Hindawi
International Journal of Agronomy
Volume 2023, Article ID 8832165, 9 pages
https://doi.org/10.1155/2023/8832165

Research Article

Genetic Diversity and Association of Yield-Related Traits in Taro (*Colocasia esculenta* (L.) Schott) Sourced from Different Agroecological Origins of Nigeria

Tilahun Wondimu Fufa[1,2] **Happiness Ogba Oselebe**[2] **Charles Okechukwu Amadi,**[3] **Temesgen Matewos Menamo**[4] **and Wosene Gebreselassie Abtew**[4]

[1]*Oromia Agricultural Research Institute, Addis Ababa, Ethiopia*
[2]*Department of Crop Science, Ebonyi State University, Abakaliki, Nigeria*
[3]*National Root Crops Research Institute, Umudike, Nigeria*
[4]*College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia*

Correspondence should be addressed to Wosene Gebreselassie Abtew; wosish@yahoo.com

Received 5 May 2023; Revised 2 December 2023; Accepted 4 December 2023; Published 11 December 2023

Academic Editor: Maria Serrano

Taro's production is characterized by low productivity due to a lack of sufficient improved cultivars suited to the different growing areas coupled with biotic and abiotic stresses. The first step in plant breeding program is to examine and quantify variations for traits of interest in a given set of genotypes so those variations can be exploited in breeding programmes. One hundred taro accessions were evaluated for 16 quantitative traits in a simple lattice design with the objective of estimating variability and determine and quantify association of characters with yield. Multienvironment trial analysis combined over seasons showed highly significant differences among taro accessions for several traits. Yield per plant showed a strong, positive, and highly significant genotypic correlation with plant height (0.99), leaf area (0.82), corm weight (0.99), and cormel weight (0.99). Genotypic path coefficient analysis showed plant height (1.49), leaf area (0.97), corm weight (0.76), and cormel weight (0.21) exerted a high positive direct effect on yield per plant indicating true relationship between the characters. Accessions EBNFC054, EBNFC045, EBNFC100, EBNFC046, EBNFC032, EBNFC075, EBNFC084, EBNFC057, and EBNFC037 were superior and could be promoted to field evaluation. This assessment of variability and associations can assist breeders to tap the potential of the genotypes for certain traits and identify major traits that could be used as a basis for the selection of superior taro genotypes.

1. Introduction

Taro (*Colocasia esculenta* (L.) Schott) is one of the world's most ancient food crops, with a history of more than 2,000 years in cultivation [1]. It originated in south central Asia, while high diversity was reported in Southeast Asia [2]. It is morphologically diverse, with over 10,000 landraces worldwide [3], and about 10 ecotypes have been reported growing in Nigeria [4].

Taro is largely produced and consumed in tropical and subtropical countries [5], and Nigeria is the largest taro producer in the world [6]. Only the skins of the taro corm and the true anatomical roots have not been reported as food; meanwhile, the corms, blades, petioles, and inflorescences are edible. The corm has been reported to have high starch, while the leaf contains high protein [7]. Among tuber crops, taro is perhaps the most widely prepared or processed into more consumable forms [8]. It is a staple food, mainly for resource-poor rural dwellers in south eastern Nigeria [4], and is regularly consumed as a main component or as a soup thickener [5].

As is true for some crops, taro remains an orphan, and so far, no improved variety is available in Nigeria. It is chiefly characterized by low productivity, disease susceptibility and poor eating quality [9]. Specifically, taro yield was estimated at 3.94 t ha^{-1} in Nigeria in 2021, which was very far below the global average yield of 9.50 t ha^{-1} [6]. Yield is a complex trait governed by several genes that govern a number of yield components and are also influenced by environmental factors, signifying indirect selection breeding to improve taro yield.

The first step in any plant breeding program is to identify plants that exhibit variation for the traits of interest. Desirable traits combination should be sought among plants in existing populations such as recommended cultivars, breeding lines and landrace [10]. To have a good choice of characters for selection of desirable genotypes, the estimate of heritability, genetic advance, and knowledge of association of component traits with yield is of great importance to plant breeders as it helps them make selection with more precision and accuracy [11]. Heritability estimate can be used to predict gain from selection [12]. Genetic correlation is a measure of the extent to which the same gene, or closely linked genes, cause simultaneous variation in two different traits [13]. Path analysis further permits the partitioning of the correlation coefficients into components of direct and indirect factors of association and provides an effective tool in finding out the direct and indirect contribution of different contributing characters towards yield [14].

Many researchers have reported broad-sense heritability and distinguished a number of positive and significant associations of yield and yield attributing characters and their direct and indirect effects in different root and tuber crops. For instance, in taro [15, 16], Tania [15, 17–19], sweet potato [20, 21], and anchote [22, 23], thus, the current study was intended to estimate genetic variability and characters association in taro so as to identify the major traits of importance that could be used as a basis in taro breeding to select superior genotypes.

2. Materials and Methods

2.1. Plant Material. A total of 100 taro accessions were used in this study (Table 1). The accessions were originally collected from five states of Nigeria, i.e., Ebonyi state (21), Anambra (20), Enugu (20), Imo (19), and Abia (20) in 2018. The test collections were comprised of all landraces.

2.2. Description of Site. The field trial was carried out at Ebonyi State University, Department of Crop Production and Landscape Management teaching and experimental field, Abakaliki, Nigeria, during the rainy seasons of 2018 and 2019. The site is situated at 06°4′ N and 08°65′ E at 55.5 metre above sea level. The area receives annual rainfall of 1700 to 2000 mm with 80% to 90% relative humidity. The mean minimum, maximum, and average temperatures were 22°C, 32°C, and 28°C, respectively. The predominant soil is hydromorphic with moderate to reddish brown silty clay subsoil. The site is also good for the production of root crops like cassava and yam among the others.

2.3. Experimental Design and Trial Management. The experiment was laid out using a 10×10 simple lattice design with two replicates [24]. Each accession was established in a plot size of 5 m^2 consisting of one row of 5 m in length. The spacing between rows and plants was 1 m and 0.5 m, respectively [25, 26]. Ten cormels with an average weight of 50 g were used for planting. It was planted on 25th May, 2018 and 28th May, 2019. All management practices like weeding and earthing-up were done as recommended during all growth period.

2.4. Data Collection. Data were recorded on 16 quantitative traits from five randomly taken plants. The descriptor, code and description of the characters are presented in Table 2. The traits include number of leaves per plant, plant height (cm), petiole length (cm), leaf length (cm), leaf breadth (cm), leaf area, number of suckers per plant, days to maturity, yield per plant (kg), corm length (cm), corm diameter (cm), cormel diameter (cm), cormel length (cm), corm weight (g), cormel weight (g), and total yield (t ha^{-1}). These data were recorded following a descriptor of taro developed by the International Board for Plant Genetic Resources [27]. Morphological data were recorded at maximum growth stage (120 days after planting), while corm and corm-related traits were recorded at harvest (180 to 220 days after planting).

2.5. Data Analysis. Normality and equal variance test and transformation of data for some characters were done using Minitab software [28]. Descriptive statistics were used to depict variations that emerge from quantitative traits. Quantitative traits were subjected to multienvironment trail analysis (META) based on simple lattice design in order to verify differences among accessions. Phenotypic and genotypic variances and coefficient of variations were estimated as per the procedure suggested by [29]. Broad sense heritability (h_B^2) was estimated using the formula suggested by [30]. Genetic advance (GA) at selection intensity (K) of 10% was calculated by the formula suggested by [31]. Genetic advance as percentage of mean (GAM) was computed to compare the extent of predicted genetic advance of different characters under selection. Genotypic and phenotypic correlation components between traits were estimated using the equation suggested by [32]. For path analysis, yield per plant was taken as a dependent variable, while others were considered independent variables. Direct and indirect effect of independent variables on yield per plant was estimated using formula suggested by [14]. Correlation analysis was carried out using META R [33], while path analysis was done using Excel.

3. Results

3.1. Variation for Quantitative Traits among Taro Accessions. Multienvironment trial analysis (META) results of 16 quantitative traits are presented in Table 3. META combined over seasons (environment) showed highly significant ($P \leq 0.01$) differences among the tested accessions for plant

Table 1: List of taro landraces used in the study.

Entry no.	Collection name of designation	Regions of collection (state)
1	EBNFC001	Ebonyi
2	EBNFC002	Ebonyi
3	EBNFC003	Ebonyi
4	EBNFC004	Ebonyi
5	EBNFC005	Ebonyi
6	EBNFC006	Ebonyi
7	EBNFC007	Ebonyi
8	EBNFC008	Ebonyi
9	EBNFC009	Ebonyi
10	EBNFC010	Ebonyi
11	EBNFC011	Ebonyi
12	EBNFC012	Ebonyi
13	EBNFC013	Ebonyi
14	EBNFC014	Ebonyi
15	EBNFC015	Ebonyi
16	EBNFC016	Ebonyi
17	EBNFC017	Ebonyi
18	EBNFC018	Ebonyi
19	EBNFC019	Ebonyi
20	EBNFC020	Ebonyi
21	EBNFC021	Ebonyi
22	EBNFC022	Anambra
23	EBNFC023	Anambra
24	EBNFC024	Anambra
25	EBNFC025	Anambra
26	EBNFC026	Anambra
27	EBNFC027	Anambra
28	EBNFC028	Anambra
29	EBNFC029	Anambra
30	EBNFC030	Anambra
31	EBNFC031	Anambra
32	EBNFC032	Anambra
33	EBNFC033	Anambra
34	EBNFC034	Anambra
35	EBNFC035	Anambra
36	EBNFC036	Anambra
37	EBNFC037	Anambra
38	EBNFC038	Anambra
39	EBNFC039	Anambra
40	EBNFC040	Anambra
41	EBNFC041	Anambra
42	EBNFC042	Enugu
43	EBNFC043	Enugu
44	EBNFC044	Enugu
45	EBNFC045	Enugu
46	EBNFC046	Enugu
47	EBNFC047	Enugu
48	EBNFC048	Enugu
49	EBNFC049	Enugu
50	EBNFC050	Enugu
51	EBNFC051	Enugu
52	EBNFC052	Enugu
53	EBNFC053	Enugu
54	EBNFC054	Enugu
55	EBNFC055	Enugu
56	EBNFC056	Enugu
57	EBNFC057	Enugu
58	EBNFC058	Enugu
59	EBNFC059	Enugu

Table 1: Continued.

Entry no.	Collection name of designation	Regions of collection (state)
60	EBNFC060	Enugu
61	EBNFC061	Enugu
62	EBNFC062	Imo
63	EBNFC063	Imo
64	EBNFC064	Imo
65	EBNFC065	Imo
66	EBNFC066	Imo
67	EBNFC067	Imo
68	EBNFC068	Imo
69	EBNFC069	Imo
70	EBNFC070	Imo
71	EBNFC071	Imo
72	EBNFC072	Imo
73	EBNFC073	Imo
74	EBNFC074	Imo
75	EBNFC075	Imo
76	EBNFC076	Imo
77	EBNFC077	Abia
78	EBNFC078	Imo
79	EBNFC079	Imo
80	EBNFC080	Imo
81	EBNFC081	Imo
82	EBNFC082	Abia
83	EBNFC083	Abia
84	EBNFC084	Abia
85	EBNFC085	Abia
86	EBNFC086	Abia
87	EBNFC087	Abia
88	EBNFC088	Abia
89	EBNFC089	Abia
90	EBNFC090	Abia
91	EBNFC091	Abia
92	EBNFC092	Abia
93	EBNFC093	Abia
94	EBNFC094	Abia
95	EBNFC095	Abia
96	EBNFC096	Abia
97	EBNFC097	Abia
98	EBNFC098	Abia
99	EBNFC099	Abia
100	EBNFC100	Abia

height, petiole length, number of suckers per plant, days to maturity, yield per plant, cormel weight, and total yield, while nonsignificant for number of leaves per plant, leaf length, leaf breadth, leaf area, corm length, corm diameter, cormel length, and cormel diameter. META for individual seasons (Table 4) showed a highly significant ($P \leq 0.01$) differences among the studied accessions for all traits except cormel length which showed significant ($P < 0.05$), while accessions did not differ statistically significantly for corm diameter.

3.2. Performance of Genotypes. The estimate of range and pooled mean performance of accessions for total yield and yield related traits are presented in Table 3. Yield performance of taro accessions ranged from 1.25 t ha^{-1} to 18.03 t ha^{-1} with

Table 2: Quantitative descriptors for agromorphological characterization of taro accessions.

Descriptor	Code	Description
Number of leaves per plant	NLPP	All leaves were counted from plant emergence to 150 days after planting (DAP)
Plant height (cm)	PHt	Measured from collar region to the attachment point between the leaf petiole and the lamina of the tallest leaf by ruler
Petiole length (cm)	PL	Measured from base of the petiole to the attachment point of the tallest leaf by ruler
Leaf length (cm)	LL	Measured at longest point in two large sized leaves by ruler
Leaf breadth (cm)	LB	Measured at widest point in two large sized leaves by ruler
Leaf area	LAI	Calculated as $L \times W \times 0.75$
Number of sucker's per plant	NSPP	All suckers counted
Days to maturity (days)	DM	Calculated by counting the number of days taken from planting to final harvest of the crop
Yield per plant (kg)	YPP	Weighed all corm and cormels obtained from each plant by sensitive scale
Corm weight (g)	COW	Weighed by sensitive balance
Corm length (cm)	COL	Measured from the distal end of the corm to the proximal end, where the outer leaf petiole is attached to the corm by calliper
Corm diameter (cm)	COD	Measured at the maximum circumference of the corm using calliper
Cormel weight (g)	CRW	Weighed by sensitive balance
Cormel length (cm)	CRL	Measured from the distal end to the proximal end of the cormel by calliper
Cormel diameter (cm)	CRD	Measured at the maximum circumference of the cormel by calliper
Total yield (t ha^{-1})	TY	Yield per plot converted to yield per hectare (t ha^{-1})

Table 3: META combined over seasons, estimates of range, mean, standard deviation, and coefficient of variation (CV %) for 16 characters of 100 taro accessions at Abakaliki, Nigeria (2018 and 2019).

Traits	Estimates of range		Mean		Standard deviation	CV (%)
	Min	Max	2018	2019		
NLPP	7.40	12.40	10.134**	9.13**	0.93	4.25
PHT	35.00	110.00	72.95**	77.60**	13.61	9.97
PL	16.67	69.00	32.15**	31.49**	6.42	13.49
LL	5.00	72.00	47.87**	46.39	8.18	12.92
LB	16.50	56.40	36.43**	35.30*	5.82	11.60
LAI	0.02	0.25	0.13**	0.12*	0.04	21.20
NSPP	1.00	14.40	7.03**	8.48**	2.31	17.04
MD	178.00	213.00	196.1**	192.01**	10.36	2.96
YPP	0.05	1.16	0.67**	0.67**	0.21	16.34
COL	2.26	9.36	6.69*	6.67*	1.08	11.09
COD	2.62	11.06	6.74**	6.74**	1.22	10.73
CRL	3.40	8.38	5.69**	5.86**	0.85	10.59
CRD	2.45	5.95	3.71*	3.71*	0.48	8.26
COW	0.04	0.39	0.17**	0.17**	0.70	22.48
CRW	16.21	84.30	41.50**	37.91**	10.32	17.32
TYLD	1.25	18.08	9.49**	10.67**	3.57	16.13

NLPP: number of leaves per plant, PHt: plant height (cm), PL: petiole length (cm), NSPP: number of suckers per plant, MD: days to maturity, YPP: yield per plant (kg), CRW: cormel weight (g) and total yield (tons/ha), leaf length, leaf breadth, leaf area, corm length, corm diameter, cormel length, and cormel diameter.

a pooled mean of 10.08 t ha^{-1}. Sixty percent of the total accessions gave yield above pooled mean yield (10.08 t ha^{-1}). Based on 10% selection intensity, the first ten top high yielders were EBNFC051, followed by EBNFC054, EBNFC045, EBNFC100, EBNFC046, EBNFC032, EBNFC075, EBNFC084, EBNFC057, and EBNFC037. From the top yielder's five accessions (i.e., EBNFC051, EBNFC054, EBNFC045, EBNFC046, and EBNFC057) were collected from Enugu state, two (EBNFC084 and EBNFC100) from Abia, two (EBNFC 032 and EBNFC037) from Anambra, and one (EBNFC075) from Imo state (Table 1).

Number of leaves per plant ranged from 7.40 to 12.40 with pooled mean of 9.63. Plant height ranged from 35 cm to 110 cm with a mean of 75.28 cm. Petiole length ranged from 16.67 cm to 69.00 cm with mean of 31.82 cm. Leaf length ranged from 5.00 cm to 72.00 cm with a mean of 47.31 cm. Leaf breadth ranged from 16.50 cm to 56.40 cm with a mean of 35.86 cm. Number of suckers per plant ranged from one to 14.40 with a mean of 7.76. Days to maturity ranged from 178 to 213 days with a mean of 197 days. Yield per plant ranged from 0.05 kg to 1.16 kg with a mean of 0.67 kg. Corm length ranged from 2.26 cm to 9.36 cm with a mean of 6.70 cm. Corm diameter ranged from 2.62 cm to 11.06 cm with a mean of 6.74 cm. Cormel length ranged from 3.40 cm to 8.38 cm with a mean of 5.78 cm while cormel diameter ranged from 2.45 cm to 5.95 cm with a mean of 3.71 cm. Corm weight ranged from 0.04 kg to 0.39 kg with a mean of 0.17 kg. Cormel weight ranged from 16.21 g to 84.30 g with a mean of 39.71 g.

Table 4: Multi environment trial analysis for individual seasons, Abakaliki (2018 and 2019).

Environment	Statistic	NLPP	LL	LB	LAI	COL	COD	CRD	CRL	COW
2018	Heritability	0.57	0.60	0.50	0.56	0.38	0.57	0.32	0.39	0.65
	Genotype variance	0.17	24.56	8.38	0.00	0.26	0.58	0.03	0.14	0.00
	Residual variance	0.27	33.05	16.65	0.00	0.86	0.88	0.14	0.43	0.00
	Grand mean	10.13	47.87	36.43	0.13	6.70	6.74	3.71	5.69	0.17
	LSD	0.80	8.99	5.86	0.04	1.14	1.41	0.43	0.83	0.08
	CV (%)	5.09	12.01	11.20	21.60	13.81	13.92	10.24	11.56	28.36
	Replicates	2	2	2	2	2	2	2	2	2
	Genotype significance	0.00	0.00	0.00	0.00	0.03	0.00	0.09	0.03	0.00
2019	Heritability	0.57	0.41	0.53	0.59	0.38	0.57	0.32	0.67	0.65
	Genotype variance	0.17	14.80	10.37	0.00	0.26	0.58	0.03	0.32	0.00
	Residual variance	0.27	42.56	18.09	0.00	0.86	0.88	0.14	0.32	0.00
	Grand mean	9.13	46.39	35.30	0.13	6.70	6.74	3.71	5.87	0.17
	LSD	0.80	8.40	6.30	0.04	1.14	1.41	0.43	0.93	0.08
	CV (%)	5.65	14.06	12.05	21.13	13.81	13.92	10.24	9.57	28.36
	Replicates	2	2	2	2	2	2	2	2	2
	Genotype significance	0.00	0.02	0.00	0.00	0.03	0.00	0.09	0.00	0.00

NLPP: number of leaves per plant, LL: leaf length, LB: leaf breadth, LAI: leaf area, COL: corm length, COD: corm diameter, CRL: cormel length and CRD: cormel diameter.

3.3. Estimation of Variability. Genotypic and phenotypic variance of all traits studied among taro accessions are presented in Table 5. Genotypic and phenotypic variance ranged from 0.001 to 56.79 and 0.001 to 80.39, respectively. High phenotypic variance values were noted for plant height (80.39), cormel weight (45.83), leaf length (31.11) petiole length (18.42), and days to maturity (41.98). Whereas, high genotypic variance value 56.79, 25.73, 21.84, and 20.31 were noted for plant height, days to maturity, leaf length, and cormel weight, respectively. The lowest genotypic and phenotypic variance were noted for leaf area, yield per plant and corm weight.

Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) values for all traits studied among taro accessions are presented in Table 3. A high percentage of PCV was observed for leaf area (80.67%), followed by corm weight (58.82%), total yield (28.25%), yield per plant (21.11%), and number of suckers per plant (20.66%). Moderate PCV was noted for cormel weight (17.05%), corm diameter (15.56%), petiole length (13.49%), corm length (12.58%), plant height (11.91%), leaf length (11.835%), and leaf breadth (10.663%). The remaining traits showed low PCV. Likewise, a high percentage of GCV were observed for leaf area (76.923%), followed by corm weight (58.824%), total yield (24.118%), and yield per plant (21.108%). Moderate percentage of GCV was noted for the number of suckers per plant (16.950%), yield per plant (14.925%), corm diameter (14.613%), corm length (11.268%), and plant height (10.011%), while other traits showed a low percentage of GCV.

3.4. Estimation of Heritability and Genetic Advance. The estimate of broad-sense heritability for all traits studied among taro accessions is presented in Table 5. Very high heritability values were noted for the number of leaves per plant (87%), corm length (81%), corm diameter (88%), corm weight (89%), and cormel diameter (80%). Moderate high heritability were noted for plant height (71%), leaf length (70%), leaf area (75%), number of suckers per plant (67%), days to maturity (61%), yield per plant (66%), cormel length (65%), and total yield (73%), while petiole length (55%), and cormel weight (44%) were showed moderate heritability.

Genetic advance as percentage of mean (GAM %) values for all traits is presented in Table 3. Genetic advance as percentage of mean ranged from 3.53% to 129.31%. Most studied traits had relatively high genetic advance (>10%). Traits with high GAM include leaf area (129.31%), total yield (36.13%), corm weight (22.48%), corm diameter (24.08%), yield per plant (18.52%), corm length (17.72%), plant height (14.77%), leaf length (14.58%), cormel weight (13.26%), leaf breadth (13.18%), petiole length (12.93%), cormel diameter (12.29%), and cormel length (11.27%). The lowest genetic advances (<10%) were noted for the number of leaves per plant (9.20%) and days to maturity (3.53%).

3.5. Relationships among Quantitative Traits. Phenotypic correlation (r_p) and genotypic correlation (r_g) estimates of all traits studied among taro populations are presented in Table 6. Yield per plant had showed a strong, positive, and highly significant genotypic correlation with plant height (0.99), petiole length (0.99), leaf length (0.85), leaf breadth (0.92), leaf area (0.82), corm length (0.71), corm diameter (0.91), corm weight (0.99), and cormel weight (0.99). Cormel diameter (0.49) and cormel length (0.69) showed a moderate, positive, and highly significant genotypic correlation with yield per plant. Likewise, yield per plant had strong, positive and highly significant phenotypic correlation with plant height (0.72), while petiole length (0.51), leaf length (0.53), leaf breadth (0.54), leaf area (0.51), corm length (0.40), corm diameter (0.56), number of cormels per plant (0.37), cormel diameter (0.34), cormel length (0.47), corm weight (0.68), and cormel weight (0.61) had showed a moderate positive and highly significant phenotypic correlation with yield per plant. But yield per plant showed

Table 5: Estimate of variability for 16 quantitative characters of 100 taro accessions tested at Abakaliki, Nigeria (2018 and 2019).

Traits	σ_g^2	σ_{gl}^2	σ_p^2	σ_e^2	GCV (%)	PCV (%)	H_b^2 (%)	GA	GMA (%)
NLPP	0.290	0.010	0.330	0.170	5.592	5.965	87.879	0.886	9.200
PHT	56.790	18.990	80.390	56.380	10.011	11.910	70.643	11.116	14.766
PL	10.060	7.500	18.420	18.420	9.968	13.488	54.615	4.114	12.928
LL	21.840	0.010	31.110	37.080	9.916	11.835	70.203	6.872	14.581
LB	10.300	0.010	14.620	17.310	8.950	10.663	70.451	4.728	13.183
LAI	0.010	0.010	0.011	0.010	76.923	80.670	91.743	0.168	129.307
NSPP	1.730	0.800	2.570	1.750	16.950	20.659	67.315	1.894	24.406
MD	25.730	15.470	41.980	34.040	2.572	3.286	61.291	6.969	3.534
YPP	0.010	0.010	0.020	0.020	14.925	21.108	50.000	0.124	18.522
COL	0.570	0.010	0.710	0.550	11.268	12.576	80.282	1.187	17.719
COD	0.970	0.010	1.100	0.520	14.613	15.561	88.182	1.623	24.082
CRL	0.210	0.040	0.320	0.370	7.928	9.787	65.625	0.652	11.272
CRD	0.090	0.010	0.120	0.020	8.086	9.337	75.000	0.456	12.290
COW	0.001	0.010	0.001	0.010	58.824	58.824	92.593	0.053	31.413
CRW	20.310	27.400	45.830	47.270	11.349	17.048	44.316	5.265	13.259
TYLD	5.910	3.060	8.110	2.665	24.118	28.252	72.873	3.642	36.132

Genotypic (σ_g^2), genotype by environment (σ_{gl}^2), phenotypic ($\sigma^2 p$) and residual (σ_e^2) components of variances, genotypic (GCV) and phenotypic (PCV) coefficient of variability, broad-sense heritability (H_b^2), expected genetic advance (GA) and genetic advance as a percentage of mean (GAM %), NLPP: number of leaves per plant, PHt: plant height (cm), PL: petiole length (cm), NSPP: number of suckers per plant, MD: days to maturity, YPP: yield per plant (kg), CRW: cormel weight (g) and total yield (tons/ha), leaf length, leaf breadth, leaf area, corm length, corm diameter, cormel length, and cormel diameter.

Table 6: Genetic correlation (below diagonal) and phenotypic correlation (above diagonal) of 13 quantitative traits of 100 taro accessions studied at Abakaliki, Nigeria, in 2018 and 2019.

Traits	NLPP	PHt	PL	LL	LB	LAI	COL	COD	CRD	CRL	COW	CRW	YPP
NLPP	1	−0.46**	−0.47**	−0.33**	−0.31**	−0.30**	−0.14ns	−0.32**	−0.30**	−0.29**	−0.41**	−0.35**	−0.48**
PHt	−0.54**	1	0.71**	0.72**	0.72**	0.70**	0.45**	0.34**	0.29*	0.64**	0.52**	0.55**	0.72**
PL	−0.57**	0.88**	1	0.59**	0.57**	0.57**	0.28*	0.35**	0.26*	0.41**	0.52**	0.42**	0.59**
LL	−0.45**	0.99**	0.76**	1	0.91**	0.98**	0.31**	0.20ns	0.25*	0.55**	0.34**	0.41**	0.53**
LB	−0.47**	0.96**	0.69**	0.99**	1	0.96**	0.37**	0.14ns	0.24*	0.60**	0.34**	0.46**	0.54**
LAI	−0.43**	0.96**	0.72**	0.99**	0.99**	1	0.32**	0.15ns	0.23ns	0.56**	0.32**	0.41**	0.51**
COL	−0.14ns	0.66**	0.51**	0.48**	0.56**	0.48**	1	0.55**	−0.13ns	0.52**	0.54**	0.14ns	0.40**
COD	−0.33**	0.53**	0.57**	0.29*	0.24*	0.23*	0.55**	1	0.23ns	0.10ns	0.79**	0.33**	0.56**
CRD	−0.33**	0.44**	0.42**	0.41**	0.40**	0.36**	−0.10ns	0.29*	1	0.01ns	0.23ns	0.59**	0.34**
CRL	−0.38**	0.92**	0.64**	0.94**	0.97**	0.93**	0.80**	0.19ns	0.05ns	1	0.32**	0.40**	0.47**
COW	−0.45**	0.75**	0.84**	0.51**	0.54**	0.47**	0.55**	0.78**	0.33**	0.52**	1	0.51**	0.68**
CRW	−0.69**	0.99**	0.99**	0.92**	0.99**	0.99**	0.75**	0.99**	0.99**	0.29**	0.99**	1	0.61**
YPP	−0.64**	0.99**	0.99**	0.85**	0.92**	0.82**	0.71**	0.91**	0.49**	0.69**	0.99**	0.99**	1

Note: *, **: significant at probability level of 0.05 ($r = 0.23$) and 0.01 values ($r = 0.29$), respectively. rg = genotypic correlation, rp = phenotypic correlation. NLPP: number of leaves per plant, PHt: plant height (cm), PL: petiole length (cm), LL: leaf length (cm), LB: leaf breadth (cm), LAI: leaf area (square centimetre), COL: corm length (cm), COD: corm diameter (cm), CRD: cormel diameter (cm), CRL: cormel length (cm), COW: corm weight (g), CRW: cormel weight (g).

a moderate, negative, and highly significant correlation with number of leaves per plant ($r_g = 0.64$ and $r_p = 0.48$), respectively.

3.6. Path Coefficient Analysis. The path analysis result at the genotypic level is presented in Table 7. Plant height (1.49) exerted a high positive and direct effect on yield per plant. The indirect effects of plant height on yield per plant via leaf area (0.93), corm weight (0.53), cormel weight (0.21), corm length (0.08), cormel length (0.07), and cormel diameter (0.02) were positive. Leaf area (0.97) exerted a high positive and direct effect on yield per plant. The indirect effects of leaf area on yield per plant via plant height (1.43), corm weight (0.35), and cormel weight (0.21) were positive. Corm weight (0.74) exhibited a high positive and direct effect on yield per plant. Positive and indirect effects were also found via plant height (1.12), leaf area (0.46), corm length (0.07), cormel diameter (0.05), cormel length (0.02), corm weight (0.73), and number of leaves per plant (0.13) on yield per plant.

Cormel weight (0.21) exhibited a positive and direct effect on yield per plant. Positive and indirect effects were also exerted through plant height (1.48), leaf area (0.96), corm length (0.09), cormel diameter (0.02), cormel length (0.04), cormel weight (0.21), and number of leaves per plant (0.09) on yield per plant. However, corm length (0.12) exhibited low positive and direct effect on yield per plant. Positive and indirect effects on yield per plant were also found via leaf area (0.47), corm weight (0.41), cormel weight (0.16), cormel length (0.06), and number of leaves per plant (0.03) on yield per plant. Cormel diameter

Table 7: Estimate of direct (bold diagonal) and indirect effect (off diagonal) at genotypic level of 13 quantitative traits on yield per plant among 100 taro accessions tested at Abakaliki, Nigeria (2018 and 2019).

Traits	NLPP	PHt	PL	LL	LB	LAI	COL	COD	CRD	CRL	COW	CRW	rg
NLPP	**−0.2**	−0.8	0.43	0	0.81	−0.42	−0.02	0.07	−0.02	−0.03	−0.33	−0.15	**−0.64****
PHt	0.11	**1.49**	−0.66	−0.01	−1.65	0.93	0.08	−0.11	0.02	0.07	0.56	0.21	**0.99****
PL	0.11	1.31	**−0.75**	−0.01	−1.19	0.7	0.06	−0.11	0.02	0.05	0.62	0.21	**0.99****
LL	0.09	1.48	−0.57	**−0.01**	−1.72	0.97	0.06	−0.06	0.02	0.07	0.38	0.19	**0.85****
LB	0.09	1.43	−0.54	−0.01	**−1.72**	0.97	0.07	−0.05	0.02	0.07	0.4	0.21	**0.92****
LAI	0.09	1.43	−0.38	−0.01	−1.70	**0.97**	0.06	−0.05	0.02	0.07	0.35	0.21	**0.82****
COL	0.03	0.98	−0.38	0.00	−0.96	0.47	**0.12**	−0.11	−0.01	0.06	0.41	0.16	**0.71****
COD	0.07	0.79	−0.43	0.00	−0.41	0.22	0.07	**−0.20**	0.02	0.01	0.58	0.21	**0.91****
CRD	0.07	0.66	−0.32	0.00	−0.69	0.35	0.00	−0.06	**0.05**	0	0.25	0.21	**0.49****
CRL	0.08	1.37	−0.48	−0.01	−1.67	0.90	0.10	−0.04	0.00	**0.08**	0.39	0.06	**0.69****
COW	0.09	1.12	−0.63	−0.01	−0.93	0.46	0.07	−0.16	0.02	0.04	**0.74**	0.21	**0.99****
CRW	0.13	1.48	−0.74	−0.01	−1.70	0.96	0.09	−0.20	0.05	0.02	0.73	**0.21**	**0.99****

Note: residual = 0.228, *: significant, **: highly significant, NLPP: number of leaves per plant, PHt: plant height (cm), PL: petiole length (cm), LL: leaf length (cm), LB: leaf breadth (cm), LAI: leaf area (square centimetre), COL: corm length (cm), COD: corm diameter (cm), CRD: cormel diameter (cm), CRL: cormel length (cm), COW: corm weight (g), CRW: cormel weight (g), rg: genotypic correlation.

(0.05) showed a low positive and direct effect on yield per plant. A positive and indirect effect was also found via leaf area (0.35), corm weight (0.25), cormel weight (0.21), cormel diameter (0.66), and number of leaves per plant (0.07) on yield per plant. Cormel length (0.08) exhibited a low positive and direct effect on yield per plant. Positive and indirect effects also found through plant height (1.37), leaf area (0.90), corm weight (0.39), cormel weight (0.06), and number of leaves per plant (0.08) on yield per plant.

4. Discussion

4.1. Variability in Quantitative Traits. META combined over seasons in the current study showed highly significant ($P \leq 0.01$) differences among the tested accessions for most traits (Table 3). These significant variations among tested taro accessions for the characters showed the existence of variability to have an effective selection. The variation observed for measured quantitative traits in this study were in agreement with the earlier findings of some researchers [34, 35] who had reported high variability for same traits among 14 taro genotypes studied in India.

PCV and GCV values are considered as high if they are ≥20%, medium 10–20%, and low ≤10% [36]. The present study showed higher PCV than GCV estimates for all characters (Table 5) indicating existence of variability among accessions for the characters studied. Besides, PCV and GCV in this study were close to one another for most characters indicating the environmental effects are small. Higher genotypic variances and coefficients of variation for most of the characters than their corresponding environmental variances are also indicative of the existence of variation at the genotypic level. The present work is in line with the work [34] that reported higher PCV than GCV among 14 taro genotypes studied in Ethiopia [37] and India [38].

4.2. Heritability and Genetic Advance in Quantitative Traits. Estimate of genetic advance is more useful as a selection tool when considered jointly with high genotypic coefficients of variation and high heritability values [39]. In this study, high heritability values with high genetic advance as a percentage of the mean (>10%) were observed for corm weight and leaf area indicating these characters are principally under genetic control (due to the high additive gene effect) and selection for these traits can be achieved through their phenotypic performance. For traits with a high heritability value but a moderate value of genetic advance (such as corm length) careful selection is needed. Similarly, characters with high heritability values but a low value of genetic advance (i.e., number of leaves per plant) may be governed by nonadditive gene action or a high genotype by environmental interaction and used for the development of hybrid varieties. Lower heritability values and GAM (%) implies most of the variations for these traits were environmental, and such traits require more management practice than selection to improve the traits performance. Similar work was reported by many researchers on different crop plants [15, 22, 34, 37–42].

4.3. Associations in Quantitative Traits. In the present study, most traits had a higher genotypic correlation coefficient than phenotypic correlation indicating the association among characters was largely due to genetic variance and the reverse is because of environmental variance [43]. Besides, most characters showed a positive correlation both at the genotypic and phenotypic level with yield per plant. The positive and significant association might be due to the effect of genes, a result of the presence of strong coupling linkage between their genes, or the character may be the result of pleiotropic genes that could control these characters in the same direction [44]. Yet again, from this finding some characters showed negative and significant association among each other. Such negative correlation might be because of the fact that different genes or pleiotropic genes that have dominance on the character may control the character in different direction [44]. Yield per plant was positively and significantly ($P < 0.01$) correlated with most traits indicating these traits are useful for indirectly selecting high-yielding varieties, as selection for yield per se is not effective because of the complex nature of the trait. The present finding is in line with the work [45] that reported a similar scenario.

4.4. Direct Effects of Characters on Yield. Plant height, leaf area, corm weight, and cormel weight exerted a positive direct effect on yield per plant. These characters also observed a strong, positive, and highly significant genotypic correlation with yield per plant. The high correlation coefficient of these characters with yield per plant was largely due to the direct effect. As the direct effect and genotypic correlation between the two traits are positive, it indicates a true relationship. The cause and effect relationships are the products of interacting characters influencing each other [11]. In line with this finding, many researchers reported the same among taro [45, 46] and Tania [15, 45, 46].

5. Conclusion

This study assessed the phenotypic variability of 100 taro accessions collected from five states of Nigeria. The analysis of variance revealed the existence of phenotypic variability among the studied accessions. High genotypic coefficient of variation, heritability, and genetic advance were observed for leaf area, corm diameter, plant height and corm weight. The result of the genotypic correlation coefficient as proved by path analysis also showed plant height, leaf area, corm, and cormel weight have a positive and significant direct effect on yield per plant. Thus, it can be concluded that these characters exert a high positive direct effect on yield t at the genotypic level and hold the highest merits to be selected in breeding programs towards improving yield in taro. The presence of morphological variation between genotypes will give opportunity for studying the accessions at the molecular level and searching of functional alleles that could be used in marker-assisted selection.

Data Availability

The data used to support the findings of this study are available from the corresponding and first authors.

Conflicts of Interest

The authors declare that they no conflicts of interest.

Acknowledgments

This research was funded by the European Union Commission through the MoBreed Project (Intra-Africa Academic Mobility Scheme). We are thankful to all farmers and agriculture extension services in five states of Nigeria. We also thank Ebonyi State University for valuable assistance during accessions collection and field experimentation. Tilahun Wondimu, from the Oromia Agricultural Research Institute, Ethiopia, is a scholar of the "Intra-Africa Academic Mobility Scheme" under the project grant number 2016–2988 on "Enhancing training and research mobility for novel crops breeding in Africa (MoBreed)" funded by the Education, Audiovisual, and Culture Executive Agency (EACEA) of the European Commission. The project provided a scholarship for academic training and research mobility and a research grant to the first author to complete a PhD degree at Ebonyi State University (Nigeria).

References

[1] P. J. Matthews, "An introduction to the history of taro as a food," *The Global Diversity of Taro*, vol. 6, 2010.

[2] H. Chaïr, R. Traore, M. Duval et al., "Genetic diversification and dispersal of taro (*Colocasia esculenta* (L.) Schott)," *PLoS One*, vol. 11, no. 6, Article ID e0157712, 2016.

[3] S. C. Miyasaka, M. R. Bellinger, M. B. Kantar et al., *Genetic Diversity in Taro (Colocasia Esculenta) Genetic Diversity In Horticultural Plants*, Springer, Berlin, Germany, 2019.

[4] C. O. Amadi, J. Onyeka, G. O. Chukwu, and B. C. Okoye, "Hybridization and seed germination of taro (*Colocasia esculenta*) in Nigeria," *Journal of Crop Improvement*, vol. 29, no. 1, pp. 106–116, 2015.

[5] A. O. Ubalua, F. Ewa, and O. D. Okeagu, "Potentials and challenges of sustainable taro (*Colocasia esculenta*) production in Nigeria," *Journal of Applied Biology and Biotechnology*, vol. 4, no. 01, pp. 053–059, 2016.

[6] F. Faostat, "Crop statistics," 2021, https://www.fao.org/faostat/en/#data/QCL.

[7] M. Temesgen and N. Retta, "Nutritional potential, health and food security benefits of Taro *Colocasia esculenta* (L.): a review," *Food Science and Quality Management*, vol. 36, 2015.

[8] S. Abdulrahman, A. Abdullahi, and B. Muhammad, "Analysis of constraints to cocoyam production in kaduna state, Nigeria," *Journal of Scientific Research and Reports*, vol. 6, no. 3, pp. 210–216, 2015.

[9] N. Mgbedike, U. Celestine, O. Josephine, and A. Cletus, "Strategies for improving cocoyam production among farmers in anambra state, nigeria," *Journal of Education and General Studies*, vol. 1, 2017.

[10] N. C. Stoskopf, D. T. Tomes, B. R. Christie, and B. R. Christie, *Plant Breeding: Theory and Practice*, CRC Press, Boca Raton, FL, USA, 2019.

[11] D. Mukherjee, M. A. Roquib, N. D. Das, and S. Mukherjee, "A study on genetic variability, character association and path Co-efficient analysis on morphological and yield attributing characters of taro [*Colocasia esculenta* (L.) Schott]," *American Journal of Plant Sciences*, vol. 7, no. 03, pp. 479–488, 2016.

[12] J. B. Holland, W. E. Nyquist, and C. T. Cervantes-Martínez, "Estimating and interpreting heritability for plant breeding: an update," *Plant Breeding Reviews*, vol. 22, 2003.

[13] A. Hallauer and J. Miranda, *Quantitative Genetics in Maize Breeding*, Iowa State University Digital Press, Ames, IA, USA, 2nd edition, 1988.

[14] D. R. Dewey and K. Lu, "A correlation and path-coefficient analysis of components of crested wheatgrass seed production 1," *Agronomy Journal*, vol. 51, no. 9, pp. 515–518, 1959.

[15] S. Fantaw, A. Nebiyu, and T. Mulualem, "Estimates of genetic components for yield and yield related traits of Tannia (*Xanthosoma sagittifolium* (L.) Schott) genotypes at Jimma, Southwest Ethiopia," *African Journal of Agricultural Research*, vol. 10, no. 1, pp. 23–30, 2014.

[16] K. Paul, M. Bari, S. Islam, and S. Debnath, "Genotypic and phenotypic correlation coefficient studies for taro (*Colocasia esculenta* (L.) Schott.)," *Bangladesh Journal of Botany*, vol. 43, no. 1, pp. 113–117, 2014.

[17] R. Yadav, N. Rai, D. Yadav, and S. Sanwal, "Correlation, pathcoefficient and genetic diversity pattern in Colocasia (*Colocasia fsculfnta*) genotypes," *Vegetable Science*, vol. 34, no. 2, pp. 153–156, 2007.

[18] V. Pandey, M. Ojha, and P. Singh, "Genetic variability and correlation studies in arvi (*Colocasia esculenta* L. var. Antiquarum)," *Vegetable Science*, vol. 36, no. 3s, pp. 431–434, 2009.

[19] G. E. Nwofia, Q. U. Okwu, and E. U. Mbah, “Response of thirteen tannia accessions to variations in planting date in the humid tropics,” *Open Agriculture*, vol. 4, no. 1, pp. 213–226, 2019.

[20] E. Tsegaye, E. V. Devakara Sastry, and N. Dechassa, “Correlation and path analysis in sweet potato and their implications for clonal selection,” *Journal of Agronomy*, vol. 5, no. 3, pp. 391–395, 2006.

[21] P. L. Tirkey, J. Singh, P. Chaurasia, and D. Sarnaik, “Character association and path coefficient studies in sweet potato (*Ipomoea batatas* (L.) Lam.) genotypes,” *Journal of Plant Development Sciences*, vol. 3, no. 1, pp. 137–143, 2011.

[22] W. Tilahun, A. Sentayehu, A. Amsalu, and G. Weyessa, “Variability and association of quantitative traits in anchote (*Coccinia abyssinica* (Lam.) Cogn.) in Ethiopia,” *International Journal of Plant Breeding and Genetics*, vol. 8, no. 1, pp. 1–12, 2014.

[23] T. W. Fufa, “Genetic variability and association in yield and yield related traits in anchote [Coccinia abyssinica (LAM.) COGN],” unpublished Msc thesis, Jimma University, Jimma, Ethiopia, 2012.

[24] F. Yates, “A new method of arranging variety trials involving a large number of varieties,” *The Journal of Agricultural Science*, vol. 26, no. 3, pp. 424–455, 1936.

[25] P. Ogbonna, K. Orji, N. Nweze, and P. Opata, “Effect of planting space on plant population at harvest and tuber yield in taro (*Colocasia esculenta* L),” *African Journal of Agricultural Research*, vol. 10, no. 5, pp. 308–316, 2015.

[26] R. Tumuhimbise, H. Talwana, D. Osiru et al., “Growth and development of wetland-grown taro under different plant populations and seedbed types in Uganda,” *African Crop Science Journal*, vol. 17, no. 1, 2010.

[27] A. Ivančič and V. Lebot, *Descriptors for Taro:(Colocasia Esculenta)*, Bioversity International, Rome, Italy, 1999.

[28] D. Arend, *Minitab 17–Statistical Software*, Minitab. Inc, State College, PA, USA, 2010.

[29] G. W. Burton and E. H. DeVane, “Estimating heritability in tall fescue (Festuca arundinacea) from replicated clonal material,” *Agronomy Journal*, vol. 45, no. 10, pp. 478–481, 1953.

[30] R. Singh, *Biometrical Methods in Quantitative Genetic Analysis*, Kalyani Publishers, New Delhi, India, 1985.

[31] R. W. Allard, *Principles of Plant Breeding*, vol. 13, John Wiley and Sons, Hoboken, NJ, USA, 1999.

[32] P. Miller, J. Williams Jr, H. Robinson, and R. Comstock, “Estimates of genotypic and environmental variances and covariances in upland cotton and their implications in selection 1,” *Agronomy Journal*, vol. 50, no. 3, pp. 126–131, 1958.

[33] G. Alvarado, M. López, M. Vargas et al., *META-R (Multi Environment Trial Analysis with R for Windows)*, International Maize and Wheat Improvement Center (CIMMYT), Texcoco, Mexico, 2015.

[34] V. Choudhary, P. S. Kumar, J. George, M. Kanwat, and R. Saravanan, “Genetic variability and character association in taro (*Colocasia esculenta* (L.) Schott.) under Mid-Hills of Arunachal Pradesh,” *Journal of Root Crops*, vol. 37, no. 2, p. 155, 2013.

[35] K. Paul and M. Bari, “Estimates of genetic components for yield and related traits in Cocoyam,” *The Agriculturists*, vol. 10, no. 2, pp. 127–132, 2012.

[36] S. Deshmukh, M. Basu, and P. Reddy, “Genetic variability, character association and path coefficients of quantitative traits in Virginia bunch varieties of groundnut,” *Indian Journal of Agricultural Sciences*, vol. 56, no. 12, pp. 816–821, 1986.

[37] T. Mulualem and G. WeldeMichael, “Study on genotypic variability estimates and interrelation ship of agronomic traits for selection of taro (*Colocasia esculenta* (L.) Schott) in Ethiopia,” *Sky Journal of Agricultural Research*, vol. 2, no. 11, pp. 132–137, 2013.

[38] M. Sachan, “Characterization and genetic variability in taro,” *Journal of Hill Agriculture*, vol. 8, no. 1, pp. 17–20, 2017.

[39] H. W. Johnson, H. Robinson, and R. E. Comstock, “Genotypic and phenotypic correlations in soybeans and their implications in selection 1,” *Agronomy Journal*, vol. 47, no. 10, pp. 477–483, 1955.

[40] D. Cheema, H. Singh, A. Dhatt, A. Sidhu, and N. Garg, “Studies on genetic variability and correlation for yield and quality traits in arvi [colocasia esculenta (L.) Schott]. Paper presented at the I international conference on indigenous vegetables and legumes,” *Prospectus for Fighting Poverty, Hunger and Malnutrition*, vol. 752, 2006.

[41] K. Paul and M. Miah, “Genetic variability, correlation and path coefficient studies in elephant foot yam (*Amorphophallus campanulatus* Bl.),” *Journal of Scientific Research*, vol. 5, no. 2, pp. 371–381, 2013.

[42] F. Solomon, N. Amsalu, and M. Tewodros, “Estimates of genetic components for yield and yield related traits of Tannia (*Xanthosoma sagittifolium* (L.) Schott) genotypes at Jimma, Southwest Ethiopia,” *African Journal of Agricultural Research*, vol. 10, no. 1, pp. 23–30, 2015.

[43] A. A. A. El-Mohsen, S. R. A. Hegazy, and M. H. Taha, “Genotypic and phenotypic interrelationships among yield and yield components in Egyptian bread wheat genotypes,” *Journal of Plant Breeding and Crop Science*, vol. 4, no. 1, pp. 9–16, 2012.

[44] M. Kearsey and H. Pooni, *The Genetical Analysis of Quantitative Traits*, Chapman and Hall, New York, NY, USA, 1996.

[45] K. Paul and M. Bari, “Studies on direct and indirect effects of different plant characters on yield of taro (*Colocasia esculenta* L. Schott) Var. Antiquorum,” *The Agriculturists*, vol. 9, no. 1-2, pp. 89–98, 1970.

[46] K. Paul, M. Bari, and S. Debnath, “Correlation and path coefficient studies of yield and yield attributing characters in panikachu, *Colocasia esculenta* (L.) Schott,” *Journal of Bangladesh Academy of Sciences*, vol. 37, no. 2, pp. 131–137, 2014.