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RESEARCH ARTICLE

Association Studies In Sorghum For Stay Green And Yield Associated Traits

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ABSTRACT

The present investigation was carried out with five segregating populations in sorghum to assess the association between grain yield and its correlated traits. In correlation coefficients, three crosses *viz.,* Cross 1, Cross 3 and Cross 5 showed significant positive association of grain yield with flag leaf length, flag leaf width, harvest index, plant height, number of leaves per plant, leaf chlorophyll index, stem girth, test weight (Cross 5), panicle weight, panicle length (except Cross 1) and biological yield and inter association of such traits were almost positive. Hence these three crosses could be exploited simultaneously for grain yield and other correlated traits by selection. From path coefficient analysis, it is concluded that the biological yield and harvest index had high positive direct effect on single plant yield in all crosses evaluated in the study. They also exhibited high indirect contribution on yield through yield components traits that could be used as yield determinants for further improvement in the population.

Keywords: *Sorghum; Drought; Grain yield; Correlation coefficient; Path analysis*

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench.) is the third important cereal in India after rice and wheat. It is staple food crop for millions of poor in semi-arid tropics of Africa and Asia (Haussmann *et al.,* 2002). Sorghum originated in northeastern quadrant of Africa and it is highly adapted to drought prone areas (Nimbalkar *et al.,* 1988; Sharma *et al.,* 2006). Drought stress during the post flowering stage creates negative impact on yield and studies indicate that the post-flowering drought adaptation in sorghum is associated with stay green trait and it is highly associated with reduced lodging and resistance towards stem rot. Rosenow and Clark, 1981 describe stay green trait as an indicator of drought tolerance. In general, number of ways exists in plants to remain green (Borrell *et al.,* 2014). The following classification describes the stay green trait as functional or cosmetic. Type A: Delayed senescence comprised with stay green phenotype, Type B: Reduced senescence, Type C: Green leaf with reduced photosynthesis rate, Type D: Rapid death at harvest maintains the greenness in plants and Type E: Plant phenotype remains green. Functional stay green trait includes type A, fB & E and indicates the occurrence of photosynthetic activity during grain filling stage. Cosmetic stay green trait includes type C & D and indicates that the plant remains green but the occurrence of photosynthetic activity gets disconnected.

Crop productivity is highly influenced by functional stay green trait but in some cases, stay green nature occurs due to smaller panicle or panicle with less grain filling. Thus, the both stay green and grain

yield act as principal components for selection (Rosenow *et al*., 1983). Several authors has been reported that the stay green trait is highly associated with number of tillers, number of grains, abiotic and biotic stress tolerance in several crops (Luche *et al.,* 2004). In Sorghum, achievement on the development of stay green nature in elite variety 'R16' using the donor 'B35' achieved through the marker assisted backcross breeding. Characterization of existing genetic variability and selection in population would pave the way for increasing the grain yield. Hence, the present study was carried out to identify the association between the grain yield and its correlated traits in F_3 populations of sorghum towards the enhancement of grain yield.

MATERIAL AND METHODS

The experiment was conducted at the Department of Millets, Tamil Nadu Agricultural University, Coimbatore. It was carried out to assess the association between grain yield and its associated traits in sorghum. It comprised of five parents *viz*., IS18551, CO30, CO26, K8 and B35 and five F_3 populations *viz*., K8 × IS18551 (Cross 1), CO26 × IS18551, CO26 × B35, CO30 × IS18551 and CO30 × B35. Plants were raised with a spacing of 15cm × 45cm and cultivation practices were adopted as per the recommendation. Selfing was done in each plant of F_3 populations. Biometrical observations were recorded in each cross of F_3 populations and ten randomly selected plants in parents. Observations on 14 traits *viz*., days to flowering, plant height, number of leaves per plant, leaf chlorophyll index, flag leaf length, flag leaf width, stem girth, panicle length, panicle weight, biological yield, test weight, harvest index, stay green trait and single plant yield were recorded. The coefficients of simple correlation between various characters were estimated in F_3 generations using the following formula

$$r = \frac{Cov_{.xy}}{\sqrt{(var_x . var_y)}}$$

Whereas, r =correlation coefficient between characters x and y, Cov_{xy}=covariance between the characters x and y, Var_x=variance of x and Var_y=variance of y. The relative influence of yield components on yield by themselves (direct effects) and through other traits (indirect effects) were evaluated by the method of path coefficient analysis as suggested by Dewey and Lu (1959). In path analysis, correlation coefficients were partitioned into its direct and indirect effects. The direct and indirect effects were classified as per the suggestions given by Lenka and Misra, 1973. It was categorized as very high – more than 1.00, high – 0.30 to 0.99, moderate – 0.20 to 0.29, low – 0.10 to 0.19 and negligible – 0.0 to 0.09.

RESULTS AND DISCUSSION

The number of yield component traits influences the complex nature of grain yield. The information of association between yield and its component characters and inter association among them would be very useful in formulating an effective and viable breeding programme for improvement of grain yield.

Correlation studies gives the strength of association between different the characters and helps for simultaneous improvement of related characters. Simple correlation coefficients between single plant yield and its component traits were computed individually in F_3 generation of all crosses and presented in Tables 1 to 5.

Correlation between single plant yield and its component characters

In the present investigation, days to flowering showed no significant association in four crosses and it is significant and negatively correlated in Cross 4. The similar finding was observed by Sindagi *et al*. (1970); Elangovan *et al.* (2007); Liang *et al.* (1969); Jadhav *et al.* (1994) and Veerabadhiran and Palanisamy (1994). Flag leaf length (except Cross 4) and harvest index showed significant and positive correlation with grain yield in all crosses. Similar findings for harvest index was reported earlier by Specht *et al.* (1999) and Shrotria and Singh, (1988). A significant and positive correlation was recorded for plant height, number of leaves per plant, leaf chlorophyll index, flag leaf width, stem girth with grain yield in all crosses except in Cross 2 and Cross 4. A similar trend was observed for panicle weight and biological yield in all the five crosses. Bucheyeki *et al.* (2009) and Iyanar *et al.* (2001) reported similar observations on panicle weight. Prakash et al. (2010) and Elangovan et al. (2007) recorded similar findings for plant height. Similar findings with leaf chlorophyll index were reported by Wanous *et al.* (1991); Borrell *et al.*(2000) and

Xu *et al.* (2000). Panicle length showed a significant and positive correlation with grain yield in Cross 3, Cross 4 and Cross 5. Test weight recorded significant and positive correlation with grain yield in Cross 2 and Cross 5. Warkad *et al*. (2010) and Elangovan *et al*. (2007) observed a similar finding.

Inter correlation among yield components

The inter correlation among the yield components showed the nature and the extent of relationship with each other. This might be useful for the simultaneous improvement of different characters along with grain yield in the breeding programme. In the present study, days to flowering showed significant and positive correlation with flag leaf length and flag leaf width in Cross 1, with panicle length in Cross 1 and Cross 2 and with test weight in Cross 5. Warkad *et al*., 2010 and Elangovan *et al*., 2007, also reported such positive association with test weight. Plant height exhibited significant and positive correlation with flag leaf length, flag leaf width in all crosses except Cross 4, with stem girth except in Cross 2 and Cross 4, with panicle length except in Cross 4, with panicle weight except in Cross 2 and Cross 4, with stay green trait in Cross 3 and Cross 5, with leaf chlorophyll index in Cross 1, Cross 3 and Cross 5 and with test weight in Cross 1 and Cross5. Number of leaves per plant had positive and significant correlation with harvest index in Cross 1, with flag leaf length, flag leaf width, panicle length, panicle weight and test weight in Cross 3, with leaf chlorophyll index in Cross 4, panicle weight in Cross 1, Cross 3 and Cross 5, stem girth in Cross 3 and Cross 5 and biological yield in Cross 3 and Cross 5.Similar relationship was observed by Elangovan *et al.* (2007) and Tiwari *et al.* (2003).

Leaf chlorophyll index had significant and positive correlation with test weight and stay green trait in Cross 1 and Cross 3, with flag leaf width in Cross 3 and Cross 4, harvest index in Cross 4 and Cross 5, panicle length in all crosses except Cross 2 and Cross 5, panicle weight and biological yield in all crosses except Cross 2 and stem girth in Cross 1, Cross 3 and Cross 4. Panicle length had positive and significant association with test weight in Cross 1 and Cross 5, with panicle weight and biological yield in Cross 3, Cross 4 and Cross 5 and with stay green trait in Cross 1, Cross 3 and Cross 5.

Panicle weight had positive association with biological yield and harvest index in all crosses, with test weight in Cross 2 and Cross 5 and with stay green trait in Cross 1 and Cross 2. Panicle weight having positive association with test weight was reported by Giriraj and Goud (1983). Biological yield had significant and positive association with test weight in Cross 2, with stay green trait in all crosses except Cross 4, with harvest index in Cross 4 and negatively significant association with harvest index in Cross 1. Similar result of positive association of biological yield with harvest index was reported by Shrotria and Singh (1988).

Path coefficient analysis

The Path analysis is the tool to specify the causes and measures of the relative contribution of each variable to yield. In the present study, direct and indirect effects of yield contributing components on grain yield were worked out (Table 6 to table 10).

Direct effect

In the present investigation, the residual effect was ranged from 0.04 to 0.09, which indicated the adequacy of the characters chosen for the study. The direct effect of biological yield and harvest index was high and positive in all crosses except Cross 4. The similar result was found by Jain and Patel (2013) for biological yield. Panicle weight recorded high and positive direct effect on grain yield in Cross 1 and Cross 4 and moderate and positive in Cross 3. Other characters in all crosses showed low and negligible direct effect on grain yield.

Indirect effect

Days to flowering recorded negligible indirect effect though all traits in all crosses except Cross 4 and Cross 5. It showed low and positive indirect effect through harvest index in Cross 5. Plant height recorded negligible indirect effect through all the characters in all crosses except through panicle weight (low and positive) in Cross 1 and Cross 3 (moderate and positive) and biological yield (high and positive) in Cross 3 and Cross 5.

Number of leaves per plant exhibited negligible indirect effect through all traits in all crosses except through panicle weight (low and positive) in Cross 1 and Cross 3, and through biological yield in Cross 3 (high and positive) and Cross 5 (moderate and positive). Leaf chlorophyll index reading recorded low and positive indirect effect through panicle weight in Cross 1, moderate and positive in Cross 5,

moderate and positive through biological yield in Cross 3 and Cross 5. Flag leaf length recorded low and positive indirect effect through panicle weight in Cross 1 and harvest index in Cross 1 and Cross 2 while through biological yield it was positive and moderate in Cross 3 and high and positive in Cross 5. A low and negligible indirect effect was exhibited by flag leaf length through all other traits in all crosses. Stem girth's indirect effect through biological yield was moderate and positive in Cross 3 and high and positive in Cross 5 and panicle weight was moderate and positive in Cross 4. Panicle weight recorded moderate and positive indirect effect through biological yield and harvest index in Cross 1 and high and positive effect through biological yield in Cross 3. Biological yield recorded moderate and positive indirect effect through panicle weight in Cross 3 and moderate and positive in Cross 1 while it was high and positive in Cross 4. This was an agreement with the findings of Specht *et al.* (1999) and Shrotria and Singh (1988). Test weight recorded moderate and positive indirect effect through biological yield in Cross 2 and Cross 5 and through harvest index in Cross 5. Indirect influence of harvest index through panicle weight was moderate, positive in Cross 1, high and positive in Cross 4, low, and positive in Cross 3. Through biological yield, stay green trait recorded moderate and positive indirect effect in Cross 2 and high and positive indirect effect in Cross 3. Donald (1962) reported similar results.

CONCLUSION

Three crosses *viz.,* Cross 1, Cross 3 and Cross 5 showed significant positive association of grain yield with flag leaf length, flag leaf width, harvest index, plant height, number of leaves per plant, leaf chlorophyll index, stem girth, test weight (Cross 5), panicle weight, panicle length (except Cross 1) and biological yield and inter association of such traits were almost positive. Hence these three crosses could be exploited simultaneously for grain yield and other correlated traits by selection. From path coefficient analysis, it is concluded that the biological yield and harvest index had high positive direct effect on single plant yield in all crosses evaluated in the study. They also exhibited high indirect contribution on yield through yield components traits that could be used as yield determinants for further improvement in the population.

Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Originality and plagiarism

We are ensure that we have written and submit only entirely original works, and if we have used the work and/or words of others, that has been appropriately cited.

Consent for publication

We (Shamini K and Selvi B) are agreed to publish the content.

Competing interests

There were no conflict of interest in the publication of this content

Data availability

All the data of this manuscript are included in the MS.

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Table 1: Simple correlation coefficients of14 characters of Cross 1 in F_3 populations of sorghum

Characters	DF	PH	NL/P	LCI	FLL	FLW	SG	PL	PW	BY	TW	HI	SGT	SPY
DF	1.000	0.155	-0.047	0.034	0.221**	0.270**	0.011	0.221**	-0.085	0.033	0.135	-0.109	0.161	-0.063
PH		1.000	0.009	0.208*	0.417**	0.429**	0.275**	0.237**	0.296**	0.068	0.258**	0.246**	0.103	0.274**
NL/P			1.000	0.035	0.124	0.097	0.063	0.035	0.219*	0.039	0.052	0.229**	0.092	0.218*
LCI				1.000	0.125	0.104	0.203*	0.284**	0.285**	0.279**	0.377**	0.11	0.242**	0.312**
FLL					1.000	0.974**	0.204*	0.337**	0.229**	-0.039	0.214*	0.296**	0.251**	0.218*
FLW						1.000	0.183*	0.364**	0.181*	-0.057	0.243**	0.263**	0.217*	0.170*
SG							1.000	0.068	0.261**	0.084	0.073	0.241**	0.133	0.267**
PL								1.000	-0.008	0.096	0.594**	-0.065	0.205*	0.006
PW									1.000	0.625**	0.074	0.477**	0.367**	0.993**
BY										1.000	0.092	-0.359**	0.189*	0.623**
TW											1.000	0.029	0.144	0.090
HI												1.000	0.233**	0.498**
SGT													1.000	0.373**
SPY														1.000

*Significant at 5% level **Significance at 1% level

Table 2: Simple correlation coefficients of14 characters of Cross 2 in F_3 populations of sorghum

Characters	DF	PH	NL/P	LCI	FLL	FLW	SG	PL	PW	BY	TW	HI	SGT	SPY
DF	1.000	0.075	-0.046	0.151	-0.013	-0.032	0.023	0.29**	-0.100	0.018	-0.146	-0.146	0.117	-0.059
PH		1.000	-0.150	0.104	0.385**	0.339**	0.055	0.498**	0.111	0.071	0.103	0.091	0.151	0.121
NL/P			1.000	0.006	0.146	0.166	0.055	-0.153	0.030	-0.019	0.025	0.116	0.064	0.028
LCI				1.000	0.203	0.173	0.189	0.149	0.091	0.026	0.038	0.132	0.139	0.092
FLL					1.000	0.855**	0.062	0.292**	0.213	0.092	0.170	0.334**	0.283*	0.245*
FLW						1.000	0.022	0.195	0.160	0.049	0.042	0.329**	0.158	0.190
SG							1.000	0.039	0.056	0.072	0.159	-0.050	0.008	0.045
PL								1.000	0.175	0.293**	0.292**	-0.146	0.277*	0.185
PW									1.000	0.889**	0.237*	0.492**	0.529**	0.985**
BY										1.000	0.301**	0.086	0.425**	0.882**
TW											1.000	-0.057	0.133	0.232*
HI												1.000	0.393**	0.537**
SGT													1.000	0.556**
SPY														1.000

*Significant at 5% level **Significance at 1% level

Table 3: Simple correlation coefficients of14 characters of Cross 3 in F_3 populations of sorghum

Characters	DF	PH	NL/P	LCI	FLL	FLW	SG	PL	PW	BY	TW	HI	SGT	SPY
DF	1.000	0.128	0.020	-0.026	0.034	0.034	0.055	0.163	0.143	0.125	-0.148	0.021	0.071	0.125
PH		1.000	0.52**	0.372**	0.375**	0.379**	0.447**	0.494**	0.848**	0.96**	0.144	0.005	0.491**	0.837**
NL/P			1.000	0.127	0.352**	0.317**	0.285*	0.29*	0.481**	0.574**	0.287*	-0.023	0.228	0.477**
LCI				1.000	0.316**	0.331**	0.247*	0.368**	0.324**	0.377**	0.255*	0.027	0.373**	0.34**
FLL					1.000	0.801**	0.315**	0.269*	0.31**	0.394**	0.244*	-0.074	0.218	0.316**
FLW						1.000	0.374**	0.264*	0.275*	0.4**	0.231*	-0.178	0.174	0.268*
SG							1.000	0.150	0.265*	0.415**	0.129	-0.201	0.31**	0.254*
PL								1.000	0.525**	0.53**	0.205	0.125	0.443**	0.532**
PW									1.000	0.874**	0.144	0.462**	0.599**	0.989**
BY										1.000	0.212	0.007	0.516**	0.87**
TW											1.000	-0.024	0.152	0.161
HI												1.000	0.3**	0.491**
SGT													1.000	0.612**
SPY														1.000

*Significant at 5% level **Significance at 1% level

Table 4: Simple correlation coefficients of14 characters of Cross 4 in F_3 populations of sorghum

Characters	DF	PH	NL/P	LCI	FLL	FLW	SG	PL	PW	BY	TW	HI	SGT	SPY
DF	1.000	-0.012	-0.061	-0.043	0.135	-0.145	-0.107	-0.213	-0.253	-0.250	-0.040	-0.155	0.099	-0.267*
PH		1.000	0.62**	0.117	0.028	0.197	0.058	0.065	0.055	0.028	0.226	0.180	-0.129	0.085
NL/P			1.000	0.29*	-0.130	0.153	0.035	0.093	0.106	0.051	0.168	0.219	0.053	0.114
LCI				1.000	-0.074	0.309*	0.287*	0.585**	0.633**	0.577**	0.164	0.607**	0.125	0.65**
FLL					1.000	0.212	-0.061	0.035	-0.007	-0.029	0.239	0.055	0.060	-0.013
FLW						1.000	0.181	0.288*	0.223	0.253	0.143	0.222	-0.083	0.231
SG							1.000	0.219	0.324*	0.330*	0.108	0.197	0.160	0.317*
PL								1.000	0.954**	0.890**	-0.037	0.734**	0.126	0.949**
PW									1.000	0.940**	0.022	0.739**	0.158	0.997**
BY										1.000	0.038	0.512**	0.133	0.941**
TW											1.000	0.014	0.050	0.040
HI												1.000	0.022	0.742**
SGT													1.000	0.152
SPY														1.000

*Significant at 5% level **Significance at 1% level

Table 5: Simple correlation coefficients of 14 characters of Cross 5 in F_3 populations of sorghum

Characters	DF	PH	NL/P	LCI	FLL	FLW	SG	PL	PW	BY	TW	HI	SGT	SPY
DF	1.000	-0.048	-0.146	0.069	-0.034	-0.043	0.103	-0.122	0.026	-0.035	0.268*	0.217	0.043	0.102
PH		1.000	0.422**	0.366**	0.683**	0.467**	0.560**	0.689**	0.862**	0.932**	0.372**	0.083	0.342**	0.749**
NL/P			1.000	0.194	0.147	0.114	0.378**	0.162	0.418**	0.403**	-0.078	0.118	0.123	0.375**
LCI				1.000	0.221	0.152	0.098	0.216	0.364**	0.319*	0.240	0.302*	0.231	0.409**
FLL					1.000	0.550**	0.367**	0.540**	0.562**	0.637**	0.187	-0.092	0.228	0.429**
FLW						1.000	0.333**	0.288*	0.409**	0.428**	0.106	-0.104	-0.063	0.267*
SG							1.000	0.443**	0.452**	0.508**	0.171	-0.023	0.222	0.379**
PL								1.000	0.562**	0.643**	0.298*	-0.044	0.293*	0.448**
PW									1.000	0.938**	0.407**	0.382**	0.237	0.905**
BY										1.000	0.392**	0.139	0.293*	0.818**
TW											1.000	0.423**	0.263*	0.558**
HI												1.000	0.016	0.673**
SGT													1.000	0.238
SPY														1.000

*Significant at 5% level **Significance at 1% level

Table 6: Direct (diagonal) and indirect effects of yield components with single plant yield of Cross 1 of F_3 populations in sorghum

Characters	DFF	PH	NL/P	LCI	FLL	FLW	SG	PL	PW	BY	TW	HI	SGT	SPY
DF	**0.017**	-0.0017	0.0004	-0.0002	0.0102	-0.0137	0.000	-0.0015	-0.0434	0.015	0.0011	-0.0462	0.0001	-0.063
PH	0.0026	**-0.0109**	-0.0001	-0.0014	0.0192	-0.0217	-0.0009	-0.0016	0.1517	0.031	0.002	0.1045	0.0000	0.2744**
NL/P	-0.0008	-0.0001	**-0.0084**	-0.0002	0.0057	-0.0049	-0.0002	-0.0002	0.1121	0.018	0.0004	0.097	0.0000	0.2184*
LCI	0.0006	-0.0023	-0.0003	**-0.0066**	0.0058	-0.0053	-0.0007	-0.0019	0.1459	0.1276	0.0029	0.0465	0.0001	0.3124**
FLL	0.0038	-0.0046	-0.001	-0.0008	**0.0461**	-0.0493	-0.0007	-0.0022	0.1174	-0.0179	0.0017	0.1255	0.0001	0.2179*
FLW	0.0046	-0.0047	-0.0008	-0.0007	0.0449	**-0.0506**	-0.0006	-0.0024	0.0929	-0.0261	0.0019	0.1116	0.0001	0.17*
SG	0.0002	-0.003	-0.0005	-0.0013	0.0094	-0.0093	**-0.0034**	-0.0005	0.1336	0.0385	0.0006	0.1023	0.0000	0.2666**
PL	0.0038	-0.0026	-0.0003	-0.0019	0.0155	-0.0184	-0.0002	**-0.0066**	-0.004	0.044	0.0046	-0.0274	0.0001	0.0064
PW	-0.0014	-0.0032	-0.0018	-0.0019	0.0106	-0.0092	-0.0009	0.0001	**0.5124**	0.2852	0.0006	0.2023	0.0001	0.9927**
BY	0.0006	-0.0007	-0.0003	-0.0018	-0.0018	0.0029	-0.0003	-0.0006	0.3201	**0.4566**	0.0007	-0.1522	0.0001	0.6231**
TW	0.0023	-0.0028	-0.0004	-0.0025	0.0098	-0.0123	-0.0003	-0.0039	0.0381	0.0421	**0.0078**	0.0123	0.0001	0.0903
HI	-0.0019	-0.0027	-0.0019	-0.0007	0.0136	-0.0133	-0.0008	0.0004	0.2444	-0.1639	0.0002	**0.4241**	0.0001	0.4977**
SGT	0.0027	-0.0011	-0.0008	-0.0016	0.0116	-0.011	-0.0005	-0.0014	0.1882	0.0862	0.0011	0.0987	**0.0003**	0.3726**

Residual effect = 0.0504

Table 7:Direct (diagonal) and indirect effects of yield components with single plant yield of Cross 2 of F_3 populations in sorghum

Characters	DF	PH	NL/P	LCI	FLL	FLW	SG	PL	PW	BY	TW	HI	SGT	SPY
DF	**0.0006**	0.0011	0.0004	0.0004	-0.0006	0.0013	0.0000	-0.0027	-0.0194	0.0118	0.0001	-0.0544	0.0020	-0.0593
PH	0.0000	**0.0146**	0.0014	0.0003	0.0170	-0.0135	0.0001	-0.0047	0.0216	0.0475	-0.0001	0.0338	0.0026	0.1209
NL/P	0.0000	-0.0022	**-0.0091**	0.0000	0.0065	-0.0066	0.0001	0.0014	0.0059	-0.0126	0.0000	0.0432	0.0011	0.0277
LCI	0.0001	0.0015	-0.0001	**0.0028**	0.0090	-0.0069	0.0003	-0.0014	0.0177	0.0173	0.0000	0.0491	0.0024	0.0919
FLL	0.0000	0.0056	-0.0013	0.0006	**0.0442**	-0.0339	0.0001	-0.0027	0.0415	0.0617	-0.0001	0.1245	0.0049	0.2451*
FLW	0.0000	0.0050	-0.0015	0.0005	0.0378	**-0.0397**	0.0000	-0.0018	0.0312	0.0330	0.0000	0.1228	0.0027	0.1900
SG	0.0000	0.0008	-0.0005	0.0005	0.0028	-0.0009	**0.0016**	-0.0004	0.0109	0.0484	-0.0001	-0.0185	0.0001	0.0448
PL	0.0002	0.0073	0.0014	0.0004	0.0129	-0.0077	0.0001	**-0.0094**	0.0342	0.1957	-0.0001	-0.0544	0.0048	0.1854
PW	-0.0001	0.0016	-0.0003	0.0003	0.0094	-0.0064	0.0001	-0.0016	**0.1948**	0.5942	-0.0001	0.1835	0.0092	0.9847**
BY	0.0000	0.0010	0.0002	0.0001	0.0041	-0.0020	0.0001	-0.0027	0.1732	**0.6684**	-0.0001	0.0322	0.0074	0.8818**
TW	-0.0001	0.0015	-0.0002	0.0001	0.0075	-0.0017	0.0003	-0.0027	0.0461	0.2009	**-0.0005**	-0.0214	0.0023	0.2322*
HI	-0.0001	0.0013	-0.0011	0.0004	0.0148	-0.0131	-0.0001	0.0014	0.0958	0.0576	0.0000	**0.3733**	0.0068	0.5370**
SGT	0.0001	0.0022	-0.0006	0.0004	0.0125	-0.0063	0.0000	-0.0026	0.1030	0.2838	-0.0001	0.1467	**0.0174**	0.5565**

Residual effect = 0.0735

Table 8: Direct (diagonal) and indirect effects of yield components with single plant yield of Cross 3 of F_3 populations in sorghum

Characters	DF	PH	NL/P	LCI	FLL	FLW	SG	PL	PW	BY	TW	HI	SGT	SPY
DF	**-0.0022**	0.0027	-0.0002	0.0001	0.0006	-0.0001	-0.0009	0.0017	0.0366	0.0766	0.0007	0.0075	0.0019	0.125
PH	-0.0003	**0.0213**	-0.0039	-0.001	0.0061	-0.0006	-0.0072	0.0051	0.2171	0.5861	-0.0007	0.002	0.0134	0.8374**
NL/P	0.0000	0.0111	**-0.0076**	-0.0004	0.0057	-0.0005	-0.0046	0.003	0.1231	0.3508	-0.0014	-0.0082	0.0062	0.4772**
LCI	0.0001	0.0079	-0.001	**-0.0028**	0.0051	-0.0005	-0.004	0.0038	0.083	0.23	-0.0012	0.0097	0.0102	0.3403**
FLL	-0.0001	0.008	-0.0027	-0.0009	**0.0163**	-0.0012	-0.005	0.0028	0.0793	0.2409	-0.0012	-0.0262	0.006	0.316**
FLW	-0.0001	0.0081	-0.0024	-0.0009	0.0131	**-0.0015**	-0.006	0.0027	0.0704	0.2445	-0.0011	-0.0634	0.0047	0.2681*
SG	-0.0001	0.0095	-0.0022	-0.0007	0.0051	-0.0006	**-0.016**	0.0016	0.0678	0.2533	-0.0006	-0.0716	0.0085	0.254*
PL	-0.0004	0.0105	-0.0022	-0.001	0.0044	-0.0004	-0.0024	**0.0103**	0.1344	0.3236	-0.001	0.0445	0.0121	0.5324**
PW	-0.0003	0.0181	-0.0036	-0.0009	0.0051	-0.0004	-0.0042	0.0054	**0.2561**	0.5338	-0.0007	0.1643	0.0164	0.9891**
BY	-0.0003	0.0205	-0.0044	-0.0011	0.0064	-0.0006	-0.0066	0.0055	0.2238	**0.6107**	-0.001	0.0027	0.0141	0.8697**
TW	0.0003	0.0031	-0.0022	-0.0007	0.004	-0.0004	-0.0021	0.0021	0.0368	0.1293	**-0.0048**	-0.0086	0.0041	0.1609
HI	-0.0001	0.0001	0.0002	-0.0001	-0.0012	0.0003	0.0032	0.0013	0.1184	0.0046	0.0001	**0.3555**	0.0082	0.4905**
SGT	-0.0002	0.0105	-0.0017	-0.001	0.0036	-0.0003	-0.005	0.0046	0.1535	0.3149	-0.0007	0.1065	**0.0273**	0.612**

Residual effect = 0.0788

Table 9: Direct (diagonal) and indirect effects of yield components with single plant yield of Cross 4 of F_3 populations in sorghum

Characters	DF	PH	NL/P	LCI	FLL	FLW	SG	PL	PW	BY	TW	HI	SGT	SPY
DF	**-0.0209**	-0.0005	0.0019	-0.0014	-0.0011	0.0006	0.0020	0.0064	-0.2244	-0.0235	-0.0003	-0.0062	0.0010	-0.2666*
PH	0.0003	**0.0441**	-0.0190	0.0039	-0.0002	-0.0007	-0.0011	-0.0019	0.0492	0.0027	0.0017	0.0072	-0.0013	0.0848
NL/P	0.0013	0.0274	**-0.0307**	0.0096	0.0011	-0.0006	-0.0006	-0.0028	0.0945	0.0048	0.0013	0.0088	0.0005	0.1145
LCI	0.0009	0.0051	-0.0089	**0.0333**	0.0006	-0.0012	-0.0053	-0.0175	0.5620	0.0542	0.0013	0.0243	0.0013	0.6501**
FLL	-0.0028	0.0013	0.0040	-0.0025	**-0.0082**	-0.0008	0.0011	-0.0010	-0.0062	-0.0027	0.0018	0.0022	0.0006	-0.0132
FLW	0.0030	0.0087	-0.0047	0.0103	-0.0017	**-0.0038**	-0.0033	-0.0086	0.1979	0.0238	0.0011	0.0089	-0.0008	0.2307
SG	0.0022	0.0026	-0.0011	0.0095	0.0005	-0.0007	**-0.0183**	-0.0066	0.2875	0.0310	0.0008	0.0079	0.0016	0.3170*
PL	0.0044	0.0029	-0.0029	0.0195	-0.0003	-0.0011	-0.0040	**-0.0299**	0.8467	0.0836	-0.0003	0.0294	0.0013	0.9493**
PW	0.0053	0.0025	-0.0033	0.0211	0.0001	-0.0008	-0.0059	-0.0285	**0.8875**	0.0883	0.0002	0.0296	0.0016	0.9974**
BY	0.0052	0.0013	-0.0016	0.0192	0.0002	-0.0010	-0.0060	-0.0266	0.8345	**0.0939**	0.0003	0.0205	0.0013	0.9412**
TW	0.0008	0.0100	-0.0052	0.0054	-0.0020	-0.0005	-0.0020	0.0011	0.0198	0.0036	**0.0077**	0.0006	0.0005	0.0398
HI	0.0032	0.0080	-0.0067	0.0202	-0.0005	-0.0008	-0.0036	-0.0219	0.6556	0.0481	0.0001	**0.0400**	0.0002	0.7418**
SGT	-0.0021	-0.0057	-0.0016	0.0042	-0.0005	0.0003	-0.0029	-0.0038	0.1405	0.0125	0.0004	0.0009	**0.0101**	0.1522

Residual effect = 0.0487

Table 10: Direct (diagonal) and indirect effects of yield components with single plant yield of Cross 5 of F_3 populations in sorghum

Characters	DF	PH	NL/P	LCI	FLL	FLW	SG	PL	PW	BY	TW	HI	SGT	SPY
DF	**-0.0047**	-0.0042	-0.0026	-0.0006	-0.0004	-0.0004	0.0010	0.0031	-0.0021	-0.0245	0.0108	0.1263	0.0001	0.1018
PH	0.0002	**0.0890**	0.0075	-0.0034	0.0076	0.0043	0.0056	-0.0172	-0.0688	0.6604	0.0150	0.0485	0.0007	0.7492**
NL/P	0.0007	0.0375	**0.0177**	-0.0018	0.0016	0.0010	0.0038	-0.0040	-0.0334	0.2855	-0.0031	0.0690	0.0002	0.3748**
LCI	-0.0003	0.0326	0.0034	**-0.0093**	0.0025	0.0014	0.0010	-0.0054	-0.0291	0.2260	0.0097	0.1759	0.0004	0.4087**
FLL	0.0002	0.0608	0.0026	-0.0021	**0.0111**	0.0050	0.0036	-0.0135	-0.0449	0.4516	0.0075	-0.0535	0.0004	0.4290**
FLW	0.0002	0.0416	0.0020	-0.0014	0.0061	**0.0091**	0.0033	-0.0072	-0.0327	0.3029	0.0043	-0.0607	-0.0001	0.2674*
SG	-0.0005	0.0498	0.0067	-0.0009	0.0041	0.0030	**0.0099**	-0.0110	-0.0361	0.3596	0.0069	-0.0134	0.0004	0.3786**
PL	0.0006	0.0613	0.0029	-0.0020	0.0060	0.0026	0.0044	**-0.0249**	-0.0449	0.4552	0.0120	-0.0259	0.0006	0.4479**
PW	-0.0001	0.0767	0.0074	-0.0034	0.0063	0.0037	0.0045	-0.0140	**-0.0798**	0.6647	0.0164	0.2225	0.0005	0.9053**
BY	0.0002	0.0829	0.0071	-0.0030	0.0071	0.0039	0.0050	-0.0160	-0.0749	**0.7085**	0.0158	0.0811	0.0006	0.8182**
TW	-0.0013	0.0331	-0.0014	-0.0022	0.0021	0.0010	0.0017	-0.0074	-0.0325	0.2776	**0.0403**	0.2466	0.0005	0.5580**
HI	-0.0010	0.0074	0.0021	-0.0028	-0.0010	-0.0010	-0.0002	0.0011	-0.0305	0.0985	0.0170	**0.5829**	0.0000	0.6726**
SGT	-0.0002	0.0304	0.0022	-0.0022	0.0025	-0.0006	0.0022	-0.0073	-0.0189	0.2074	0.0106	0.0096	**0.0019**	0.2376

Residual effect =0.09