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Research Article

VARIABILITY AND ASSOCIATION STUDIES OF PHENOTYPIC CHARACTERS CONTRIBUTING TO YIELD IN FONIO MILLET (*DIGITARIA IBURUA* STAPF) ACCESSIONS

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Abstract: The study on fourteen fonio accessions explored the available variability, investigated component association and grouped the total variability into Principal components. The experiment was conducted with three replications using Randomized Complete Block Design. Most characters showed Significant differences among the accessions at 5% probability level. Phenotypic coefficient of variability was more significant than genotypic coefficients, indicating environmental impacts, though minimal. Grain yield was highly influenced by number of tillers and height, as indicated by correlation and path coefficients. Plant height and days to maturity showed positive impact on fonio yield. Among the nine principal components realized, three had eigen values greater than one, contributing a total variation of about 79.2%. PC1 had the highest Eigen value of 3.77 with the highest load (-0.442) in days to maturity. Selection and hybridization with attention on plant height, number of tillers per plant and panicle length of the population could help improve on the grain yield.

Keywords: correlation, fonio, principal components analysis, variability, yield.

Introduction

Fonio (*Digitaria* spp.), sometimes called fundi in most West African Countries but specifically known as acha in Nigeria [KALAT, 2014], is indigenous to West Africa. The cereal (*Digitaria* spp.) represents a unique component of millet~~s~~ biodiversity. It is regarded as the oldest cultivated African cereal [CRUZ & BEAVOGUI, 2016; DACHI & al. 2016]. Over 300,000 ha is devoted to fonio cultivation yearly in West Africa [BEZPALY, 1984]. FAO (2009) statistics showed that 448,247 ha of fonio was harvested and 480,227 tons of grains produced during the 2008/2009. In Nigeria, two cultivable species (*D. iburua* and *D. exilis*) are recognized. *Digitaria iburua*, also called black fonio, is less recognized for improvement [ADOUKONOU-SAGBADJA & al. 2010]. *D. iburua* has a high amount of magnesium, zinc and manganese compared to other cereals. It also contains a significant amount of thiamine (Vitamin B1), riboflavin (Vitamin B2), calcium and phosphorous compared to white rice [NRC,

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1996]. *Digitaria iburua* is autogamous, variability is mostly among component lines with little adaptation and less flexibility. According to BUDAK & al. (2004), there are changes in the population's genetic structure by selection because of the preserved superior alleles. When selection is applied, the genetic variance may be reduced to attain specific breeding objectives. According to SUNESON (1956), the population's improvement will be slow but in the long run, sufficient for obtaining attractive plant material. Assessing variability in *D. iburua* population is essential step towards its improvement [MISHRA & al. 2015], because environment is reported to have a high influence on yield, and polygenes are a complex character in most crop plants [ISONG & BALU, 2017].

Partitioning of the variability into heritable and non-heritable can be done using the genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (H^2), and genetic advance expressed as a percentage of the mean (GAM%). The combination of heritability and genetic advance is more effective and reliable for predicting breeding value by selection [MISHRA & al. 2015; RAMANJINAPPA & al. 2011; PATIL & al. 1996]. Fonio yield depends on its components and their interaction. The relationship may result either from developmental or genetic factors [BALOCH & al. 2014]. The contributing components of the complex characters are obtained from the correlation, however, path analysis is accurate in analysing the direct and indirect components of a character [ISONG & BALU, 2017]. Some authors [LIAQAT & al. 2015; IQBAL & al. 2006] also pointed out that in majority of crop species, the selection criterion for complex traits is developed using path coefficient analysis and the interaction between the traits. Hence, parameters affecting yield improvement can be analyzed using correlation and path coefficient analysis [REDDY & al. 2015]. Canonical or vector analysis (Principal Component Analysis) can also be used to indicate the character(s) contributing most of the variability in the population. In lieu of the aforementioned, this investigation seeks to analyse the variability as well as component association and to group the total variability into Principal components for effective selection in the population.

Material and methods

Location of the experiment

The location for the investigation was Acha (Fonio) research field of Acha Research Programme, National Cereals Research Institute, Badeggi, Nigeria. Badeggi is located at Latitude 9°45' N and Longitude. 6°07' E in the Southern Guinea Savannah of Nigeria.

The genetic materials and field experimentation

Fourteen (14) *D. iburua* accessions; Asaogba, Eburi iki, Eburi okwa, Eburi istimu, Eburi suum, Eburu Anime, iacho, egboba, ikiota, Kojegicho, Kojegichoonobi, Nachelenchia, Naram, Nashelleng and Tuwonta were raised in three replications in Randomized Block Design (RBD). The genetic materials were planted in plots of 3 m x 4 m each by broadcasting method with a seed rate of 25 kg/ha. Cultural practices like irrigation, soil conditioning, fertilizer application, weed and pest control were followed. The nutrient requirement was 15:15:15 NPK inorganic fertilizer, applied in two splits of 30 kg N/ha, 30 kg P_2O_2 and 30 kg/ha K_2O at 4 and 8 weeks after planting (WAP), respectively.

Data collection

The observations from randomly tagged 5 plants per plot were made on number of tillers per plant (NTPP), number of nodes per tiller (NNPT), spike length (SL), number of panicles per plant (NPPP), panicle length (PL), plant height (PH), days to 50% flowering (DFPF), days to maturity (DM) and grain yield (GY).

Statistical Analysis

AGRISTAT statistical analyses software was used to obtain the mean data for *per se* performance, analysis of variance (ANOVA) and variability parameters viz; phenotypic, genotypic and environmental variations, according to LUSH (1940), phenotypic and genotypic coefficient of variation, according to BURTON (1952). Broad sense heritability (Hb%) according to LUSH (1940) and Genetic advance over mean (%) as described by JOHNSON & al. (1955). In ANOVA, where the mean showed significant difference at a 5% probability level, Least Significant Difference (LSD) was used for mean separation. Also, association studies were carried out using correlation matrix and Path coefficient analyses. Statistical Tools for Agricultural Research package (STAR), version 2.0.1 of 2014 was employed to group the variability into different Principal components as described by SAEED & al. (2014).

Results and discussions

Analysis of variance, per se performance and descriptive statistics results are presented in Table 1, Genetic and Phenotypic Variability are in Table 2, Correlations are presented in Table 3, Regression and Direct Path are in Table 4 while Principal Components analysis is indicated in Table 5.

At 5% probability level, all the traits studied showed significant differences among the mean values implying that sufficient variability existed amongst the traits, breeders have a high opportunity to improve the traits by selection and hybridization according to [UMAR & al. 2020]. The accession Eburi iki recorded the highest yield value (836.10kg/ha) while Naram had the lowest yield of 425.00 kg/ha. Nashelleng, a *D. iburua* species recorded the tallest plants, corroborating the reports of ISONG & al (2022). Nashelleng also had the highest number of tillers per plant and number of nodes per tiller but required more days for 50% flowering and are late maturing. The phenotypic coefficient of variation ranged from 7.09 in plant height to 19.60 in grain yield. Also, genotypic coefficient of variation (GCV) values were from 7.0981 in plant height to 19.5633 in grain yield. Following the classification by SIVASUBRAMANIAN & MADHAVAMENON (1973), plant height was low for both parameters; grain yield was high for both parameters, while the other seven traits were moderate for the two variance parameters. In all the traits under study, the phenotypic coefficient of variability was higher than the genotypic coefficients of variation, indicating that the environment imparted though minimally on all the traits TEJASWINI & al. (2017).

Heritability, the proportion of genotypic variance in the phenotypic variance, was determined broadly by a method prescribed by LUSH (1940). According to JOHNSON & al. (1955) classification, all the traits recorded high heritability.

The expected genetic advance under selection indicated that all the traits under study had high genetic advance over mean (GAM) [JOHNSON & al. 1955]. By the findings of SAKTHI & al. (2007), heritability of all traits in this population is associated with high genetic advance, implying that cumulative gene effects are related to the heritability, also selection could be effective. Correlation analysis provided the basis to predict the corresponding change in one character at the expense of proportionate change in the other character. Genotypic correlation co-efficient between fonio grain yield with eight (8) biometric traits and inter-correlation among themselves were analyzed, and the result showed that phenotypic characters are higher than the magnitude of genotypic correlation. The fonio grain yield has positive correlation with number of tillers, nodes, height and length of panicle. At 5% probability level, panicle length was significantly correlated with grain yield, while number of tillers per plant and plant height were significantly correlated with grain yield at 1% probability for both phenotypic and genotypic correlations. According to AGUADO & al. (2008), the selection of these desired traits could help improve the grain yield of the fonio. The correlation among the yield component traits is important in deciding which trait to be given due attention in exercising selection. The association between the quantitative yield contributing traits like tillers with length of panicle and height; spike length with panicle length, plant height, days to 50% flowering and days to maturity; panicle length with plant height, days to 50% flowering and days to maturity; plant height with days to 50% flowering and days to maturity; days to 50% flowering with days to maturity are all positively and significantly correlated at 1% probability level at N minus 2 degrees of freedom for both the genotypic and phenotypic associations. This inter-correlation result corresponds with the findings of BASBAG & GENCER (2007) working on interspecific cotton hybrids. Therefore, selection based on these important yield contributing traits could bring about a breakthrough in fonio grain yield under interspecific hybridization.

Path coefficient analysis was derived following the methods described by DEWEY & LU (1959) to differentiate the genotypic correlation coefficients into direct and indirect effects. Based on the direct and indirect effects classification scale given by LENKA & MISHRA (1973), spike length and days to 50% flowering had very high but negative direct path effects on fonio grain yield. Conversely, plant height and days to maturity also demonstrated very high but positive direct path effects on fonio grain yield. The implication for direct selection of plant height and days to maturity as yield components will be directly felt in the early generation of population development. Panicle length was high and positive, while panicles in each plant had low direct, but positive path effects on fonio grain yield. From the study of grain yield and its components, high genetic variability, as indicated by the analysis of variance and variance components, existed amongst the components in fonio. KHAN (2003) suggested how to indicate the variability pattern and possibly group them into components. Following the method described in ISONG & al. (2017), mean data of fourteen (14) *D. iburua* accessions were subjected to Principal Component (PC) analysis. Nine (9) principal components were realized, and only three (3) of them had eigen values greater than one, contributing variations of about 79.2% of the total variation in the population. Therefore, the three (3) principal components are important in explaining the total variability and grouping of the components. The highest variability of 41.9% recorded by the first PC was contributed mostly by spike length, panicle length, days to 50% flowering and days to maturity. The second and third PCs having 23.4% and 13.9% respectively were mostly associated with the grain yield, number of tillers per plant and number of panicles per plant.

Table 1. *Per se* performance, descriptive statistics and analysis of variance for yield and yield attributes of 14 *Digitaria iburua* accessions

Accessions	NTPP	NNPT	SL (cm)	NPPP	PL (cm)	PH (cm)	DFPF	DM	GY (Kg/ha
Asaogba	11.00	16.40	12.23	8.00	11.40	123.43	68.33	89.67	741.67
Eburi iki	20.33	13.60	15.70	9.33	19.50	131.43	74.67	99.67	836.10
Eburi okwa	16.00	13.40	15.50	7.00	15.53	120.80	78.33	101.00	516.67
Eburi istimu	14.00	15.43	14.50	9.00	13.43	110.40	69.33	100.00	541.67
Eburi suum	15.00	11.80	14.50	8.00	12.80	129.70	84.33	100.33	538.87
Eburu Anime	13.00	11.90	16.10	10.00	14.33	118.43	81.00	104.00	480.53
iacho-egboba	16.00	14.80	9.70	9.00	11.23	117.63	69.00	89.00	608.33
ikiota	18.00	11.80	15.10	10.00	14.43	116.20	73.33	103.00	686.13
Kojegicho	15.00	15.10	12.10	8.00	10.50	119.80	68.33	98.00	538.87
Kojegichoonobi	19.00	12.40	11.50	7.00	11.80	112.80	72.67	103.00	650.00
Nachelenchia	17.00	16.87	10.90	9.00	12.70	113.80	57.67	84.00	756.73
Naram	12.00	16.57	11.10	7.00	11.50	106.40	69.00	91.67	425.00
Nashelleng	21.00	16.87	11.83	8.00	14.50	134.40	88.00	108.67	758.33
Tuwonta	19.00	16.80	8.90	10.00	11.20	109.60	60.67	84.00	666.67
Mean	**16.17**	**14.55**	**12.83**	**8.52**	**13.20**	**118.92**	**72.48**	**96.86**	**624.80**
Max	**21.00**	**16.87**	**16.10**	**10.00**	**19.50**	**134.40**	**88.00**	**108.67**	**836.10**
Min	**11.00**	**11.80**	**8.90**	**7.00**	**10.50**	**106.40**	**57.67**	**84.00**	**425.00**
SE	**0.13**	**0.37**	**0.35**	**0.13**	**0.03**	**0.09**	**1.69**	**0.84**	**6.44**
CV%	**0.95**	**3.08**	**3.35**	**1.81**	**0.27**	**0.09**	**2.86**	**1.06**	**1.26**
LSD 5%	**0.46**	**1.35**	**1.29**	**0.46**	**0.11**	**0.32**	**6.25**	**3.08**	**23.71**

N/B: NTPP = number of tillers per plant; NPPP = number of panicles per plant; SL= spike length; NNPT = number of nodes per tiller; PL= panicle length; PH = plant height; DFPF = days to 50% flowering; DM = days to maturity and GY= grain yield.

Table 2. Variance components, heritability and genetic advance for grain yield and yield components in 14 accessions of *Digitaria iburua* studied

Components	Phenotypic variance	Genotypic variance	Environmental variance	Phenotypic coefficient of variation	Genotypic coefficient of variation	Broad sense herita-bility (%)	Genetic advance over mean (%)
NTPP	9.43	9.41	0.02	18.99	18.97	99.75	39.03
NNPT	4.24	4.04	0.20	14.16	13.82	95.25	27.78
SL	5.69	5.51	0.19	18.59	18.29	96.75	37.05
NPPP	1.24	1.22	0.02	13.07	12.95	98.08	26.42
PL	5.64	5.64	0.001	17.99	17.98	99.98	37.05
PH	71.26	71.25	0.01	7.09	7.09	99.98	14.62
DFPF	73.74	69.43	4.31	11.85	11.49	94.16	22.98
DM	61.10	60.06	1.05	8.07	8.00	98.29	16.34
GY	15002.53	14940.41	62.12	19.61	19.56	99.59	40.22

N/B: NTPP = number of tillers per plant; NPPP = number of panicles per plant; SL = spike length; NNPT = number of nodes per tiller; PL = panicle length; PH = plant height; DFPF = days to 50% flowering; DM = days to maturity and GY = grain yield.

Table 3. Genotypic and phenotypic correlations of yield and yield attributes of 14 *D. iburua* accessions

		NTPP	**NNPT**	**SL**	**NPPP**	**PL**	**PH**	**DFPF**	**DM**	**GY**
NTPP	g	1.000	-0.051	-0.106	0.192	0.429**	0.324*	0.141	0.244	0.621**
	p	1.000	-0.060	-0.104	0.197	0.428**	0.324*	0.135	0.238	0.619**
NNPT	g		1.000	-0.690**	-0.089	-0.357*	-0.195	-0.519**	-0.596**	0.226
	p		1.000	-0.665**	-0.115	-0.347*	-0.191	-0.483**	-0.562**	0.219
SL	g			1.000	0.119	0.719**	0.383*	0.580**	0.675**	-0.133
	p			1.000	0.117	0.707**	0.376*	0.559**	0.662**	-0.130
NPPP	g				1.000	0.224	-0.054	-0.215	-0.159	0.295
	p				1.000	0.222	-0.053	-0.212	-0.166	0.291
PL	g					1.000	0.523**	0.447**	0.482**	0.368*
	p					1.000	0.523**	0.434**	0.479**	0.367*
PH	g						1.000	0.697**	0.480**	0.443**
	p						1.000	0.676**	0.475**	0.442**
DFPF	g							1.000	0.864**	-0.141
	p							1.000	0.831**	-0.139
DM	g								1.000	-0.111
	p								1.000	-0.110
GY	g									1.000
	p									1.000

N/B: NTPP = number of tillers per plant; NPPP = number of panicles per plant; SL = spike length; NNPT = number of nodes per tiller; PL = panicle length; PH = plant height; DFPF = days to 50% flowering; DM = days to maturity and GY = grain yield; g = genotypic; p = phenotypic; ** = significant at 1% probability; * = significant at 5% probability

Table 4. Path coefficients of grain yield with yield components in *D. iburua* accessions studied

	NTPP	NNPT	SL	NPPP	PL	PH	DFPF	DM	**Correlation Coefficient**
NTPP	**-0.356**	0.015	0.137	0.036	0.385	0.358	-0.223	0.268	0.621**
NNPT	0.018	**-0.293**	0.892	-0.016	-0.321	-0.215	0.817	-0.656	0.226
SL	0.038	0.202	**-1.293**	0.022	0.646	0.423	-0.914	0.744	-0.133
NPPP	-0.068	0.026	-0.154	**0.185**	0.202	-0.060	0.340	-0.175	0.295
PL	-0.153	0.104	-0.929	0.041	**0.899**	0.578	-0.704	0.531	0.368*
PH	-0.115	0.057	-0.495	-0.010	0.470	**1.106**	-1.098	0.529	0.443**
DFPF	-0.050	0.152	-0.750	-0.040	0.402	0.770	**-1.576**	0.951	-0.141
DM	-0.087	0.175	-0.873	-0.029	0.433	0.531	-1.361	**1.101**	-0.111

RESIDUE = 0.3738. **Bold figures in Diagonals** indicate direct effect on fonio grain yield
N/B: NTPP = number of tillers per plant; NPPP = number of panicles per plant; SL = spike length; NNPT = number of nodes per tiller; PL = panicle length; PH = plant height; DFPF = days to 50% flowering; DM = days to maturity and GY = grain yield.

Table 5. Principal component analysis (PCA) for 9 variables in 14 *D. iburua* accessions

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
NTPP	-0.172	0.509	0.124	-0.643	0.164	-0.122	0.240	0.294	0.311
NNPT	0.340	0.229	0.349	0.408	0.116	-0.691	-0.116	0.121	0.161
SL	-0.417	-0.193	-0.328	0.318	0.264	0.028	-0.203	0.305	0.613
NPPP	-0.017	0.307	-0.698	0.012	-0.540	-0.351	-0.021	0.015	-0.061
PL	-0.400	0.233	-0.190	0.254	0.537	-0.176	0.372	-0.242	-0.412
PH	-0.367	0.214	0.349	0.388	-0.431	0.227	0.215	0.478	-0.189
DFPF	-0.432	-0.174	0.289	-0.033	-0.353	-0.260	0.203	-0.588	0.346
DM	-0.442	-0.167	0.144	-0.280	0.012	-0.326	-0.625	0.146	-0.400
GY	-0.067	0.632	0.082	0.153	0.022	0.358	-0.521	-0.390	0.114
Statistics									
Proportion of variance	0.419	0.234	0.139	0.076	0.056	0.041	0.023	0.009	0.004
Cumulative proportion	0.419	0.653	0.792	0.868	0.924	0.965	0.988	0.996	1.000
Eigen Values	3.769	2.108	1.252	0.685	0.499	0.372	0.205	0.078	0.034

N/B: NTPP = number of tillers per plant; NPPP = number of panicles per plant; SL = spike length; NNPT = number of nodes per tiller; PL = panicle length; PH = plant height; DFPF = days to 50% flowering; DM = days to maturity and GY = grain yield.

Conclusions

Sufficient positive genetic variability was recorded in the fonio population, all the traits under study showed significant differences at 5% probability level. Environment had minimal impact on all the traits under study. The phenotypic coefficient of variability showed higher figures than the genotypic coefficients of variation. High heritability and high Genetic Advance over mean (GAM) associated with all traits, indicates that heritability is largely due to additive gene effects. Selection based on correlation, path coefficient and Principal component analyses results will bring breakthroughs in breeding for fonio grain yield under interspecific hybridization. Plant height and days to maturity showed a direct positive effect on the grain yield, direct selection of these traits would be directly felt in the early generation of population development.

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