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Correlation and path analysis studies for productivity and grain quality traits in *rabi* sorghum (*Sorghum biocolar* (L.) Moench)

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Abstract
Rabi sorghum is an fourth most important food crop because of its excellent grain quality, nutritional status, low glycemic index and gluten-free along with higher yield. Among selected mini core accessions, seed yield per plot exhibited highly significant positive association with fodder yield, 100 seed weight, seed volume and seed size at both phenotypic and genotypic level. Whereas in promising varieties, association between seed yield per plot, ear head width, 100 seed weight and bulk density was significantly positive at both levels. Among selected mini core accessions, path analysis showed that highly significant positive direct effect through ear head length, fodder yield, seed size and seed amylose on seed yield per plot. In case of selected promising varieties, high positive direct effect of plant height and ear head length seed yield per plant, indicating true relationship between these characters with grain yield per plant and direct selection for these traits will be rewarding for improvement of grain yield per plant.

Keywords: Sorghum, mini core, correlation, path analysis

Introduction
Sorghum (*Sorghum bicolor* (L.) Moench) is the fourth most important cereal crop following rice, wheat, maize and staple food in the same central parts of the world. Worldwide, it is cultivated on 41.07 million ha with production of 58.42 million tones (Anonymous 2019a) [1]. In India, sorghum having 5.00 million ha area with 4.5 million tones production and 900 kg/ha productivity (Anonymous 2019b) [2]. *Rabi* sorghum is highly valued as a food crop because of its excellent grain quality, nutritional status and low glycemic index and gluten-free (Taylor *et al.* 2006) [3]. It is grown mainly for human consumption about more than 35% of its production; the rest is used primarily for animal feed, alcohol production and industrial products [(FAO, 1995) [4]; (Awika and Rooney, 2004) [5]; (Dicko *et al*., 2006) [6]; (Mehmood *et al*., 2008) [7]]. As a food crop, sorghum can provide a healthy diet for human nutrition (Mudjisihino and Damardjati, 1987) [8]. Nutritional qualities like seed protein and seed amylose content are the important aspects, where there is necessity and scope to improve nutritional and roti quality of sorghum. Where, starch is a major nutritional component in plant grains consisting primarily of amylose and amylopectin. Regular grains contain about 20%-30% is amylose while waxy grains contain a much lower percentage (<1% amylose) (Jane *et al.*, 1999) [9] and the remaining 80%-70% is amylopectin. The chemical properties of the less-branched amylose molecule contribute to its nutritional value. Amylose is digested more slowly, providing beneficial effects on human health and also significantly influences on cooking quality like viscosity, swelling power, solubility and water absorption capacity. The amylose content in 100 sorghum lines ranged from 7.1 to 31.3%. Waxy sorghums were reported to have low amylose content. The water soluble amylose of the 45 cultivars ranged from 4.8 to 12.7% by Hulse *et al.* (1980) [10]. Subramanian *et al.* (1982) [11] evaluated 45 sorghum genotypes on physiochemical characteristics and roti quality of flour and revealed that quantity of water soluble protein, amylose and sugar influences the roti quality. Chavan *et al.* (2009) [12] used twenty local land races, 92 genotypes and seven improved cultivars of sorghum along with check M 35-1 to study nutritional quality parameter and *roti* quality. Local land races were promising for protein, sugar and soluble protein content. The nutritional properties of sorghum are unique and variety dependent. It is noted for the relatively low digestibility of both protein and starch with great potential for weight and obesity

management. Studies on rice (Juliano, 1979) [13] indicated the importance of amylose and protein on the cooking and eating quality of rice. Hence, there is need to generate the information on the grain quality nutritional quality like seed protein and seed amylose content are the important for roti quality. Some varieties are rich in polyphenols, especially condensed tannins, as natural antioxidants (Dykes and Rooney 2006) [14].

Post rainy season sorghums is superior over *kharif* sorghum with respect to grain and fodder quality as the grains are white, bold, harder, round and lustrous in appearance as they are less prone to diseases and pests. Hence, study of grain quality is as important as that of the yield in *rabi* sorghum. According to Kent and Evers (1994) [15], the kernel characteristics of shape, size and mass are the most important in respect of cereal grain quality. Sorghum *roti* quality was influenced by flour, and dough properties including grain quality characters. Genetic variation existing among pearly white grain types for *roti* quality could be explained through this breeding program. The nutritional constituents viz., crude protein, soluble proteins, and soluble amylose content were mostly responsible for the good quality *roti*. Organoleptic quality traits viz., colour and texture were associated with better quality of *roti* in sorghum.

Yield is a complex character controlled by polygenic loci, which depends upon many independent contributing characters and highly influenced by the fluctuations in environment. Knowledge of the magnitude and type of association between yield with its components themselves greatly help in evaluating the contribution of different components towards yield. Hence, selection of plants based directly on yield would not be very reliable. Besides, the information on the nature of association between yield and its components helps in simultaneous selection for many characters associated with yield improvements (Mahajan *et al*., 2011) [16].

Correlation studies provide information on the nature and extent of association between any two pairs of metric characters. Hence it could be possible to bring genetic improvement in one character by selection of the other of a pair (Nyadanu and Dikera *et al*. 2014) [17]. Correlation measure the level of dependence traits and out of numerous correlation coefficients. A positive genetic correlation between two desirable traits makes the job of the plant breeder easy for improving both traits simultaneously (Girish *et al*.,2016) [18]. Mahajan *et al.* (2011) [19] indicated the positive association of plant height and panicle length with grain yield per plant of sorghum

The estimates of correlations alone may be often misleading due to mutual cancellation of component traits. So, it becomes necessary to study path coefficient analysis, which takes in to account the casual relationship in addition to degree of relationship. The path coefficient analysis initially suggested by Wright (1921b) [20] and described by Dewey and Lu (1959) [21] allows partitioning of correlation coefficient into direct and indirect contributions (effects) of various traits towards dependent variable and thus helps in assessing the cause-effect relationship as well as effective selection. Hence, this study was aimed to analyze and determine the traits having greater interrelationship with grain yield utilizing the correlation and path analysis.

Mini core collection (10% accessions of the core collection or 1% of entire collection) represents the whole range of variation of cultivated sorghum and is an ideal material for assessing the exact nature and magnitude of variability. Mini core collection is considered as a gateway for utilization of diversity present in large germplasm collection for crop improvement (Upadhyaya, *et al.* 2009) [22]. Hence, sorghum mini core collection was assessed in the present study for yield and grain quality and compared with released varieties of post rainy season.

Material and Methods

The plant material for this experiment comprised of (a) 24 selected mini core collection out of 208 mini core accessions based on grain hardness, grain colour and grain lustre along with M 35-1 as check variety (Tablle-1). The mini core collection of sorghum obtained from DSR Hyderabad. (b) Sixteen selected released/promising varieties of *rabi* sorghum which are commonly grown in northern Karnataka (Table-2). The experiment was laid out in medium deep black soil under rain fed condition. The randomized block design was followed separately with two replications and each entry was sown in four rows of 4 m length with inter row spacing of 45 cm and intra row spacing of 15 cm. Observations on all quantitative characters like plant height (cm), panicle length (cm), panicle width (cm), seed yield per plot (g), 100 seed weight (g), seed volume (ml), bulk density (g/ml), true density (g/ml), seed size (mm), seed protein (%), seed amylose (%), seed amylopectin (%) and seed yield/plot (kg).

Seed size was measured by using Vernier Callipers where length, breadth and thickness of seeds were recorded. Seed density classified into two types *viz.*, true density and bulk density. Seed bulk density was measured by hundred gram of seeds were weighed and volume was recorded in a measuring jars. Whereas, seed true density was observed by known weight of seeds placed in a measuring jar containing known quantity of toluene. Increase in volume was recorded after pouring seeds in measuring jar. Seed volume was noted with countable numbers of seeds were placed in a measuring jar. Grain quality characters like seed luster, seed color, seed shape and seed hardness was recorded by measuring the grinding time required to obtain a fixed volume of flour from the grains. Mean of five plants for each entry was worked out and used for statistical analysis.

Estimation of biochemical parameters: (a) Seed protein (per cent): Protein content of selected genotypes was estimated by using Microkjeldhal method. Total nitrogen was estimated by using Kel-plus (digestion and distillation unit). Crude protein value was obtained by multiplying the total nitrogen by the conversion factor. (b) Amylose content and amylopectin content (percent); Total amylose was estimated by following the method of Soubhagya and Bhattacharya (1979) [23], 100 mg sample was taken in a 100 ml volumetric flask, disperse 1 ml of alcohol followed by 10 ml of 1 N NaOH leave it for overnight, make the volume upto 100 ml from distilled water. From this extract 2.5 ml was taken, add 20ml distilled water, add 3 drops of phenolphthalein indicator, it will change to pink color, add 0.1 N HCl, till it becomes colourless, now add 1 ml of 0.2 per cent iodine solution, make volume made up to 100 ml. The purple-blue was read at 590 nm. Amylopectin will be calculated by subtracting total amylose from 100.

Result and Discussion

Correlation coefficient is a statistical measure, which denotes the degree and magnitude of association between any two casually related variables. This association is due to pleitropic gene action or linkage or more likely both. In plant breeding correlation coefficient analysis measures the mutual relationship between two characters and it determines character association for improvement yield and other economic characters. Since the association pattern among yield components help to select the superior genotypes from divergent population based on more than one interrelated characters. Thus information on the degree and magnitude of association between characters is of prime important for the breeder to initiate any selection plan (Khadakabhavi *et al.,* 2017) [24].

Genotypic correlation coefficient provides measures of genetic association between traits and thus helps to identify the more important as well as less important traits to be considered in breeding programmes. For most of the association in this study, the genotypic correlation coefficients are higher than phenotypic correlation coefficients. Higher genotypic correlations of characters than phenotypic correlation coefficients had earlier been reported [(Alhassan *et al*., 2008) [25] and (Khadakabhavi *et al.*,2017) [24]. Expressions of higher genotypic than phenotypic correlations are indications of strong inherent relationships between these characters (Johnson, 1955) [26]. However, when phenotypic correlations are higher than genotypic correlations, environmental effect or non-additive effects are acting on the trait in the same direction.

Among selected mini core accessions, seed yield per plot exhibited highly significant positive association with fodder yield (0.3913**G, 0.364**P), 100 seed weight (0.3912**P, 0.3268**G), seed volume (0.4169**G, 0.4041**P) and seed size (0.6429**P, 0.58**P) at both phenotypic and genotypic level (Table-3). Whereas in promising varieties, association between seed yield per plot, ear head width (0.8566**g, 0.8392**P), 100 seed weight (0.9002**G, 0.8758**P) and bulk density (0.4358**G,0.3817**P) was significantly positive at both levels (Table-4). Similar results were also reported by Bahaa *et al.,* (2013) [27] that grain yield/panicle had showed positive significant association at both levels with characters like test weight and seed density. Malghan and Kajjidoni (2019) [28] reported that Grain yield per plant expressed significant genotypic and phenotypic correlation coefficients with plant height (0.46** G, 0.45** P), 100–seed weight (0.70** G, 0.69** P) and fodder yield per plant (0.70** G, 0.68** P).

However it was interesting to note that 100 seed weight trait exhibited significant positive association with grain yield across the both group of genotypes under study suggesting that 100 seed weight as an important attribute with immense contribution in determining seed yield. Similar results were reported by Potdukhe *et al.* (1994) [29] Ezeaku and Mohammed (2006) [30] , Aruna and Audilakshmi (2008) [31], Sharma *et al*. (2006) [32] , Elangovan *et al*. (2007) [33] and Warkad *et al*. (2010) [34],Vijaya *et al.,* (2012) [35] also noticed that seed yield per plant had significant and positive association with 100-seed weight.

Correlation analysis provides the information on inter relationship of plant characters. The 100 seed weight had highly significant positive association with seed yield per plant, ear head width and seed size. Fodder yield exhibited significant positive association with plant height, suggesting the improvement of fodder yield based on selection on plant height. Mohammed *et al.* (1993) [36] observed that fodder yield was positively associated with plant height. Seed volume exhibited significant positive association with ear head width, 100 seed weight and seed size, whereas, ear head width, 100 seed weight and seed volume had highly significant positive association among themselves. Among selected promising varieties, ear head width, 100 seed weight had significant positive association among themselves, so that selection can be practiced based on these traits which could possible to improve the grain yield.

Among selected mini core accessions, seed protein and seed amylose content were associated significantly in negative direction. Similarly, true density and bulk density were associated significantly in negative direction. Highly significant negative association was found between seed amylose and amylopectin content. Similar results were reported by Wang *et al.* (2005) [37] indicating significant negative correlation between amylose content and protein content. Whereas, the strong negative relationship that grain yield has with protein content has been observed repeatedly across cereal grains (Slafer *et al*. 1990) [38]; (Simmonds 1995) [39]; (Feil 1997) [40].Whereas in promising varieties positive association was found between seed protein content with plant height, seed protein and seed size were significant in negative direction. Similarly, seed amylose content and ear head length were associated significantly in negative direction, suggesting that both cannot be improved simultaneously. Seed yield per plot had non significant association with most of the grain quality characters like seed protein, seed amylose content and seed amylopectin content in both collections, selection for these traits could be done without detrimental effect on grain yield and it may be possible to improve these grain quality traits along with the high seed yield.

The association between seed yield and seed size was significant in positive direction in selected mini core collections. Whereas, non significant in selected promising varieties revealing that further contribution of seed size towards grain yield appears to be limited among the promising varieties. However there is an indication that further grain yield improvement can be achieved through the contribution of bulk density and true density, wherein the bulk density exhibited significant positive association with grain yield in promising varieties compared to non significant association in selected mini core accessions.

Path coefficient analysis measures the direct influence of one variable upon the other and permits separation of correlation coefficient into components of direct and indirect effects, provides actual information on contribution of characters and thus forms the basis for selection to improve the yield. The results of direct and indirect effects on grain yield at genotypic level are represented in the table-5 and 6. Among selected mini core accessions, path analysis showed that highly significant positive direct effect through ear head length (0.1581P,0.0131G), fodder yield (0.4347P, 0.2192), seed size (0.4484P,0.6041G) and seed amylose (0.1516P,0.2465G) on seed yield per plot (Table-5). In case of selected promising varieties, high positive direct effect of plant height (0.2435P, 4.8478G) and ear head length (0.0731P,0.04973G) seed yield per plant (Table-6), indicating true relationship between these characters with grain yield per plant and direct selection for these traits will be rewarding for improvement of grain yield per plant. Similar results were noticed by Jeyaprakash *et al.* (1997) [41] in their study involving 65 sorghum genotypes and inferred that grain yield was significant positive association with panicle width and dry fodder yield. Plant height also had a positive significant association with grain yield at the genotypic level. Aml *et al.* (2012) [42] in an experiment on 25 restorer lines of sorghum, path analysis showed that panicle length had low but positive direct effect on grain yield and positive indirect effect was through, plant height, panicle length and panicle width, whereas its indirect effect was negative through 1000- kernel weight. A positive and high direct effect of a character on grain yield reveals the effectiveness of a character for direct selection. High direct effect along with positive and high indirect effect through other characters provides a better chance for a character to be selected through breeding programmes. The 100 seed weight had significant positive association with seed yield per plot at the both levels but its direct effect was positive only at phenotypic level where it had high direct effect on grain yield, it indicates that selection can be performed for this trait in order to increase with grain yield and selection can be performed for 1000 grain weight trait in order to increase with grain yield. Similar results reported by Veerabadhiran and Kennedy (2001) [43] who correlated 75 sorghum genotypes and noticed that grain yield per plant exhibited significant positive correlation with 100-grain weight, which contributed high direct effect towards grain yield. On contrary 100 seed weight had negative direct effect on grain yield at genotypic level. The significant association at genotypic level mainly due to its indirect positive effect through seed volume, seed size and true density. So, these traits have to be considered while selecting the genotypes for seed yield per plot. Whereas, true density had negative association with seed yield and it had high negative direct effect at both levels. So, true density is not effective for the improvement of seed yield.

It was interesting to note that, ear head width and 100 seed weight had positive association with seed yield per plot at both the levels but these had positive direct effect only at phenotypic level and negative at genotypic level. The significant association at genotypic level was due to its high positive indirect effect in case of ear head width via plant height, seed volume, bulk density, seed protein and seed amylose content and these traits have to be considered while selecting the genotypes for seed yield per plot.

Bulk density exhibited positive association with seed yield per plot at the both levels and it was positive indirect effect at genotypic level and negative indirect effect at phenotypic level, its positive association was due to high positive indirect effect via ear head width, fodder yield per plot, plant height, seed amylose content, 100 seed weight and true density. Hence, these traits have to be considered while selecting the genotypes for seed yield per plot.

Plant height exhibited high direct effect (4.878) on seed yield per plot but its correlation was non significant therefore high direct effect was nullified by negative indirect effect of seed protein (-5.7633) followed by ear head width (-0.2694) on seed yield per plot. Similarly, seed amylose had high positive indirect effect via bulk density (3.4521) on seed yield but it was nullified by other negative indirect effects, so amylose content showed non significant association with seed yield per plot.

It was interesting to note that, selected mini core accessions true density had significant negative association with seed yield and it had negative direct effect on seed yield. Whereas, the same association in selected promising varieties was recorded as non significant, wherein true density had positive direct effect on grain yield at phenotypic level, but negative direct effect at genotypic level. The positive association was mainly due to high indirect positive effect via bulk density, seed protein and seed amylose content. In case of selected mini core accessions, seed volume exhibited significant positive coupled with positive direct effect on seed yield at genotypic level, but its positive association was mainly due to indirect effects *via* 100 seed weight and seed size. But among selected varieties, association between these traits were non significant and both had negative direct effect.

However it was interesting to note that, 100 seed weight exhibited significant positive association with seed yield across both the groups of genotypes under study at both levels. 100 seed weight had positive direct effect at the phenotypic level but negative direct effect at genotypic level both in selected mini core accessions and selected promising varieties. Positive association at the genotypic level mainly due to their positive indirect effect via seed volume and seed size among selected mini core collections, whereas among selected promising varieties it was mainly due to positive indirect effect via plant height, bulk density and seed protein content.

From the results of this study, it could be concluded that there were most of the traits evaluated were positively associated among themselves and could be improved simultaneously for yield and other agronomic characters. It further concluded that characters such as panicle length, 1000 grain weight, bulk had higher correlation and direct effect on grain yield. 100 seed weight exhibited significant positive association with seed yield across both the groups of genotypes. Therefore, due consideration should be given to these characters, while planning a breeding strategy for increased yield per plant.

Table 1: Evaluation of selected genotypes of mini core collections (Experiment-Ia)

Sl. No.	Accession number	Seed hardness	Seed lustre	Seed color
1	IS-473	Very hard	Lustrous	White
2	IS-1041	Hard	Lustrous	White
3	IS-2379	Very hard	Non lustrous	Light brown
4	IS-3971	Very hard	Intermediate	Creamy straw
5	IS-4515	Hard	Lustrous	White
6	IS-5295	Very hard	Intermediate	Chalky white
7	IS-5301	Very hard	Lustrous	White
8	IS-12697	Hard	Intermediate	Brown
9	IS-12937	Very hard	Lustrous	Light red
10	IS-12945	Very hard	Lustrous	White
11	IS-13294	Very hard	Intermediate	Light brown
12	IS-13459	Hard	Lustrous	Brown
13	IS-13971	Very hard	Intermediate	Light brown
14	IS-15931	Hard	Lustrous	Chalky white
15	IS-19153	Very hard	Lustrous	White
16	IS-22720	Hard	Lustrous	White
17	IS-24139	Very hard	Intermediate	White
18	IS-28849	Hard	Intermediate	White
19	IS-29358	Very hard	Intermediate	Light yellow
20	IS-30443	Very hard	Lustrous	Chalky white
21	IS-30450	Very hard	Non lustrous	Brown
22	IS-30572	Very hard	Intermediate	Yellow
23	IS-13893	Hard	Intermediate	Reddish brown
24	IS-13782	Very hard	Intermediate	Red
25	M35-1	Hard	Lustrous	White

.

Table 2: List of selected released/promising varieties of *rabi* sorghum (Experiment-b)

Sl. No.	Varieties name
1	DSV-4
2	SPV-86
3	SPV-1829
4	BJV-44
5	DSV-5
6	A-1
7	CSV-216R (Phule Yashoda)
8	Phule Vasudha
9	Phule Revathi
10	M35-1 (Akola source)
11	M35-1 (Bijapur source)
12	Barsi Jowar
13	Kodmurki (popular local)
14	SVD-803 (Advanced breeding lines)
15	SVD-808 (Advanced breeding lines)
16	SVD-770 (Advanced breeding lines)

Table 3: Phenotypic and Genotypic correlation analysis for seed yield and yield components in selected mini core collections of sorghum (2012-13).

Traits		Plant height (cm)	Ear head length (cm)	Ear head width (cm)	Fodder yield/ plot (kg)	100-seed weight (gm)	Seed volume (ml)	Bulk density (g/ml)	True density (g/ml)	Seed size (mm)	Seed protein (%)	Seed Amylose (%)	Seed amylopectin (%)	Seed yield /plot (kg)
Plant height (cm)	P	1	0.5684**	-0.0615	0.5725**	-0.1268	-0.129	0.2498	0.1349	-0.0301	0.1084	0.0934	-0.0934	0.0011
	G	1	0.5843**	-0.0544	0.6075**	-0.1326	-0.134	0.2552	0.1423	-0.0549	0.1087	0.0841	-0.0841	0.0166
Ear head length	P		1	-0.1076	-0.0416	-0.3699**	-0.4028**	-0.1211	0.2527	-0.2554	-0.0618	0.0755	-0.0755	-0.2228
	G		1	-0.1117	-0.0618	-0.3896**	-0.4065**	-0.1171	0.2533	-0.2596	-0.0592	0.0837	-0.0837	-0.2392
Ear head width (cm)	P			1	-0.0985	0.8154**	0.806**	0.0392	-0.0446	0.3709**	0.0546	-0.1566	0.1566	0.1483
	G			1	-0.1357	0.8260**	0.8314**	0.0317	-0.0319	0.4325**	0.035	-0.1611	0.1611	0.1398
Fodder yield/plot (kg)	P				1	-0.0159	0.024	0.1357	-0.1276	0.0714	0.1153	0.1096	-0.1096	0.364**
	G				1	-0.0303	0.018	0.1553	-0.1336	0.1298	0.1015	0.1139	-0.1139	0.3913**
100 seed weight (g)	P					1	0.9726**	0.0662	-0.18	0.5765**	0.0563	-0.1584	0.1584	0.3768**
	G					1	0.9960**	0.0591	-0.192	0.6640**	0.0463	-0.1671	0.1671	0.3912**
Seed volume (ml)	P						1	0.0611	-0.2485	0.6175**	0.0985	-0.2002	0.2002	0.4041**
	G						1	0.0571	-0.2524	0.6804**	0.1008	-0.2167	0.2167	0.4169**
Bulk density (g/ml)	P							1	-0.4955**	-0.1742	-0.0764	-0.2104	0.2104	-0.113
	G							1	-0.4997**	-0.1934	-0.0841	-0.2227	0.2227	-0.1216
True density (g/ml)	P								1	-0.1477	-0.2008	0.2694	-0.2694	-0.3158*
	G								1	-0.1414	-0.1987	0.2952*	-0.2952*	-0.3352**
Seed size (mm)	P									1	0.1653	-0.2331	0.2331	0.5583**
	G									1	0.2043	-0.274	0.274	0.6429**
Seed protein (%)	P										1	-0.3565**	0.3565**	0.0215
	G										1	-0.3871**	0.3871**	0.0219

Seed amylose (%)	P											1	-1.00**	0.0586
	G											1	-1	0.0679
Seed amylopectin (%)	P												1	-0.0586
	G												1	-0.0679
Seed yield/plot (kg)	P													1
	G													1

*- significant at 5% level of probability **- significant at 1% level of probability

Table 4: Phenotypic and Genotypic correlation analysis for seed yield and yield components in promising verities of sorghum (2012-13).

Traits		**Plant height (cm)**	**Ear head length (cm)**	**Ear head width (cm)**	**Fodder yield/ plot (kg)**	**100-seed weight (gm)**	**Seed volume (ml)**	**Bulk density (g/ml)**	**True density (g/ml)**	**Seed size (mm)**	**Seed protein (%)**	**Seed Amylose (%)**	**Seed amylopectin (%)**	**Seed yield /plot (kg)**
Plant height (cm)	P	1	0.5684**	-0.0615	0.5725**	-0.1268	-0.129	0.2498	0.1349	-0.0301	0.1084	0.0934	-0.0934	0.0011
	G	1	0.5843**	-0.0544	0.6075**	-0.1326	-0.134	0.2552	0.1423	-0.0549	0.1087	0.0841	-0.0841	0.0166
Ear head length	P		1	-0.1076	-0.0416	-0.3699**	-0.4028**	-0.1211	0.2527	-0.2554	-0.0618	0.0755	-0.0755	-0.2228
	G		1	-0.1117	-0.0618	-0.3896**	-0.4065**	-0.1171	0.2533	-0.2596	-0.0592	0.0837	-0.0837	-0.2392
Ear head width (cm)	P			1	-0.0985	0.8154**	0.806**	0.0392	-0.0446	0.3709**	0.0546	-0.1566	0.1566	0.1483
	G			1	-0.1357	0.8260**	0.8314**	0.0317	-0.0319	0.4325**	0.035	-0.1611	0.1611	0.1398
Fodder yield/plot	P				1	-0.0159	0.024	0.1357	-0.1276	0.0714	0.1153	0.1096	-0.1096	0.364**
(kg)	G				1	-0.0303	0.018	0.1553	-0.1336	0.1298	0.1015	0.1139	-0.1139	0.3913**
100 seed weight (g)	P					1	0.9726**	0.0662	-0.18	0.5765**	0.0563	-0.1584	0.1584	0.3768**
	G					1	0.9960**	0.0591	-0.192	0.6640**	0.0463	-0.1671	0.1671	0.3912**
Seed volume (ml)	P						1	0.0611	-0.2485	0.6175**	0.0985	-0.2002	0.2002	0.4041**
	G						1	0.0571	-0.2524	0.6804**	0.1008	-0.2167	0.2167	0.4169**
Bulk density (g/ml)	P							1	-0.4955**	-0.1742	-0.0764	-0.2104	0.2104	-0.113
	G							1	-0.4997**	-0.1934	-0.0841	-0.2227	0.2227	-0.1216
True density (g/ml)	P								1	-0.1477	-0.2008	0.2694	-0.2694	-0.3158*
	G								1	-0.1414	-0.1987	0.2952*	-0.2952*	-0.3352**
Seed size (mm)	P									1	0.1653	-0.2331	0.2331	0.5583**
	G									1	0.2043	-0.274	0.274	0.6429**
Seed protein (%)	P										1	-0.3565**	0.3565**	0.0215
	G										1	-0.3871**	0.3871**	0.0219
Seed amylose (%)	P											1	-1.00**	0.0586
	G											1	-1	0.0679
Seed amylopectin (%)	P												1	-0.0586
	G												1	-0.0679
Seed yield/plot (kg)	P													1
	G													1

*- significant at 5% level of probability **- significant at 1% level of probability

Table 5: Phenotypic and Genotypic path analysis for seed yield and yield components in selected mini core collections sorghum (2012-13).

Traits	Plant height (cm)	Ear head length (cm)	Ear head width (cm)	Fodder yield/ plot (kg)	100-seed weight (gm)	Seed volume (ml)	Bulk density (g/ml)	True density (g/ml)	Seed size (mm)	Seed protein (%)	Seed Amylose (%)	Seed amylopectin (%)	Seed yield/plot (kg)
Plant height (cm)	-0.2221	0.0899	0.0114	0.2489	-0.0587	0.0229	-0.0402	-0.042	-0.0135	-0.0095	0.0142	0	0.0011
	0.007	0.0077	0.0092	0.1332	0.0912	-0.1103	-0.0433	-0.0487	-0.0332	-0.017	0.0207	0	0.0166
Ear head length (cm)	-0.1263	0.1581	0.0199	-0.0181	-0.1714	0.0717	0.0195	-0.0787	-0.1145	0.0054	0.0114	0	-0.2228
	0.0041	0.0131	0.0189	-0.0136	0.2679	-0.3359	0.0198	-0.0866	-0.1568	0.0092	0.0206	0	-0.2392
Ear head width (cm)	0.0137	-0.017	-0.1852	-0.0428	0.3778	-0.1435	-0.0063	0.0139	0.1663	-0.0048	-0.0237	0	0.1483
	-0.0004	-0.0015	-0.1691	-0.0298	-0.568	0.687	-0.0054	0.0109	0.2612	-0.0055	-0.0397	0	0.1398
Fodder yield/plot (kg)	-0.1272	-0.0066	0.0182	0.4347	-0.0073	-0.0043	-0.0218	0.0397	0.032	-0.0102	0.0166	0	0.3640**
	0.0043	-0.0008	0.023	0.2192	0.0208	0.0148	-0.0263	0.0457	0.0784	-0.0158	0.0281	0	0.3913**
100 seed weight (g)	0.0282	-0.0585	-0.1511	-0.0069	0.4633	-0.1731	-0.0107	0.056	0.2585	-0.005	-0.024	0	0.3768**
	-0.0009	-0.0051	-0.1397	-0.0066	-0.6877	0.823	-0.01	0.0657	0.4011	-0.0072	-0.0412	0	0.3912**
Seed volume (ml)	0.0286	-0.0637	-0.1493	0.0104	0.4506	-0.178	-0.0098	0.0774	0.2769	-0.0087	-0.0304	0	0.4041**
	-0.0009	-0.0053	-0.1406	0.0039	-0.685	0.8262	-0.0097	0.0864	0.411	-0.0157	-0.0534	0	0.4169**
Bulk density (g/ml)	-0.0555	-0.0192	-0.0073	0.059	0.0307	-0.0109	-0.1609	0.1543	-0.0781	0.0067	-0.0319	0	-0.113
	0.0018	-0.0015	-0.0054	0.034	-0.0406	0.0472	-0.1695	0.1709	-0.1168	0.0131	-0.0549	0	-0.1216
True density (g/ml)	-0.03	0.0399	0.0083	-0.0555	-0.0834	0.0442	0.0797	-0.3114	-0.0662	0.0177	0.0408	0	-0.3158*
	0.001	0.0033	0.0054	-0.0293	0.132	-0.2086	0.0847	-0.3421	-0.0854	0.031	0.0728	0	-0.3352**
Seed size (mm)	0.0067	-0.0404	-0.0687	0.0311	0.2671	-0.1099	0.028	0.046	0.4484	-0.0146	-0.0353	0	0.5583**
	-0.0004	-0.0034	-0.0731	0.0285	-0.4566	0.5622	0.0328	0.0484	0.6041	-0.0319	-0.0675	0	0.6429**
Seed Protein (%)	-0.0241	-0.0098	-0.0101	0.0501	0.0261	-0.0175	0.0123	0.0625	0.0741	-0.0881	-0.0541	0	0.0215
	0.0008	-0.0008	-0.0059	0.0222	-0.0318	0.0833	0.0143	0.068	0.1234	-0.1561	-0.0954	0	0.0219
Seed Amylose (%)	-0.0208	0.0119	0.029	0.0477	-0.0734	0.0356	0.0338	-0.0839	-0.1045	0.0314	0.1516	0	0.0586
	0.0006	0.0011	0.0272	0.025	0.1149	-0.1791	0.0377	-0.101	-0.1655	0.0604	0.2465	0	0.0679
Seed amylopectin (%)	0.0208	-0.0119	-0.029	-0.0477	0.0734	-0.0356	-0.0338	0.0839	0.1045	-0.0314	-0.1516	0	-0.0586
	-0.0006	-0.0011	-0.0272	-0.025	-0.1149	0.1791	-0.0377	0.101	0.1655	-0.0604	-0.2465	0	-0.0679

Residual effect = 0.8735 (Phenotypic path)
Residual effect = 0.8620 (Genotypic path)

Table 6: Phenotypic and Genotypic path analysis for seed yield and yield components in promising verities of *rabi* sorghum (2012-13).

Traits		Plant height (cm)	Ear head length (cm)	Ear head width (cm)	Fodder yield/plot (kg)	100 seed weight (g)	Seed volume (ml)	Seed size (mm)	Bulk density (g/ml)	True density (g/ml)	Seed Protein (%)	Seed Amylose (%)	Seed Amylopectin (%)	Correlation with Seed yield/plot (kg)
Plant height (cm)	P	0.2435	0.0225	0.0938	0.0218	0.0258	0.0021	0.0015	-0.0087	-0.0021	-0.0552	-0.0946	0	0.2504
	G	4.8478	0.1527	-0.2694	-0.0165	-0.7392	0.2618	0.619	0.4289	0.1433	-5.7633	0.6033	0	0.2684
Ear head length (cm)	P	0.0751	0.0731	0.0836	0.0051	0.0296	-0.0001	0.0013	0.0103	0.0076	-0.0148	-0.2188	0	0.052
	G	1.4889	0.4973	-0.2212	-0.0053	-0.8208	-0.0137	0.4786	-0.4771	-0.6038	-1.6364	1.3579	0	0.0444*
Ear head width (cm)	P	0.0286	0.0076	0.8001	0.0025	0.117	0.0049	-0.0009	-0.0415	0.0094	0.0284	-0.117	0	0.8392**
	G	0.5957	0.0502	-2.1924	-0.0013	-3.1578	0.6668	-0.5072	1.8566	-0.7899	3.6249	0.7111	0	0.8567**
Fodder yield/plot (kg)	P	0.0324	0.0023	0.0122	0.1636	0.0137	-0.0014	-0.0005	-0.0148	0.0055	-0.0042	-0.0887	0	0.12
	G	0.7505	0.0246	-0.0273	-0.1063	-0.4866	-0.2166	-0.3408	0.694	-0.4098	-0.4246	0.6724	0	0.1295
100 seed weight (g)	P	0.0495	0.017	0.7365	0.0176	0.1271	0.0035	-0.0008	-0.0393	0.0077	0.0283	-0.0713	0	0.8758**
	G	1.0865	0.1238	-2.0992	-0.0157	-3.2981	0.5094	-0.3338	1.8391	-0.7682	3.5008	0.3557	0	0.9003
Seed volume (ml)	P	-0.0361	0.0007	-0.2807	0.0166	-0.0321	-0.014	-0.0018	-0.0096	0.0019	0.0171	0.2304	0	-0.1074
	G	-0.7637	0.0041	0.8796	-0.0139	1.0108	-1.6619	-0.6388	0.532	-0.0894	2.1092	-1.5035	0	-0.1355
Seed size (mm)	P	-0.0728	-0.0193	0.1446	0.0168	0.0209	-0.0052	-0.0049	-0.0106	0.0047	0.048	0.1378	0	0.2598
	G	-1.7682	-0.1403	-0.6552	-0.0214	-0.6487	-0.6255	-1.6972	1.0009	-0.47	6.1836	-0.8196	0	0.3384
Bulk density (g/ml)	P	0.0145	-0.0051	0.2274	0.0166	0.0342	-0.0009	-0.0004	-0.1461	0.0083	-0.0129	0.2462	0	0.3817**
	G	0.3358	-0.0383	-0.6574	-0.0119	-0.9796	-0.1428	-0.2743	6.192	-0.5999	-1.7104	-1.6775	0	0.4357**
True density (g/ml)	P	-0.0163	0.0178	0.2412	0.0289	0.0314	-0.0009	-0.0007	-0.0387	0.0313	0.0178	-0.1639	0	0.1478
	G	-0.3371	0.1457	-0.8404	-0.0211	-1.2294	-0.0721	-0.387	1.8024	-2.0608	1.8482	1.355	0	0.2034
Protein (%)	P	0.1497	0.012	-0.2533	0.0077	-0.04	0.0027	0.0026	-0.0209	-0.0062	-0.0899	-0.0037	0	-0.2392
	G	3.1221	0.0909	0.8881	-0.005	1.2902	0.3917	1.1727	1.1835	0.4256	-8.9487	0.1054	0	-0.2835
Amylose (%)	P	-0.0468	-0.0325	-0.1902	-0.0295	-0.0184	-0.0066	-0.0014	-0.0731	-0.0104	0.0007	0.4921	0	0.0839
	G	-0.972	-0.2244	0.5182	0.0238	0.3899	-0.8304	-0.4623	3.4521	0.9281	0.3134	-3.0089	0	0.1275
Amylopectin (%)	P	0.0468	0.0325	0.1902	0.0295	0.0184	0.0066	0.0014	0.0731	0.0104	-0.0007	-0.4921	0	-0.0839
	G	0.972	0.2244	-0.5182	-0.0238	-0.3899	0.8304	0.4623	-3.4521	-0.9281	-0.3134	3.0089	0	-0.1275

Residual effect = 0.8735 (Phenotypic path)
Residual effect = 0.8620 (Genotypic path)

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