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Association Studies of Morphological Traits in Grain Sorghum (*Sorghum bicolor* L.)

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Abstract

The beauty of sorghum is that it can be used as both fodder and feed. In Pakistan, sorghum is being used as a food and feed crop for animals and chickens. Production of meat and chicken can be increased with good-quality fodder and feed. Improving the suitability of sorghum for feed and fodder requires knowledge of relationships among morphological traits. Studies at the Maize and Millets Research Institute, Yusafwala, Sahiwal estimated correlation among various morphological traits, and dissected any correlation into direct and indirect effects using path coefficient analysis. Data were recorded for days to 50% anthesis, plant height, flag leaf area, brix percentage, head length, 1000 grain weight and grain yield. All traits showed highly significant variation. Chances of uncontrolled variations were reduced as the coefficient of variation was below 10%. Correlation analysis revealed that the brix value of sorghum genotypes can be increased through selection of plants with a small flag leaf area. Selection of tall plants will favour higher yield. Path analysis revealed the importance of focusing on traits of choice, because all indirect effects are negligible. Also, grain yield was highly affected by grain weight. Heritability was above 90% for all traits except days to 50% flowering (67%) and head length (81%). Genotypic correlation revealed that less flag leaf area, less head length and medium height plants help to increase the brix percentage in sorghum. These traits can be improved in diverse environments and selected for jointly. Environmental correlation showed that environment affected 50% flowering with grain yield, and head length with both grain weight and grain yield; thus, these traits cannot be selected for and improved in diverse environments.

Key Words: Brix percentage, correlation, grain yield, path analysis, stalk yield

Introduction

The annual consumption of chicken and meat in Pakistan is 987000 tones (FAOSTAT, 2016). This production could be increased by providing animals and chickens with a sufficient amount of good-quality feed and fodder. Sorghum is a good option for fulfilling this requirement. The main advantage of sorghum crop is that it can be used both as both a fodder and a grain (Chikuta, 2014). Sorghum grain contains about 9% protein (Waggle *et al*., 2012), which makes it a valuable protein source for human populations who depend on this crop (e.g. those in African countries) in times of famine.

Sorghum is an important feed and fodder crop in Pakistan, and an important food crop in Africa (Bibi *et al.,* 2010). Considerable differences among traits (e.g. panicle and grain traits) are found in sorghum, and these traits are highly influenced by the environment (Ezeaku *et al.*, 1997). In Pakistan, sorghum crops (*Sorghum bicolor*) occupy 0.195 million hectares, with a total production of 0.104 million metric tons, accounting for 12.16% of the total fodder crop production, and sorghum is estimated to be Pakistan's second largest fodder crop (Pakistan Bureau of Statistics, 2016).

The major diseases of sorghum crop are stalk rot, stem borer and root rot; other serious problems include white fly, midges and mites. In addition, cyanogenic glycosides (e.g. hydrogen cyanide, HCN) present in sorghum fodders may be fatal to ruminants (Panhwar, 2005; Kumar and Devendra, 2010; FAOSTAT, 2016).

Characterization of existing genetic diversity from seed collections is a major challenge for breeders. Estimation of association of traits with grain yield is helpful in the utilization of genetic diversity (Casa *et al*., 2008; Uphadyaya *et al*., 2009). The study of association among traits is useful in the selection of two or more traits, especially the selection of traits with respect to grain yield. Both positive and negative genetic correlation are helpful in improvement of crops, and even lack of correlation can be useful when improving two traits. Simple correlation is not sufficient for estimating the true biological relationship of all traits to yield, because grain yield is a quantitative trait of a complex nature

(Grafius, 1959). All traits are interrelated; thus, information obtained from simple correlation alone is unreliable (Khairwal *et al.,* 1999). Hence, there is a need for path analysis.

Path analysis is helpful in portioning the correlation coefficient into direct and indirect effects, which in turn is useful in assessing the cause–effect relationship and in selecting for desirable traits. The most important traits of sorghum are grain yield and brix percentage (i.e. sweetness). The sweeter the sorghum stalk, the more palatable it is to animals (Daniel, 2011). Owing to the high brix percentage, sorghum is also considered a convenient, efficient and sustainable source of renewable energy. Sorghum juice requires less processing steps and inputs for complete conversion than other bioenergy feedstocks (Worley *et al.,* 1992). Up to 85% of the brix percentage of sorghum is sucrose (Woods, 2000). The sugar content in the juice depends on the crop stage. In the early stages, sucrose is abundant; however, after heading, fructose is dominant (Sipos *et al.,* 2009). The brix percentage of sorghum juice ranges from 10% to 25% (Reddy *et al.,* 2007; Ritter *et al.,* 2004), and the grain of sorghum also contains some juice (Rao *et al.,* 2009).

The aim of this study is to estimate the relationships between various traits and grain yield, using correlation and path analysis. An understanding of this relationship will be useful when jointly selecting for increased grain yield and brix percentage in sorghum.

Material and Methods

In 2015, 30 sorghum accessions were planted at the Maize and Millet Research Institute, Yusafwala, Sahiwal, Pakistan in a randomized complete block design with three replications. The size of the plots was 5 × 3 m. All agronomic practices (e.g. irrigation, fertilizer application, pesticide application, hoeing and thinning) were followed at appropriate times. Five plants were selected randomly from each entry for data collection.

Data were collected for the following traits: days to 50% anthesis, plant height, flag leaf area, brix percentage, head length, 1000 grain weight and grain yield. The statistical significance of differences among accessions was determined according to Steel *et al*., 1998, with the help of Statistix (version 8.1) software. The correlation coefficient was computed from variance and covariance components, as suggested by Burton (1952), Wright (1960 and 1968) and Narasimharao and Rachie (1964). The correlation coefficient was partitioned into direct and indirect causes according to Dewey and Lu (1959), Turner and Stevens (1959), and Wright (1960) with the help of R software (R Core Team, 2013).

Results and Discussion

Highly significant variation was present among all traits, indicating that these data were highly suitable for correlation and path analysis. The coefficient of variation (CV) of all traits was less than 10% which indicated that chances of uncontrolled variation were low in this experiment (Table 1). The brix value was negatively correlated with flag leaf area and plant height, whereas significant positive correlation was found between days to 50% flowering and head length. Similarly, plant height showed significant positive correlation with flag leaf area and grain yield (Table 2). The brix value of sorghum genotypes can be increased by joint selection of plants with this trait and less flag leaf area. Selection for tall plants will favour higher yield. Badwal (1997) and Naim *et al*. (2012) found significant positive correlation between plant height and grain yield. Significant positive correlation between plant height and leaf area was also reported by Tesso *et al.* (2011). Yield and yield components were partitioned into direct and indirect effects. This analysis showed that plant height positively affected the grain yield (Table 3).

The direct effect of plant height (0.192) was highest while the negative direct effect of the flag leaf area (–0.215) was highest overall. The direct effects of days to 50% flowering and grain weight were almost the same (0.141). The brix value had the lowest direct affect (–0.092). The low-level direct effect of days to 50% flowering on grain yield was cancelled out by its indirect effect on all other traits; thus, the genotypic correlation with grain yield was not significant. The contribution of days to 50% flowering to grain yield was highest through plant height (0.036) but was negative through flag leaf area (–0.033), brix value (–0.004) and head length (–0.044). The low-level direct effect of plant height (0.192) was also cancelled out by indirect effects; one indirect effect (flag leaf area) was negative (–0.063), but the overall contribution of the other indirect effects were sufficient to cancel out the direct effect, meaning that the genotypic correlation was not significant. The contribution of flag leaf area to grain yield was highest through plant height (0.056); its contribution to days to 50% flowering was 0.022, brix percentage was 0.024, head length was 0.006 and grain weight was 0.003. The negative direct affect (–0.215) was of moderate level, meaning that the overall genotypic correlation was negative.

Although all the indirect effects were of negligible value, their cumulative effects were sufficient to make genotypic correlation non-significant. Similar findings were observed for the brix value. The highest positive contribution of brix value to grain yield was through flag leaf area (0.056) and days to 50% flowering, and the highest negative contributions were through plant height (–0.090), head length (–0.028) and grain weight (–0.010). The low-level direct effect of the brix value was highly negative (–0.092); hence, its genetic correlation was negative and its genotypic correlation was non-significant because of the cumulative effect of the indirect values. Head length behaved in a similar pattern, contributing most strongly through days to 50% flowering, and to some extent via flag leaf area (0.009) and grain weight (0.027). Its low-level direct effect (–0.130) was highly negative, meaning that the genetic correlation was negative. Genotypic correlation of grain weight was significant. Its indirect effects were most strongly due to plant height (0.030), days to 50% flowering and brix value.

Its contribution was negative via flag leaf area (–0.005) and head length (–0.025). Its low-level direct effect (0.141) was not high enough to compensate for the indirect value; hence, its genotypic correlation was significant (Table 3). According to Nadarajan and Gunasekaran (2008) all indirect values are of negligible level. In this study, the direct effect of all traits were of a low level except for flag leaf area, which was of moderate level (Nadarajan and Gunasekaran, 2008). These results show that, for selection, attention should focus on the trait of choice because indirect effects have little importance. The low value of the residual factor (0.008) indicated that 99% of variability in grain yield is explained by an independent factor, meaning that the selection of traits for grain yield is good. Grain weight is an advantageous character that should be the focus of efforts to increase grain yield (Reddy *et al*., 1988).

Genotypic and phenotypic variances were high for all traits from environmental variances; this finding indicated that heritability of all traits was high. Plant height, flag leaf area and brix percentage had the highest heritability (almost 100%), whereas day to 50% flowering had the lowest heritability (67%) (Table 4). Hence, it will be useful to select for these traits in future breeding programs. These results are in line with those of Basu (1981), Abu-Gasim and Kambal (1985); Bello *et al.* (2007); Naim *et al.* (2012) found similar results.

The genotypic, phenotypic and environmental correlations are presented in Table 5. The genotypic correlation of days to 50% flowering with plant height, flag leaf area, head length, grain weight and grain yield was greater than the environmental correlation. Similarly, the genotypic correlation of plant height with flag leaf area, brix percentage, head length, grain weight and grain yield was greater than the environmental correlation. The genotypic correlation of brix percentage with flag leaf area was also of higher magnitude than environmental correlation. These results indicated that these traits have an inherent relationship and are less affected by the environment. They also showed significant genotypic correlation for days to 50% flowering with head length; for plant height with brix percentage, head length and grain yield; for flag leaf area with brix value; and for head length with brix percentage. All correlations were positive except for the correlation of brix percentage with plant height and flag leaf area. Also plant height and head length had a negative genotypic correlation, indicating their significance for selection.

To increase the brix percentage of sorghum, plants with a small flag leaf area, small head length and medium height will be desirable. These traits can be improved in diverse environments and can be selected for jointly. While environmental correlation of days to 50% with brix percentage, head length, grain weight were of higher magnitude than genotypic correlation. Also grain yield with flag leaf area; grain weight with brix percentage; head length with grain weight and grain yield; grain weight with grain yield have higher magnitudes than genotypic correlation. The environmental correlations of grain weight and grain yield with head length have highly significant positive values. Grain weight and grain yield with head length have significant environmental correlation of higher magnitude than genotypic correlation, indicated that these traits were affected by the environment and cannot be selected for and improved in diverse environments. Similar results were found by Reddy *et al.* (1988); Khairwal *et al.* (1999).

Conclusion

These correlation studies showed that the brix value of sorghum genotypes can be increased by selecting this trait jointly with small flag leaf area. Selection of tall plants will favour a higher yield. Heritability of all traits was above 90% except for days to 50% flowering (67%) and head length (81%). Path analysis showed that grain yield was highly affected by grain weight. Both genotypic and phenotypic correlation showed that the traits that are desirable for increasing the brix percentage of sorghum are small flag leaf area, small head length and medium height plants. These traits can be improved in diverse environments and can be selected for jointly. Grain weight and grain yield with head length were affected by the environment; thus, it will not be possible to jointly select for and improve these traits in diverse environments.

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Table 1. Analysis of variance

Source	DF	Days to 50% flowering	Plant height	Flag leaf area	Brix %	Head length	Grain weight	Grain yield
Replication	2	176.48	838.8	1227.4	29.43	17.28	47.14	592333
Genotype	29	**21.3**	**16174.1**	**26213.6**	**45.40**	**80.91**	**88.71**	**1366555**
Error	58	3.11	9.5	12.8	0.11	5.78	0.41	10982
Total	89	200.89	17022.4	27453.8	74.94	103.97	136.26	1969870
CV		2.27	1.29	1.36	2.46	9.21	2.41	2.53

Bold values represent values that are significant at 5%

Table 2. Simple correlations of sorghum traits

	Brix %	Days to 50% flowering	Flag leaf area	grain weight	Grain yield	Head length
Days to 50% flowering	0.0618					
Flag leaf area	**–0.2549**	0.1376				
Grain weight	–0.0624	0.1356	0.0287			
Grain yield	–0.1443	0.1708	–0.0907	0.1799		
Head length	0.2043	**0.3406**	–0.0284	0.2037	–0.0469	
Plant height	**–0.4634**	0.1603	**0.2929**	0.1620	**0.2538**	–0.1857

Bold values represent values significant at 5%

Table 3. Direct (diagonal) and indirect effect path coefficients

	Days to 50% flowering	Plant height	Flag leaf area	Brix %	Head length	Grain weight	Grain yield
Days to 50% flowering	**0.142**	0.036	-0.033	-0.004	-0.044	0.015	0.133
Plant height	0.027	**0.192**	-0.063	0.043	0.028	0.022	0.250
Flag leaf area	0.022	0.056	**-0.215**	0.024	0.006	0.003	-0.104
Brix %	0.006	-0.090	0.056	**-0.092**	-0.028	-0.010	-0.159
Head length	0.048	-0.042	0.009	-0.020	**-0.130**	0.027	-0.107
Grain weight	0.016	0.030	-0.005	0.006	-0.025	**0.141**	**0.163**

Bold values represent values significant at 5%, Residual effect^2 = 0.008

Table 4. Variances of all traits

	Days to 50% flowering	Plant height	Flag leaf area	Brix %	Head length	Grain weight	Grain yield
Variety	21.92	6174.09	26213.65	45.40	80.90	88.71	1366555
Significance (V)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CV	2.27	1.29	1.36	2.46	9.21	2.41	2.53
Genotypic	6.27	5388.18	8733.63	15.11	25.04	29.43	451857.70
Phenotypic	9.38	5397.72	8746.39	15.18	30.82	29.84	462839.30
Environmental	3.11	9.54	12.77	0.07	5.78	0.41	10981.65
Heritability	0.67	1.00	1.00	1.00	0.81	0.99	0.98

Table 5. Phenotypic, genotypic and environmental correlations

		Plant height	Flag leaf area	Brix %	Head length	Grain weight	Grain yield
Days to 50% flowering	r_p	0.154	0.128	0.038	**0.336**	0.083	0.097
	r_g	0.188	0.155	0.04	**0.337**	0.109	0.113
	r_e	0.021	0.059	0.141	0.351	–0.078	0.061
Plant height	r_p	**1.000**	**0.291**	**–0.468**	–0.194	0.157	**0.248**
	r_g	**1.000**	**0.291**	**–0.469**	**–0.217**	0.157	**0.25**
	r_e	**1.000**	–0.194	**–0.3**	0.097	0.17	0.153
Flag leaf area	r_p		**1.000**	**–0.259**	–0.035	0.022	–0.102
	r_g		**1.000**	**–0.26**	–0.044	0.023	–0.104
	r_e		**1.000**	0.173	0.271	–0.089	0.169
Brix percentage	r_p			**1.000**	0.2	–0.07	–0.156
	r_g			**1.000**	**0.217**	–0.069	–0.159
	r_e			**1.000**	0.156	–0.092	0.049
Head length	r_p				**1.000**	0.193	–0.067
	r_g				**1.000**	0.194	-0.107
	r_e				**1.000**	**0.38**	**0.429**
Grain weight	r_p					**1.000**	0.164
	r_g					**1.000**	0.163
	r_e					**1.000**	0.201
Grain yield	r_p						**1.000**
	r_g						**1.000**
	r_e						**1.000**

Bold values represent values significant at 5%, r_p=phenotypic variance, r_g=genotypic variance, r_e=environmental variance