in the studied lines. These nine lines exhibited high phenotypic and genotypic variances for most of the traits. Significant mean squares were obtained for almost all traits in the individual analysis of variance as well as the combined analysis across environments, suggesting that, this sorghum population was highly variable for almost all the traits, therefore, would respond to selection. Cultivar performances estimated by compromise programming technique. This technique of multi-objective criteria ranked the cultivars in descending order of preference as: IS.9830, S-grass W, Abu70, TX624.A, KEN24.A, S-grass R, KEN41.A, TX623.A, and KEN16.A as the promising cultivars in terms of Fresh weight (t/ha), Dry weight (t/ha), Crude protein (%),Crude fiber (%),HCN (p p m), Plant height/ (cm), Days to 50% flowering, No. of leaves/ plant, No. of tillers/ plant, Plant density/m^2, Stem diameter (cm), Leaf area (cm^2), Leaf to stem ratio, and Shoot to root ratio. With respect to all decision-makers the cultivar IS.9830 is always ranked as first choice, while the cultivar KEN16.A ranked as least preferred three times by Economist, farmer, and agronomist and as next to the last by animal specialist and with equal weights. Individual and the combined analyses indicated that most characters had higher genotypic and phenotypic variance components than the environmental variance estimates, which is indicative that character expression in this sorghum population was genetic and can be exploited in breeding programs.

Key words: Sorghum cultivars; growth traits; yield components; variability; multi-criterion Decision Making; Compromise programming.

Introduction

Phenotypic variability in sorghum for yield and other traits has been reported by many workers [23,10,12,26,17,8,1,5,6]. Progress in plant breeding programs depends on the extent of genetic variability present in a population. This is because selection of desirable genotypes for hybrid industry will not be effective unless a considerable amount of variation is existing in the genotypes under investigation. In sorghum breeding programs and hybrid development, sorghum breeders used a diverse inbred grown across a wide range of environments. Effects of environmental factors on phenotypic variability of sorghum were indicated by Foitz patrick and Nix [7]; Lewis *et al*. [15] and Mohammed [18].

The phenotypic variability in a given environment can be measured easily, but it reflects non genetic as well as genetic influence on the phenotypic expression. Therefore, genetic variability, cannot easily be measured. The genetic facts are inferred from phenotypic observations, which are the results of interactions of genotype and the environment. Lukhele and Obilana [16], Kambal and Abu-Gasim [2] reported that genetic variability varies with location. Consequently, they considered

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in their research studies spatial variations to ascertain results stability across environments.

The area under forage crops in Sudan has recently witnessed a rapid increase to meet the growing need for animal products. In Khartoum State (according to statistics of Ministry of Agriculture, 2006), forage crops represent around 80 % of the total area cultivated, the majority of which was cropped to the traditional type Abu Sab'in [*Sorghum bicolor* (L). Moench]. Abu Sab'in, though merited by high productivity and vigor in growth, is known to have poor quality attributes because the stalks are dry, non sweet and sparsely leafed . Lack of cultivars with high yield, good quality and well adapted to Sudan environments is the most important problem facing forage sorghum production in the Sudan. Mohammed [18] stated that very few efforts have been exerted to develop improved forage cultivars from the local stocks. Efforts for developing forage was only confined to introduction and testing of the exotic hybrids. Khair [13] reported that, shortage in forage seeds, poor knowledge about forage sorghum production technique among farmers, the method of making up forage sorghum into silage or hay are another problems need to be solved.

Forage sorghum productivity is just 4% of the total production of the irrigated green forages in Sudan [13]. However, the traditional animal production sector in the Sudan depends on natural ranges, which had been threatened by the encroachment of mechanized crop production schemes, seasonal bush fires, excessive use around watering sites and drought.

In the present study, therefore, the variability present in nine sorghum (*Sorghum bicolor* L. Moench) cultivars were studied with the objective of estimating the amount of genetic variability present in this local cultivars across environments and for purpose of Screening and evaluation of forage sorghum cultivars for improving forage production.

Multi criterion decision analysis (MCDA) techniques are gaining importance as potential tools for solving complex real world problems, because of their inherent ability to consider different alternative scenarios, the best of which may then be analyzed in depth before being finally implemented. [9,25,20]. In order to apply MCDA techniques, it is important to specify the following:

The objectives, which indicate the directions of state change of the system under examination and need to be maximized, minimized or maintained in the same position.

The attributes, which refer to the characteristics, factors and indices of the alternative management scenarios. An attribute should provide the means for evaluating the attainment level of an objective.

The constraints, which are restrictions on attributes and decision variables that can or cannot be expressed mathematically.

In MCDA the aim is not to obtain an optimal solution, as would be the case with only one objective, but a "non-inferior" or "non-dominated" solution. This is a solution that improves all objective functions. Other solutions cannot improve a single objective without causing a degradation of at least one other objective.

Materials And Methods

Experimental Design, Management and Plant Materials:

During the 2002-2003 cropping seasons two locations were chosen as experimental environments for the evaluation of the collected cultivars in replicated trials. The experiment was carried out at Demonstration Farm, Faculty of Agriculture, University of Khartoum, Shambat (15o75′N, 32o72′E), and the Demonstration Farm, Arab Authority for Agricultural Investment and Development (A.A.A.I.D), Omdoum (15^{o}56′N, 32^{o}59′E) over the period from August to October 2002 at Shambat1, and the period from April to June 2003 at both Shambat 2 and Omdoum under irrigation conditions.

The plant material used in this study composed of nine selected cultivars of forage sorghum (*Sorghum bicolor* L. Moench).They includes Abu70, IS.9830, Sudan grass W and Sudan grass R and five exotic cytoplasm male sterile lines (CMS). The experiment was laid out in a randomized complete block design with three replications at each location and season.

The experimental area was disc ploughed, disc harrowed and leveled. Ridging was north-south, 70 cm a part. The land was divided into 3 × 3.5 m plots, each composed of 4 ridges two meters long. Seeds were sown on the 8th of August 2002, the 21th of April 2003 and the 23th of April 2003 at Shambat1, Shambat2 and Omdoum, respectively. Seed rate applied was 15kg/fed, the seeds were sown on the top of the ridge. Nitrogen fertilizer (urea 46% N) was applied in one dose of 77 kg/fed three weeks after planting. Hand weeding was frequently done to get rid of weeds. Irrigation was scheduled at 10 – 12 days intervals.

Data Collection and Assessment:

Forage yield traits:

At harvest (after the plants had reached the 50% flowering) one meter length was taken from the two inner rows to measure forage fresh weight (ton/ha) and forage dry weight (ton/ha). Quality traits measured at Shambat 2 and Omdoum includes: Crude protein (%)determined by micro-kjeldhal method [19], Crude fiber (%) Determined according to the method of AOAC using fibertic system

1010oC heat extraction and HCN (p p m). For measuring HCN (p p m) ten plants were taken randomly from each plot in Shambat 2, Omdoum locations. They were milled in a pressure machine, the extracted juice was filtered through centrifuge model 3500 at 5000 rounds per minute. Then the spectrophotometer was used to determine the absorption of the juice at wavelength (λ) 293 nm, then the glycoside concentration was calculated according to the formula described by British Pharmacopoeia [4].

Growth traits:

For data collection of growth traits, except plant density and days to 50% flowering, 10 plants were randomly selected from the two inner rows in each plot, and then data were recorded on:

1- Plant height (cm): where the plant height was measured from the ground level to the tip of the panicle (head).
2- Days to 50% flowering (days) which is Obtained by counting the number of days from sowing date up to the day when 50% of the plants in each plot had reached flowering.
3- Number of leaves/plant: They were counted at harvest.
4- Number of tillers/plant: They were counted at harvest.
5- Plant density (number of plants/m^2): This trait was measured before harvest by counting number of plants per unit area.
6- Stem diameter (cm): Measured as the average thickness of the stem at the fourth internodes from the top of the plant .
7- Leaf area (cm^2): The length and the maximum width of the fourth leaf from the top of the plant were measured at the harvest, then the leaf area was calculated according to Ibrahim *et al*. method [11].
8- Leaf to stem ratio: Mean of the dry weight of the leaves 12 to Mean of the dry weight of the stem.
9- Shoot to root ratio: Mean of the dry weight of the shoot to Mean of the dry weight of the root.

The means for the studied yield, quality and growth traits of the nine cultivars of forage sorghum, evaluated at each one of the three locations is given in table 1. The Combined means of the different traits of the nine cultivars of forage sorghum averaged over three locations s (Shambat 1, Shambat 2 and Omdoum) is shown in table 2.

Table 1: Means for some yield, quality and growth traits of the nine cultivars of forage sorghum, evaluated at: Shambat 1.

Cultivars	Fresh weight (t/ha)	Dry weight (t/ha)	Plant height (cm)	Days to 50% flowering (days)	No. of leaves/ plant	No. of tillers/ plant	Plant density /m^2	Stem diameter (cm)	Leaf area (cm^2)	Leaf to stem ratio	Shoot to root ratio
Abu70	22.6	5.8	172.8	61.3	10.7	0.4	48.3	1.1	283.5	0.9	4.0
IS.9830	32.5	8.2	142.7	51.7	11.0	0.8	51	1.2	246	0.6	3.4
S-grass W	17.7	3.9	147.9	39.0	9.0	2.7	189.7	0.5	84.3	2.2	1.3
S-grass R	15.5	3.2	118.9	63.0	9.0	3.4	148	0.6	107.0	1.0	0.7
TX623.A	11.7	3.4	62.9	70.3	9.0	1.0	33.0	1.3	245.4	2.5	1.5
TX624.A	25.1	5.4	76.8	64.0	10.3	0.8	46.3	1.5	328.9	1.5	2.5
KEN16.A	18.0	3.8	80.3	71.0	12.0	0.9	29.7	1.5	248.9	1.1	2.9
KEN24.A	10.4	2.6	61.6	72	9.3	2.0	35.0	1.4	228.5	3.9	1.4
KEN41.A	20.2	3.6	71.8	70.3	9.7	1.7	46.0	1.0	198.3	1.9	2.5
Overall mean	19.3	4.4	104	62.5	10	1.5	69.7	1.1	219	1.7	2.2
C.V%	32.6	35.1	17.6	44.0	11.1	95.5	26.5	20.8	12.0	43	54.7
LSD	10.9	2.7	31.7	4.8	1.9	2.5	32.0	0.4	45.3	1.3	2.1

Table 1 (Cont.) Shambat 2.

cultivars	Fresh weight (t/ha)	Dry weight (t/ha)	Plant height (cm)	Days to 50% flowering (days)	No. of leaves/ plant	No. of tillers/ plant	Plant density /m2	Stem diameter (cm)	Leaf area (cm2)	Leaf to stem ratio	Shoot to root ratio
Abu70	16.8	6.0	7.9	39.0	394.7	169.6	62.3	13.7	0.3	34.0	1.4
IS.9830	29.2	9.9	8.3	38.2	309.3	149.5	57.7	13	0.3	32.0	1.5
S-grass W	27.4	10.8	7.4	37.0	380.9	175.9	47.3	10.3	0.2	109.3	0.7
S-grass R	24.5	8.3	7.9	37.8	226.7	158.8	67.7	11.3	0.1	97.7	0.7
TX623.A	17.6	5.1	7.9	35.9	452.7	91.7	77.0	11.7	0.7	27.3	1.3
TX624.A	14.3	4.6	9.2	35.4	292.9	91.2	86.0	12	0.6	24.3	1.3
KEN16.A	6.1	1.7	7.9	35.9	374.7	77.9	85.0	11.3	0.7	16.3	1.2
KEN24.A	16.7	6.9	8.8	36.7	388.4	84.2	83.7	10.3	0.3	30.7	1.2
KEN41.A	9.2	2.8	8.3	37.7	339.3	75.7	80.3	11.3	0.4	38.3	1.4
Overall mean	18	6.2	8.2	37.1	362.1	119.4	71.9	11.7	0.4	45.6	1.2
C.V%	59.8	60.8	6.7	6.4	17.1	7.3	3.1	13.4	110.3	37.8	12.5
LSD	18.6	6.6	1.3	5.5	143.1	15.0	3.8	2.7	0.8	29.8	0.3

Table 1 (Cont.) Omdoum.

Parental lines	Fresh weight (t/ha)	Dry weight (t/ha)	HCN (ppm)	Plant height (cm)	Days to 50% flowering (days)	No. of leaves/ plant	No. of tillers/ plant	Plant density /m2	Stem diameter (cm)	Leaf area (cm2)	Leaf to stem ratio	Shoot to root ratio
Abu70	31.7	9.2	313.2	79.8	61.3	16.7	0.0	39.7	1.4	314.1	0.7	3.5
IS.9830	43.1	11.2	302.5	147.2	56.0	14.3	0.2	68.3	1.0	250.4	0.8	3.3
S-grass.W	34.3	12.0	305.7	124.9	49.7	10	1.3	332.7	0.9	83.9	0.8	3.1
S-grass.R	39.8	11.3	297.9	126.5	56.0	10.7	1.0	215.7	0.3	102.6	0.7	2.8
TX623.A	34.5	8.6	309.3	67.5	72.0	12.3	0.0	54.0	1.0	217.6	0.8	2.7
TX624.A	31	7.7	297.2	64.3	81.7	11.3	0.0	89.3	1.4	258.6	0.8	2.9
KEN16.A	36.9	9.2	299	50.2	89.7	11.3	0.0	69.0	1.9	255.8	0.8	2.7
KEN24.A	31.2	7.8	296.4	64.6	91.3	11.3	0.0	61.0	1.4	219.7	0.8	2.6
KEN41.A	53.8	10.4	303.5	59.1	75.3	14.3	0.0	84.0	1.4	277	0.9	3.2
Overall mean	37.4	9.7	302.8	87.2	70.3	12.5	0.3	112.6	1.2	220	0.8	3.1
C.V%	11.3	18.7	2.8	18.3	16.0	8.7	70.6	40.3	54.5	22.7	1.5	24.9
LSD	7.3	3.1	19.4	27.6	19.4	1.9	0.4	78.6	0.1	86.4	0.2	1.3

Table 2: The Combined means of the different traits of the nine cultivars of forage sorghum averaged over three locations s (Shambat 1, Shambat 2 and Omdoum).

Cultivar	Fresh weight (t/ha)	Dry weight (t/ha)	Crude protein (%)	Crude fiber (%)	HCN (p p m)	Plant height/ (cm)	Days to 50% flowering (days)	No. of leaves/ plant	No. of tillers/ plant	Plant density /m^2	Stem diameter (cm)	Leaf area (cm^2)	Leaf to stem ratio	Shoot to root ratio
Abu70	23.7	7.0	8.3	37.5	353.9	140.7	61.7	13.7	0.2	40.7	1.3	267.8	0.9	5.4
IS.9830	34.9	9.8	9.0	41.4	305.9	146.4	55.1	12.8	0.4	50.4	1.2	235.9	0.9	3.6
S-grass W	26.5	8.9	8.1	38.2	343.3	149.6	45.3	9.8	1.4	210.6	0.7	82.4	1.3	4.4
S-grass R	26.6	7.6	8.6	39.6	312.3	134.7	62.2	10.3	1.5	153.8	0.6	106.3	0.9	2.1
TX623.A	21.3	5.7	8.3	37.6	381	74	73.1	11.0	0.6	38.1	1.2	220	2.2	2.1
TX624.A	23.4	5.9	9.9	36.4	294.8	77.4	77.2	11.2	0.5	53.3	1.4	259.2	1.7	3.6
KEN16.A	20.3	4.9	7.9	40.1	336.7	69.5	81.9	11.6	0.5	38.3	1.6	218	1.6	2.8
KEN24.A	19.4	5.8	9.4	38.7	342.4	70.2	82.3	10.3	0.8	42.2	1.3	207.5	2.6	2.7
KEN41.A	27.7	5.6	9.0	36.2	321.4	68.7	75.3	11.8	0.7	56.1	1.3	212.3	2.2	2.8
Overall mean	24.9	6.8	8.7	38.4	332.4	103.5	68.3	11.4	0.7	76.0	1.2	201.1	1.6	3.3
C.V%	30.5	38.1	8.4	6.6	13.3	14.4	10	11.2	120	39.5	34.9	17.2	38.2	45.9
LSD	7.2	2.5	1.1	3.8	66.4	14.1	6.4	1.2	0.8	28.4	0.4	32.7	0.6	1.4

Statistical Analysis:

To estimate the extent or magnitude of variation among these cultivars the data obtained was subjected to single statistical analysis of variance for each environment separately based on plot means followed by a combined analysis of the data across the three environments; these were done according to methods described by Singh and Chaudhary [24]. Comparison between genotypes means were separated using the least significant difference (LSD) at 5% level of significance. Components of variance were used for the estimation of coefficients of variation(c.v) as described by Singh and Chaudhary [24]. The computer program M-STAT was used for statistical analysis. The data were analyzed separately and combined based on randomized complete block design.

Phenotypic variability:

Analysis for phenotypic variability was carried out for all recorded traits, i.e., for yield, quality and growth traits. Locations, genotypes and replications were regarded as random variables. The test of homogeneity of variance revealed heterogeneity of the error mean squares for yield, quality, number of leaves, number of tillers and leaves to stem ratio among the cultivars.

Compromise Programming:

In this study, we used the Compromise Programming (CP) model for screening phenotypic variability for growth and yield traits in Sorghum. It is employed to rank different traits in Sorghum for studying the adoption of the best forage Sorghum cultivar for the three locations.

Criteria Decision Making (MCDM) includes of numerous mathematical techniques in multiple that can be used based on studies. MCDM includes Multiple Objective Decision-Making (MODM) and Multiple. Attribute Decision Making (MADM). MODM programming is used to design the models. The main objective of MADM is ranking and choosing the best alternatives. In this study, based on objectives and different criteria related to various cultivars of Sorghum(bicolor L. Moench), we used the Compromise Programming (CP), which is one of the MADM that can be used in ranking cultivars of forage Sorghum and also determining the best system. CP is a distance – based technique designed to identify non-dominated solutions which are closest to an ideal solution using a quasi–distance measure [21,27].

Compromise programming was used to choose the optimum element from a set of efficient solutions as proposed by Zeleny [28]. CP starts by establishing the ideal point whose coordinates are given by the optimum values of the various objectives of the decision maker. The ideal point is usually infeasible. If it is feasible then there is no conflict among objectives. When the ideal point is infeasible the optimum element or compromise solutions is given by the efficient solution that is closer to the ideal point. Thus, the degree of closeness as relative deviation d1 between the jth objective and its ideal value is defined by employing the operative structure of CP as summarized in the following way. First, the degree of closeness dj between the jth objective and its ideal is defined by:

$$d_j = (Z_j^{*} - Z_j'(x)) / (Z^{*}_j - Z_{*j}) \qquad (1)$$

$X \varepsilon F$

Where F is the set of all feasible farm plans and X is a vector of the decision variables. $X \in F$ thus denotes the linear constraints and non-negatively restrictions component of the standard LP problem. For $L = \infty$ where the maximum of the individual deviations is minimized, the best compromise farm plan was obtained by solving the linear problems. In order to measure the distances between each solution and the ideal point the following distance function was used.

$$L_p(A_i) = \sum_{j=1}^{K} [\sum jk (u_j d_j)^p]^{1/p} \qquad (2)$$

Where $L_p(A_i)$ is the distance metric which is a function of the decision alternative A_i. Parameter P, u_j is the standardized form of the criterion weight where $1 \leq P \leq \infty$ that shows the sensitivity of decision maker about evaluations. Compromise programming procedure is applied in five steps as given in the conceptual flow chart of figure 1 [22]. The parameter P in the above expression weights the deviations according to their magnitudes. Greater weight is given to the longest deviations as the magnitude of P increases. Thus, with P = 1 the maximum of the individual deviation is minimized ■j represents the weights to dj signifying the importance of the discrepancy between the jth objective and its ideal value. In the study four sets of ■j were considered to obtain the different compromise solutions under the assumptions of varying weights for the discrepancies. The magnitude of K in the present case was also four i.e., the number of objectives considered for optimization. Lj representing the longest distance geometrically was minimized by using the following linear programming problem for obtaining the best compromise farm plan.

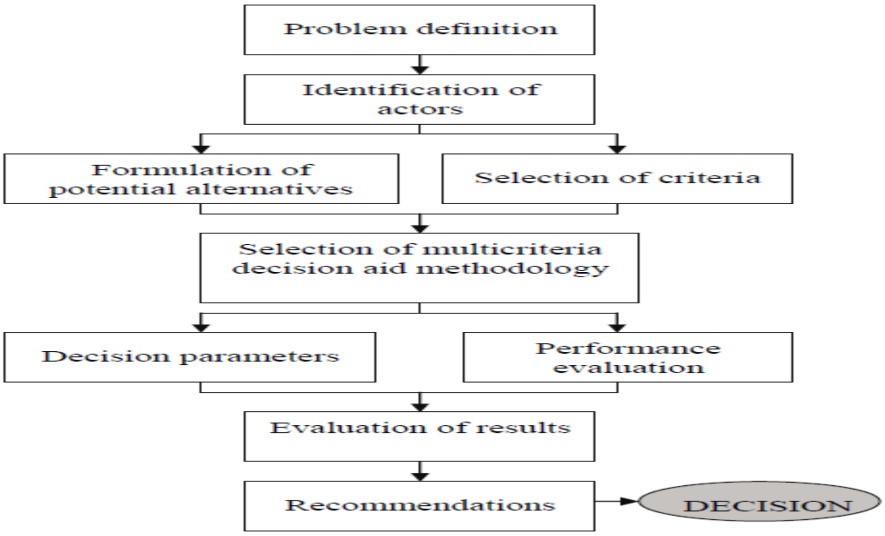

Fig. 1: Flow chart of the framework of Compromise programming technique.

In this study, results of performance of investigated cultivars with respect to various criteria (traits) are used to evaluate and rank genotypes of Sorghum(bicolor L. Moench) that are shown in Table 3.

For in depth investigation other different criteria were considered. Consequently, three weight groups were employed. In the first group, all criteria have the same weight. In the second, third and fourth groups, criteria weights were assigned in the range of 0.0 to 1.0 by economist, animal production specialist, a farmer and agronomist (Table 4).

Results And Discussion

Performance of Forage Sorghum cultivars over locations:

The significant mean square values obtained from the analysis of variance for the individual location suggests that differences existed between the sorghum cultivars for most characters, indicating that they are highly variable (Table 5). The significant mean square values obtained for location (Table 6), for some of the characters indicated that the conditions in the two locations were not similar in many ramifications.

Table 3: Payoff matrix of the performance of investigated cultivars with respect to various criteria (traits).

Cultivar	Fresh weight (t/ha)	Dry weight (t/ha)	Crude protein (%)	Crude fiber (%)	HCN (ppm)	Plant height (cm)	Days to 50% flowering (days)	No. of leaves / plant	No. of tillers / plant	Plant density /m2	Stem diameter (cm)	Leaf to area (cm2)	Leaf stem ratio	Shoot to root ratio
Abu70	24	7	8.3	38	354	141	62	14	0.2	41	1.3	268	0.9	5.4
IS.9830	35	9.8	9	41	306	146	55	13	0.4	50	1.2	236	0.9	3.6
S-grass W	27	8.9	8.1	38	343	150	45	10	1.4	211	0.7	82	1.3	4.4
S-grass R	27	7.6	8.6	40	312	135	62	10	1.5	154	0.6	106	0.9	2.1
TX623.A	21	5.7	8.3	38	381	74	73	11	0.6	38	1.2	220	2.2	2.1
TX624.A	23	5.9	9.9	36	295	77	77	11	0.5	53	1.4	259	1.7	3.6
KEN16.A	20	4.9	7.9	40	337	70	82	12	0.5	38	1.6	218	1.6	2.8
KEN24.A	19	5.8	9.4	39	342	70	82	10	0.8	42	1.3	208	2.6	2.7
KEN41.A	28	5.6	9	36	321	69	75	12	0.7	56	1.3	212	2.2	2.8
Max	35	9.8	9.9	41	381	150	82	14	1.5	211	1.6	268	2.6	5.4
Min	19	4.9	7.9	36	295	69	45	10	0.2	38	0.6	82	0.9	2.1
Max-Min	16	4.9	2	5	86	81	37	4	1.3	173	1	185	1.7	3.3

Table 4: Vectors of maximum (best) and minimum (worst) values and four sets of criterion weights.

Evaluation Indicator	Equal weights	Economist	Animal Production Specialist	Farmer	Agronomist	Max	Min	Max- in
Fresh weight (t/ha)	1.0	0.2	0.1	0.1	0.2	35	19.4	15.5
Dry weight (t/ha)	1.0	0.2	0.1	0.1	0.2	9.8	4.9	4.9
Crude protein (%)	1.0	0.1	0.1	0.1	0.1	9.9	7.9	2.0
Crude fiber (%)	1.0	0.0	0.1	0.1	0.0	41	36.2	5.2
HCN (ppm)	1.0	0.1	0.1	0.1	0.0	381	295	86.2
Plant height/ (cm)	1.0	0.1	0.1	0.1	0.1	150	68.7	80.9
Days to 50% flowering	1.0	0.0	0.1	0.1	0.1	82	45.3	37.0
No. of leaves/ plant	1.0	0.1	0.1	0.1	0.1	13.7	9.8	3.9
No. of tillers/ plant	1.0	0.1	0.1	0.1	0.1	1.5	0.2	1.3
Plant density/m2	1.0	0.1	0.1	0.1	0.1	211	38.1	172.5
Stem diameter (cm)	1.0	0.0	0.1	0.1	0.0	1.6	0.6	1.0
Leaf area (cm2)	1.0	0.1	0.1	0.1	0.0	268	82.4	185.4
Leaf to stem ratio	1.0	0.0	0.1	0.1	0.1	2.6	0.9	1.7
Shoot to root ratio	1.0	0.0	0.1	0.1	0.0	5.4	2.1	3.3

The forage Sorghum cultivars revealed spatial variation for most of the investigated yield and growth traits (Table 7). Accordingly, the average fresh and dry weights produced differed from location to another in yield traits and most of growth traits. Compared to Shambat 1 and Shambat 2, Omdoum dry weight was found to be more productive. Most of the traits showed the same trend except HCN content, plant height and number of tillers, which were slightly lower at Omdoum. Table 5 showed significant differences for most of the investigated traits, at each location separately. In the combined analysis, the variation due to genotypes and genotype × locations was significant ($P \leq 0.05$) for most of the traits of forage Sorghum cultivars (Table 7).

1- Phenotypic variability:

The phenotypic variability for yield traits (Fresh weight (t/ha): and Dry weight (t/ha)), quality traits(Crude protein (%),Crude fiber (%), and HCN (ppm)) and Growth traits: Plant height (cm), Days to 50% flowering (days), Number of leaves/plant, Number of tillers/plant, Plant density (m^2),Stem diameter (cm): Leaf area (cm2),Leaf to stem ratio, and Shoot to root ratio) among the nine forage sorghum cultivars is described as follows:

Table 5: Performance of cultivars of forage sorghum for yield, quality and growth traits, at the three locations (Shambat 1, Shambat 2 and Omdoum)

Source of variation	Shambat 1	Shambat 2	Omdoum	Mean	$L.S.D_{(0.05)}$
Fresh weight (t/ha)	19.3	18	37.4	24.9	7.2
Dry weight (t/ha)	4.4	6.2	9.7	6.8	2.5
Crude protein (%)	~	8.2	9.3	8.7	1.1
Crude fiber (%)	~	37.1	39.8	38.4	3.8
HCN (ppm)	~	362.1	302.8	332.4	66.4
Plant height (cm)	104	119.4	87.2	103.5	14.1
Days to 50% flowering (days)	62.5	71.9	70.3	68.3	6.4
No. of leaves/plant	10	11.7	12.5	11.4	1.2
No. of tillers/plant	1.5	0.4	0.3	0.7	0.8
Plants density/m^2	69.7	45.6	112.6	76	28.4
Stem diameter (cm)	1.1	1.2	1.2	1.2	0.4
Leaf area (cm^2)	219	164.2	220	201.1	32.7
Leaf to stem ratio	1.7	2.3	0.8	1.8	0.6
Shoot to root ratio	2.2	4.5	3.1	3.3	1.4

~ = these values were not measured in the location Shambat 1.

Table 6: Mean squares from the individual analysis of variance for some yield, quality and growth traits of cultvars of forage sorghum, evaluated at Shambat 1, Shambat 2 and Omdoum

	Shambat 1			Shambat 2			Omdoum		
Source of variation	Replication	genotype	Error	Replication	genotype	Error	Replication	Genotype	Error
Fresh weight (t/ha)	49.3^{NS}	140.1*	39.6	60.1^{NS}	184.7^{NS}	115.4	138.2**	164.4**	17.7
Dry weight (t/ha)	0.09^{NS}	9.3*	2.4	5.6^{NS}	28.2^{NS}	14.4	17.4*	7.5^{NS}	3.3
Crude protein (%)	~	~	~	20.6**	0.6^{NS}	0.3	0.4^{NS}	1.3^{NS}	0.8
Crude fibe (r%)	~	~	~	0.1^{NS}	2.9^{NS}	5.7	9.7^{NS}	23.4^{NS}	7.2
HCN (ppm)	~	~	~	13681.9^{NS}	4976.6^{NS}	3850	0.2^{NS}	67^{NS}	71.1
Plant height (cm)	478.6^{NS}	5328.6**	335.5	493.7*	5478.4**	75.1	531.6^{NS}	3821.8**	253.7
Days to 50% flowering (days)	1.9^{NS}	35..5**	7.6	8.8^{NS}	570.6**	4.9	48.1^{NS}	708.8**	125.9
No. of leaves/plant	3.4^{NS}	3.4*	1.2	5.8^{NS}	3.7^{NS}	2.4	0.3^{NS}	14.2**	1.2
No. of tillers/plant	7.2^{NS}	3.1^{NS}	2.1	0.6^{NS}	0.1^{NS}	0.2	0.03^{NS}	0.8**	0
Plants density/m^2	317.4^{NS}	9971.4**	341.4	92.4^{NS}	3379**	296.1	4561.1^{NS}	28382.9**	2062
Stem diameter (cm)	0.015^{NS}	0.4**	0.1	0.1^{NS}	0.3**	0.02	0.04^{NS}	0.6^{NS}	0.4
Leaf area (cm^2)	670.1^{NS}	18652.9**	685.1	224.3^{NS}	6104.8**	400.2	7467.5^{NS}	18044.3**	2494
Leaf to stem ratio	1.2^{NS}	3.2**	0.5	1.4^{NS}	4.7**	0.6	0.04^{NS}	0.01^{NS}	0.01
Shoot to root ratio	0.2^{NS}	3.4^{NS}	1.5	3.1^{NS}	20.6**	4.7	1^{NS}	0.4^{NS}	0.6

*, ** = significant at P = 0.05 and P = 0.01, respectively.

Table 7: Mean squares from combined analysis of variance for some yield, quality and growth traits of nine cultivar lines of forage sorghum, evaluated at Shambat 1, Shambat 2 and Omdoum.

Source of variation	Location	Error	Genotypes	Gen. x loc.	Error
Fresh weight (t/ha)	3164.1**	82.5	203.7**	142.8**	57.6
Dry weight (t/ha)	195.5**	7.7	24.8**	10.1^{NS}	6.7
Crude protein (%)	11.2^{NS}	10.5	1.7*	0.2^{NS}	0.5
Crude fiber (%)	64.6^{NS}	4.9	12^{NS}	14.3^{NS}	6.4
HCN (ppm)	31694.7^{NS}	6841	2853.4^{NS}	2190.3^{NS}	1961
Plant height (cm)	7017.1**	501	12764.3**	932.3**	221.4
Days to 50% flowering (days)	680.8**	19.6	1480.7**	79.1^{NS}	46.1
Number of leaves/plant	43.2**	3.2	13.8**	3.7*	1.7
Number of tillers /plant	12.5^{NS}	2.6	1.7*	1.1^{NS}	0.8
Plants density/m^2	31167.4**	1657	34830.8**	3451.2**	899.7
Stem diameter (cm)	0.1^{NS}	0.04	1**	0.4^{NS}	0.2
Leaf area (cm^2)	27496.4*	2787	37018.3**	2891.9**	1193
Leaf to stem ratio	15.1**	0.9	3.8**	2**	0.4
Shoot to root ratio	36.5**	1.3	10.8**	6.8**	2.3

*, ** = significant at P = 0.05 and P = 0.01, respectively.

a-Yield traits:

Yield traits (Fresh weight (t/ha): and Dry weight (t/ha)).

Fresh weight (t/ha):

The separate analysis of variance Table 6 showed significant ($P \leq 0.05$), non-significant and highly significant ($P \leq 0.01$) differences for this trait at Shambat 1, Shambat 2 and Omdoum, respectively. The overall mean for the nine cultivars was 19.4, 18.0 and 37.4 (t/ha) at Shambat 1, Shambat 2 and Omdoum, respectively. At Shambat 1, the highest (32.5 t/ha) and the lowest (10.4 t/ha) fresh weights for the nine cultivars were scored by genotypes IS.9830 and KEN24.A, respectively (Table 6). At Shambat, 2, the highest (29.2 t/ha) and the lowest (6.1 t/ha) fresh weights for the nine cultivar lines were obtained by IS.9830 and KEN16.A, respectively. At Omdoum, the highest (54.0 t/ha) and lowest (31.0 t/ha) fresh weights for the nine cultivar lines were scored by genotypes KEN41.A and TX624.A, respectively.

Dry weight (t/ha):

The separate analysis of variance Table 4 and.5 showed non-significant differences for this trait at Shambat 1, Shambat 2 and Omdoum except for cultivar lines at Shambat 1 (significant at $P \leq 0.05$). The overall mean for cultivar lines was 4.4, 6.2 and 9.7 (t/ha) at Shambat 1, Shambat 2 and Omdoum, respectively. At Shambat 1, the highest (8.2 t/ha) and lowest (2.6 t/ha) dry weights for cultivar lines scored by IS.9830 and KEN24.A, respectively. At Shambat 2, for the cultivar lines scored the highest (10.8 t/ha) and the lowest (1.73 t/ha) dry weights were scored by Sudan grass W and KEN16.A, respectively. At Omdoum, for the cultivar lines the highest (12.0 t/ha) and the lowest (7.7 t/ha) dry weights were obtained by Sudan grass W and TX624.A, respectively.

b-Growth traits:

Plant height (cm), Days to 50% flowering (days), Number of leaves/plant, Number of tillers/plant, Plant density (m2),Stem diameter (cm): Leaf area (cm2), Leaf to stem ratio: Shoot to root ratio.

Plant height (cm):

The combined analysis of variance for the parental lines revealed highly significant differences ($P \leq 0.01$) among the genotypes and a highly significant genotypes × location interaction (Table 6.0). For the genotypes, the overall mean averaged over locations was 103.5 (Table 7). For the genotypes, the highest (149.6 cm) and the lowest (69.0 cm) means averaged over three locations were recorded for Sudan grass W and KEN41.A, respectively.

Days to 50% flowering (days):

The combined analysis of variance revealed highly significant differences ($P \leq 0.01$) for the genotypes. The overall mean across locations for the genotypes was 68.3 (days), (Tables 7). For the genotypes the highest (82.3) and the lowest (45.3) combined values for this trait obtained by KEN24.A and Sudan grass W, respectively (Table 5).

Number of leaves/plant:

For the genotypes the separate analysis of variance for this trait revealed significant differences ($P \leq 0.05$) at Shambat 1, non-significant differences at Shambat 2 and highly significant differences ($P \leq 0.01$) at Omdoum (Table 6). The overall mean of this trait for the genotypes was 10.0 at Shambat 1; 11.7 at Shambat 2; and 12.5 at Omdoum (Table 6).

At Shambat 1, for the genotypes the highest number of leaves/plant (12.0) and the lowest (9.0) were detected for KEN16.A and Sudan grass W, respectively. At Shambat 2, for the genotypes the highest number of leaves/plant (13.7) and the lowest (10.3) were detected for Abu70 and KEN24.A, respectively. At Omdoum, for the genotypes the highest number of leaves/plant (16.7) and the lowest (10.0) were recorded for Abu70 and Sudan grass W, respectively.

Number of tillers/plant:

For the genotypes the separate analysis of variance for this trait revealed non-significant differences at Shambat 1 and Shambat 2 and highly significant differences ($P \leq 0.01$) at Omdoum. (Table 6). For the genotypes, the overall mean for this trait was 1.5, 0.4 and 0.3 at Shambat 1, Shambat 2 and Omdoum, respectively. (Table 5). At Shambat 1, for the genotypes the highest number of tillers/plant (3.4) and the lowest (0.4) were recorded for Sudan grass R and Abu70, respectively. At Shambat 2, for the genotypes the highest (0.7) and the lowest (0.1) number of tillers/plant were detected for TX623.A and Sudan grass R. At Omdoum, for the genotypes the highest (1.3) and lowest (0.0) were observed by Sudan grass W and TX623.A, respectively.

Plant density (m^2):

The combined analysis of variance of plant density for the studied lines revealed highly significant differences for genotypes and genotype × locations interactions (Table 4). The overall mean of the genotypes averaged over the three locations was 76.0 (Table 7). The genotypes means averaged over the three locations the highest (210.6) and the lowest (38.1) plants/m^2 were attained by Sudan grass W and TX623.A, respectively.

Stem diameter (cm):

The combined analysis of variance across locations for this trait for the genotypes revealed highly significant differences ($P \leq 0.01$) among genotypes, and non-significant differences for genotypes × locations interaction. (Table 4). The overall mean across location for this trait was 1.2 cm for the genotypes (Table 7). For the genotypes, the highest (1.6) and the lowest (0.6) cm values of stem diameter averaged over the three locations were attained by KEN16.A and Sudan grass R, respectively.

Leaf area (cm^2):

The combined analysis of variance for the genotypes revealed highly significant differences ($P \leq 0.01$) among genotypes and genotypes × locations interaction. (Table 6). The overall mean averaged over the three locations for this trait was 201.1 for the genotypes (Table 7). For the genotypes means averaged over the three locations the highest (267.8) and the lowest (82.4) cm2 leaf area values were attained by Abu70 and Sudan grass W, respectively.

Leaf to stem ratio:

The separate analysis of variance of the genotypes for this trait revealed highly significant differences ($P \leq 0.01$) at Shambat 1 and Shambat 2, and non-significant differences at Omdoum. (Table 6). The overall mean of this trait of this trait was 1.7 at Shambat 1, 2.3 at Shambat 2 and 0.8 at Omdoum (Table 4). At Shambat 1, the highest (3.9) and lowest (0.6) values of leaf to stem ratio were recorded for KEN24.A and IS.9830, respectively. At Shambat 2, the highest (4.2) and the lowest (1.0) values were and attained by KEN41.A and Abu70, respectively. At Omdoum, the highest (0.9) and the lowest (0.7) values for this trait were detected for KEN41.A and Sudan grass R, respectively (Table 4).

Shoot to root ratio:

The combined analysis of variance for this trait revealed highly significant differences ($P \leq 0.01$) among genotypes and genotypes × locations interaction, (Table 6). The overall mean averaged over the three locations was 3.3 and 3.5 (Table 7). The highest (5.4) and the lowest (2.1) combined values averaged over the three locations for this trait were attained by Abu70 and TX623.A, respectively, (Table 7).

Quality traits:

These traits were measured at Shambat 2 and Omdoum, therefore Shambat 1 is not included in the analysis of variance. The separate analysis of variance at Shambat 2 and Omdoum revealed non-significant differences for Sorghum cultivar (Tables 1 and 2).

Crude protein (%):

The overall mean for this trait for the cultivar lines was 8.2 and 9.3 at Shambat 2 and Omdoum, respectively (Table 1). At Shambat 2, the highest (9.2) and the lowest (7.4) crude protein percentage for the cultivar lines were obtained by TX624.A and Sudan grass W, respectively. At Omdoum for the cultivar lines, the highest (10.5) and the lowest (7.9) of crude protein percentage were attained by genotypes TX624.A and KEN16.A, respectively (Table 1).

Crude fiber (%):

The genotypes overall mean for this trait was 39.8 at Shambat 2 and 37.1 at Omdoum. (Table 1). At Shambat 2 for the genotypes the highest (39.0) and the lowest (35.4) crude fiber percentage were scored by Abu70 and TX624.A, respectively. At Omdoum for the parental lines, the highest (44.7) and the lowest (36.0) crude fiber percentage were attained by IS.9830 and Abu70, respectively.

HCN (ppm):

For the genotypes the overall mean of this trait was 362.1 at Shambat 2 and 302.8 at Omdoum (Table 1). At Shambat 2, the highest (452.7) and the lowest (292.4) HCN content among the genotypes were scored by TX623.A and TX624.A, respectively. At Omdoum, for the genotypes the highest (313.2) and the lowest (296.4) HCN content were scored by Abu70 and KEN24.A, respectively.

Discussions:

1-Phenotypic variability:

Individual analysis of variance revealed highly significant differences for most of yield and growth traits . The estimated high variation among the investigated genotypes could be attributed to genetic and environmental conditions as well as to their interactions. The high significant differences among the investigated cultivars for most traits suggest differences among the studied genotypes in their pedigree. These results are in accordance with similar findings recorded by many workers in sorghum [23,10,2,1,3,5,8].

Variation in quality traits were non-significant at the three locations. This indicates relatively consistent ranking of performance of the investigated genotypes at the three locations for these traits. The lack of variation among these genotypes could be attributed to low genetic effects for these traits or large effects of environmental factors. Similar results for quality traits were estimated by Mohammed [18]. The combined analysis of variance revealed highly significant differences between locations for most of the combined traits. This indicates sufficient diversity between the three environments. In addition, the significant genotype × location interaction for most of the traits indicate the differential response of the genetic material used in the study to change in season and location. However, the non-significant genotype × location interaction for some traits illustrate that the response of genotypes to different locations was the same. Thus, the variability of genotypes over locations in this study can be recognized as an important factor influencing the performance of a genotype in a certain environment, that means selection for high yielding cultivars with relatively stable performance can be achieved through multi locations and/or season testing. These findings were in agreement with many workers [2,1,4,17,18]. The overall means for most of yield and growth traits at Omdoum seemed to be higher than those at Shambat 1 and Shambat 2, that means these traits were less stable and more affected by change in environment. On the other side, the overall means of quality traits were relatively similar in their overall means at the three locations indicating that these traits were more stable and less affected by environmental changes. These changes of the overall means of the investigated traits could be attributed to genetic, environmental factors and to genetic × environment interaction. These results agree with Abu El-Gasim and Kambal [2]; Abdalla [1]; Bushara [4]; Mohammed [19].

2-Multi-criteria analysis for evaluation and Screening of Genotypes:

The multi-criteria optimization using Compromise Ranking Method, for evaluation and selection alternative sorghum cultivar is presented. The emphasis is on ranking these cultivars first if all evaluation criteria are considered of equal weights. The effect of changing indicator weights is investigated to reflect the preferences of an economist, animal Production specialist, a farmer, an agronomist and an overall evaluation. The relative distance, for each alternative cultivar, from the ideal point for each decision maker (Lp), their respective rank . are shown in table 8.

Table 8: Values of Lp – matrices and ranking of each Sorghum cultivar for various decision-makers and for equal weight set.

	Equal weights		Economist		Animal Production Specialist		Farmer		Agronomist		Over all	
Cultivar	L p	Rank	L p	Rank	L p	Rank	L p	Rank	L p	Rank	L p	Rank
Abu70	7.110	2.000	0.561	4.000	0.711	2.000	0.549	3.000	0.594	6.000	17.000	3.000
IS.9830	6.219	1.000	0.312	1.000	0.622	1.000	0.421	1.000	0.397	1.000	5.000	1.000
S-grass W	7.723	3.000	0.491	2.000	0.772	3.000	0.538	2.000	0.529	2.000	12.000	2.000
S-grass R	8.577	7.000	0.560	3.000	0.858	7.000	0.601	6.000	0.576	4.000	27.000	6.000
TX623.A	8.706	9.000	0.711	8.000	0.871	9.000	0.646	8.000	0.695	8.000	42.000	8.000
TX624.A	8.173	5.000	0.620	6.000	0.817	5.000	0.600	5.000	0.590	5.000	26.000	4.000
KEN16.A	8.658	8.000	0.780	9.000	0.866	8.000	0.654	9.000	0.743	9.000	43.000	9.000
KEN24.A	7.845	4.000	0.676	7.000	0.784	4.000	0.578	4.000	0.616	7.000	26.000	5.000
KEN41.A	8.273	6.000	0.609	5.000	0.827	6.000	0.601	7.000	0.570	3.000	27.000	7.000

On the basis of the results and compromise programming analysis shown in table 8 the cultivars overall ranking can be given in descending order of preference as: IS.9830, S-grass W, Abu70, TX624.A, KEN24.A, S-grass R, KEN41.A, TX623.A, and KEN16.A. With respect to all decision-makers the cultivar IS.9830 is always ranked as first choice, while the cultivar KEN16.A ranked as least preferred three times by Economist, farmer, and agronomist and as next to the last(number 8) by animal specialist and with equal weights. However, statistical analysis of Phenotypic and genotypic variability did not give an overall index that capture all evaluation indicators in one numerical value to rank the suitability of each cultivar to the prevailing environment.

Conclusions:

Fourteen characters involving Fresh weight (t/ha), Dry weight (t/ha), Crude protein (%),Crude fiber (%),HCN (p p m), Plant height/ (cm), Days to 50% flowering, No. of leaves/ plant, No. of tillers/ plant, Plant density/m^2, Stem diameter (cm), Leaf area (cm^2), Leaf to stem ratio, and Shoot to root ratio and other parameters were used for screening forage Sorghum cultivars ; there was considerable variability present in the materials analyzed. These results would be useful in choosing populations to use in a breeding program to improve productivity and in selecting the most cultivar which accepted by various decision makers. The variation in the studied evaluation criteria could be effectively manipulated with appropriate breeding methods to develop improved varieties, synthetics and hybrids for use by farmers and the industries.

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