Received: 24 Aug 2022 | Revised: 29 Apr 2023 | Accepted: 10 May 2023

Electronic Journal of Plant Breeding

Research Note

Character association and path analysis in kodo millet (*Paspalum scrobiculatum* L.) with relation to yield and its attributing traits

Dhrumi Dalsaniya[1], Arna Das[1*], Kinal Patel[1], Sneha Macwana[1], D. J. Parmar[2], Mayur Sonagara[1], Dipak A. Patel[3], Vikas Pali[4]

[1]Department of Genetics and Plant Breeding, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat - 388110
[3] Department of Agricultural Statistics, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat - 388110
[2] Department of Agricultural Biotechnology, Anand Agricultural University, Anand, Gujarat - 388110
[4] Hill Millet Research Station, Anand Agricultural University, Dahod, Gujarat.
***E-Mail**: arna_das@aau.in

Abstract
Kodo millet (*Paspalum scrobiculatum* L.) is an important nutri-cereal. Gujarat, a Western state in India with favorable edapho-climatic factors may contribute in augmenting kodo millet production if suitable crop improvement programme is implemented. Study of character association reveals important yield component traits which could be selected for overall yield enhancement hence in development of better genotypes. In the present investigation, 49 genotypes of kodo millet were evaluated during *kharif* 2021 for 19 quantitative traits with an aim to identify important yield components. Genotypic (r_g) and phenotypic correlation (r_p) coefficients were estimated followed by path coefficient analysis. The study revealed that direct selection based on harvest index and fodder yield per plant may help in augmenting grain yield as the traits had strongest positive association and maximum direct effect on grain yield per plant. Crude protein content (%) and plant height appeared to be most important characters for indirect selection.

Keywords: Kodo millet, Correlation, Path analysis, Yield components

Kodo millet (*Paspalum scrobiculatum* L.) is a tetraploid (2n=4x=40) small grained cereal which belongs to the family poaceae (gramineae). Plants with more herbage are grown for fodder purpose also (Suthediya *et al*., 2021). The crop originated in tropical Africa, and is domesticated in India about 3000 years ago (Upadhyaya *et al*., 2016). It is widely distributed in the tropics and subtropics of the World and is grown mainly in Indian sub-continent and West Africa (https://www.fao.org/). It is known as varagu, kodo, haraka, arakalu, cow grass, rice grass, ditch millet, native paspalum, or Indian crown grass. The crop might be described as incompletely domesticated with some authors calling it “pseudo- cultivated” (Blench, 1997).

Kodo millet is an excellent source of nutrients. Its iron, magnesium, calcium, fibre and vitamin (Yadav and Jain, 2006) content are better than that of foxtail millet and is comparable to that of other small millets. It is rich in vitamin B complex, especially niacin, B6 and folic acid (Muthamilarasan *et al*., 2015). Its low glycemic index (Nirubana *et al*., 2019) makes it a good substitute to rice and wheat. Moreover, kodo millet has been reported to have higher anti-oxidant activity compared to other millets (Hegde and Chandra, 2005; Chandrasekara and Shahidi, 2010). Better storage life makes kodo millet a crop for food security. Millets are nutritionally superior and are equipped with better stress tolerance in comparison to major cereals, like, rice, wheat and maize. But its cultivation in India, as well as in the world has witnessed a sharp decline in the last few decades due to predominance of the above said crops. Currently, millets are gaining popularity due to rediscovery of its nutritional benefits by health conscious consumers around the world. In view of this fact, United Nation (UN) declared the year 2023 as “International Year of Millets” to improve its production and create awareness about millets.

In India, the cultivation area under millet has increased in the last couple of years (Kumar *et al*., 2017). Among all the small millets, kodo millet has the highest productivity in India. It is grown as a food source in the states of Madhya Pradesh, Chhattisgarh, Gujarat, Karnataka and parts of Tamil Nadu. In Gujarat small millets are grown mainly in hilly and tribal regions.

Knowledge of association between yield and its component traits helps in a great way to formulate selection strategies to develop suitable genotypes. Such correlations can also be partitioned into direct and indirect effects through path coefficient analysis which further helps in indirect selection for yield through its component traits (Amein *et al*., 2020). Systematic breeding efforts for sustainable yield, which have so far been neglected, could augment its production and fetch economic benefits to kodo millet farmers. Keeping the above facts in view, the present investigation has been undertaken.

A total of 49 different genotypes of kodo millet were collected from Hill Millet Research Station, Anand Agricultural University, Dahod. The materials were planted in randomized complete block design with three replications at the Experimental Farm of Department of Genetics & Plant Breeding, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat (22^o 35’ N, 72^o 55’ E, 45.01 meters above mean sea level), during *kharif*, 2021, with a spacing of 30 × 10 cm. All the recommended package of practices were followed to raise a good crop.

A total of 16 different quantitative characters were recorded as listed and described in DUS guidelines for kodo millet (https://www.plantauthority.gov.in/). Three biochemical parameters, *viz*., crude protein content (%) (AOAC, 1965), total carbohydrate content (%) (Hedge and Hofreiter, 1962), total phenol content (%) (Singleton *et al*., 1999) were also recorded.

Genotypic correlation coefficients and phenotypic correlation coefficients were estimated as suggested by Hazel *et al*. (1943). Path coefficient analysis was carried out according to Dewey and Lu (1959).

All the genotypes under study differed significantly from one another as evident from analysis of variance (**Table 1**).

Estimates of all the genotypic correlation coefficients were found to be higher than all the estimates of phenotypic correlation coefficients except for a few traits (**Table 2**), where r_p estimates were higher than r_g *i.e.* between days to 50% flowering and number of raceme per tiller, panicle length and days to 50% flowering, days to 50% flowering and fodder yield per plant, fodder yield per plant and crude protein content, crude protein content and days to maturity, crude protein content and number of raceme per tiller. It indicated that most of the associations were genetically controlled, whereas environment was responsible for the exceptions.

Grain yield per plant was found to be significantly and positively correlated with number of productive tillers per plant (r_g = 0.35 and r_p = 0.31), fodder yield per plant (r_g = 0.31 and r_p = 0.27) and harvest index (r_g = 0.76 and r_p = 0.74) both at genotypic and phenotypic levels. Significant positive association suggested that increase in that component character will increase grain yield per plant in kodo millet. Similar finding of significant and positive correlation of grain yield with number of productive tillers per plant was reported by Yadava and Jain *et al.* (2006). At both the levels, grain yield per plant showed non-significant positive correlation with the component traits, *viz*., flag leaf blade length (r_g = 0.02 and r_p = 0.01), flag leaf blade width (r_g = 0.11 and r_p = 0.08), raceme length (r_g = 0.09 and r_p = 0.08), number of raceme per tiller (r_g = 0.09 and rp = 0.08), total carbohydrate content (r_g = 0.08 and r_p = 0.07) and crude protein content (r_g =0.04 and rp = 0.03). Such non-significant positive association of grain yield with flag leaf blade length and flag leaf blade width was reported by Nirubana *et al.* (2021) in kodo millet.

Positive association suggested that increase in one component character will increase grain yield per plant. Some of the characters had positive association with grain yield either at genotypic or at phenotypic level only. Moreover, the association was non-significant negative with days to 50% flowering (r_g = -0.09 and r_p = -0.07), peduncle length (r_g = -0.15 and r_p = -0.14), culm branching (r_g = -0.12, r_p = -0.09), panicle length (r_g = -0.06, r_p = -0.05), plant height (r_g = -0.09, r_p = -0.08), days to maturity (r_g = -0.10, r_p = -0.08), 1000 grain weight (r_g = -0.07, r_p = -0.06) and total phenol content (r_g = -0.08, r_p = -0.07) at both the levels. Non-significant negative association of grain yield with plant height was reported by Sao *et al.* (2018). Negative association of grain yield with component traits suggested improvement in that character will decrease the grain yield per plant in kodo millet.

The three major yield components as revealed from the correlation study are number of productive tillers per plant, fodder yield per plant and harvest index. Number of productive tillers per plant had positive association with the other two components indicating that selection for this trait, will consequently improve the other two traits and grain yield per plant.

https://doi.org/10.37992/2023.1402.061

Table 1. Analysis of variance for quantitative characters in kodo millet

S. No.	Characters	Mean Sum of Squares		
		Replication	Genotype	Error
	d.f.	2	48	96
1	Number of basal tillers per plant	1.104	1.829**	0.357
2	Days to 50% flowering	1.190	39.346**	2.795
3	Flag leaf blade length (cm)	0.780	56.805**	0.253
4	Flag leaf blade width (cm)	0.003	0.022**	0.001
5	Peduncle length (cm)	0.035	8.708**	0.040
6	Number of productive tillers per plant	0.352	1.350**	0.133
7	Culm branching	0.129	1.058**	0.163
8	Panicle length (cm)	0.062	2.576**	0.041
9	Raceme length (cm)	0.067	3.073**	0.040
10	Number of raceme per tiller	0.006	0.345**	0.029
11	Plant height (cm)	0.108	227.278**	1.832
12	Days to maturity	6.857	137.204**	4.281
13	1000 seed weight (g)	0.015	0.797**	0.005
14	Grain yield per plant (g)	1.860	57.613**	0.875
15	Fodder yield per plant (g)	19.646	192.932**	11.648
16	Harvest index (%)	9.169	70.075**	3.544
17	Total carbohydrate (%)	0.901	189.416**	1.335
18	Crude protein (%)	0.181	5.275**	0.097
19	Total phenol (%)	0.005	0.006**	0.001

** Significant at 1% level of significance

Days to 50% flowering and days to maturity mostly maintained negative association with vegetative traits and other major yield components. It indicated early flowering and early maturing genotypes had less vegetative growth but provide better yield as more vegetative growth delays onset of reproductive phase hence maturity. Peduncle length, panicle length and raceme length were positively associated indicating their inter-relationship.

It is evident from **Table 2** that taller plants did not confirm larger leaves, or higher yield or profuse branching or longer panicles and raceme, which suggested plant height to be a trait of less importance in improvement of kodo millet. Positive association of 1000 grain weight with flag leaf blade length evidently indicated that size of flag leaf indeed improves source to sink relationship.

Harvest index predictively was associated positively with number of basal and productive tillers but negatively with panicle and raceme length and fodder yield, indicating that greater vegetative growth reduces economic performance. Fodder yield per plant and harvest index were associated negatively and significantly as expected, but both of them were major yield components, hence this confusion can be resolved with further analysis of trait association for direct and indirect effects through path analysis.

All three biochemical parameters though were interrelated either positively or negatively with each other, but none of the parameter had any positive impact on grain yield or on any component trait.

Genotypic correlation coefficients were only considered for path analysis as those were desirable and were higher than phenotypic correlation coefficients. The direct and indirect contribution of each component character towards grain yield per plant in kodo millet is presented in **Table 3**. Path analysis provides information about yield components and relative importance of each component *via* others. Coefficient between causal factors and direct effect when are nearly similar, it reveals true and perfect relationship between the component characters, hence direct selection for those characters will be effective.
Harvest index and fodder yield per plant were positively associated with grain yield per plant. Both the traits recorded maximum direct effect (1.028 and 0.703, respectively) on grain yield per plant.

Positive direct effects on grain yield per plant were also obtained for raceme length (0.245), days to maturity (0.045), total phenol (0.035), number of basal tillers per plant (0.030), culm branching, (0.028), number of raceme per tiller (0.020), number of productive tillers per plant (0.010), 1000 grain weight (0.018) and plant height

https://doi.org/10.37992/2023.1402.061

Table 2 Correlation coefficients among different characters in kodo millet

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	r_g	1.00																		
	r_p	1.00																		
2	r_g	0.28	1.00																	
	r_p	0.20*	1.00																	
3	r_g	-0.09	0.14	1.00																
	r_p	-0.07	0.09	1.00																
4	r_g	0.02	-0.07	0.02	1.00															
	r_p	0.01	-0.04	0.01	1.00															
5	r_g	0.11	0.01	-0.05	0.43**	1.00														
	r_p	0.08	-0.02	-0.01	0.39**	1.00														
6	r_g	-0.15	0.11	0.26	-0.04	0.08	1.00													
	r_p	-0.14	0.07	0.24**	-0.03	0.07	1.00													
7	r_g	0.35*	0.10	-0.17	0.23	0.14	-0.16	1.00												
	r_p	0.31**	0.03	-0.12	0.18*	0.12	-0.14	1.00												
8	r_g	-0.12	-0.25	-0.08	0.27	0.05	0.15	-0.33*	1.00											
	r_p	-0.09	-0.19*	-0.07	0.22**	0.02	0.13	-0.25**	1.00											
9	r_g	-0.06	-0.21	0.12	-0.05	-0.13	0.15	-0.02	0.22	1.00										
	r_p	-0.05	-0.15	0.13	-0.04	-0.10	0.14	-0.01	0.18*	1.00										
10	r_g	0.09	-0.26	0.11	-0.05	-0.11	0.07	-0.02	0.17	0.98**	1.00									
	r_p	0.08	-0.19*	0.08	-0.04	-0.10	0.06	-0.01	0.12	0.94**	1.00									
11	r_g	0.09	-0.06	0.01	0.13	-0.02	-0.09	0.24	0.06	-0.08	-0.14	1.00								
	r_p	0.08	-0.02	0.03	0.11	-0.06	-0.08	0.21*	0.03	-0.07	-0.11	1.00								
12	r_g	-0.09	-0.09	-0.07	-0.26	-0.14	0.13	-0.04	0.04	0.07	0.08	-0.13	1.00							
	r_p	-0.08	-0.06	-0.07	-0.25**	-0.12	0.12	-0.03	0.02	0.06	0.07	-0.10	1.00							
13	r_g	-0.10	0.17	0.54**	0.16	0.18	0.13	-0.07	-0.07	0.22	0.25	-0.07	-0.06	1.00						
	r_p	-0.08	0.13	0.53**	0.15	0.15	0.12	-0.04	-0.01	0.21*	0.23**	-0.06	-0.06	1.00						
14	r_g	-0.07	-0.19	0.14	0.22	0.15	0.14	-0.17	0.13	0.14	0.14	0.14	-0.08	0.02	1.00					
	r_p	-0.06	-0.14	0.13	0.21*	0.12	0.13	-0.13	0.10	0.13	0.13	0.13	-0.07	0.01	1.00					
15	r_g	0.31*	-0.03	0.02	0.03	0.15	0.03	0.17	-0.02	0.23	0.22	-0.17	0.08	-0.02	0.27	1.00				
	r_p	0.27**	0.02	0.04	0.02	0.13	0.02	0.14	0.01	0.21*	0.21*	-0.11	0.07	-0.01	0.25**	1.00				
16	r_g	0.76**	0.29*	-0.10	0.02	0.01	-0.14	0.23	-0.10	-0.20	-0.24	0.21	-0.15	-0.13	-0.25	-0.37**	1.00			
	r_p	0.74**	0.17*	-0.08	0.01	-0.02	-0.13	0.19*	-0.08	-0.18*	-0.22**	0.16	-0.14	-0.09	-0.23**	-0.43**	1.00			
17	r_g	0.08	0.22	0.10	0.05	0.06	0.20	0.05	-0.12	0.02	-0.10	0.21	-0.06	-0.11	0.06	-0.08	0.18	1.00		
	r_p	0.07	0.16	0.09	0.04	0.04	0.19*	0.03	-0.09	0.01	-0.09	0.19*	-0.05	-0.10	0.05	-0.07	0.17*	1.00		
18	r_g	0.04	0.25	-0.04	0.05	0.18	0.10	0.17	0.07	0.07	0.05	0.01	-0.02	0.08	-0.11	0.03	0.02	0.16	1.00	
	r_p	0.03	0.20*	-0.02	0.04	0.13	0.09	0.16	0.06	0.06	0.04	0.03	-0.01	0.09	-0.10	0.04	0.01	0.15	1.00	
19	r_g	-0.08	-0.32*	0.23	-0.20	-0.27	0.05	-0.01	-0.03	0.23	0.22	-0.15	-0.04	0.04	0.04	-0.13	-0.02	-0.05	-0.22	1.00
	r_p	-0.07	-0.24**	0.20	-0.19*	-0.25**	0.04	0.01	-0.02	0.22**	0.21**	-0.12	-0.03	0.03	0.03	-0.12	-0.01	-0.04	-0.21**	1.00

*, ** significant at 5% and 1% level of significance respectively r_g = Genotypic correlation coefficient r_p = Phenotypic correlation coefficient

1. Grain yield per plant (g) 2. Number of basal tillers per plant 3. Days to 50% flowering 4. Flag leaf blade length (cm) 5. Flag leaf blade width (cm) 6. Peduncle length (cm) 7. Number of productive tillers per plant 8. Culm branching 9. Panicle length 10. Raceme length 11. Number of raceme per tiller 12. Plant height 13. Days to maturity 14. 1000 grain weight 15. Fodder yield per plant (g) 16. Harvest index (%) 17. Total carbohydrate 18. Crude protein 19. Total phenol

https://doi.org/10.37992/2023.1402.061

Table 3. Direct and indirect effect of different characters on grain yield in kodo millet

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Genotypic correlation with GY/P
1	**0.030**	-0.004	0.002	0.001	0.001	0.001	-0.007	0.057	-0.065	-0.001	0.001	0.008	-0.003	-0.019	0.296	-0.005	-0.001	-0.011	0.277
2	0.004	**-0.025**	0.001	0.001	-0.001	-0.002	-0.002	-0.034	0.028	0.001	0.001	0.024	0.002	0.016	-0.107	-0.002	0.001	0.008	-0.091
3	-0.002	0.001	**-0.026**	-0.004	0.001	0.002	0.008	0.013	-0.012	0.003	-0.001	0.007	0.004	0.023	0.014	-0.001	0.001	-0.007	0.019
4	0.001	0.001	-0.011	**-0.009**	0.001	0.001	0.001	0.036	-0.026	0.001	-0.001	0.008	0.003	0.108	0.005	-0.001	-0.001	-0.009	0.106
5	0.003	-0.006	0.001	-0.001	**-0.004**	-0.002	0.004	-0.041	0.017	-0.002	0.001	0.006	0.003	0.019	-0.147	-0.004	0.001	0.002	-0.153
6	0.003	0.004	-0.006	-0.001	0.001	**0.010**	-0.009	0.004	-0.004	0.005	0.001	-0.003	-0.003	0.116	0.240	-0.001	-0.001	0.001	0.354*
7	-0.008	0.002	-0.007	0.001	-0.001	-0.003	**0.028**	-0.062	0.040	0.001	0.001	-0.003	0.002	-0.015	-0.100	0.003	0.001	-0.001	-0.123
8	-0.006	-0.003	0.001	0.001	-0.001	0.001	0.006	**-0.276**	0.240	-0.002	0.001	0.010	0.003	0.161	-0.202	0.001	0.001	0.008	-0.059
9	-0.008	-0.003	0.001	0.001	0.001	0.001	0.005	-0.271	**0.245**	-0.003	0.001	0.011	0.002	0.156	-0.242	0.002	0.001	0.008	-0.095
10	-0.002	0.001	-0.003	0.001	0.001	0.002	0.002	0.022	-0.034	**0.020**	-0.001	-0.003	0.003	-0.121	0.217	-0.005	0.001	-0.005	0.092
11	-0.003	0.002	0.007	0.001	-0.001	0.001	0.001	-0.019	0.019	-0.002	**0.004**	-0.003	-0.001	0.054	-0.150	0.001	0.001	-0.001	-0.091
12	0.005	-0.014	-0.004	-0.002	-0.001	-0.001	-0.002	-0.061	0.062	-0.001	0.001	**0.045**	0.001	-0.001	-0.131	0.003	0.001	0.002	-0.102
13	-0.006	-0.004	-0.006	-0.001	-0.001	-0.002	0.004	-0.039	0.033	0.003	-0.001	0.001	**0.018**	0.190	-0.259	-0.001	0.001	0.002	-0.068
14	-0.001	-0.001	-0.001	-0.001	0.001	0.002	-0.001	-0.063	0.054	-0.003	0.001	0.001	0.005	**0.703**	-0.383	0.002	0.001	-0.005	0.307*
15	0.009	0.003	0.001	0.001	0.001	0.002	-0.003	0.054	-0.058	0.004	-0.001	-0.006	-0.005	-0.262	**1.028**	-0.004	0.001	0.001	0.762**
16	0.007	-0.003	-0.001	-0.001	-0.001	0.001	-0.003	-0.001	-0.024	0.004	0.001	-0.005	0.001	-0.055	0.187	**-0.022**	-0.001	-0.002	0.081
17	0.008	0.001	-0.001	-0.002	0.001	0.002	0.002	-0.018	0.011	0.001	0.001	0.004	-0.002	0.024	0.025	-0.004	**-0.003**	-0.008	0.038
18	-0.010	-0.006	0.005	0.002	0.001	0.001	-0.001	-0.064	0.053	-0.003	0.001	0.002	0.001	-0.091	-0.007	0.001	0.001	**0.035**	-0.081

*, ** significant at 5% and 1% level of significance respectively.
Residual effect = 0.0067

S. No.	Character name	S. No.	Character name	S. No.	Character name
1.	Number of basal tillers per plant	7.	Culm branching	13.	1000 seed weight (g)
2.	Days to 50% flowering	8.	Panicle length (cm)	14.	Fodder yield per plant (g)
3.	Flag leaf blade length (cm)	9.	Raceme length	15.	Harvest index (%)
4.	Flag leaf blade width (cm)	10.	Number of raceme per tiller	16.	Total carbohydrate (%)
5.	Peduncle length (cm)	11	Plant height (cm)	17	Crude protein (%)
6.	Number of productive tillers per plant	12.	Days to maturity	18.	Total phenol (%)
					GY/P = Grain yield per plant

(0.004). This result was in accordance with Yadava and Jain *et al.* (2006) and Nirubana *et al*. (2021) in kodo millet. On the other hand, panicle length (-0.277), flag leaf blade length (-0.026), days to 50% flowering (-0.025), total carbohydrate content (-0.022), flag leaf blade width (-0.009), peduncle length (-0.004) and crude protein content (-0.003) had negative direct effect on grain yield per plant.

Positive and negative indirect effects on grain yield were observed *via* 324 trait combinations among 18 component characters through path analysis. It was observed that 12 out of 18 component characters contributed positively *via* crude protein content (%), followed by plant height and number of productive tillers per plant. On the other hand, days to 50% flowering, total carbohydrate content (%) and total phenol content (%) were the three characters through which maximum negative indirect effects on grain yield were contributed by the 18 component characters.

From the above results, thus it clear that direct selection based on harvest index and fodder yield per plant may help in augmenting grain yield in the experimental material, whereas crude protein content (%), plant height and number of productive tillers per plant are the most important characters for indirect selection. In the early stages of the crop, plant height is the trait to be selected for better yielding genotypes.

It can be concluded from the present study that biochemical parameters can be considered for identifying better yielding genotypes in kodo millet. Moreover, the outcome from character association and path analysis could be further utilized in crop improvement programmes of kodo millet.

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