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Research Article

Evaluation of Fonio (*Digitaria exilis*) Varieties for Improved Agronomic Traits in the Guinea and Sudan Savannah Agroecological Zones of Ghana

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Background and Objective. Fonio is categorized as one of the neglected, under-utilized, or orphan crops of West Africa due to its poor yields and inadequate research information for its improvement and use. The need to improve the agronomic traits of this crop and also explore the possibility of growing it in different agroecologies has been felt over the years. A study was therefore conducted during the 2019 cropping season to determine variations among Fonio accessions and also assess the influence of genotype/accession, location, and genotype x location on growth and total grain yield of Fonio. *Materials and Methods*. Five accessions of the crop were planted in two locations in northern Ghana (Guinea and Sudan savannah) and replicated three times using factorial experiment in randomized complete block design. *Results*. The study indicated significant ($P < 0.05$) variations among accessions for most of the attributes measured. Accession OUSAI with 75 days to physiological maturity (DPHM) recorded highest grain yield of 1015.10 kg/ha, and NFAS4 with 98 DPHM recorded the least grain yield of 713.23 kg/ha. The most lodged accession was OUAS1 which recorded 65% lodging of its total plant population, and the least lodged accessions (NFAS4 and EYAS5) recorded about 10% lodging each. *Conclusion*. The results demonstrated a significant ($P < 0.05$) diversity among the accessions used in the study and influence of genotype/accession x location on growth and total grain yield of Fonio.

1. Introduction

Fonio (*Digitaria exilis* Stapf) is an indigenous cereal of the Saharan Africa [1, 2]. It is also known as acha, hungry rice, or petit mil. Fonio belongs to the class Monocotyledoneae, order Dactyloctenium, and the grass family *Poaceae* [3]. The genus *Digitaria* has two known cultivated species: *D. exilis* Stapf and *D. iburua* Stapf [1]. *D. exilis* is widely grown throughout West Africa, while *D. Iburua* is reported to be restricted to Nigeria and the northern parts of Benin and Togo [4]. Fonio yields well on poor soils with low rainfall [5]. The crop is now grown as a staple, major complementary cereal, or cash crop in parts of the West African Savannah. The seed is richer in protein than other known cereals in West Africa. The gel filtration profiles of the albumin, globulin, prolamin, and glutelin fractions of Fonio show a similar number of peaks to durum wheat [6].

According to [1], Fonio was known as *Kabuga* in the Northern Territories of the then Gold Coast (now Ghana), and among the large *Dagomba*-speaking group as *Kabega*. Today, most members of the ethnic groupings in that area do not know the crop. In Ghana, production of Fonio has become limited to the Yendi, Saboba, Chereponi, Zabzugu, and Tatale-Sanguli administrative districts. The crop is mainly popular among the Dagomba, Anufo, Bassare, Kabre, and Konkomba peoples. The grain has good nutrition quality and attractive flavor and expands well. The grain is used in preparing a variety of food items such as porridge, jollof, and tuo-zafi, and for brewing beer. The straw and chaff are fed to animals. It is also used to reinforce mud for building and as thatch for roofing. Considering the risk of losing the crop from the farming systems of the country, and the fact that it has great potential in meeting food and nutritional security, there is the need to assemble the remaining landraces of the crop for conservation and future improvement.

Food insecurity remains one of the main problems of modern Africa, where famine continues to threaten peace and stability in the agrarian continent. This appears to be the price modern Africa must pay for forsaking most of its native crops (of which Fonio, *Digitaria exilis*, *and iburua* are members) that sustained Africa for thousands of years [7, 8]. Notwithstanding the importance of Fonio in traditional farming system, research strives toward its improvement remaining insignificant. Acha (Fonio) faces challenges like inappropriate crop husbandry and lacks improved varieties which considerably affects its productivity [9]. Inadequate attention by researchers and policy makers has resulted to under-exploitation of its genetic potential. Fonio is a small-scale farmers' crop with numerous nutritional properties, and little inputs in its cultivation yield quite a substantial income and food to many households, thereby giving possible developmental options to the rural poor. The crop is crucial to food security, particularly in seasons of hunger and critical periods when food reserves in the households are low [10]. Research findings are needed for identification of variations among landraces and available germplasm for improvement of Fonio. The traditional husbandry practices such as broadcasting seeds at unspecified rates depending on availability and farmers' proficiency often lead to low yields and therefore need improvement [8]. Genetic study is seen as underlying factor toward usage of hereditary material for crop improvement. Basic understanding of the diversity existing among any genetic material and its phylogenetic linkage to the wild relations serves as vital platform for drafting of any crop improvement program as it provides scientists with needed information to draw conclusions [11]. This study was therefore conducted to determine variations among Fonio accessions and also assess the influence of genotype/accession, location, and genotype x location on growth and total grain yield of Fonio.

2. Materials and Methods

2.1. Experimental Site. The experiment was conducted at Paga in the Kassena Nankana west district of Upper East Region of Ghana, in the Sudan savannah agroecology (SSAE), and Nyankpala ($9^0 25^1 41^{11}$N, $0^0 58^1$ 042^{11}W), Northern Region of Ghana in the Guinea savannah agroecology (GSAE). Rainfall was erratic in both locations during the study period. Annual mean precipitation and daily average temperature during the trial period (2019) were 940 mm and 27.7°C, and 1149 mm and 26.5°C for SSAE and GSAE, respectively.

These agroecological zones are characterized by unimodal tropical monsoon with single cropping season. This single cropping season is constrained by the harmattan period which commence in December and ends in April. The soils of Ghana are developed from highly weathered parent material. Percent organic matter and nitrogen are particularly low in the savannah and transition zones. Alluvial and eroded shallow soils are common to the Savannah agroecological zones of Ghana [12]. Most soils in Ghana are inherently infertile (Table 1).

2.2. Experimental Materials. Five Fonio accessions were used: Ouagadougou (OUAS1), Eyadema (EYAS5), Namba (NAAS2), Kpenteke (KPAS3), and Nfonikpa (NFAS4). OUAS1 and EYAS5 are the most commonly cultivated and high yielding accessions obtained from Burkina Faso and Togo, respectively. The accessions are named after the capital city of Burkina Faso (Ouagadougou) and the first African president of the republic of Togo (Gnassingbe Eyadema) by Fonio farmers in these countries. The other three accessions Namba (NAAS2), Kpenteke (KPAS3), and Nfonikpa (NFAS4) are commonly cultivated accessions in Ghana by the Konkombas and Anufos (Chokosis) people in Saboba, Chereponi, and Tatale districts of the republic of Ghana [14]. Therefore, the names of the accessions are in Konkomba and Chokosi languages.

2.3. Field Preparation, Experimental Design, and Planting. The fields from both locations were ploughed and harrowed prior to planting. The experiment was a 2×5 factorial experiment laid out in randomized complete block design replicated three times. Seed beds of $4\,m^2$ with 0.75 m between beds and 1 m between replications were used. Sowing was done on 25 and 31 July 2019 in the Guinea and Sudan savannah agroecologies, respectively, in furrows of 0.25 m apart on each bed with farrow depth of 0.003 m. Seed rate of 25 kg/ha was used, and the seeds were gently spread in the furrows and covered with a thin film of soil.

2.4. Data Collection. Data were collected on number of leaves at reproductive maturity, basal leaf sheath color at 4WAP and spikelet color, number of racemes per plant, plant height at maturity, days to physiological maturity, number of tillers per plant, days to 50% flowering, lodging, number of panicles per stalk, leaf area, 1000-seed weight, and total grain yield.

2.5. Data Analysis. Data collected were subjected to analysis of variance (ANOVA) using Genstat statistical package edition 12. UPGMA cluster analysis, Pearson's correlation coefficient (PCC), and principal component analysis (PCA) were also computed using Minitab. The means were separated using LSD (5%).

3. Results

3.1. Effect of Accession on Growth Parameters

3.1.1. Shoot Growth, Leaf Development, and Lodging Phenomenon in Fonio. The data for the two locations were combined and analyzed, and the results indicated that accession NAAS2 produced the lowest number of 7 leaves,

Table 1: Average soil fertility status of seven administrative regions of Ghana.

Region	Soil pH	OM (%)	Total N (%)	Available P (mg/kg soil)	Available Ca (mg/kg soil)
Greater Accra	5.40–8.20	0.10–1.70	0.05–0.90	0.80–144.00	14.00–147.00
Western	3.8.0–7.10	1.00–5.70	1.0–7.50	0.4–11.30	28–420.00
Ashanti	4.3–7.80	1.50–3.00	0.10–0.30	0.10–12.00	50.00–100.00
Brong Ahafo	3.50–6.70	0.30–1.70	No data	0.1–64.30	16–140.00
Northern	4.50–6.70	0.60–2.00	0.02–0.05	2.50–10.00	45.00–90.00
Upper West	6.00–6.80	0.50–1.30	0.01–0.07	2.00–7.40	52.00–152.00
Upper East	5.10.0–6.80	1.10–2.50	0.06–0.14	1.80–14.80	44–152.00

Source: Wood [13]

while NFAS4 and EYAS5 produced the highest number of 10 leaves (Table 2). There were significant differences ($P \leq 0.05$) between NAAS2 on the one hand, and NFAS4 and EYAS5 on the other hand with respect to leave production. NFAS4 recorded the highest plant height of 93.79 cm, while KPAS3 recorded the least plant height of 72.66 cm. There was a significant difference ($P \leq 0.05$) between NFAS4 and KPAS3 for shoot production. Leaf area development was highest among NFAS4 (8.28 cm^2), but this was not significantly different ($P > 0.05$) from that of EYAS5 which recorded a leaf area of 8.23 cm^2. NFAS4 produced the highest number of tillers per plant (10 tillers), while KPAS3 and NAAS2 produced the lowest number of 7 tillers per plant. Accession OUAS1 was the most lodged and recorded a score of 4.75 for lodging representing about 65% of its total plant population (Table 2). Two accessions (NFAS4 and EYAS5) scored least lodging means of 2.75 and 2.88, respectively, representing about 10% of its total plant population each. There was no statistical difference ($P > 0.05$) between locations for lodging in Fonio, so was the interaction impact of accession and location on lodging (Table 3).

3.1.2. Flower Production and Physiological Maturity in Fonio. The varieties EYAS5 and NFAS4 took a maximum of 64 days to flower, while OUAS1 took a minimum of 45 days to flower (Table 4). There was a significant difference ($P \leq 0.05$) in terms of the number of days to flowering between the varieties OUAS1 on the one hand, and EYAS5 and NFAS4 on the other hand. EYAS5 and NFAS4 took a maximum of 98 days to attain physiological maturity, and these were significantly different from all the other three varieties with respect to days to physiological maturity.

3.2. Effect of Accession on Grain Yield and Yield Components. OUAS1 recorded the highest grain yield of 1015.10 kg/ha, followed by KPAS3 with 920.62 kg/ha, while NFAS4 recorded the least grain yield of 713.23 kg/ha (Table 4). The grain yield produced by OUAS1 (1015.10 kg/ha) was however not significantly different ($P \geq 0.05$) from that of KPAS3 (920.62 kg/ha), but significantly ($P > 0.05$) differed from EYAS5 and NFAS4 (Table 4). For grain weight, KPAS3 recorded the highest of 53 g, and this was significantly ($P \leq 0.05$) different from the other four accessions. Significant ($P \leq 0.001$) variation was also observed among accessions for panicle number per plant (Table 3). Accession NFAS4 recorded the highest average number of panicles per plant (10.54), while OUAS1 recorded the lowest of 6.79 panicles per plant (Table 4).

3.3. Effect of Location on Growth Parameters

3.3.1. Effect of Location on Shoot Growth, Leaf Development, and Lodging Phenomenon in Fonio. All the accessions grown in the Guinea savannah agroecology (GSAE) recorded the least average number of 8 leaves, while those accessions grown in the Sudan savannah agroecology (SSAE) recorded the highest average number of 9 leaves (Table 5). There was a significant difference ($P \leq 0.05$) between the GSAE and the SSAE with respect to leaf production.

For leaf area development, there was a significant difference ($P \leq 0.05$) between the two locations. The GSAE recorded the lowest average leaf area of 5.21 cm^2, while the SSAE recorded the highest average leaf area of 6.12 cm^2. The SSAE also performed relatively better in terms of shoot growth, recording the highest average plant height 91.11 cm, while the GSAE recorded the lowest average plant height of 74.10 cm (Table 5).

3.3.2. Effect of Location on Flower Production and Physiological Maturity. Both the GSAE and the SSAE took the same average number of days (54.20) to flower (Table 5). However, the GSAE recorded the lowest average panicle number per plant (4.12 panicles) as compared to the SSAE which recorded highest average panicle number per plant (11.92 panicles). There was therefore a significant difference ($P \leq 0.05$) between the two agroecologies with respect to panicle production (Table 5). For days to attain physiological maturity, the two agroecologies (GSAE and SSAE) took the same average number of days (86.20 days) to attain physiological maturity. There was therefore no significant difference ($P > 0.05$) between the two locations with respect to number of days to attain physiological maturity.

3.4. Effect of Location on Grain Yield and Yield Components. All the accessions grown in GSAE recorded a maximum of 913.25 kg//ha average grain yield, while the accessions grown in the SSAE recorded a minimum of 788.42 kg/ha average grain yield (Table 5). There was a significant difference ($P \leq 0.05$) between the two agroecologies with respect to grain production (Table 5). Plants grown at GSAE recorded the highest 1000 grain weight (0.52 g), while plants grown

Table 2: Effect of accession on shoot growth, leaf development, and lodging phenomenon in Fonio.

Accession	Agronomic trait					
	Plant height (cm)	Tiller number per plant (TNP)	Leaf area (cm^2)	Number of leaves per plant (NLP)	Basal leaf sheath color (BLSC)	Lodging in Fonio (LG)
EYAS5	92.94	9.26	8.23	10.07	2.00	2.88
KPAS3	72.66	7.27	4.04	7.58	3.00	3.79
NAAS2	76.75	7.44	3.99	7.40	2.17	4.04
NFAS4	93.79	10.18	8.28	10.31	2.00	2.75
OUAS1	76.89	7.69	3.80	7.40	3.00	4.75
Means	82.61	8.37	5.67	8.55	2.43	3.64
SEM	1.794	0.195	0.222	0.235	0.037	0.092
LSD (0.05)	5.049	0.549	0.624	0.661	0.105	0.139
CV (%)	10.6	11.4	19.2	13.5	7.5	6.6

SEM = Standard error of means.

Table 3: Analysis of variance for yield and yield components as influenced by accession, location, and accession x location interaction during the 2019 cropping season.

Source of variation	df	F probability (0.05)							
		Number of leaves per plant	Plant height (cm)	Tiller number per plant	Leaf area (cm^2)	1000 grain weight (g)	Grain yield (kg/ha)	Panicle number per plant (PNP)	Lodging in Fonio (LG)
Accession	4	≤0.001	≤0.001	≤0.001	≤0.001	≤0.048	≤0.003	≤0.001	≤0.027
Location	1	≤0.001	≤0.001	≤0.001	≤0.001	≤0.433	≤0.027	≤0.001	≤1.000
Accession x location	4	≤0.651	≤0.001	≤0.001	≤0.001	≤1.000	≤0.150	≤0.013	≤0.150
Residual	80								
Total	119								
SEM		0.235	1.794	0.195	0.222	0.007	62.123	0.185	≤0.001
CV (%)		13.50	10.60	11.4	19.20	7.00	35.80	11.05	10.50

SEM = Standard error of means.

Table 4: Effect of accession on yield and yield components.

Accession	Agronomic trait					
	Grain yield (kg/ha)	1000 grain weight (g)	Panicle number per plant (PNP)	Days to physiological maturity	Days to 50% flowering	Number racemes per panicle (NRP)
EYAS5	720.73	0.51	8.21	98.00	64.00	3.38
KPAS3	920.62	0.53	7.50	80.00	49.00	3.10
NAAS2	884.48	0.52	7.04	80.00	49.00	2.88
NFAS4	713.23	0.51	10.54	98.00	64.00	3.17
OUAS1	1015.10	0.51	6.79	75.00	45.00	3.28
Means	850.83	0.52	8.02	86.20	54.20	3.16
SEM	62.123	0.007	0.444	5.000	7.000	0.082
LSD (0.05)	174.838	0.029	1.250	9.500	8.400	0.231
CV (%)	35.8	7.0	27.1	21.0	20.0	12.7

SEM = Standard error of means.

from SSAE recorded the lowest grain weight of 0.51 g (Table 5). There was a significant difference ($P \leq 0.05$) between the two agroecologies with respect to grain weight. Location effect was significant ($P \leq 0.001$) for panicle production (Table 3). The highest mean number of panicles per plant (11.92) was recorded by the SSAE, while the lowest mean number of panicles per plant (4.12) was recorded by the GSAE.

Table 5: Effect of location on growth and yield parameters.

Agronomic trait	Location		Means	SEM	LSD (0.05)
	GSAE	SSAE			
Grain yield (kg/ha)	913.25	788.42	850.835	39.290	110.577
Leaf area (cm^2)	5.21	6.12	5.665	0.140	0.395
Number of leaves per plant	8.01	9.09	8.550	0.149	0.418
Plant height (cm)	74.10	91.11	82.605	1.135	3.193
Panicle number per plant (PNP)	4.12	11.92	8.020	0.562	0.790
Basal leaf sheath color (BLSC)	2.47	2.40	2.435	0.024	0.066
Number racemes per panicle (NRP)	3.12	3.20	3.160	0.052	0.146
Days to 50% flowering	54.20	54.20	54.200	≤0.001	≤0.001
1000 grain weight (g)	0.52	0.51	0.515	0.005	0.013
Days to physiological maturity	86.20	86.20	86.200	≤0.001	≤0.001
Tiller number per plant (TNP)	7.53	9.20	8.365	0.123	0.347
Lodging in Fonio (LG)	3.63	3.65	3.64	≤0.001	0.030

GSAE = Guinea savannah agroecology; SSAE = Sudan savannah agroecology; SEM = standard error of means.

3.5. *Effect of Accession X Location Interaction on Growth and Yield Parameters*

3.5.1. Effect of Accession X Location Interaction on Growth Parameters. There was a significant accession X location interaction on various growth parameters (Table 3). Accession EYAS5 performed better in terms of shoot length and tiller number production in both locations as compared to the other four accessions (Table 6). NFAS4 recorded the highest number of 11 leaves in the SSAE and the lowest of 10 leaves for the GSAE. Leaf production was generally higher among NFAS4 and EYAS5 grown in both locations as compared to the other three accessions. In general, leaf production was significantly higher ($P \leq 0.05$) for all accessions grown in the SSAE as compared to those that were grown in the GSAE. NFAS4 recorded the highest leaf area 8.76 cm^2 for the GSAE, while the lowest leaf area of 7.81 cm^2 was recorded for the SSAE. The EYAS5 also produced relatively broader leaves in the GSAE as compared to that of the SSAE (Table 6). On the contrary, accessions OUAS1, KPAS3, and NAAS2 produced relatively broader leaves in the SSAE as compared to that of the GSAE.

3.5.2. Effect of Accession X Location Interaction on Yield and Yield Components. There was a significant ($P \leq 0.05$) interaction between accession and location for panicle number per plant, but there was however no significant ($P > 0.05$) accession x location interaction for grain yield and 1000 grain weight (Table 5). Accessions grown in GSAE recorded a maximum mean grain yield of 913.25 kg//ha, while the accessions grown in the SSAE recorded a minimum mean grain yield of 788.42 kg/ha (Table 7). There was a significant difference ($P \leq 0.05$) between the two agroecologies with respect to grain production (Table 7). OUAS1 produced the highest grain yield (1090.42 kg/ha) in the SSAE as compared to that of the GSAE (939.79 kg/ha). However, there was no significant difference between the two locations for grain yield. Grain yield was generally higher among accessions EYAS5 (823.33 kg/ha), KPAS3 (998.96 kg/ha), NAAS2 (951.25 kg/ha), and NFAS4 (852.92 kg/ha) grown in the GSAE as compared to the SSAE which recorded the lowest grain yield of 618.12 kg/ha, 842.29 kg/ha, 817.71 kg/ha, and 573.54 kg/ha, respectively.

The GSAE generally produced higher grain weight among all the accessions relative to the grain weights produced in the SSAE (Table 7). Panicle number produced was also higher for all accession grown in the SSAE as compared to the GSAE. The highest panicle number of 11.75 was produced by EYAS5 within the SSAE, while the lowest of 4.67 panicles was produced in the GSAE.

3.6. Principal Component of Yield (CP) Analysis. Principal component analysis showed that the first four PCs had eigenvalues > 1 contributed 99% of the total variance. The major contributors to the first two components were total grain yield, tiller number per plant, plant height, days to physiological maturity, number of racemes, and many others as captured in Table 8.

3.7. Pearson's Correlation Coefficient and Cluster Analysis. Most of the traits exhibited positive and significant ($P \leq 0.05$) correlation with each other. However, few traits exhibited insignificant ($P > 0.05$) correlation and others were negatively correlated (Table 9). Grain yield had positive and highly significant correlation with stem color, basal leaf sheath, total leaf area, days to 50% flowering, and days to maturity. It also had positive and significant correlation with number of tillers per plant and number of racemes per panicle.

The dendrogram below used correlation between variables to identify similarities between the accessions. The five Fonio accessions were grouped into three clusters, the OUAS1 cluster, NAAS2 and KPAS3 clusters, and NFAS4 and EYAS5 clusters. Also, all the accessions form one cluster group at about 99.08% similarity (Figure 1). The wide intercluster distances observed showed that there are less similarities between clusters. The OUAS1 cluster, and NFAS4 and EYAS5 clusters took more than half of the phenogram (Figure 1), and this reveals how wide and heterogeneous the accessions are between clusters. However, within cluster distances were very narrow and recording above 99% similarity coefficient and depicting less intra-cluster diversity.

Table 6: Influence of accession X location interaction on growth parameters.

Accession	Plant height (cm)		Tiller number per plant (TNP)		Leaf area (cm^2)		Number of leaves per plant		Basal leaf sheath color (BLSC)	
	GSAE	SSAE	GSAE	SSAE	GSAE	SSAE	GSAE	SSAE	GSAE	SSAE
EYAS5	92.35	93.54	9.52	8.99	8.58	7.88	9.85	10.29	2.00	2.00
KPAS3	63.35	81.96	6.37	8.16	3.08	4.99	6.94	8.22	3.00	3.00
NAAS2	64.29	89.22	6.31	8.56	2.89	5.09	6.81	7.98	2.33	2.00
NFAS4	87.67	99.92	8.71	11.65	8.76	7.81	9.62	11.00	2.00	2.00
OUAS1	62.83	90.94	6.75	8.62	2.74	4.85	6.83	7.97	3.00	3.00
Means	74.10	91.12	7.53	9.20	5.21	6.12	8.01	9.09	2.47	2.40
SEM	2.537		0.276		0.314		0.332		0.053	
LSD (0.05)	7.141		0.777		0.882		0.935		0.148	

SEM = Standard error of means.

Table 7: Influence of accession X location interaction on yield and yield components.

Accession	Grain yield (kg/ha)		1000 grain weight (g)		Panicle number per plant (PNP)		Days to physiological maturity		Days to 50% flowering		Number racemes per panicle (NRP)	
	GSAE	SSAE	GSAE	SSAE	GSAE	SSAE	GSAE	SSAE	GSAE	SSAE	GSAE	SSAE
EYAS5	823.33	618.12	0.52	0.51	4.67	11.75	98.00	98.00	64.00	64.00	3.38	3.38
KPAS3	998.96	842.29	0.54	0.53	3.00	12.00	80.00	80.00	49.00	49.00	3.02	3.18
NAAS2	951.25	817.71	0.53	0.52	2.50	11.58	80.00	80.00	49.00	49.00	2.83	2.92
NFAS4	852.92	573.54	0.51	0.50	6.25	14.83	98.00	98.00	64.00	64.00	3.17	3.17
OUAS1	939.79	1090.42	0.51	0.50	4.17	9.42	75.00	75.00	45.00	45.00	3.21	3.36
Means	913.25	788.42	0.52	0.51	4.12	11.92	86.20	86.20	54.20	54.20	3.12	3.20
SEM	87.855		0.010		0.628		≤0.001		≤0.001		0.116	
LSD (0.05)	247.258		0.029		1.768		≤0.001		≤0.001		0.326	

SEM = Standard error of means.

Table 8: Principal components analysis of agro-morphological traits of Fonio.

PC	Eigenvalue	Total (%) variance	PHM	NRP	RL	TNP	PNP	NLP	LA	DPHM	GY (kg/ha)	1000 GW (g)	BLSC	SKC
PC1	11.7	65	0.259	−0.09	−0.27	0.245	0.235	0.265	0.139	0.275	0.261	−0.18	−0.21	−0.03
PC2	3.6	20	0.161	0.412	0.036	0.049	0.077	0.12	0.402	−0.04	−0.15	0.367	−0.12	0.359
PC3	1.35	7.5	−0.03	−0.3	0.084	0.21	0.239	−0.09	−0.15	−0.07	0.042	−0.05	−0.22	0.518
PC4	1.17	6.5	−0.09	0.06	−0.14	0.373	0.406	0.084	0.025	0.014	0.075	−0	0.549	−0.09

PNP = panicle number per plant; BLSC = basal leaf sheath color, PHM = plant height at maturity; NLP = number of leaves per plant; LA = leaf area; GY = grain yield; 1000 GW = thousand grain weight; SKC = spikelet color; RL = root lodging; DPHM = days to physiological maturity; TNP = tiller number per plant; NRP = number of racemes per plant.

4. Discussion

4.1. Effect of Fonio Accession and Location on Growth Parameters. The results showed highly significant ($P \leq 0.05$) difference among accessions for plant height at maturity. The late maturing accession NFAS4 with 98 days to physiological maturity recorded the highest average plant height of 93.79 cm, and KPAS3 with 80 days to physiological maturity recorded the shortest mean plant height (72.66 cm). The difference in maturity date among accessions might have affected their nutrient use efficiency, hence the difference in height between the tallest late maturing accessions and the shortest early maturing accessions. However, difference in height observed across locations suggests that the accessions might be genetically diverse and respond differently to the different agroecologies. The average plant height recorded for the five accessions was 82.61 cm. This result is in tandem with the findings of [15] who reported that Fonio reached a height of about 30 cm to 80 cm at maturity.

Interaction effect of location and accession produced significant ($P \leq 0.05$) difference on number of tillers per plant. Accessions varied significantly ($P \leq 0.05$) for tiller number per plant. Location produced significant ($P \leq 0.05$)

Table 9: Correlation among agro-morphological traits.

Traits	PHM	RL	TNP	PNP	NLP	LA	D50 (%) F	DPHM	GY	1000 GW	BLSC	SKC
PH	1.00											
NRP	0.250*											
RL	−0.29*	1.00										
TNP	0.62**	−0.1 ns	1.00									
PNP	0.59**	0.09 ns	0.98**	1.00								
NLP	0.63**	0.58**	0.46**	0.44**	1.00							
LA	0.7**	0.46**	0.38**	0.64**	0.72**	1.00						
D50 (%) F	0.53**	0.78**	0.23*	0.26*	0.74**	0.8**	1.00					
DPHM	0.53**	0.78**	0.23*	0.22*	0.74**	0.8**	1.00**	1.00				
GY	−0.08 ns	0.35**	0.26*	0.28*	0.19ns	0.27*	0.35**	0.35**	1.00			
1000 GW	−0.19 ns	−0.02	−0.12	−0.14	0.05 ns	−0.1 ns	0.12 ns	0.12 ns	0.08 ns	1.00		
BLSC	−0.46**	0.55**	−0.22*	−0.21*	0.55**	0.62**	0.76**	0.76***	0.3**	0.08 ns	1.00	
SKC	0.002 ns	0.17 ns	0.04 ns	0.05 ns	0.05 ns	0.001 ns	0.09**	−0.1 ns	0.03 ns	−0.17 ns	0.16 ns	1.00

Correlation is significant (**) at ($P < 0.001$), is significant (*) at ($P < 0.05$), and is nonsignificant (ns). D50 (%) F = days to 50% flowering.

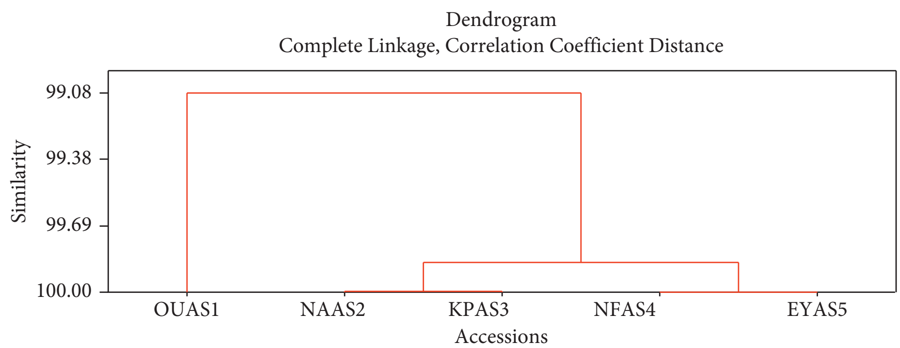

Figure 1: Phenogram showing phenotypic diversity among Fonio accessions.

effect on number of tillers per plants. The significant diversity among accessions observed for tiller number per plant averaging 8.02 tillers for five accessions supports the report of [16] where significant variation among black Fonio (*Digitaria iburua*) accessions for number of tillers per plants was established in northern Nigeria. Similarly, Clottey et al. [17] reported varied number of tillers per plant, averaging 8 tillers in thirteen Fonio landraces assembled in Ghana. The results therefore suggest that tillering in Fonio might be dependent on the location as well as the genetic potential of the accession.

The interaction effect of location and accession was significant ($P \leq 0.05$) on leaf area development in Fonio. The largest and smallest average total leaf area for SSAE was recorded by EYAS5 and OUAS1 (7.88 cm^2 and 4.85 cm^2), respectively. Diversities observed validate the morphologically difference noticed for canopy architecture among accessions across locations which were conspicuously grouped into two. Accessions EYAS5 and NFAS4 had longer and broader leaves, while the other three accessions (OUAS1, NAAS2, and KPAS3) had narrow and shorter leaves. This suggests that the expression of Fonio growth potential with respect to leaf area is dependent on the genotypes as well as environmental factors. There was highly significant ($P \leq 0.05$) variation among accessions for leaf area development. Accessions (NFAS4 and EYAS5) recorded the largest leaf area of 8.28 cm^2 and 8.23 cm^2, respectively. Genotype OUAS1 recorded the smallest leaf area of 3.80 cm^2. The variation between locations for total leaf area development was also significant ($P \leq 0.05$). SSAE recorded larger average total leaf area of 6.12 cm^2 compared to GSAE with average total leaf area of 5.21 cm^2.

Accessions varied significantly ($P \leq 0.05$) for number of leaves per Fonio plant. The late maturing accessions EYAS5 and NFAS4 with 98 days to physiological maturity registered the highest mean number of leaves per plant compared to the three early maturing accessions OUAS1, NAAS2, and KPAS3. There was significant ($P \leq 0.05$) difference between locations for leaf production. The SSAE produced more leaves per plant as compared to the GSAE. Despite the significant difference observed among accession and location for number of Fonio leaves per plant, the study showed that the three early maturing accessions OUAS1, NAAS2, and KPAS3 did not differ significantly from one another but significantly differed from the late accessions NFAS4 and EYAS5 for number of leaves per plant. This finding was obvious as these early maturing accessions showed many morphological similarities in many of the traits measured, like days to 50% flowering, leaf area, and plant height at maturity. These findings suggest that the choice of accession, place of cultivation, and fertility status of the soil involved should be a concern in Fonio cultivation, especially if it is grown for fodder. However, number of leaves did not positively translate into grain yield as the best yielding accession OUAS1 was among accessions which recorded lesser number of leaves. In similar vein, SSAE in which Fonio was more vegetative gave less total grain yield (788.42 kg/ha) as compared to GSAE which gave grain yield of 913.25 kg/ha.

4.2. Effect of Fonio Accession and Location on Yield and Yield Components. Significant difference ($P \leq 0.05$) was observed among accessions for 1000 grain weight, accession KPAS3 recorded the heaviest 1000 GW of 0.53 g, and the least accessions in terms of grain weight were EYAS5 and NFAS4 which recorded the same grain weight of 0.51 g. The effect of location on 1000-grain weight of Fonio was not significant ($P > 0.05$), so was the interaction effect of location and Fonio accession on 1000 grain weight. The grand mean for 1000 grain weight was 0.52 g, and this falls within the finding of Nyam et al. [18] who recorded 1000 grain weight between 0.51 g and 0.75 g. The results are also in line with the report of Hammad et al. [19], where they recorded variability among Fonio genotypes for 1000 grain weight. These diversities observed among Fonio genotypes across its production zones can be exploited through selection of genotypes with superior grain weight for improvement. The variations in grains weight among Fonio accessions further consolidate the richness of Fonio germplasm across its production centers.

The number of racemes per panicle varied statistically among the five accessions. The accession EYAS5 recorded the highest number of racemes (3.38), and accession NAAS2 recorded the least number of racemes per panicle (2.88). The significant ($P \leq 0.05$) diversity observed among Fonio accessions for racemes number per panicle was expected. Hilu et al. [20] also reported that *Digitaria exilis* bears terminal digitate panicle inflorescence of 2–5 slender racemes like primary branches. However, the result did not support the report of Sekloka et al. [21] whose work did not establish significant ($P \leq 0.05$) variation among the accessions collected from Boukoumbe in the republic of Benin for racemes number per panicle. Relating the number of racemes to Fonio grain yield, OUAS1 which recorded the second highest number of racemes per panicle was adjudged the best yielding accession in terms of total grain yield. However, accession EYAS5 which recorded the highest number of racemes among all accessions did not perform well in terms of grain yield. Many factors like plant stand, length, and quality of filled racemes which were not considered in this research might have accounted for this low grain yield of accession EYAS5 despite the fact that it recorded the highest number of racemes per panicles. However, it is worth acknowledging that the diversity in racemes among the accessions will be a good trait to consider in breeding programs for improvement of grain yields in Fonio. The results suggest that expression of racemes number in Fonio is mainly influenced by genotype which is heritable and could be improved through selection and breeding.

The influence of accessions on Fonio total grain yield showed significant ($P \leq 0.05$) difference. The grand mean for the five Fonio accessions was 850.83 kg/ha. OUAS1 recorded the highest grain yield (1015.10 kg/ha), while NFAS4 recorded the least grain yield of 713.23 kg/ha. Location had significant ($P \leq 0.05$) influence on Fonio grain yield. Fonio performed better in GSAE with grain yield of 913.25 kg/ha compared to SSAE which had grain yield of 788.42 kg/ha. Interaction effect of accession and location on total grain yield was not significant ($P > 0.05$).

These observations are evident that the five Fonio accessions varied for grain yield. The yields recorded on per hectare bases are higher than the 500–800 kg/ha reported by Kuta et al. [7] as the average yield in West Africa. This finding proposes that the factors accessions and location as well as the husbandry practices (row planting, spacing between rows and plots, and weeding) implored in this study were effective in increasing Fonio grain yield. Grain yields in general for all treatments oscillated between 713 kg/ha to 1015 kg/ha. This is in conformity with the finding of [22] in which he indicated that Fonio yields or productivity differed statistically across its production areas and extremely affected by climate, and that regional average yield hovers around 0.600 tons/ha and 0.900 tons/ha and peaking at 1.50 ton/ha. It also suggests that the accessions studied especially OUAS1, KPAS3, and NAAS2 which recorded total grain yields above 800 kg/ha each might be high yielding.

Fonio accessions were statistically highly diverse ($P \leq 0.05$) for lodging. OUAS1 was the most lodged and recorded a score of 4.75 for lodging representing about 65% of its total plant population. Two accessions (NFAS4 and EYAS5) scored least lodging means of 2.75 and 2.88, respectively, representing about 10% of its total plant population each. There was no statistical difference ($P > 0.05$) between locations for lodging in Fonio, so was the interaction impact of accession and location on lodging. The above observation suggests that lodging in Fonio is inherent and might not significantly be affected by environmental factors. The finding consolidates the report of Vodouhe et al. [10], in which they indicated that lodging is a major setback in Fonio production as a result of its tender shoot which easily lodge leading to loss of grains and making it tedious to harvest. It was observed in this study that lodging in *Digitaria exilis* is severe at late vegetative phase of its growth cycle. However, it is worth suggesting that the severity of the above phenomenon might be dependent on the fertility status of the soil in question, as Fonio tends to lodge more in fertile soil than soils with less fertility, based on the findings of this study.

Interaction influence of accession x location was significant ($P \leq 0.05$) for number of panicles per Fonio plant. Significant ($P \leq 0.001$) variation was also observed among accessions for panicle number per plant. Location effect was also significant ($P \leq 0.001$) for panicle number per plant. The SSAE favored number of panicles per plants with mean number of 11.92 panicles per plant as against 4.12 panicles per plant for GSAE. The above findings are an indication that panicles formation in Fonio is highly dependent on the genotype, environment, and the interactions between these factors. However, in this study the number of panicles per plant did not significantly affect grain yield. Factors like unfilled panicles, lodging, smaller and short panicles, low-quality grains, and many other factors might have accounted for this happening.

4.3. Principal Component of Yield (CP) Analysis. Principal component analysis showed that the first four PCs had eigenvalues > 1 contributed 99% of the total variance. The major contributors to the first two components were total grain yield, tiller number per plant, plant height, days to physiological maturity, number of racemes, and many others as captured in Table 8. The principal component analysis is a powerful tool in obtaining parental lines for a successful breeding program. Principal component analysis is mostly used in plant sciences for the reduction of variables and grouping of genotypes. It also reflects the significance of the largest contributor to the total variability at each axis of differentiation [23]. The principal component analysis grouped the total variances into four PCs. These are the major contributors to the total diversity among the accessions due to the study of various traits. The first principal component (PC1) contributing 65% of total variation is in line with the finding of Nyam et al. [18] in which PC1 contributed 87.1% of total variation. PC2 was responsible for about 20% of the total variation. PC1 contributing about 65% to total variance means that all the traits which contributed most to PC1 are traits responsible or are much associated with grain yield in Fonio. This finding provides an information that might be helpful in the choice of traits for Fonio improvement programs.

4.4. Pearson's Correlation Coefficient and Cluster Analysis. Most of the traits exhibited positive and significant ($P \leq 0.05$) correlation with each other. However, few traits exhibited insignificant ($P > 0.05$) correlation and others were negatively correlated. Grain yield had positive and highly significant correlation with stem color, basal leaf sheath, total leaf area, days to 50% flowering, and days to maturity. It also had positive and significant correlation with number of tillers per plant and number of racemes per panicle. These traits that are significant and positively correlated can be improved synergically, by improving one of the other traits that are positively and significantly affected. These findings resonated the report of Sekloka et al. [21] who indicated that most of the traits they studied had positive and significant correlation. The findings of Nyam et al. [18] also reported significant correlations among 30 Fonio accessions. Plant height at maturity insignificantly and negatively correlated with grain yield in Fonio. This means that increase in Fonio height might not significantly increase yield. This explains why the tallest and late maturing accessions, EYAS5 and NFAS4, recorded lowest grain yield of 720.70 kg/ha and 713.00 kg/ha, respectively, compared to the grain yield of the shortest and early maturing accessions, OUAS1 (1015.01 kg/ha), KPAS3 (920.60 kg/ha), and NAAS2 (884.50 kg/ha). These findings support the report of Ibrahim et al. [24] who indicated Fonio grain yield showed negative correlation with plant height at maturity.

A dendrogram uses correlation between variables to identify similarities between the accessions. The five Fonio accessions were grouped into three clusters, the OUAS1 cluster, NAAS2 and KPAS3 clusters, and NFAS4 and EYAS5 clusters. The wide inter-cluster distances observed showed that there are less similarities between clusters. The OUAS1 cluster, and NFAS4 and EYAS5 clusters took more than half of the phenogram (Figure 1), and this reveals how wide and heterogeneous the accessions are between clusters. However, within cluster distances were very narrow and recording above 99% similarity coefficient and depicting less intra-cluster diversity. This is similar to the reports of Nyam et al. [18] which detailed about 93.59 to 100% similarity coefficient among accessions and indicated that the genotypes studied were genetically diverse for many traits measured. This further explains the diversity and richness of Fonio germplasm.

5. Conclusion and Recommendations

5.1. Conclusion. Accession OUAS1 was the earliest maturing as well as the highest yielding accession, while NFAS4 was late maturing and the poorest yielding accession. Guinea savannah agroecology recorded the highest grain yield as compared with Sudan savannah agroecology. Accession and location interaction was significant for grain yield and most of the growth parameters.

There was a positive and significant correlation between grain yield and the following growth parameters: stem color, basal leaf sheath color, leaf area, days to emergence of flag leaf, days to 50% flowering, days to physiological maturity, and number of racemes per panicle.

5.2. Recommendations. For purposes of grain yield, accession OUAS1, with 70–80 days to physiological maturity, is recommended for use by farmers in the Guinea and Sudan savannah agroecologies of Ghana. For maximum grain yield production, the Guinea savannah agroecology is the most suitable agroecology for the cultivation of Fonio.

Data Availability

No data were used in this study.

Additional Points

Fonio is nutritionally important and therefore plays an important role in food security in Africa. The crop also has high level of genetic and morphological variabilities among existing accessions. Therefore, there is the need to improve upon Fonio production. Scientists from the universities and research institutions, through collaborative research, ought to improve upon the crop from all its production zones, targeting the following traits: higher number of racemes per plant, higher spikelet number per panicle, effective number of panicles per plant, larger seed size, and resistance to lodging.

Conflicts of Interest

The authors have declared no conflicts of interest.

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