The Bioscan
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES

20(4): 1846-1852, 2025 www.thebioscan.com

Characters association and path analysis Studies in colored pericarp sorghum (*Sorghum bicolor* (L.) Moench)

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DOI: 10.63001/tbs.2025.v20.i04.pp1846-1852

KEYWORDS
Sorghum, colored pericarp, trait association, multivariate analysis, grain quality,drought tolerance

Received on:

20-08-2025

Accepted on:

17-11-2025

Published on:

30-12-2025

Abstract

The present study was conducted to elucidate the interrelationships among grain quality attributes and drought-responsive traits in colored pericarp sorghum (*Sorghum bicolor* (L.) Moench). The objective of the study is to identify the key components contributing to overall grain quality improvement. A diverse set of genotypes was evaluated under field conditions during *rabi* 2019–20, and genotypic correlation and path coefficient analyses were carried out. Character association revealed that grain yield per plant showed significant positive associations with days to 50% flowering, plant height, number of primaries per panicle, panicle length, panicle width, days to physiological maturity, threshability, and fodder yield per plant, while panicle type, grain color, and 100-seed weight exhibited non-significant but positive associations. These results indicate the relevance of these traits in breeding programmes aimed at enhancing yield potential in sorghum. Path coefficient analysis further demonstrated that traits such as days to 50% flowering, panicle type, panicle length, panicle width, days to physiological maturity, threshability, grain color, and fodder yield exerted positive direct effects on grain yield, suggesting that selection based on these traits would be highly effective. Several traits, including plant height, number of primaries per panicle, panicle length, panicle width, grain color, and fodder yield, exhibited high heritability coupled with positive genotypic correlations with grain yield, indicating the potential for their simultaneous improvement through simple selection. Although glume color displayed a negative association with grain yield, genetic improvement of this trait alongside yield remains feasible by disrupting undesirable linkages through random mating in segregating generations. Overall, the findings highlight kernel hardness, grain density, and other positively associated traits as promising selection criteria for developing nutritionally superior and drought-adaptive sorghum cultivars suitable for dryland agro-ecosystems.

1.INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the most important cereal crops in the semi-arid tropics, cultivated extensively for food, fodder and industrial uses. Its inherent tolerance to heat, drought and low-input production environments makes it a vital component for dryland agriculture in India and Africa. Colored pericarp sorghum, in particular, has gained renewed attention due to its superior nutritional and functional properties, including higher phenolics, antioxidants and dietary fibre, which contribute to improved human health benefits. The development of high-quality sorghum varieties that combine nutritional superiority with drought adaptation has therefore become an important breeding priority. Understanding interrelationships among grain quality traits and drought-responsive characters is crucial for efficient selection in crop improvement. Since most economic traits are quantitatively inherited and governed by multiple genes, selection based on a single trait often leads to limited genetic progress. Correlation analysis provides insight into the degree and direction of association among traits, helping breeders identify characters that contribute meaningfully to improvement in yield or quality. However, correlation alone does not partition direct and indirect contributions, which can lead to misinterpretation when traits are interrelated. Path coefficient analysis, therefore, complements correlation by breaking down the total association into direct and indirect effects, allowing precise identification of the traits exerting real causal influence on the target character. In sorghum, most studies have focused on yield and shoot fly tolerance, while comprehensive evaluations of grain quality traits in pigmented sorghum remain limited. Pigmented pericarp types are particularly interesting because grain quality attributes such as kernel hardness, grain density, phenolic content and carbohydrate levels are strongly expressed and likely interconnected at genetic and metabolic levels.

2. MATERIALS AND METHODS

This experiment was conducted at the Sorghum Research Station, VNMKV, Parbhani during rabbi 2019–20. A total of 81 genotypes, including 76 colored pericarp germplasm lines sourced from IIMR and ICRISAT along with five checks, were evaluated under a Randomized Block Design with two replications. Each entry was raised in a single 3.0 m row with 45 cm × 15 cm spacing. A recommended fertilizer dose of 80:40:40 NPK kg/ha was applied, and standard agronomic practices were followed to maintain a healthy crop. Sowing was carried out by dibbling on 16 November 2019. Five randomly selected plants per plot were tagged for detailed observations, and the mean values were used for analysis. Data were recorded on major quantitative traits including days to 50% flowering, plant height, number of primaries per panicle, panicle length and width, panicle type, days to physiological maturity, 100-seed weight, threshability, grain yield per plant, and fodder yield. Qualitative traits such as grain color and glume colour were also assessed using standard scoring scales. Shoot fly resistance parameters including seedling vigour, seedling glossiness, dead heart incidence, trichome density, and leaf angle were recorded following established protocols. The recorded data were subjected to statistical analysis, including analysis of variance, estimation of genetic variability parameters, heritability, genetic advance, correlation, and path coefficient analysis, to understand trait relationships and identify components contributing to yield and grain quality improvement.

Table 1. Experimental materials details

Germplasm line	Germplasm Name	Germplasm line	Germplasm Name
GP 1	RIL 40274-2	GP 42	YPT 1021
GP 2	ISSVT 714	GP 43	IS-23891
GP 3	RIL 40853-1	GP 44	ISSVT 108
GP 4	ISSVT 346	GP 45	ICRISAT 409
GP 5	IS 11189	GP 46	RIL 32919-2
GP 6	RIL 40141-1	GP 47	YPT-1030
GP 7	RIL 40261-2	GP 48	ISSVT 102
GP 8	GD	GP 49	ISSVT104
GP 9	ISSVT 223	GP 50	ISSVT-710
GP 10	GP 2843	GP 51	GP 93
GP 11	RIL 41056-1	GP 52	GP 716
GP 12	ISSVT 108	GP 53	IS-15466
GP 13	ISSVT 109	GP 54	YPT-1015
GP 14	GP 2016-1	GP 55	GP 3138
GP 15	GP 595	GP 56	ICSR-93036
GP 16	RIL 40276-1-1	GP 57	627(ICSB)
GP 17	GP 55690	GP 58	RIL 40369-1
GP 18	GP 576	GP 59	RIL 40679-1-2
GP 19	RIL 40261-2	GP 60	RIL 40818-3-1
GP 20	RIL 40158-2	GP 61	GP 40053-1-2
GP 21	GP 2375	GP 62	GP 520
GP 22	GP 211	GP 63	RIL 32919-1
GP 23	GP 2017-5	GP 64	IS-23143
GP 24	RIL 40395-2	GP 65	YPT 1014
GP 25	ISSVT 325	GP 66	RIl 40679-3-1
GP 26	GP 2028	GP 67	GP 587
GP 27	GP 1539	GP 68	GD-62417
GP 28	RIL 32919-2	GP 69	Bajra type
GP 29	GP 374	GP 70	GP 75
GP 30	GP 920	GP 71	BT×623
GP 31	ISSVT 306	GP 72	RIL 40679-1-1
GP 32	GP 564	GP 73	RIL 40274-2
GP 33	B-35	GP 74	YPT 1412
GP 34	GP 53	GP 75	YPT-1007
GP 35	ICRISAT 109	GP 76	ICSR-93026
GP 36	ISSVT 712	P.Moti	P.Moti
GP 37	GP 3104	Udgir local	Udgir local
GP 38	GP 1673	CSV 22R (C)	CSV-22R
GP 39	ISSVT 324	IS18551 (RC)	DJ-6514
GP 40	GP 44	DJ6514 (SC)	IS-18551
GP 41	IC-9108		

3. RESULTS AND DISCUSSION

The improvement of grain yield in sorghum depends on understanding the relationship among component traits that influence productivity. The information regarding germplasm used in the present investigation are presented in table number 2. Correlation analysis therefore provides a useful basis for identifying traits that can be targeted for direct and indirect selection in breeding programs. The correlation coefficients for various characters are presented in table number 3. In the present investigation, genotypic correlation coefficients were usually higher than phenotypic correlations, indicating strong inherent genetic association among characters, which was in agreement with earlier findings reported by Ramaling et al. (2016), Zinzala et al. (2018) and Kandelwal et al. (2015). Grain yield, being a complex trait influenced by many physiological and morphological components, requires an understanding of the interrelationship of dependent and independent traits to facilitate effective selection of superior genotypes. Days to 50% flowering exhibited strong and positive association with plant height, number of primaries per panicle, panicle length, panicle width, days to physiological maturity and threshability at both phenotypic and genotypic levels, and also maintained a significant positive relationship with grain yield per plant. Similar relationships have been documented by Chittapur et al. (2015), Ramaling et al. (2016) and Zinzala et al. (2018). Plant height recorded significant positive association with panicle length and days to physiological maturity, especially at the genotypic level. The strong relationship between tall plants and late maturity is consistent with the reported linkages between the height locus Dw2 and Ma1, a major locus conditioning photoperiod sensitivity (Quinby and Karper 1967). This trait also showed positive correlation with grain yield at both levels, supporting previous observations by Awari et al. (2003), Ramaling et al. (2016) and Godbharle et al. (2010).

Number of primaries per panicle was significantly and positively correlated with panicle length and threshability, and also showed a strong positive association with grain yield, reinforcing its use as an important indirect yield-selection criterion as suggested by Cheralu and Rao (1989) and Jain and Patel (2014). Panicle type showed positive association with 100-seed weight and grain color, suggesting that concurrent improvement in panicle compactness and grain characteristics is possible through suitable breeding strategies. Panicle length and panicle width were among the most influential traits, displaying consistently high positive correlations with days to maturity, threshability, fodder yield and grain yield at both the phenotypic and genotypic levels. These findings align with earlier reports by Awari et al. (2003) and Kandelwal et al. (2015). Days to physiological maturity also exhibited significant positive correlation with threshability, 100-seed weight and grain yield, supporting earlier findings by Ramaling et al. (2016). Grain and glume color showed weak to moderate associations with yield, indicating largely independent inheritance patterns and minimal direct contribution to grain productivity. Test weight exhibited weak positive correlation with grain yield, contrasting with stronger correlations observed in studies involving less diverse material sets (Ezeaku and Mohammed 2005; Aba and Obilana 1994). Threshability and fodder yield per plant demonstrated strong positive associations with grain yield, suggesting that dual-purpose ideotypes combining high grain productivity and quality forage production can be successfully developed. Similar associations have been reported by Cheralu and Rao (1989), Kandelwal et al. (2015) and Jimmy et al. (2017). These results collectively indicate that days to flowering, number of primaries, panicle dimensions, threshability and fodder yield play the most significant role in determining grain productivity and therefore represent high-priority targets for selection.

Table 2. Genotypic and phenotypic correlation coefficient for grain yield and it's attributing characters in colored pericarp sorghum

Characters		Days to50% flowering	Plant height (cm)	No. of primaries per panicle	Panicle type (1-9score)	Panicle length (cm)	Panicle width (cm)	Days to physiological maturity	Grain color (1-5score)	Glume color (1-6score)	100-seed weight(g)	Threshability(%)	Fodder yield (g/plant)	Grain yield (g/plant)
Daysto50%flowering	G	1.000	0.312**	0.279*	-0.101	0.345**	0.252*	0.540**	0.008	-0.089	0.039	0.394**	0.176	0.516**
	P	1.000	0.358**	0.306**	-0.113	0.401**	0.308**	0.613**	0.012	-0.095	0.109	0.439**	0.192	0.468**
Plant height(cm)	G		1.000	0.042	-0.193	0.277*	0.065	0.215	0.021	-0.150	-0.024	0.168	0.233*	0.234*
	P		1.000	0.044	-0.201	0.319**	0.079	0.252*	0.021	-0.151	-0.046	0.192	0.211	0.219
No. of primaries per panicle	G			1.000	0.185	0.341**	0.203	0.212	-0.019	-0.182	0.072	0.371**	0.189	0.388**
	P			1.000	0.188	0.385**	0.224*	0.234*	-0.020	-0.184	0.091	0.409**	0.211	0.370**
Panicle type (1-9score)	G				1.000	0.028	0.100	-0.034	0.217	0.130	0.224*	0.121	0.023	0.146
	P				1.000	0.030	0.117	-0.057	0.221*	0.133	0.276*	0.134	0.017	0.139
Panicle length(cm)	G					1.000	0.444**	0.371**	0.086	-0.041	-0.024	0.598**	0.410**	0.748**
	P					1.000	0.510**	0.493**	0.097	-0.042	-0.013	0.683**	0.445**	0.662**
Panicle width(cm)	G						1.000	0.317**	0.029	-0.058	0.018	0.520**	0.292**	0.669**
	P						1.000	0.416**	0.031	-0.060	0.013	0.599**	0.333**	0.606**
Days to physiological maturity	G							1.000	0.032	-0.076	0.147	0.344**	0.185	0.550**
	P							1.000	0.044	-0.084	0.243*	0.441**	0.259*	0.450**
Grain color(1-5score)	G								1.000	0.183	-0.336**	-0.019	-0.084	0.050
	P								1.000	0.182	-0.450**	-0.016	-0097	0.042
Glume color(1-6score)	G									1.000	-0.209	-0.158	-0.247*	-0.119
	P									1.000	-0.269*	-0169	-0273*	-0.120
100-seedweight(g)	G										1.000	0.115	0.124	0.103
	P										1.000	0.129	0.163	0.108
Threshability(%)	G											1.000	0.486**	0.950**
	P											1.000	0.543**	0.932**
Fodder yield(kg/plant)	G												1.000	0.597**
	P												1.000	0.530**
Grain yield(g/plant)	G													1.000
	P													1.000

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Table 3. Direct and in direct effects (genotypic and phenotypic level) of yield components on grain yield in color pericarp sorghum

Characters		Days to 50% flowering	Plant height(cm)	Numberof primaries per panicle	Panicle type(1-9score)	Panicle length (cm)	Paniclewidth (cm)	Days to physiological maturity	Graincolor (1-5score)	Glume color (1-6score)	100 - seed weight (g)	Threshability(%)	Fodder yield/plant(g)	Grain yield/Plant(g)
Daysto50%flowering	G	**0.088**	-0.004	-0.010	-0.006	0.041	0.030	0.055	0.000	-0.002	-0.003	0.303	0.024	0.516**
	P	**0.068**	0.006	-0.000	-0.003	0.027	0.031	0.041	0.000	-0.002	0.000	0.284	0.015	0.468**
Plant height(cm)	G	0.031	**-0.013**	-0.001	-0.011	0.032	0.007	0.022	0.000	-0.004	0.001	0.133	0.034	0.234*
	P	0.021	**0.019**	-0.000	-0.006	0.021	0.008	0.016	0.000	-0.004	-0.000	0.121	0.020	0.219
Number of primaries per panicle	G	0.027	-0.000	**-0.033**	0.010	0.039	0.022	0.021	-0.000	-0.005	-0.003	0.283	0.027	0.388**
	P	0.019	0.000	**-0.003**	0.006	0.026	0.025	0.016	-0.000	-0.005	0.001	0.268	0.016	0.370**
Panicle type(1-9score)	G	-0.010	0.002	-0.006	**0.055**	0.003	0.011	-0.005	0.004	0.004	-0.009	0.092	0.002	0.146
	P	-0.007	-0.003	-0.000	**0.032**	0.002	0.012	-0.002	0.009	0.004	0.003	0.087	0.002	0.139
Panicle length(cm)	G	0.035	-0.004	-0.012	0.001	**0.102**	0.050	0.044	0.002	-0.001	0.000	0.472	0.057	0.748**
	P	0.023	0.005	-0.001	0.000	**0.078**	0.055	0.028	0.003	-0.001	-0.000	0.432	0.036	0.662**
Panicle width(cm)	G	0.027	-0.001	-0.007	0.006	0.052	**0.098**	0.037	0.000	-0.001	-0.000	0.414	0.042	0.669**
	P	0.017	0.001	-0.000	0.003	0.035	**0.125**	0.024	0.001	-0.001	0.000	0.375	0.025	0.606**
Days to Physiological maturity	G	0.054	-0.003	-0.007	-0.003	0.050	0.040	**0.090**	0.001	-0.002	-0.008	0.305	0.033	0.550**
	P	0.037	0.004	-0.000	-0.001	0.029	0.039	**0.076**	0.001	-0.002	0.002	0.248	0.016	0.450**
Grain color(1-5score)	G	0.001	-0.000	0.000	0.012	0.010	0.003	0.004	**0.022**	0.005	0.015	-0.011	-0.012	0.050
	P	0.000	0.000	0.000	0.007	0.006	0.003	0.002	**0.041**	0.005	-0.004	-0.014	-0.007	0.042
Glume color(1-6score)	G	-0.008	0.002	0.006	0.007	-0.004	-0.005	-0.007	0.004	**0.030**	0.009	-0.117	-0.035	-0.119
	P	-0.006	-0.002	0.000	0.004	-0.003	-0.007	-0.005	0.007	**0.031**	-0.002	-0.114	-0.021	-0.120
100 Seed weight(g)	G	0.009	0.000	-0.003	0.015	-0.001	0.001	0.022	-0.010	-0.008	**-0.033**	0.089	0.020	0.103
	P	0.002	-0.000	-0.000	0.007	-0.001	0.002	0.011	-0.014	-0.006	**0.013**	0.083	0.011	0.108
Threshability(%)	G	0.038	-0.002	-0.013	0.007	0.070	0.058	0.039	-0.000	-0.005	-0.004	**0.691**	0.069	0.950**
	P	0.027	0.003	-0.001	0.003	0.047	0.065	0.026	-0.000	-0.005	0.001	**0.721**	0.043	0.932**
Fodder yield/plant(g)	G	0.017	-0.003	-0.007	0.001	0.045	0.032	0.023	-0.002	-0.008	-0.005	0.376	**0.128**	**0.597****
	P	0.012	0.004	-0.000	0.000	0.032	0.036	0.014	-0.003	-0.007	0.001	0.351	**0.088**	**0.530****

Residual effect = 0.280
*Significant at5 percent level, ** Significant at 1 percent level

The direct and indirect effects were for various characters are presented in table number 3. While correlation gives the strength of association among traits, it does not separate direct from indirect effects on grain yield. Path analysis was therefore performed to quantify these contributions. Days to 50% flowering recorded a positive direct effect on grain yield and exhibited major indirect contributions through threshability and days to maturity at both levels, suggesting that improvement in earliness could simultaneously enhance yield when associated traits are favourably inherited. These findings are consistent with Aml et al. (2012). Plant height registered a small negative direct effect at the genotypic level but its indirect effect through threshability and fodder yield was strong enough to result in an overall positive association with grain yield. Similar trends were observed in earlier analyses by Wankhede et al. (1985).

Number of primaries per panicle showed a small negative direct effect, but a strong positive indirect effect through threshability, indicating that its contribution to grain yield is largely mediated by panicle threshing efficiency. Panicle type had a moderate positive direct effect and important indirect contributions via threshability, in agreement with observations by Potdukhe et al. (1992). Panicle length and panicle width recorded some of the highest direct effects on grain yield and substantial indirect effects through threshability, fodder yield and maturity, confirming them as major yield-determining characters as also highlighted by Aml et al. (2012). Days to physiological maturity exerted a positive direct effect on grain yield, with important indirect contributions through threshability, supporting the findings of Patel et al. (1993). Grain and glume color registered low direct effects and minor indirect contributions, confirming their limited role in determining grain yield.

Test weight exerted a small direct effect but recorded stronger indirect contributions to yield via threshability, aligning with Patel et al. (1993). Threshability exhibited the highest positive direct effect on grain yield at both phenotypic and genotypic levels, and also contributed significant indirect effects through panicle length, panicle width and fodder yield, making it one of the strongest determinants of yield performance. Similar conclusions were drawn by Kandelwal et al. (2015) and Reha and Biradar (2015). Fodder yield also showed a positive direct effect along with substantial indirect contributions via threshability and panicle traits, reinforcing its importance in dual-purpose sorghum improvement, a finding supported by Sriram and Rao (1983) and Reha and Biradar (2015).

The residual values obtained in path analysis suggested that although the studied characters accounted for most of the explained variation in grain yield, some variability remains attributable to additional physiological or biochemical factors not included in the present study. From a breeding perspective, simultaneous improvement of multiple quantitative traits remains challenging due to the polygenic nature of most yield-related attributes and the complexity of their genetic control. Even with modern molecular breeding and genome-assisted selection, optimizing many traits at once is difficult, reinforcing the need to prioritize a smaller set of traits with strong direct and indirect contributions to yield. Based on the results of correlation and path analysis, traits such as panicle length, panicle width, threshability, days to maturity, fodder yield and number of primaries per panicle emerged as the most reliable selection criteria for enhancing grain yield in colored pericarp sorghum.

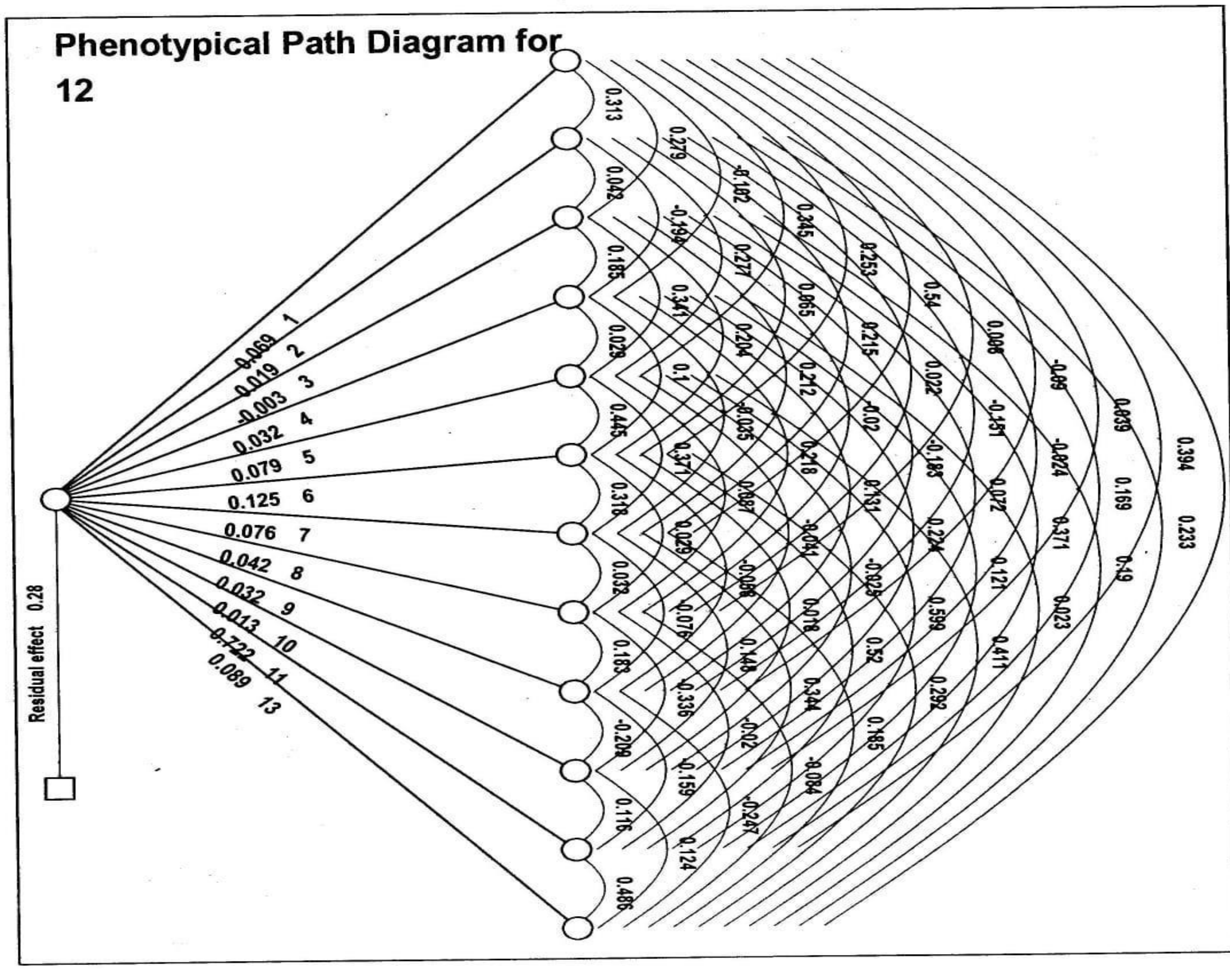

Figure 1. Phenotypic path diagram for grain yield & it's attributing traits in colored pericarp sorghum

4. CONCLUSION

The study demonstrated that grain yield in colored pericarp sorghum is largely influenced by traits such as panicle length, panicle width, threshability, days to maturity, number of primaries per panicle and fodder yield, which exhibited strong positive correlations and substantial direct contributions to yield. These traits therefore represent reliable selection criteria for breeding high-yielding and drought-adaptive sorghum genotypes. Although some traits such as grain and glume colour showed limited direct impact on yield, their improvement remains possible through selection and recombination in segregating generations. Overall, prioritizing key yield-contributing traits can facilitate the development of nutritionally superior and climate-resilient sorghum cultivars suitable for dryland production systems.

Plate1. High yielding genotypes of colored pericarp sorghum

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