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Research Application Summary

Gene action of selected grain and forage dual purpose sorghum genotypes

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Abstract

Sorghum is an important food and feed source in mixed crop-livestock production systems where its dual usage is a preferred option, especially among the resource poor small-scale farmers. This study was undertaken to estimate the combining ability of grain and forage sorghum genotypes in F_1 combinations for several traits as a criteria for improving dual purpose sorghum cultivars. A total of 23 crosses were evaluated alongside their parents at three locations in two seasons. Results indicated that the gene action for the traits under observation was controlled by both additive and non-additive genetic effects. Majority of the parental lines had significant GCA estimates for all traits except line 20 for grain yield, lines 22 and 34 for plant height, line 35 for leaf-stem ratio, and line 22 for days to flowering. Significant (P d" 0.05) SCA estimates were prominent in majority of the individual parental combinations for all traits except leaf area and leaf-stem ratio. The results of this study suggested that both inter and intra allelic interactions were involved in the expression of the traits. The predominance of additive genetic control implies that use of parents with suitable significant GCA effects is most appropriate for improving sorghum cultivars for dual purpose while the different parental combinations (grain by forage, forage by grain) that showed high specific combining ability indicated the role of dominance gene action.

Key words: Biomass, combining ability, gene action, grain yield

Résumé

Le sorgho est une source d'alimentation humaine et animale importante dans les systèmes mixtes de production agropastoraux où son double usage est une option privilégiée, en particulier parmi les ressources pauvres petits agriculteurs. Cette étude a été entreprise pour évaluer l'aptitude à la combinaison de grains et de génotype de fourrage de sorgho dans des combinaisons de F_1 pour plusieurs traits comme critères pour l'amélioration des cultivars de sorgho à double usage. Un total de 23 croisements a été évalué aux côtés de leurs parents à trois endroits en deux saisons. Les résultats indiquent que l'action de gènes pour les traits sous observation a été contrôlée à la fois par les effets génétiques additifs et non additifs. La majorité des lignées parentales avait un GCA signifiant estime pour tous les caractères sauf la ligne 20 pour le rendement en grain, les lignes 22 et 34 pour la hauteur de la plante, la ligne 35 pour le rapport feuille-tige, et la ligne 22 pour les jours à la floraison. Les estimations de signifiant SCA (P d “0,05) ont été importantes dans la majorité des combinaisons parentales individuelles pour tous les caractères sauf la surface foliaire et le rapport feuille-tige. Les résultats de cette étude montrent que les deux interactions inter et intra alléliques ont été impliqués dans l’expression des traits. La prédominance de contrôle génétique additif implique que l’utilisation des parents ayant des effets signifiants GCA appropriés est le plus approprié pour l’amélioration des cultivars de sorgho a doublé objectif tandis que les différentes combinaisons parentales (grain par fourrage, fourrage par grain) qui ont montré une combinaison de capacité spécifique élevée ont montré le rôle de l’action des gènes de dominance.

Mots clés: biomasse, aptitude à la combinaison, l’action des gènes, le rendement en grains

Background

Sorghum (*Sorghum bicolor* (L) Moench) is an important food and feed crop of dry land agriculture because of its wide range of adaptability to various agro-ecological conditions. It is a self-pollinating, diploid (2n = 2X = 20) with a genome 25 % of the size of maize or sugar cane (Rai *et al.*, 1999). In developing countries, sorghum is primarily used as a food crop (Bawazir, 2009), and has been improved to a great extent for grain (Williams *et al*., 1997). However, in the developed countries, it is used primarily as a feed crop (Chakauya *et al*., 2006). Given that crop- livestock production systems are the most common form of land use in semi-arid areas of Africa (Mativavarira *et al.*, 2011) among the resource poor small scale farmers who rely on crop residues as livestock feed (Sibanda *et al*., 2011), genetic improvement of this crop for dual usage as grain and fodder is needed.

Traits like grain and fodder yield are governed by polygenes with complex gene action (Jain and Patel, 2014), hence understanding the gene action would help plant breeders in selecting appropriate breeding methods. Combining ability studies provide useful information regarding the selection of suitable parents for effective hybridization programmes and indicate the nature and magnitude of various types of gene action involved in the expression of quantitative characters (Bernardo, 2014). The process also helps in ensuring accumulation of desirable unfixable or fixable gene effects (Nadarajan and Gunasegaram, 2005).General combining ability (GCA) was described by Falconer (1989) as the mean performance of a genotype when crossed with a series of other genotypes. The performance of a cross can deviate from the average general combining ability of two parental lines due to genetic effects that are specific to that cross and this deviation is referred to as specific combining ability (SCA) (Bernardo, 2014). The differences in GCA are mainly due to additive effects and higher order additive interactions while differences in SCA may be attributed to non-additive gene effects. The analysis of combining ability, therefore, allows broad inferences on the nature of gene effects for a trait under selection. The grain and fodder yields are primary traits targeted for improvement of dual purpose sorghum productivity through exploitation of heterosis. This study was therefore undertaken to estimate the general and specific combining ability and heterosis of different grain and forage sorghum genotypes in F_1 combinations for grain yield, biomass and related traits as a criteria for developing superior dual purpose sorghum cultivars.

Study description

Eight sorghum genotypes were selected based on their performance for high grain and fodder yield in a prior diversity study and used as parental lines in this study. The genotypes comprised four grain and four forage sorghum cultivars which were crossed to generate 23 crosses following the half diallel mating design scheme (Griffing, 1956) at Makerere University Agricultural Research institute Kabanyolo (MUARIK) in 2013. The 23 crosses and parents were sown in randomized complete block design with three replications at MUARIK in 2014 (Season A and B), Mbarara Zonal Agricultural Research Station in 2014 season B and National Semiarid Agricultural Research institute (NaSARRI) in 2014 season B. MUARIK is located at 0Ú28'N; 32'37'E and is 1200 m asl with mean daily temperatures of 20ÚC. NaSARRI is located at 1Ú39'N; 33'27'E, and is 1038 m asl with mean daily temperatures of 24ÚC and Mbarara is located at 0.6Ú13'S; 30'65'E and is 1445 m asl. Each genotype was planted in four 3 m rows, 0.6 m apart with an intra row spacing of 0.3 m. A distance of 1 m was left between plots and 2 m between replications. Data were collected on days from planting to 50 % flowering, grain yield, 1000 seed weight, plant height, above ground biomass, Leaf-stem ratio and Leaf area (Leaf number × Leaf length × Leaf width × 0.75) were calculated following recommended sorghum descriptors (IBPGR/ICRISAT, 1993).

Combining ability estimates were done according to Griffing's model I (fixed model for parental effects), method 4 (exclusion of parents and reciprocal F_1's) diallel analysis procedures (Griffing, 1956) following the model: $Y_{ij} = \mu + g_i + g_j + s_{ij} + e_{ij}$, where Y_{ij} = mean of the F_1 resulting from crossing i^{th} parent and j^{th} parent, μ = population mean, g_i = GCA effect of i^{th} parent, g_j = GCA effect of j^{th} parent, s_{ij} = SCA effect of the cross between i and j parent. The GCA of the i^{th} line in the diallel can be defined as the mean performance of the crosses having i^{th} line as one of its parents. The SCA of the i^{th} and j^{th} cross in array can be defined as the deviation in mean of this cross from the mean of that array. All data analysis were done using GenStat statistical package (VSN International, 2011).

Results

The estimates of general combining ability effects of parents for seven traits are presented in Table 1. The significant (P<0.05) GCA effects for parents 20 and 29 indicated that these lines were good combiners for 1000 seed weight. Significant (P<0.05) estimates of GCA effects were observed for all parental lines except 22 for days to 50 % flowering although only lines 20, 41, and 42 significantly (P<0.001) reduced the flowering dates. Lines 20 and 29 had significant (P <0.05) GCA for Leaf area although only line 29 contributed significantly (P<0.05) to higher Leaf area in the crosses. Significant (P<0.05) GCA effects for leaf-stem ratio were observed in all the lines except line 35. All the parental lines had significant GCA effects for Plant height, grain yield and biomass except lines 20 and 34 for grain yield and plant height, respectively.

Table 1. Estimates of general combining ability effects for eight parental lines

Parents	DTF	LA (m^2)	LSR	P Ht (m)	TSW (g)	GY (t ha^{-1})	B (t ha^{-1})
22 (F)	-0.35	0.01	-0.03***	0.71	0.69	-0.10**	1.98***
24 (F)	2.72***	0.04	-0.06***	43.55***	0.18	0.53***	11.37***
29 (F)	1.35***	0.16*	-0.01*	13.01***	1.97 **	-0.31***	5.94***
34 (F)	4.08***	-0.04	0.04***	1.03	0.59	-0.17***	3.27***
35 (G)	5.13***	0.05	0.00	22.77***	0.69	0.04*	0.99*
41 (G)	-2.12***	0.01	-0.01**	10.09**	1.23	0.38***	4.76***
20 (G)	-7.50***	-0.18*	0.04***	-38.63***	2.71***	0.07*	-9.53***
42 (G)	-2.77***	-0.07	0.02***	-45.61***	1.26	0.26***	6.63***

(F) = Forage sorghum, (G) = Grain sorghum, ***, **, * = significant at 0.001, 0.01 and 0.05 respectively. DTF= Days to 50 % Flowering; LA= leaf area; LSR= Leaf-stem Ratio; P Ht= Plant height; TSW=1000 Seed Wt; GY= Grain Yield; B= Biomass

Table 2. Estimates of specific combining ability effects

Cross	DTF	LA (m^2)	LSR	P Ht (m)	TSW (g)	GY (t ha^{-1})	B (t ha^{-1})
22×20	-3.02**	-0.04	-0.10***	2.32	-1.4	0.14	-2.73***
24×20	1.66	0.02	0.07***	7.18	1.33	0.18*	7.04***
29×20	-2.96**	-0.12	0.03***	-8.28	-4.31**	-0.07	-9.03***
29×22	0.67	-0.09	-0.07***	-10.22	-0.36	-0.38***	1.06
29×24	1.93	-0.08	0.00	4.54	1.84	-1.03***	5.69***
34×20	-0.02	0.10	0.03***	-16.9**	0.51	-0.64***	1.14
34×22	-3.83***	0.11	-0.01*	31.47***	1.07	-0.52***	0.87
34×29	4.46***	-0.15	-0.05***	0.46	1.62	1.28***	1.45
35×20	6.71***	0.10	-0.12***	56.65***	1.83	-0.43***	2.37**
35×22	-0.55	0.01	0.08***	-41.78***	-0.03	0.81***	0.38
35×24	-1.4	-0.01	-0.08***	-28.53***	-3.09*	0.17*	1.73*
35×29	-1.11	-0.01	0.10***	4.11	2.32	0.69***	-4.82***
35×34	1.57	0.05	0.03***	5.6	-2.05	-0.67***	4.50***
41×20	-2.37*	-0.06	0.09***	-40.97***	2.02	0.82***	1.21
41×22	6.04***	0.10	-0.02**	26.6***	4.01**	0.13	8.54***
41×24	-3.14**	0.13	-0.03***	13.75*	-2.04	-0.04	-6.04***
41×29	-4.66***	-0.06	0.05***	-6.01	-3.28*	-0.43***	-13.37***
42×22	0.69	-0.09	0.12***	-8.39	-3.29*	-0.18*	-8.13***
42×24	0.95	-0.06	0.04***	3.06	1.96	0.73***	-8.42***
42×29	1.65*	0.51***	-0.07***	15.4**	2.17	-0.05	19.02***
42×34	-2.18*	-0.11	0.00	-20.62***	-1.15	0.54***	-7.97***
42×35	-5.24***	-0.13	-0.01	3.94	1.02	-0.57***	-4.16***
42×41	4.13***	-0.12	-0.09***	6.62	-0.71	-0.47***	9.66***

The estimates for specific combining ability are presented in Table 2. Significant non-additive effects were observed in some of the crosses. Of the five crosses that showed significant (P< 0.05) estimates of SCA effects only cross 41×42 was positive for 1000 seed weight. SCA effects were significant (P<0.05) in 15 crosses for days to 50 % flowering although reduction in flowering duration was only seen in eight crosses. Only 42×29 cross showed significant (P<0.001) non-additive effects for leaf area while all crosses but three showed significance (P<0.05) for leaf- stem ratio with nine showing positive (P<0.05) significant effects. Ten crosses had significant (P<0.05) estimates of SCA effects for plant height. All but five crosses showed significant (P<0.05) estimates of SCA effects for grain yield and biomass. Eight crosses had positive significant (P<0.05) SCA effects.

Discussion and recommendations

The primary criteria for selection of desirable parents are usually based on mean values and additive gene action (Nguyen *et al*., 1997). Girma *et al.* (2010) suggested that crossing two parents showing the highest general combining ability for a desirable trait may produce the best performing cross due to an increased frequency of favorable genes. Based on the estimates of GCA effects, it was observed that parental lines 20 and 29 would be the best combiners for 1000 seed weight. Only the grain sorghums contributed to reducing the flowering days because of the negative significant GCA estimates suggesting that the grain sorghums generally tended to flower earlier than the forage sorghums owing to their inherent genetic makeup. This makes grain sorghums useful in reducing the flowering date of forage sorghums. Neither additive nor non-additive effects were statistically significant for Leaf area in the analysis of variance possibly because it was derived from the leaf parameters which were largely influenced by the environment. However, parental line 29 showed significant estimate of GCA implying that it was a good combiner for leaf area. Girma *et al*. (2010) reported significant estimates of GCA for leaf area in some of the induced sorghum mutants. The estimates of GCA for leaf-stem ratio indicated that lines 20, 34 and 42 were the best combiners for this trait because of the positive GCA. Lines 24, 35 and 41 were the best combiners for both plant height and grain yield due to the positive significant (P<0.05) GCA estimates. All the parental lines had positive significant (P<0.05) GCA effects for biomass except lines 20 and 35 which had negative GCA estimates indicating that theses two were not the best for this trait. Similar results were reported for fodder yield and its components by Prakash *et al*. (2010).

Lines 29, 41 and 42 were generally good combiners for four different traits out of seven traits while lines 20 and 35 were good general combiners for at least three different traits. However, lines 24, 41 and 42 were the best general combiners for grain yield and biomass due to the positive significant GCA effects. The superior combining ability of best combiners could be exploited in hybrid or recurrent selection programmes. Additive variance is associated with effective response to selection (Valiolla, 2012) hence small numbers of parents with desired GCAs can be used to generate crosses for sorghum improvement.

The performance of a cross can deviate from the average general combining ability of two parental lines and this deviation is referred to as specific combining ability. Only Cross 41 ×

22 out of the 23 crosses had positive significant (P<0.01) estimate of SCA effects for 1000 seed weight, implying that GCA effects were more important for this trait. Nguyen *et al.* (1997) reported similar findings for 100 seed weight. The estimates of SCA for leaf-stem ratio were significant (P<0.05) in 20 out of 23 crosses but only nine crosses were desirable as they had positive SCA estimates. Although this trait was controlled by both additive and non-additive gene action, SCA effects had a slightly higher influence as observed from the slightly larger mean square value than GCA (Table 1). Of the eighteen crosses that showed significant (P<0.05) estimates for grain yield and biomass only eight crosses had positive significant estimates for SCA suggesting that non additive effects were important for these two traits. Mwije *et al.* (2014) indicated that parents with the best GCA effects did not necessarily produce crosses with desirable SCA effects as was observed in this study.

The results of this study suggested that both inter and intra allelic interactions were involved in the expression of the traits. The predominance of additive genetic control implies that use of parents with suitable significant GCA effects is most appropriate for improving sorghum cultivars for dual purpose while the different parental combinations (grain by forage, forage by grain) that showed high specific combining ability indicated the role of dominance gene action.

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