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Breeding for dual purpose attributes in sorghum: Effect of harvest option and genotype on fodder and grain yields

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A study was conducted across different seasons during 2012 to 2013 to investigate the effect of harvest options and genotype on the dual fodder and grain yield in sorghum. The treatments were arranged in split–split plot design with the harvest options assigned to the main plot and the genotypes to the sub plot. The study revealed that performance of dual sorghum genotypes differed across harvest options and seasons. To maximize the benefits gained from dual sorghum genotypes, different harvest options for fodder and grain need to be investigated. When the option is to harvest the main crop as forage and the ratoon as grain crop, the cultivars Abjaro during winter and S.25Abu70 during summer were suggested. If the option is to harvest the grain and stover from the main crop, either Abjaro or S.25Abu70 could be suggested, depending on what is favored by farmers: Earliness of S.25Abu70 or the high stover yield of Abjaro.

Key words: Abjaro, Abu Sabein, main crop, ratoon, shambat, Sudangrass, stover.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important cereal grain crop in the world. It is thought to have been originated in north-eastern Africa around Ethiopia, Sudan and East Africa (Dogget, 1988; Acquaah, 2007). Sorghum is unique in its ability to produce under a wide array of harsh environmental conditions. Thus, it is undoubtedly the crop of poor people providing cheap sources for food and feed specially in the sub-Saharan Africa, and India.

Initially, sorghum grain is used primarily for food; however, its use as a feed exceeds its use as food since the mid of 1960s, especially in developed countries (Dendy, 1995). In view of the pressing demand for fodder coupled with the fact that grain sorghum is the stable diet for millions of poor people, it is imperative to reconsider the present mono-commodity breeding strategy of sorghum. Kelly et al. (1991) questioned the strategy of strictly adopting grain-yield criteria in evaluating sorghum genotypes arguing that fodder's contribution to the total value of sorghum production has increased considerably. Residues of sorghum are becoming important feed sources for livestock raised by resource-poor smallholders in

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Table 1. The selected sorghum genotypes used in the study (Shambat, 2012 - 2013).

Genotype	Group (population)	Initial usage	Grain color	Mid-rib color
Abjaro	Abjaro	Grain	White	White
Abnaffain	Dual check	Grain/forage	White	White/green
E-35-1	Sweet sorghum	Forage	White	Green
S.25Abu70	Abu Sabein	Forage	White	Green
S.03Abu70	Abu Sabein	Forage	White	Green
SG08	Sudan grass	Forage	White	Green
SG51	Sudan grass	Forage	White	Green

southern Asia and sub-Saharan Africa (Mohanraj et al., 2011). However, attributes relating to crop residue improvement has been largely ignored, with emphasis being placed on grain yield. Thus, dwarf high-yielding grain cultivars with fewer residue has been released in the early days of cereal improvement programs (Reddy and Sanjana., 2003). The same situation exists in Sudan, where breeding objectives were set to develop short statured combinable grain cultivars. Since recognition of crop residues as a viable source of feed, emphasis has been shifted to dual-purpose cultivars for grain and forage. Stover traits can be easily incorporated into existing breeding programs to generate superior dual-purpose (grain/fodder) sorghum varieties suited to smallholder farmers.

Sudan is endowed with a wealth of genetic variability in sorghum (Yasin, 1978) enabling selection for most economic traits. Local efforts to exploit such variability to develop dual sorghum types have been very limited and mostly directed towards developing improved grain types. Simultaneous improvement of sorghum for both fodder and grain attributes will result in developing dual cultivars that maximize grain and fodder yields and reducing costs of productions by saving time, labor and inputs under the constraints imposed by the environment and the prevailing production systems. Hence, the end result will be increasing the incomes of poor-resource farmers and sustaining their food security. Therefore, a breeding program has been launched to develop dual purpose fodder/grain sorghum genotypes and we are able to identify some of the elite genotypes. Further investigations are, however, needed to explore different factors required to increase the benefits gained from developing dual purpose varieties.

The objectives of this work were to investigate the performance of dual purpose (grain/fodder) sorghum genotypes under different harvest options required to maximize the benefits gained from combining grain and fodder attributes in one cultivar.

MATERIALS AND METHODS

The experimental site

The study was conducted in Shambat (lat.15° 39 N; Long.32° 31 E) in the Research Farm of the Collage of Agricultural Studies, Sudan University of Science and Technology during the summer season of 2012 and the winter season of 2012/2013. The soil is heavy clay, non-saline, non-sodic with pH 7.8. The summer season has short rainy period extending from July to September with scant and fluctuating precipitation. The min-max temp during summer averaged 26 to 39°C. The winter is dry with 16 to 35°C average min-max temperature.

Treatments and experimental design

Six sorghum genotypes (Table 1) selected for their high performance dual purpose ability were used in the study. The selection criteria and the steps followed to develop these genotypes are presented in the companion paper. The genotypes were tested against the check Abnaffain, a traditional dual grain/forage cultivar. The performance of the 7 genotypes was assessed under two harvest options viz:

1. Option 1 (HOP1): The crop was cut at heading time to evaluate forage production and the ratoon (regenerated crop) was evaluated for grain production
2. Option 2 (HOP2): The crop was left to grow up to grain maturity to evaluate both grain and stover yield

The treatments were replicated 4 times in split- split plot design with the harvest options assigned to the main plot and genotypes to the sub plot.

The experiment

The study was conducted during the summer and winter seasons. Sowing dates were effected on 13 July 2012 and 15 October 2012, respectively. The plot consists of 4 ridges 6 m long spaced at 0.75 m. Sowing method, planting density and management practices were similar to those mentioned in the accompanying paper.

The data taken included: Forage yield (t/ha), grain yield in kg/ha (estimated from 3 replicates), stover yield, days to boot (taken in ratoon crop), days to heading, plant height (cm) and stem diameter (cm).

Statistical analysis

The data sets of each harvest option in each season was subjected to single ANOVA before performing the combined analysis which was carried out for characters that showed homogeneous error variance (Snedecor and Cochran, 1967). Analysis of variance of split plot in RCB design was performed as per Cochran and Cox (1957). The statistical packages GenStat (2011) was used to run the analysis.

Table 2. Mean squares of the main and interaction effects of harvest options and genotypes for grain yield in sorghum (Shambat Winter, 2012).

Source of variation	Df	Grain yield (kg/ha)	
		Summer season	Winter season
Harvest option (HOP)	1	27692448**	47314941**
Residual	2	201585	54690
Genotype (G)	6	1669009**	2832419**
G x HOP	6	678620**	925038**
Residual	30	133490	143138

**, Highly significant at 0.01 probability level.

Table 3. Performance of dual sorghum genotypes for HOPI* (Shambat, 2012).

Genotype	Green matter yield (t/ha)			Dry matter yield (t/ha)			Ratoon grain yield (kg/ha)	
	Winter	Summer	Combined	Winter	Summer	Combined	Winter	Summer
Abjaro	47.9	42.5	45.2	10.5	11.4	10.9	1504	890
Abnaffain	21.2	21.9	21.5	3.61	5.53	4.57	474	319
E-35-1	32.6	32.1	32.3	6.09	9.91	8.00	332	379
S.25Ab70	43.8	34.1	39.0	8.29	8.00	8.14	575	849
S.03Ab70	41.5	32.6	37.0	7.58	7.13	7.35	668	578
SG51	36.9	23.8	30.3	6.77	6.10	6.44	421	536
SG08	36.5	26.8	31.6	6.86	6.29	6.57	376	301
Mean	37.2	30.5	33.9	7.10	7.76	7.43	621	550
SE±	3.07	2.101	1.860	0.581	0.542	0.397	98.5	75.6
LSD (5%)	9.12	6.241	5.334	1.726	1.609	1.139	303.4	233.0
CV (%)	16.5	13.8	15.5	16.4	14.0	15.1	31.7	27.5

HOP1*= Forage crop harvested at heading time followed by grain crop harvested from ratoon.

RESULTS AND DISCUSSION

In each harvest option, highly significant differences were detected among genotypes for all traits studied in both seasons. The same is true for traits analyzed under combined analysis across seasons. Differences between harvest options and genotypes for grain yield were highly significant (Table 2). The interaction of genotypes with harvest options for gain yield was highly significant indicating that the genotypes performed differently in each harvest option with regard to grain yield. This may imply the need for evaluating dual sorghum cultivars across different harvest options.

Main and ratoon crop option (HOP1)

When harvesting the main crop for forage and grain from ratoon crop, Abjaro seemed to give the best forage yield and ratoon grain yield especially during winter season (Table 3). Its GMY and DMY averaged 47.9 and 10.9 t/ha, respectively. The Abu Sabein selection S.25Abu70 ranked second with respective yields of 43.8 t/ha and 8.29 t/ha. The winter ratoon grain yield of Abjaro was strikingly high (1504 kg/ha) exceeding that of S.03Abu70 (the 2nd best genotype) by > than twice and that of Abnaffain by > 3 folds. The Abu Sabein genotypes (S.03Abu70 in winter and S.25Abu70 in summer) ranked second to Abjaro in grain yield. In spite of that the choice of farmers may go for Abu Sabein since it was remarkably earlier than Abjaro especially in the summer season. This is especially true for S.25Abu70 in summer season which was 58 day earlier in heading time (Table 4) while keeping comparable ratoon grain yield to Abjaro (Table 3). The benefits gained from increased forage yield of Abjaro over that of Abu Sabein may not justify affording additional costs and implications imposed by delaying harvest for about nearly 2 months. On the other hand the Abu Sabein genotype S.25Abu70 may represent a good replacement for Abnaffain when used for producing forage and grain from main and ratoon crop, respectively.
Abjaro was significantly the latest among the material tested taking 65.5 and 115 days to heading in winter and summer seasons, respectively. Abnaffain was the earliest in winter season with 43.5 days to heading (Table 4). All genotypes headed earlier in winter than summer.

Table 4. Performance of dual sorghum genotypes for some yield related traits in HOP1* (Shambat, 2012).

Genotype	Days to heading		Plant height (cm)		Stem diameter (cm)	
	Winter	Summer	Winter	Summer	Winter	Summer
Abjaro	65.5	115	289	217	1.38	2.18
Abnaffain	43.5	70.5	153	124	1.10	1.75
E-35-1	54.5	91.3	222	147	1.25	1.55
S.25Ab70	52.8	56.8	226	198	1.33	1.38
S.03Ab70	53.8	59.5	217	196	1.20	1.58
SG51	53.3	56.8	226	187	1.25	1.15
SG08	47.5	61.0	207	183	1.08	1.38
Mean	53.0	72.9	220	179	1.23	1.56
SE±	0.757	1.355	5.55	7.22	0.0391	0.1049
LSD (5%)	2.250	4.027	16.48	21.46	0.1161	0.3118
CV (%)	2.90	3.70	5.10	8.10	6.4	13.4

HOP1*= Forage crop harvested at heading time followed by grain crop harvested from ratoon.

Table 5. Performance of dual sorghum genotypes for two ratoon yield related traits in HOP1* (Shambat, 2012).

Genotype	Ratoon days to boot		Ratoon plant height (cm)	
	Winter	Summer	Winter	Summer
Abjaro	36.3	43.5	168	156
Abnaffain	22.3	23.5	132	98.3
E-35-1	27.5	23.0	130	98.0
S.25Ab70	29.5	34.0	137	143
S.03Ab70	25.5	23.8	137	134
SG51	32.8	26.8	162	142
SG08	25.5	28.8	160	135
Mean	28.5	29.0	147	129
SE±	2.008	2.71	4.74	9.23
LSD (5%)	5.967	8.06	14.60	28.44
CV (%)	14.10	18.70	6.50	14.30

HOP1*= Forage crop harvested at heading time followed by grain crop harvested from ratoon.

However, Abjaro and E-35-1 showed contrasting difference in heading time between the two seasons with respective ranges amounting to 50 and 37 days. Hence both cultivars could be regarded as photoperiod sensitive. Sorghum is a short day plant requiring short photoperiods to flower, with some variability among varieties (Clerget et al., 2004). Late tropical land races (like Abjaro) are known to be highly photoperiod-sensitive (Clerget et al., 2007). On the other hand, Abu Sabein genotypes could be considered as neutral or slightly photoperiod sensitive with seasonal difference in heading time of 4 to 6 days. These results may explain the farmers' practice of growing Abu Sabein during most of the year (Feb to Nov) while restricting Abjaro cultivation to winter sowings. Earliness is highly favored under limited moisture conditions. It could be noted that by growing Abu Sabein in summer instead of Abjaro, the farmers can spare 55 day (Table 4), enough to allow them maximizing the benefits gained from harvesting both grain and fodder. Since, in summer, the ratoon grain yield of Abu Sabein (S.25Abu70) is comparable to that of Abjaro (Table 3), growing of this cultivar in summer is suggested for harvesting fodder from the main crop and grain from the ratoon. In contrast, in the winter season Abjaro could be regarded as the right choice for a dual fodder/grain production since it gave ratoon grain yield of more than twice of that of the best Abu Sabein genotype (Table 3) while only being 13 day later in heading time (Table 4). The above suggestions will not be affected by the difference in ratoon days to boot as it almost followed the same trend of days to heading in the main crop (Table 5). This is in agreement with the finding of Gerik et

Table 6. Performance of dual sorghum genotypes for grain and stover yields in HOP2* (Shambat, 2012).

Genotype	Grain yield (kg/ha)		Stover yield (t/ha)	
	Winter	Summer	Winter	Summer
Abjaro	4139	3086	58.6	39.8
Abnaffain	1908	1362	36.6	22.5
E-35-1	2363	1641	50.6	28.2
S.25Ab70	3678	2825	51.7	31.3
S03Ab70	3670	3293	52.6	29.9
SG51	1680	1505	48.5	28.5
SG08	1798	1508	44.8	26.8
Mean	2748	2174	49.1	29.6
SE±	287.7	285.2	4.31	1.395
LSD (5%)	886.3	878.9	12.82	4.144
CV (%)	18.1	22.7	17.6	9.4

HOP2*= Grain crop harvested at seed maturity and the stover crop evaluated thereafter**.**

Table 7. Performance of dual sorghum genotypes some related traits in HOP2* (Shambat, 2012).

Genotype	Days to booting		Plant height (cm)		Stem diameter (cm)	
	Winter	Summer	Winter	Summer	Winter	Summer
Abjaro	58.5	105	288	226	1.53	2.05
Abnaffain	33.3	64.0	181	140	1.05	1.40
E-35-1	43.3	81.8	221	150	1.13	1.43
S.25Ab70	45.8	48.5	216	183	1.15	1.40
S03Ab70	46.8	50.8	228	190	1.13	1.28
SG51	41.0	44.3	240	194	1.03	1.08
SG08	37.8	48.0	211	179	1.03	1.08
Mean	43.8	63.2	226	180	1.14	1.39
SE±	0.891	0.690	9.31	6.87	0.0397	0.0831
LSD (5%)	2.649	2.050	27.65	20.42	0.1180	0.2469
CV (%)	4.10	2.20	8.20	7.60	6.90	12.00

HOP2*= Grain crop harvested at seed maturity and the stover crop evaluated thereafter**.**

al. (1990) that suggests similar phenology of planted and ratoon crops.

Ratooning is a cultural practice to stimulate regrowth of the basal or lower epigeal buds after removal of the photo-synthetically active material. A successful grain sorghum ratoon crop depends upon the production and development of healthy, grain-bearing tillers from these buds in the stubble of the preceding crop (Wilson, 2011). In the present study, tiller development has not been evaluated; however, the large stem diameter (Table 4) might be one of the reasons behind the high ratoon grain yield of Abjaro. Thicker stems contribute to increased content of soluble carbohydrates in the stubble which has been considered essential to the ratooned plant's survival and re-growth in the absence of roots and leaves (Enserink, 1995; Oizumi, 1977).

Main crop option (HOP2)

When harvesting grain and stover from the main crop, Abjaro also kept the top rank in both attributes in winter and summer seasons with respective grain yields amounting to 4139 and 3086 t/ha, whereas the respective stover yields were 58.6 and 39.8 t/ha (Table 6). However, Abjaro yields were not significantly different from that of Abu Sabin genotypes except for stover in the summer season. Considering the lateness of Abjaro (Table 7), farmers may favor growing Abu Sabin for grain/stover production in both seasons unless the stover value of the summer season is high enough to justify growing Abjaro, or if quality aspects of the stover were considered. In the Sudan, sorghum stover has the greater contribution in maintaining the national herd (Mohammed and Zakaria, 2014). High stover yielding cultivars are becoming increasingly valued over high grain but lower stover yielding ones. Similar trends were reported in the developing countries (Traxler and Byerlee, 1993) where farmers consistently select sorghum types that would compromise the desired fodder and grain attributes. Increased stover, however, must be digestible to contribute to improvement of livestock productivity (Kristjanson and Zerbini, 1999). In this study, the quality of stover was not investigated, however, in the companion paper the data presented for leaf to stem ration showed that Abjaro was leafier than Abu Sabein genotypes. Increased leaf to stem ratio indicates better digestibility and nutritional value of sorghum fodder (Mohammed and Zakaria, 2014). Improving stover digestibility is feasible without sacrificing grain yields as considerable variations in the quality value of sorghum stover exist (Blümmel and Reddy, 2006).

Conclusion

The study revealed that performance of dual sorghum cultivars differ across harvest options and seasons. To maximize grain and fodder yields from dual sorghum cultivars, different genotypes were suggested for different harvest options in different seasons. When harvesting the main crop for forage and grain from ratoon crop, the best choice is to grow the cultivar Abjaro during winter and S.25Abu70 during summer. When harvesting grain and stover from the main crop, Abjaro also kept the top rank in both attributes in winter and summer seasons however, considering the lateness of Abjaro, farmers may favor growing Abu Sabein unless the stover value of the summer season is high enough to justify growing Abjaro, or if quality aspects of the stover were considered. Future results should focus on developing dual sorghum cultivars with high quality stover with special emphasis on improved digestibility.

Conflict of Interest

The authors have not declared any conflict of interests.

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