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Characterization of Coloured Sorghum Genotypes for Qualitative and Quantitative Characters

Akshay Kumar[1], Suvarna[1], P. H. Kuchanur[1], G. Girish[2] and M. Lakshmikanth[3]

[1]Dept. of GPB, [3]Dept. of SS&AC, College of Agriculture, UAS Raichur, Karnataka (584 104), India
[2]AICRP on Sorghum, ARS Hagari, Karnataka (583 111), India

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Corresponding suvarnagpb@uasraichur.edu.in

0000-0003-2750-4164

ABSTRACT

The experiment was conducted at College of Agriculture, Raichur, University of Agricultural Sciences, Raichur, Karnataka, India during October 2021–Februrary 2022 to characterize the 100-coloured sorghum genotypes along with four checks *viz.*, M 35-1, AKJ 1, Paiyur 2 and GS-23 for eight qualitative characters and 10 quantitative characters in an augmented block design. The results revealed that, majority of the genotypes exhibited the pigmented stem (93%) and leaves almost green (61%) at harvest, horizontal flag leaf orientation (100%), loose erect primary branches of panicle (38%), black glumes (58%), red grain colour (36%), circular grain shape (75%) and freely threshable (93%) characters. For all the quantitative characters studied, a wide range of variation was observed. For stay green character, genotype IS 21868 showed completely green leaves. Similarly, for other characters also superior genotypes were identified in this study. Such genotypes can be used further in improvement of sorghum for its grain yield. For grain yield, 14 genotypes exhibited higher yields when compared to the best check GS-23, *viz.*, IS 29032 (120.0 g), IS 6508 (119.18 g), IS 16006 (113.80 g), IS 28065 (102.88 g), IS 23890 (94.88 g), IS 28049 (94.28 g), IS 23865 (89.48 g), IS 29031 (87.98), IS 28202 (87.88), IS 31706 (86.48), IS 2582 (85.88 g), IS 28200 (83.58), IS 16398 (81.08 g) and IS 23955 (80.0 g). Eight genotypes were *on par* with GS-23. These genotypes can be further evaluated for its yield stability within and across locations.

KEYWORDS: Coloured grain, characterization, genotypes, qualitative, quantitative, sorghum, yield

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench], popularly called as jowar, is "The King of coarse cereals", "King of millets" or "Great Millet" and is the fifth most important cereal crop in the world after rice, wheat, maize and barely, in terms of production and utilization. The word sorghum is derived from the latin word "Sorgo" which means "Raising above". It is also called as *jola, jowar, cholam* in India. It is called as a failsafe crop and camel of crops, because of its drought tolerance and heat tolerance property and also its high photosynthetic efficiency. So, it is considered as an important staple food crop in arid and semi-arid regions of the world (Anagholi et al., 2000).

Sorghum is grown in India during 2021, in an area of about 4.24 mha with a production of 4.78 mt and productivity of 1130 kg ha^{-1} (Anonymous, 2022a). In Karnataka, it is grown in 1.41 m ha with a production of 1.13 million mt and productivity of 974 kg ha^{-1} during the year 2021 (Anonymous, 2022b). It is originated in Africa. It is an often cross pollinated, diploid (2n=20) and C_4 grass plant species, which belongs to the family "Graminae" and tribe "Andropogeneae". Cultivated sorghum has five basic races, *viz*., bicolor, durra, guinea, caudatum and kafir and ten intermediate races.

In coloured grain sorghum, the seed colour ranges from white to various pink, orange, red and even brown. The influence of pericarp thickness on seed colour can be seen. The grain colour content depends on the chemical composition of the pericarp. The grain's phenolic profile, particularly the bran layer, is intimately related to the colour. Red sorghum is generally associated with a phenolic component that has somewhat high concentrations but is absent of tannin, which is desirable in the brewing industry. White sorghum has a slightly higher overall phenolic content than yellow sorghum, which is higher in flavanones. Because it has coloured testa and significant concentrations of condensed tannins, brown sorghum is also known as tannin sorghum. The phenol concentration of coloured sorghum is high and it contains a unique pigment called 3-deoxyanthocyanin that doesn't have a hydroxyl group in the third carbon position. Because it is more stable under high temperatures and an alkaline pH, the pigment has a strong potential for usage as a food colouring. Additionally, sorghum is high in dietary fibre and antioxidant activity and it can provide gluten-free protein. The crop needs to be enhanced in terms of productivity, nutrition and biochemical factors (Deshmukh et al., 2021).

Collection and characterization of existing germplasm is a prerequisite for identifying potential genotype for adaptation, selection and varietal improvement programmes. Morphological, cytological, biochemical and molecular markers are commonly used in crop genetic resource characterization. Among these, morphological characterization is the first, easiest, and cheapest step in grouping germplasm, evaluating diversity and registering cultivars (Rakshit et al., 2012). Morphological characterization involves the use of both qualitative and quantitative traits for evaluating and describing genotypes of sorghum (Elangovan et al., 2009, Adugna, 2014; Alade et al., 2017, Badigannavar et al., 2017; Suvarna, 2019; Elangovan et al., 2020; Kiran, 2021 and Maruthmuthu et al., 2022). In recent years coloured grain is gaining demand because of export potential for industrial use. However, genetic studies on coloured grain germplasm is limited (Kiran et al., 2021). Therefore, the present study on characterization of coloured sorghum genotypes for qualitative and quantitative characters was conducted.

2. MATERIALS AND METHODS

The experiment was carried out during October 2021–Februrary, 2022 at the College of Agriculture, Raichur, Karnataka, India. The experimental material entails the 100-coloured sorghum genotypes with different colours, which included exotic collections obtained from R.S. Paroda gene bank, ICRISAT, Patancheru. The four checks were used in the study are M 35-1, Paiyur 2, AKJ 1 and GS-23. The list of genotypes used for the study is presented in Table 1. The experiment was conducted in an augmented design. Each entry was sown in four blocks. Each block was of 4 m length with uniform spacing of 45 cm between rows and 15 cm between plants. To grow the healthy crop, the recommended package of practices and need-based plant protection measures were used. Five plants were randomly chosen from each genotype in each entry and the following qualitative observations were recorded for plant pigmentation, flag leaf orientation, panicle compactness and shape, glume colour, grain colour, grain shape and threshability and quantitative characters recorded were days to 50% flowering (days), days to maturity (days), plant height (cm), peduncle length (cm), neck of panicle (cm), panicle length (cm), panicle width (cm), panicle weight (g), 100 grain weight (g) and grain yield plant per plant (g). The Analysis of Variance (ANOVA) was used to assess the variance components for quantitative characters.

3. RESULTS AND DISCUSSION

The variability among the 100 coloured sorghum genotypes collected from ICRISAT, Patancheru using eight qualitative traits is presented in Table 2. Among the 100 genotypes, the different characters were exhibited by the genotypes for inflorescence shape and compactness as loose erect primary branches (38 genotypes), semi-loose erect primary branches (26), compact elliptic (19), semi-compact

Table 1: List of genotypes used in present investigation and their country of origin

Sl. No.	Geno-types	Country source	Sl. No.	Geno-types	Country source	Sl. No.	Geno-types	Country source	Sl. No.	Geno-types	Country source
1.	IS522	Mexico	26.	IS18301	Niger	51.	IS23955	Yemen	76.	IS29012	Yemen
2.	IS2502	USA	27.	IS18639	Nigeria	52.	IS24001	Yemen	77.	IS29013	Yemen
3.	IS2582	USA	28.	IS18679	USA	53.	IS28056	Yemen	78.	IS29032	Yemen
4.	IS2618	USA	29.	IS19298	Sudan	54.	IS28065	Yemen	79.	IS29033	Yemen
5.	IS3579	Sudan	30.	IS19299	Sudan	55.	IS28074	Yemen	80.	IS29052	Yemen
6.	IS3817	Mali	31.	IS21868	Yemen	56.	IS28172	Yemen	81.	IS31706	Yemen
7.	IS6508	India	32.	IS22436	Sudan	57.	IS28015	Yemen	82.	IS30722	Cameroon
8.	IS7013	Sudan	33.	IS22897	Sudan	58.	IS28017	Yemen	83.	IS30736	Cameroon
9.	IS7527	Nigeria	34.	IS22942	Sudan	59.	IS28049	Yemen	84.	IS30754	Cameroon
10.	IS8222	Uganda	35.	IS19498	Sudan	60.	IS28050	Yemen	85.	IS30800	Cameroon
11.	IS8792	Zimbabwe	36.	IS20301	Niger	61.	IS28217	Yemen	86.	IS30802	Cameroon
12.	IS9664	Sudan	37.	IS20842	USA	62.	IS28224	Yemen	87.	IS30781	Cameroon
13.	IS11180	Ethiopia	38.	IS21835	Sudan	63.	IS28230	Yemen	88.	IS31906	Yemen
14.	IS12643	Ethiopia	39.	IS23890	Yemen	64.	IS28176	Yemen	89.	IS32072	Yemen
15.	IS14897	Cameroon	40.	IS23916	Yemen	65.	IS28198	Yemen	90.	IS32165	Yemen
16.	IS14904	Cameroon	41.	IS40175	Mauritania	66.	IS28200	Yemen	91.	IS32185	Yemen
17.	IS14905	Cameroon	42.	IS22949	Sudan	67.	IS28202	Yemen	92.	IS33158	Cameroon
18.	IS15098	Cameroon	43.	IS22970	Sudan	68.	IS28237	Yemen	93.	IS33159	Cameroon
19.	IS16006	Cameroon	44.	IS23864	Yemen	69.	IS28244	Yemen	94.	IS33310	Cameroon
20.	IS16169	Cameroon	45.	IS23865	Yemen	70.	IS28250	Yemen	95.	IS33317	Cameroon
21.	IS16202	Cameroon	46.	IS28000	Yemen	71.	IS28265	Yemen	96.	IS33323	Cameroon
22.	IS16310	Cameroon	47.	IS28001	Yemen	72.	IS28792	Yemen	97.	IS33336	Cameroon
23.	IS16316	Cameroon	48.	IS28009	Yemen	73.	IS28966	Yemen	98.	IS33343	Cameroon
24.	IS16398	Cameroon	49.	IS28014	Yemen	74.	IS29031	Yemen	99.	IS34723	Cameroon
25.	IS17591	Yemen	50.	IS23954	Yemen	75.	IS28982	Yemen	100.	IS35642	Chad

elliptic shape (12) and loose drooping primary branches (5) (Figure 1). Based on glume colour, the genotypes were grouped into four classes *viz*., Black, straw, reddish brown and red. The most prevalent glume colours among the genotypes was black (58 genotypes), straw (33), reddish brown (8) and red (1). Elangovan and Prabhakar (2007) evaluated the one hundred and fifty-seven landraces of Karnataka, India, showed similar variation, but the majority had brown glumes. Darker glumes are known to contribute to grain mould resistance. The variability of glume colour available in the present study may be utilized in screening for grain mould resistance in sorghum (Rajani et al., 2017). Based on threshability, the genotypes were grouped into three categories *viz*., freely threshable, partially threshable and difficult to thresh. Among them, 93 genotypes were categorized into freely threshable and seven genotypes were grouped into partially threshable. Threshability is inversely related to glume coverage as glume coverage becomes poorer with increasing threshability. Generally, in grain sorghum, threshability is easy and it is difficult in fodder types. Non senescence or stay green is the maintenance of green stems and leaves when water is limited at grain filling and maturity. Non senescence is an important trait related to drought tolerance. Stay green shows the characteristics of green leaves and stems even under limiting condition (Sri Subalakshmi et al., 2021). In the present study, 61 genotypes were showed the leaves almost green, leaves moderately green by 23 genotypes, almost dried leaves by 15 genotypes and only one genotype (IS 21868) showed completely green leaves. So, genotype IS 21868 can be used for development of drought tolerant sorghum varieties. Similar results were also reported by Dossou-Aminon et

Table 2: Characterisation of coloured grain sorghum genotypes for different qualitative characters

Sl. No.	Code	Character	No. of genotypes	Per cent
1. Flag leaf orientation				
	1	Horizontal	100	100
	2	Vertical	-	-
2. Plant pigmentation at harvest				
	1	Pigmented	93	93
	2	Tan	7	7
3. Stay green				
	1	Leaves completely green	01	01
	2	Leaves almost green	61	61
	3	Leaves moderately green	23	23
	4	Leaves almost dry	15	15
4. Inflorescence compactness and shape				
	4	Loose erect primary branches	38	38
	5	Loose drooping primary branches	05	05
	6	Semi loose erect primary branches	26	26
	8	Semi compact Elliptic	12	12
	9	Compact Elliptic	19	19
5. Glume colour				
	2	Red	1	1
	3	Straw	33	33
	8	Black	58	58
	11	Reddish brown	8	8
6. Grain colour				
	2	Reddish brown	21	21
	6	Red	36	36
	10	Purple	19	19
	11	Brown	24	24
7. Grain shape				
	1	Circular	75	75
	2	Oval	25	25
8. Threshability				
	1	Freely threshable	93	93
	2	Partially threshable	7	7

al. (2014). Colour variations in sorghum grains helps to classify them for the food product for which they will be destined (Galassi et al., 2019). Grain colour is an important

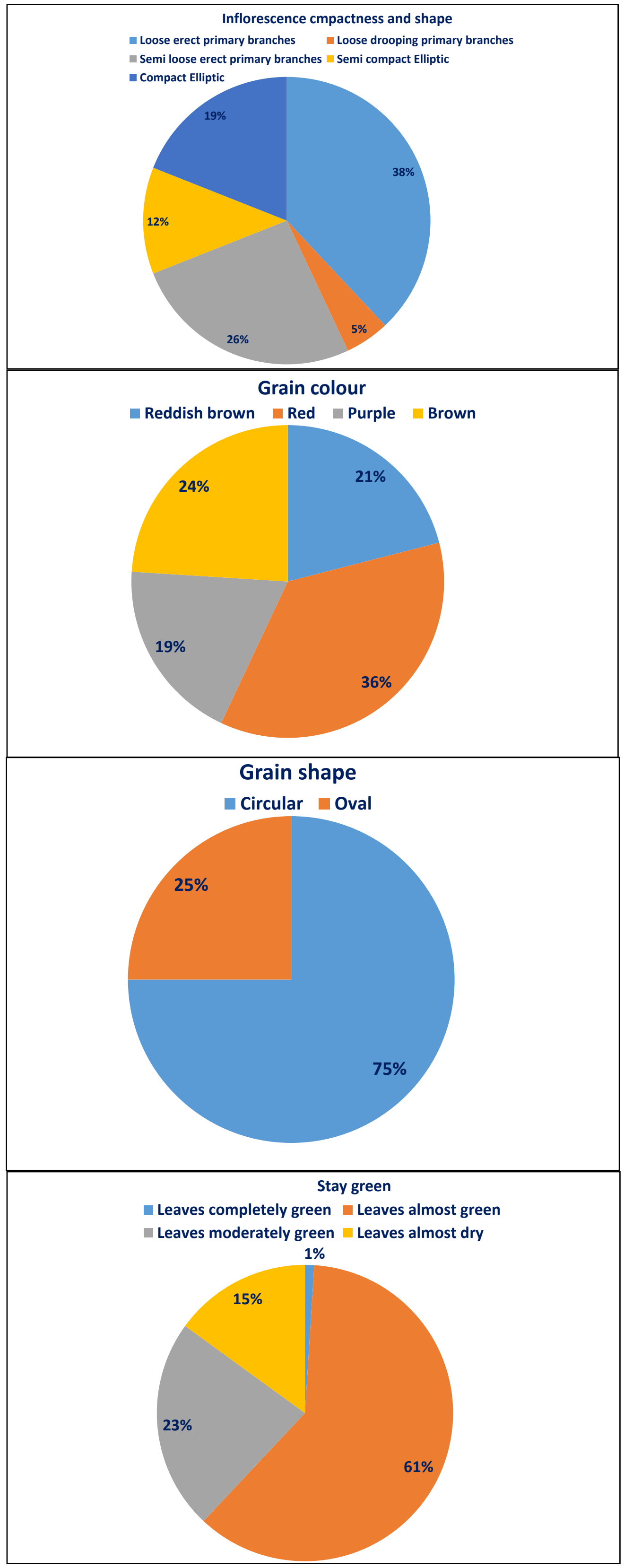

Figure 1: Per cent contribution of coloured sorghum genotypes for each qualitative character

character in sorghum morphological analysis. The dominant colour among the genotypes was red (36%), brown (24%), reddish brown (21%) and purple (19%) (Figure 2). Sorghum with white grain (greater luminosity) is commonly used in the kitchen, while sorghum with pigmented pericarp (red, reddish brown and brown grain) with a higher content of bioactive compounds, such as polyphenolic compounds, are used to produce functional beverages (Punia et al., 2021). Grain shape exhibited by genotypes, circular (75) and oval shape (25). In sorghum, plant colour is due to anthocyanin pigmentation of the leaf sheath. Genotypes with tan coloured plants showed resistance to various fungal diseases, while the genotypes with closed glumes are resistant to grain mold (Melake-Berhan et al., 1996, Murty, 2000). Pigmentation of the stem at harvest is pigmented (93) and Tan (7). The pigmentation is indication of phenolics are known to provide defense against biotic mainly against shoot fly and abiotic stresses in plants (Dixon and Paiva, 1995). Similar studies were reported by Sangwan et al. (2005) for panicle compactness and shape of panicle, Elangovan et al. (2009) and Missihoun et al. (2015) for inflorescence compactness and shape and glume colour (Figure 3).

Compact elliptical | Semicompact elliptical

Loose erect primary branches | Semi loose erect primary branches

Figure 2: Variation for inflorescence compactness and shape in coloured sorghum genotypes

3.1. Quantitative characters

The analysis of variance (Table 3) for days to 50% flowering, days to maturity, plant height (cm), peduncle length (cm),

Figure 3: Variation for grain colour in coloured grain sorghum genotype

neck of panicle (cm), panicle length (cm), panicle width (cm), panicle weight (g), 100-grain weight (g) and grain yield plant^{-1} (g) showed highly significant difference among the tested genotypes at (p<0.01) level of significance. Days to 50% flowering ranged from 51 days to 81 days with an overall mean of 65.31 days. IS 16316 (51 days) was the earliest to reach 50% flowering, followed by IS 7013 and IS 30736 (55 days) and three other genotypes. While, IS 28217 (81 days) very late to reach days to 50% flowering, followed by IS 28050 (78 days) and IS 3323 (76 days). Days to maturity varied from 100 days to 125 days with an average of 109.13 days. The genotypes *viz*., IS 522, IS 15098, IS 18301, IS 30754 were the earliest to mature (100 days) and IS 29033 (125 days) was late in maturity. The

Table 3: Analysis of variance for morphological, yield and yield attributing characters in coloured sorghum genotypes

Source of variation	DF	DFF	DM	PH	PEDL	NP	PL	PWD	PW	TW	GYPP
Blocks	3	47.42	10	1323.94	110.05	22.31	40.56	3.61	142.89	0.27	117.52
Entries (checks+ genotypes)	103	32.47**	31.31**	2560.43**	346.36**	94.02**	57.74**	9.8**	807.11**	1.28**	593.85**
Checks	3	85.42**	152.67**	3619.26**	327.64**	70.82**	3.21	0.65	520.21**	1.13**	359.64**
Genotypes	99	30.67**	26.04*	2480.46**	341.33**	91.58**	56.71**	8.86**	815.89**	1.04**	590.68**
Checks vs. Genotypes	1	51.64**	188.83**	7301.63**	900.35**	404.76**	324.01**	129.66**	798.72**	25.36**	1610.38**
Error	9	4.58	6.67	63.6	37.75	3.14	2.3	0.94	16.5	0.1	25.56

**: Significant at (p=0.01) level of significance; *: Significant at (p=0.05) level of significance; DF: Degrees of freedom; DFF: Days to 50% flowering; DM: Days to mature; PH: Plant height (cm); PEDL: Peduncle length (cm); NP: Neck of panicle (cm); PL: Panicle length (cm); PWD: Panicle width (cm); PW: Panicle weight (g); TW: 100 grain weight (g); GYPP: Grain yield plant^{-1} (g)

average plant height observed was 257.11 cm. The range for plant height was from 109.13 cm (IS 18679) to 372.80 cm (IS 12643). Peduncle length has an average of 53.12 cm, the length of the peduncle ranged from 15 cm to 105 cm. The genotype, IS 22436 (105 cm) showed the highest peduncle length, whereas the genotype IS 31906 (15 cm) had the shortest peduncle length. The range for the neck of panicle varied from 3.60 cm to 55 cm with an average of 21.67 cm. The longest neck of panicle was observed in the genotype IS 22436 (55 cm) and the shortest neck of panicle observed was in the genotype IS 18679 (3.60 cm). The range for panicle length varied from 4.40 cm to 45.40 cm, with an average mean of 22 cm. The longest panicle length was observed in the genotype IS 12643 (45.40 cm). While the shortest panicle length was observed in the genotype IS 21868 (4.40 cm). Panicle width ranged from 3.20 cm to 15.20 cm with an average of 8.18 cm. The highest panicle width was observed for the genotype IS 16316 (15.20 cm) and the lowest was observed for the genotype IS 21868 (3.20 cm). The average panicle weight recorded was 66.44 g. The highest panicle weight showed by genotype IS 29032 (158 g), while the lowest panicle weight was observed in the genotype IS 22970 (16.10 g). The character 100 grain weight was ranged from 2.06 g to 7.07 g with an average weight of 4.52 g. The highest grain weight was observed in the genotype IS 28176 (7.07 g), while the lowest grain weight was observed for IS 3817 (2.06 g). The average grain yield plant^{-1} recorded was 52.25 g, with a range of 9.58 g to 120 g. The highest grain yield plant^{-1} was observed for the genotype IS 29032 (120 g) followed by IS 6508 (119.18 g), while the lowest grain yield plant^{-1} was observed by genotype IS 11180 (9.58 g) (Table 4). Among four checks GS-23 yielded high (78.05 g plant^{-1}), which is *on par* with the other two checks M 35-1 and AKJ-1. When genotypes were compared with check GS-23, 14 genotypes *viz.*, IS 29032 (120 g), IS 6508 (119.18 g), IS 16006 (113.80 g),

Table 4: Mean, minimum, maximum and range for yield and yield attributing characters

Sl. No.	Character	Mean	Minimum	Maximum	Range
1.	Days to 50% flowering (days)	65.31	51	81	30
2.	Days to maturity (days)	109.13	96	125	29
3.	Plant height (cm)	257.11	109.60	372.80	263.20
4.	Peduncle length (cm)	53.12	15	105	90
5.	Neck of panicle (cm)	21.67	3.60	55	51.40
6.	Panicle length (cm)	22	4.40	45.40	41
7.	Panicle width (cm)	8.18	3.20	15.20	12
8.	Panicle weight (g)	66.44	16.10	158	141.90
9.	100 Grain weight (g)	4.52	2.06	7.07	5.01
10.	Grain yield plant^{-1} (g)	52.25	9.58	120	110.42

IS 28065 (102.88 g), IS 23890 (94.88 g), IS 28049 (94.28 g), IS 23865 (89.48 g), IS 29031 (87.98), IS 28202 (87.88), IS 31706 (86.48), IS 2582 (85.88 g), IS 28200 (83.58), IS 16398 (81.08 g) and IS 23955 (80.0 g) yielded significantly high (Table 5). Eight genotypes were *on par* with GS-23.

Similarly, Reddy et al. (2009) studied 29 sorghum genotypes on the basis of days to 50% flowering. Further, the studies were reported by Kannababu et al. (2013) for days to 50%

flowering and plant height. Pahuja et al. (2002) evaluated 18 sorghum hybrids on the basis of plant height. Umakanth et al. (2002) for plant height and panicle length. Elangovan and Prabhakar (2007) and Reddy et al. (2009) for panicle length and plant height. Nabi et al. (2006) for plant height.

Table 5: List of high yielding coloured grain sorghum genotypes compared to best check

Sl. No.	Genotype	Grain colour	GYPP (g)	GYPR (g)
1.	IS 29032	Purple	120	2400
2.	IS 6508	Brown	119.18	2383.60
3.	IS 16006	Brown	113.80	2276
4.	IS 28065	Red	102.88	2057.60
5.	IS 23890	Reddish brown	94.88	1897.60
6.	IS 28049	Purple	94.28	1885.60
7.	IS 23865	Red	89.48	1789.60
8.	IS 29031	Red	87.98	1759.60
9.	IS 28202	Red	87.88	1757.60
10.	IS 31706	Red	86.48	1729.60
11.	IS 2582	Brown	85.88	1717.60
12.	IS 28200	Red	83.58	1671.60
13.	IS 16398	Reddish brown	81.08	1621.60
14.	IS 23955	Red	80	1600
Check				
GS-23		White	78.05	1541

GYPP: Grain yield plant^{-1}; GYPR: Grain yield row^{-1}

4. CONCLUSION

Genotypes showed a wide range of variation for qualitative characters viz., grain colour, glume colour, stay green character and inflorescence compactness and shape and for all the quantitative characters studied. The superior genotypes were identified the characters studied. These promising genotypes can further be used in breeding programme to develop high yielding sorghum genotypes.

5. REFERENCES

Adugna, A., 2014. Analysis of *in situ* diversity and population structure in Ethiopian cultivated *Sorghum bicolor* (L.) landraces using phenotypic traits and SSR markers. Springer Plus 3, 212.

Alade, O.D., Fayeun, L.S., Obilana, A.B., 2017. Morphological evaluation of long season sorghum accessions in Akure, south west Nigeria. Proceedings of the 3rd conference of the association of seed scientists of Nigeria (ASSN), 62–69.

Anagholi, A., Kashiri, A., Mokhtarpoor, H., 2000. The study of comparison between inside forage sorghum cultivars and speed feed hybrids. Agricultural Science and Natural Resources Journal 7(4), 73–83.

Anonymous, 2022a. World agricultural production. Circular Series WAP 1-22 January 2022, United States Department of Agriculture, Foreign Agricultural Service. Accessed on https://apps.fas.usda.gov/PSDOnline/Circulars/2022/01/production.pdf.

Anonymous, 2022b. Agriculture statistics. Karnataka State Agriculture Department. Accessed on https://raitamitra.karnataka.gov.in/info-4 Agriculture+Statistics/en.

Badigannavar, A., Ashok Kumar, A., Girish, G., Ganapathi, T.R., 2017. Characterization of post-rainy season grown indigenous and exotic germplasm lines of sorghum for morphological and yield traits. Plant Breeding and Biotechnology 5(2), 106–114.

Deshmukh, S.S., Dhutmal, R.R., Jahagirdar, J.E., Shinde, A.V., 2021. Correlation and path analysis study between yield and yield components in colored pericarp sorghum (*Sorghum bicolor* (L.) Moench). The Pharma Innovation Journal 10(10), 151–155.

Dixon, R.A., Paiva, N.L., 1995. Stress-induced phenylpropanoid metabolism. Plant Cell 7(7), 1085–1097.

Dossou-Aminon, I., Yeyinou Loko, L., Adjatin, A., Eben-Ezer, B.K., Dansi, A., Rakshit, S., Cisse, N., Patil, J.V., Agbangla, C., Ambaliou, S., Akpovi, A., Akpagana, K., 2015. Genetic divergence in northern Benin sorghum (*Sorghum bicolor* L. Moench) landraces as revealed by agromorphological traits and selection of candidate genotypes. Scientific World Journal, 1–10. https://doi.org/10.1155/2015/916476.

Elangovan, M., Prabhkar, R.D.C.S., 2007. Characterization and evolution of sorghum (*Sorghum bicolor* (L.) Moench) germplasm from Karnataka, India. Karnataka Journal Agriculture Sciences 20(4), 840–842.

Elangovan, M., 2006. Evaluation of an Italian germplasm collection of (*Loliumperenne* L). through a multivariate approach. Proceedings of the Eucarpia fodder crops selection meeting, September 22–24, France, 22–24.

Elangovan, M., Prabhakar, Tonapi, V.A. Reddy, D.C.S., 2009. Collection and characterization of Indian sorghum landraces. Indian Journal of Plant Genetic Resources 22(3), 173–178.

Elangovan, M., Annapurna, A., Patil, R., Patroti, P., Pandey, S., Pandey, C.D., 2020. Characterization of 2500 indigenous collections of sorghum [*Sorghum bicolor* (L.) Moench] germplasm. Indian Journal of Plant Genetic Resources 33(3), 295–299.

Galassi, E., Taddei, F., Ciccoritti, R., Nocente, F., Gazza, L., 2019. Biochemical and technological characterization of two C4 gluten-free cereals: *Sorghum bicolor* and Eragrostis tef. Cereal Chemistry 97(1), 65–73.

Kannababu, N., Rakshit, S., Audilakshmi, S., Tonapi, V., Patil, J.V., Dhandapani, A., Reddy, D.C.S., Venugopal, K., Swarnalatha, M., Balakrishna, G., Raghunath, K., Subhakar, V., 2013. Genetic variability among Indian rainy season Sorghum cultivars revealed by morpho-agronomic traits. Indian Journal of Genetics and Plant Breeding 73(1), 110–115.

Kiran, S., Tembhurne, B.V., Girish, G., Shivaleela, Lakshmikanth, M., 2023. Genetic diversity studies for yield and yield attributing characters in colored sorghum genotypes. Indian Journal of Plant Genetic Resources 36(2), 208–215. DOI:10.5958/0976-1926.2022.00036.2.02.

Maruthamuthu, E., Venkatesh, K., Bellundagi, A., Pandey, S., Pandey, C.D., 2022. Assessment of variability in sorghum [*Sorghum bicolor* (L.) Moench] germplasm for agro-morphological traits. Electronic Journal of Plant Breeding 13(2), 488–497.

Melake-Berhan, A., Butler, L.G., Ejeta, G., Menkir, A., 1996. Grain mold resistance and polyphenol accumualation in sorghum. Journal of Agricultural and Food Chemistry 44, 2428–2434. doi: 10.1021/jf950580x.

Missihoun, A.A., Sagbadja, H.A., Sedah, P., Dagba, R.A., Ahanhanzo, C., Agbangla, C., 2015. Genetic diversity of (*Sorghum bicolor* (L.) Moench) landraces from Northwestern Benin as revealed by microsatellite markers. African Journal of Biotechnology 14(16), 1342–1353.

Murty, D.S., 2000. Breeding for grain mold resistance in sorghum: opportunities and limitations," in: Chandrashekar, A., Bandyopadhyay, R., Hall, A.J. (Eds.), Technical and institutional options for sorghum grain mold management: Proceedings of an International Consultation, 18–19 May 2000, International Crops Research Institute for The Semi-Arid Tropics (ICRISAT), Patancheru), 225–227.

Nabi, C.G., Muhammad, R., Ghulam, A., 2006. Comparison of some advanced lines of {*Sorghum bicolor* (L.) Monech} for green fodder/dry matter yields and morpho-economic parameters. Journal of Agricultural Research 44(3), 191–196.

Pahuja, S.K., Grewal, R.P.S., Singh, N., Singh, P., Jindal, Y., Pundir, S.R., 2002. Evaluation of forage sorghum hybrids for yield and morphological traits. International Sorghum and Millets Newsletter 43, 42–45.

Punia, H., Tokas, J., Malik, A., Satpal, Y., Sangwan, S., 2021. Characterization of phenolic compounds and antioxidant activity in sorghum [*Sorghum bicolor* (L.) Moench] grains. Cereal Research Communications 49(3), 343–353.

Rajani Verma, B.R., Ranwah, B.B., Ramesh, K., Ram, K., Ayush, D., Monika, M., 2017. Characterization of sorghum germplasm for various qualitative traits. Journal of Applied and Natural Science 9(2), 1002–1007.

Rakshit, S., Gomashe, S.S., Ganapathy, K.N., 2012. Morphological and molecular diversity reveal wide variability among sorghum Maldandi landraces from India. Journal of Plant Biochemistry and Biotechnology 21(2), 145–156.

Reddy, D.C.S., Audilakshmi, S., Seetharama, N., 2009, Genetic variability and divergence for DUS testing traits in sorghum (*Sorghum bicolor*). Indian Journal of Agricultural Sciences 79(4), 286–290.

Sangwan, V.P., Chauhan, P., Ram, C., 2005. Varietal identification of forage sorghum through morphological characters. Seed Research 33(1), 117–118.

Umakanth, A.V., Madhusudhana, R., Swarnlata, K., Rana, B.S., 2002. Genetic diversity studies in sorghum. International Sorghum and Millets Newsletter 43, 31–33.