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Comparative Analysis of Agromorphological Characteristics, Nutritional Values, and Phytochemical Profiles of Two *Digitaria* Species (Acha) in Dass LGA, Nigeria

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Abstract

Digitaria spp. (fonio), commonly known as acha, is an indigenous cereal crop widely cultivated in West Africa. Despite its long history of cultivation and consumption, fonio remains underutilized compared to major cereals, notwithstanding its remarkable adaptability to adverse environmental conditions and valuable nutritional attributes. This study evaluated the agromorphological characteristics, proximate composition, mineral content, and phytochemical constituents of two fonio species, *Digitaria exilis* (white fonio) and *Digitaria iburua* (black fonio), cultivated in Dass Local Government Area, Bauchi State, Nigeria. Field experiments were conducted using standard agronomic practices, while laboratory analyses were performed using established analytical procedures. Growth and yield parameters assessed included plant height, number of leaves, leaf area per plant, number of tillers per plant, spike length, and seed characteristics. Proximate and mineral analyses were carried out using standard AOAC methods, whereas phytochemical constituents were determined through qualitative screening techniques. The results revealed significant differences ($p < 0.05$) between the two species across several agronomic and nutritional parameters. *D. iburua* exhibited superior performance in vegetative growth traits, flowering characteristics, tiller production, number of seeds per spikelet, and thousand-seed weight (TSW) compared to *D. exilis*. Nutritional analysis showed that black fonio contained higher levels of crude protein (12.37%), crude fiber (1.37%), and ether extract (2.81%), whereas white fonio recorded a higher carbohydrate content (82.16%). Both species contained appreciable concentrations of calcium, magnesium, sodium, iron, and zinc, with generally higher mineral levels observed in black fonio. Phytochemical screening detected the presence of flavonoids, tannins, alkaloids, steroids, glycosides, and phenolic compounds in the fonio plant parts. These findings highlight the considerable potential of fonio as a nutrient-rich, climate-resilient cereal capable of contributing significantly to food security, improved nutrition, and sustainable agricultural development.

Keywords
Agronomic practices, Fonio, Food security, Minerals, Proximate components, Phytochemicals

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1. Introduction

Fonio (*Digitaria* spp.) called acha in Nigeria, is the oldest cultivated native cereal crops of West Africa domesticated over 5,000 to 7,000 years ago (Gar, 2002). Two most widely cultivated fonio species are *D. exilis* (white fonio) and *D. iburua* (black fonio) both indigenous and highly adaptable to semi-arid and sub-humid conditions found within the agro ecological zone of West Africa (Daichi *et al.*, 2017). Historically fonio was of nutritional and economical importance to the rural population of West Africa due to early maturation, low fertility demand soils and tolerance to drought and climate variability (NRC, 1996; Cruz *et al.*, 2011; Garba & Sabo, 2025). Acha contributed to food security at household level particularly during the seasonal food insecurity within the Northern Nigeria savannas.

There are many agronomic advantages which make fonio an important crop under a changing global climate scenario. These include rapid germination and growth, effective water usage, tolerance to drought, poor soil fertility and intermittent flooding (Adoukonou-Sagbadja *et al.*, 2006; Cruz *et al.*, 2016). It is one of the shortest maturing cereal crops; hence its cultivation cycle can last as little as 6-8 weeks from sowing to harvest in some varieties (NRC, 1996). This allows the farmers to harvest and supplement other main cereal crops such as millet, sorghum and maize, helping to avoid or mitigate food shortage common during the "hunger season" occurring in semi-arid region of West Africa.

Despite the enormous food, economic and ecological relevance of fonio, it remains one of the most underutilized and neglected cereal crops in Africa. Major cereal crops like wheat, maize and rice continue to be the focus of many agricultural research and breeding programmes whereas indigenous cereal grains such as 'acha' receive little scientific research attention (Enyiukwu *et al.*, 2020). As a result, few varieties of 'acha' are known to exist and show some primitive agronomic features such as small seed size, seed shatter, low grain yield and low adaptability to mechanization. Similarly, limited studies are available on agromorphological diversity, nutritional profile and phytochemical constituents of the local 'acha' found in Northern Nigeria (Abdullahi & Luka, 2003).

Agromorphological characterization are used for studying variations among populations, identifying useful traits and for improvement of the species (Pucher *et al.*, 2015). Several morphological traits such as plant height, tillering capacity, spike length, grain type, grain dimension and maturity period can indicate productivity and variability among the various accessions of 'acha' (Isa *et al.*, 2024). These can serve for improvement purpose especially in a challenging environment such as in the Sudan and Northern Guinea Savanna zones of Nigeria where climatic fluctuations are posing a threat to crop production (Garba **&** Sabo, 2025).

Beyond agronomic attributes, fonio has been attracting global attention for its nutritive value and healthy implication on the human diet. Fonio grain is rich in carbohydrate, fibre, essential amino acids, vitamins and minerals, naturally gluten-free (Jideani & Jideani, 2011; Ayenan *et al.*, 2017). Methionine and cysteine are the amino acids that are usually lacking in most cereal grains, but are present in significant amounts in fonio (Jideani, 2012). Being low on glycemic index and high on digestibility, fonio has been recognized as being beneficial to diabetic people and celiac patients. Thus, fonio seeds represent one approach to solve malnutrition andmicronutrient deficiency problems in developing countries.

Phytochemicals are chemical constituents present in food that confer many health benefits; they are capable of preventing many diseases and have medicinal and therapeutic effects. Flavonoids, tannins, alkaloids, saponins, phenolics, antioxidants etc are few important examples of phytochemical constituents (Sofowora, 1996; Trease & Evans,

2002, Luke & Abdullahi, 2013). Knowledge on the exact amount of the various phytochemicals within the Nigerian acha species can serve a variety of purpose including nutraceutical and pharmaceutical applications. Nevertheless, information on the phytochemical constituents of local 'accha' species in Bauchi State has not been fully explored.

The ancestral producing areas of fonio in North Eastern include Bogoro, Dass, Tafawa Balewa, Funakaye Local Government Areas (LGA) of Bauchi & Gombe states. Its being planted also in some parts of Yobe and Borno states. The Dass area experiences a tropical savanna climate and moderate precipitation which predominantly practices smallholder farming with extensive reliance on rain fed crops and indigenous production techniques inherited through generations. Though, both culturally and economically important, detailed agromorphological traits, nutrition and phytochemical components of local *Digitaria* species from this area has not been fully studied.

The current trend of food insecurity, malnutrition, environmental challenges and agricultural productivity depletion make a case for the research and utilization of resilient indigenous crop such as fonio. Detailed research on local 'acha' will pave way for crop improvement, nutritional improvement, conserve genetic resources and develop sustainable food security in Nigeria. In light of the foregoing therefore, this research was conducted to investigate the agromorphological characterization, nutritional composition and phytochemical properties of the two *Digitaria* species (*D. exilis* and *D. iburua*) cultivated in Dass LGA, Bauchi State, Nigeria. The specific objectives were to: i). to evaluate the agromorphological characteristics of the two species; ii). to determine the proximate and mineral compositions of the grains of the two species; iii). to assess the phytochemical constituents of the two species; and iv). to compare the two species based on their nutritional and phytochemical compositions.

2. Materials and Methods

2.1 Study Area

Field experiments were carried out in Dass Local Government Area (LGA) of Bauchi State, Nigeria. Geographically, the study area lies in the Northern Sudan Savanna agroecological zone, defined by $10^0$00' to $10^0$15' N latitude and $9^0$30' to $9^0$50' E longitude (Ojanuga, 2006). The region is characterized by the tropical wet and dry climate (Kppen-Geiger Aw) typical in this zone which features two main clear-cut seasons, one wet and one dry (Nimyelet *al.*, 2020). There is a well defined rainy season lasting from May to October, while the average annual rainfall ranges from 800 to 1100 mm and the average annual temperature ranges from 24^0C to 32^0C across the varying seasonal phenology (FMEnv., 2014).The region's climax vegetation includes characteristic savanna woodlands and varied shrubs, perennial grasses, and small fragmented farming lands. Most people's livelihood is based on rainfed farming, and key staple food crops grown include maize (*Zea mays*), pearl millet (*Pennisetumglaucum*), sorghum (*Sorghum bicolor*), upland rice (*Oryza sativa*) and fonio/acha (Digitaria spp.). The edaphic and climate regimes of the Dass region strongly correlate with the physiological attributes of fonio landraces which has a high agronomic vigor, outstanding tolerance to nutrient poor and marginally productive soils and inherently resilient against inconsistent rainfall pattern (Adoukonou-Sagbadja *et al.*, 2006; Jideani & Jideani, 2011).

2.2 Research Design

A comparative randomized experimental research design incorporating laboratory-based analysis evaluations were employed for the thorough characterization and comparative analysis of the two species of Digitaria. This scientific experimental plan was carried out in four progressive steps:

1. Agronomic experiment to test agronomic performance under consistent environmental conditions and agricultural management practices.

2. Agromorphological profiling to follow a specific subset of vegetative, phenological and reproductive characteristics during the crop's ontology.

3. Nutritional and mineral profile analysis to assess proximate composition, caloric value and a set of necessary minerals.

4. Phytochemical profiling to identify targeted secondary metabolites through initial qualitative analysis, and then quantify through subsequent quantitative analysis.

This layered experimental scheme followed guidelines for analysis of unutilized genetic resources ensuring that phenotypic characteristic can be benchmarked directly against chemical characteristics under the same agroecological context (Upadhyaya *et al.*, 2008; Achigan-Dako *et al.*, 2014).

2.3 Plant Material Collection and Authentication

Bulk seeds of *D. exilis* (white fonio) and *D. iburua* (black fonio) were sourced directly from small holder farmers in the Dass Local Government area, Bauchi state Nigeria. Taxonomic identification of the two species was undertaken at the Herbarium Unit of Department of Biological Sciences ATBU, Bauchi where a representative voucher specimen was prepared, indexed and deposited in the herbarium.

2.4 Preparation of the field and sowing behaviour

Field experiment was conducted in plots of experimental field defined precisely by border lines. The plots measured 3m x 2m. Manual clearance, manual hand weeding and thorough ploughing were made so that compaction could be eliminated to give a readily manageable friable seedbed matrix with an ideal structure for small seeded crops (Schippers, 2000). For accurate uniform broadcasting and placement of the seeds in the nursery beds according to common practice of the farmers, very fine seeds of the two *Digitaria* species were mixed with an equal volume of dry clean river sand then broadcast manually (Jideani & Jideani, 2011). Top dressing with fine soil immediately after broadcasting covered the seeds on the soil surface, helping to protect exposed germplasm from the effects of wind, desiccation and from being picked up by wild birds and other animals (NRC, 1996; Adoukonou-Sagbadja *et al.*, 2007).

2.5 Management Practices

2.5.1. Water Management. The experiment was carried out predominantly on rainfed plots so as to have the best possible replication of existing smallholder systems of fonio production in West Africa (Jideani & Jideani, 2011). Nevertheless, regulated surface irrigation was used periodically during short periods of drought. The surface irrigation was continued for some short duration in order to maintain soil moisture tension at desirable range to avoid the physiological water deficit of the crop at its vegetative and reproductive development stages (NRC, 1996; Kwon *et al.*, 2021).

2.5.2. Weed Control.

Weeds were controlled by a sequence of manual hoeing and rogueing at different crop developmental stages. In early vegetative stages, the process was done carefully to eliminate weeds competition for the resources within the rhizosphere and among within-species or within-or inter-species resource limitations (Schippers, 2000). Efforts were made to avoid damages on the root systems of the young crop (Upadhyaya *et al.*, 2008).

2.6 Harvest and Post-harvest Treatment of Samples

Panicles were harvested by hand when fully ripe. The two *Digitaria* species (*Digitaria exilis* and *D.iburua*) were kept apart to avoid cross-contamination. Sun-drying was carried out in the ambient laboratory condition (27 ± 2^0C) of panicles until constant equilibrium of moisture content was achieved in conformity to the existing framework of post-harvest handling of minor millets (Jideani & Jideani, 2011). The panicles were then threshed by hand. The threshed grains were de-husked by using the mortar and pestle traditional technique followed by thorough winnowing of hull and chaff from the grain (NRC, 1996; Shippers, 2000).

Before subjecting to biochemical determination, clean grains were washed with distilled water to remove dust and all adhering dirt. Washing of grain was done thoroughly and dried in an oven at gentle condition to prevent thermal degradation of labile and heat sensitive nutritional elements and phytochemical compounds and ground using analytical electric blender (Ayo *et al.*, 2020). Ground meal samples were stored in airtight polymer bag at room temperature and kept inside the desiccators to have low water activity value before laboratory analysis.

2.7 Agromorphological Characterization

Plant phenotype traits were observed weekly from seedlings' emergence until physiological maturity following strictly the prescribed description for fonio adopted by the International Plant Genetic Resources Institute (IPGRI, 2004). Agromorphological traits studied included quantitative vegetative and reproductive characteristics to fully understand the entire ontogenetic development in the two *Digitaria* species.

2.7.1 Vegetative architecture

Plant height (cm) measured using a meter ruler from the base to the tip of the longest panicle. Total number of leaves per plant and the number of productive tillers per plant were counted directly. Leaf area per plant (cm 2) was estimated using non-destructive leaf area model: length width adjustment factor tailored to small grain canopies (Radford, 1967).

2.7.2 Phonological development

Specific events were recorded daily on each whole plot. Dates were then converted to days. The following were observed and recorded: days to 50% anthesis and days to physiological maturity (shattering stage) as recorded on the respective scales of cereal phenology (Kwon *et al.*, 2021). Yield components, including reproductive development included determination of spike length (cm) and count of spikelets per panicle. Post-harvest metric parameters measured at physiological maturity were hundred seed weight adjusted to a constant moisture content (g) and the total yield in grain per plot (g) (Jideani & Jideani, 2011). All linear measurements and canopy features were taken by calibrated metric ruler and all masses and yield parameters measured using analytical balance model. All remaining morphological transitions and qualitative botanical descriptors were authenticated via standardized direct visual observation protocols (Schippers, 2000).

2.8 Nutritional analysis

Evaluation of proximate composition of the samples (two *Digitaria* species grains) was carried out in three replicates following the standard, validated procedures prescribed by Association of Official Analytical Chemists (AOAC, 2010). The moisture content was determined gravimetrically by oven-drying at 105^0 C to a constant weight (AOAC, 2010). The ash content determined using a muffle furnace at 550^0 C for 6 hours (AOAC, 2010). Crude Protein content (% dry weight) was determined by macro-Kjeldahl nitrogen method and the collected nitrogen value was converted to protein using a baseline conversion factor of 6.25 (Jones, 1941). Crude Fat content was determined through a continuous extraction in a Soxhlet apparatus using analytical grade

petroleum ether (40-60°C) as solvent (AOAC, 2010). While crude fiber content was determined through consecutive acid-base digestions followed by combustion of the remaining solid residue (AOAC, 2010). Total carbohydrate value (FAO, 2003) and total metabolizable energy were subsequently computed via modified Atwater factors (Atwater and Rosa, 1899; Merrill and Watt, 1973) using the following formulas:
Carbohydrate (%) = 100 - (% moisture} + % Ash + % Crude Protein + % Crude Fat + % Crude Fiber).

Total metabolizable energy was calculated using modified Atwater factors: Energy value (Kcal/100 g) = (4 x % Carbohydrate) + (4 x % Crude protein) + (9 x % Crude Fat).

2.9 Mineral content analysis

The element concentrations were measured after digestion of the samples using a highly oxidizing acidic mixture of concentrated nitric acid and perchloric acid (4:1v/v). Sodium (Na) and potassium (K) content was assessed by using flame photometry, calcium (Ca), Iron (Fe), Magnesium (Mg) and Zinc (Zn) content were measured by using Atomic Absorption Spectrophotometer (AAS) using standard references according to AOAC (2010) procedures.

2.10 Phytochemical analysis and quantification

Qualitative analysis of the phytochemicals was performed on the crude methanolic extract for alkaloids, flavonoids, tannins, saponins, total phenolics, steroids, and anthraquinones using diagnostic colorimetric and precipitation test method based on Sofowora (1996) and Trease and Evans (2002). Quantification of the phytochemicals that gave positive test results were done using UV- Visible Spectrophotometer technique using its respective standard graphs.

2.11 Statistical analysis

All laboratory determinations and agronomic measurements were made in triplicate (n=3) and the collected empirical data are presented as mean standard error of mean (SEM) (Field, 2013). The measurement of variations and analysis of descriptive parameters was achieved by using combined computer softwares; IMB SPSS statistics (version 26.0, IMB Corp. Armonk, N. Y, USA) and GraphPad prism (version 9.0, GraphPad software, San Diego, CA, USA). The comparisons among varieties and species on vegetatives, reproduction, nutritional, phytochemical parameters that were evaluated, a one-way analysis of variances (ANOVA) (Gomez and Gomez, 1984) was applied to test the significance of the differences observed between the two Digitaria species. Treatment means were compared by Duncan's Multiple Range test (DMRT) when F value was significant at $p<0.05$ (Duncan, 1955).

3.0 Result

3.1 Agromorphological Characteristics of White (*Digitaria exilis*) and Black (*Digitaria iburua*) Fonio Varieties

The results of agromorphological study clearly demonstrated clear variations between the two *Digitaria* species. While *D. exilis* (white fonio) was taller, produced a greater leaf area, and flowered later, *D. iburua* (black fonio) had more leaves and heavier seeds indicating stronger reproductive vigor and early maturity characteristics (Table 3.1).

Table 3.1 Agromorphological Characteristics of White (*Digitaria exilis*) and Black (*Digitaria iburua*) Fonio Varieties

Growth Parameter	White Fonio (*D. exilis*)	Black Fonio (*D. iburua*)	Significance Level
Plant Height at Week 10 (cm)	77.8 ± 1.97	56.3 ± 1.39	$P < 0.001$
Number of leaves per plant at Week 8	9.9 ± 0.23	19.0 ± 0.87	$P < 0.001$
Leaf Area at Week 9 (cm^2)	14.1 ± 0.91	11.1 ± 0.75	$P < 0.05$
Number of tillers per stand at Week 8	5.6 ± 0.16	5.0 ± 0.70	$P < 0.05$
Days to Flowering	73	58	Significant
1000-Seed Weight (g)	0.62	0.84	Significant

3.2 Reproductive Characteristics of White (*Digitaria exilis*) and Black (*Digitaria iburua*) Fonio Fonio Varieties

Black fonio showed much better reproductive performance than white fonio by having significantly greater number of seeds/spikelet (Table 2). The spike number in both varieties of fonio was comparable.

Table 3.2 Reproductive Characteristics of White (*Digitaria exilis*) and Black (*Digitaria iburua*) Fonio Varieties

Reproductive Parameter	White Fonio (*D. exilis*)	Black Fonio (*D. iburua*)	Significance
Spike Length (cm)	12.42 ± 0.47	12.72 ± 0.07	$P \leq 0.05$
Number of Seeds per Spikelet	88.3 ± 20.3	130.4 ± 8.01	$P < 0.001$
Number of Spikelets	8.0 ± 0.67	8.0 ± 1.28	NS

NS = Not Significant

3.3 Proximate Composition of White (*Digitaria exilis*) and Black (*Digitaria iburua*) Fonio

In Table 3.3 proximate composition showed black fonio to be considerably higher in protein, fat and fibre content when compared with white fonio. While white fonio was highest in carbohydrate content, and both species displayed relatively similar energy levels.

Table 3.3 Proximate Composition of White (*Digitariaexilis*) and Black (*Digitariaiburua*) Fonio

Parameter (%)	*D. exilis*	*D. iburua*	Significance
Moisture Content	3.83 ± 0.07	3.81 ± 0.00	NS
Ash Content	1.54 ± 0.01	1.69 ± 0.01	NS
Crude Protein	9.14 ± 0.02	12.37 ± 0.04	$P < 0.05$
Ether Extract (Fat)	2.26 ± 0.02	2.81 ± 0.01	$P < 0.05$
Crude Fibre	1.10 ± 0.02	1.37 ± 0.01	$P < 0.05$
Carbohydrate	82.16 ± 0.02	77.97 ± 0.04	$P < 0.05$
Energy (kcal/100 g)	385.46 ± 0.30	386.59 ± 0.08	NS

NS = Not Significant

3.4 Mineral Composition of White (*Digitaria exilis*) and Black (*Digitaria iburua*) Fonio

The black fonio recorded a higher amount of most of mineral elements (Ca, Mg, Na, Fe). These results suggests that black fonio can be a better candidate to compensate for micronutrients deficiency in rural areas (Table 3.4).

Table 3.4 Mineral Composition of White (*Digitariaexilis*) and Black (*Digitariaiburua*) Fonio

Mineral (mg/100 g)	*D. exilis*	*D. iburua*	Significance
Sodium	40.5 ± 0.35	56.5 ± 1.77	*P*< 0.05
Potassium	9.35 ± 0.18	6.10 ± 0.07	NS
Calcium	220.0 ± 0.00	520.0 ± 2.12	*P*< 0.05
Magnesium	139.0 ± 1.41	440.5 ± 3.18	*P*< 0.05
Zinc	0.44 ± 0.01	0.69 ± 0.01	NS
Iron	1.90 ± 0.00	3.00 ± 0.14	*P*< 0.05

NS = Not Significant

3.5 Qualitative Phytochemical Constituents of White (*Digitaria exilis*) and Black (*Digitaria iburua*) Fonio Fonio

Qualitative phytochemical tests (Table 3.5) showed that flavonoids, tannins, steroids, glycosides were detected in all the organs of both fonio species. However, anthraquinones were present in root only and saponins in seeds only.

Table 3.5 Qualitative Phytochemical Constituents of White (*Digitaria exilis*) and Black (*Digitaria iburua*) Fonio

Phytochemical	Shoot (*D. iburua*)	Seed (*D. iburua*)	Root (*D. iburua*)	Shoot (*D. exilis*)	Seed (*D. exilis*)	Root (*D. exilis*)
Alkaloids	+	–	+	+	–	+
Flavonoids	+	+	+	+	+	+
Saponins	–	+	–	–	+	–
Tannins	+	+	+	+	+	+
Steroids	+	+	+	+	+	+
Glycosides	+	+	+	+	+	+
Anthraquinones	–	–	+	–	–	+

Key: (+) Present; (–) Absent

3.6 Quantitative Phytochemical Composition of White (*Digitaria exilis*) and Black (*Digitaria iburua*) Fonio (mg/kg)

The qualitative phytochemical analysis (Table 6) revealed significant differences in the presence of active substances between plant parts and among Fonio species. Black fonio roots had the highest

concentration of total phenolics, white fonio shoots had the highest alkaloid content, highlighting medicinal and nutraceutical benefits of both fonio species.

Table 3.6 Quantitative Phytochemical Composition of White (*Digitaria exilis*) and Black (*Digitaria iburua*) Fonio (mg/kg)

Sample	Alkaloids	Flavonoids	Saponins	Tannins	Steroids	Total Phenolics	Phytate
Shoot *D. iburua*	118.0	183.51	BDL	138.0	149.0	122.52	92.69
Seed *D. iburua*	BDL	69.20	91.60	20.28	118.0	96.71	15.41
Root *D. iburua*	71.20	101.80	BDL	164.35	121.0	235.50	126.20
Shoot *D. exilis*	152.90	149.39	BDL	39.00	147.0	BDL	BDL
Seed *D. exilis*	BDL	62.53	48.60	104.0	109.0	119.33	24.13
Root *D. exilis*	123.15	85.25	BDL	110.22	92.0	203.70	180.95

Values are expressed as milligrams per kilogram dry weight (mg/kg DW) of plant material analyzed.
BDL = Below Detection Limit.

4.0 Discussion

The empirical data from this study identified significant agro-morphological, nutritional and phytochemical variation among both *Digitaria exilis* (white fonio) and *D.iburua* (black fonio) grown under the semi-arid agro-ecological milieu of Dass Local Government Area of Bauchi State, Nigeria. These strong interspecific variation shows that indigenous West African millets, under indigenous water and nutrient constraints, have great genetic variation, phenotypic plasticity and capacity for adaptation (Causseet *al.*, 2025).

4.1 Agro-morphological and Reproductive characteristics

Under the physiological analysis, *D. iburua* gave greater early-stage vegetative vigour by faster tillerability and a higher leaf production. These early vegetative resources allocation implies that black fonio have evolved better for efficiently harvesting resources and outsmarting early moisture stress in a drought-prone region. Meanwhile, *D. exilis* followed a different ontogeny by reaching greater plant height and a greater leaf area index (LAI) at later stages.

The differing growth dynamics is in agreement with phenological assessment of African West African fonio landraces where large variability exists between and within varieties in vegetative growth pattern and the strategy in dealing with abiotic stress (Causse *et al.*, 2025). Furthermore, the clearly variation observed in phenological characteristics, particularly the shorter days to flowering initiation in *D. iburua*, reinforces large genetic differentiation between the two varieties. Early-maturing ideotype of *D. iburua* possesses direct agronomic advantages to fit short-season, semi-arid regions and provides a reliable way for farmers to alleviate transitory food insecurity.

Profiling of reproductive traits and yield component indicates that *D. iburua* possesses a high number of seed per spikelet and greater thousand seed weight than *D. exilis*. Considering that number of seed per spikelet and thousand seed weight are the direct

indicators of overall grain yield, the superior reproductive potential in *D. iburua* suggests that it can serve as a great genetic resource for future marker-assisted selection and crop improvement efforts. Those agronomic characters are directly related to selection factors of subsistence farmers in traditional smallholder cereal production where stable crop output of high-yielding and heavier seed characters would be selected.

Analysis of proximate composition shows both Digitaria species are high quality nutrient sources with differing nutritional allocation: *D. Iburua* possesses higher values for crude protein, crude lipid and crude fiber.

The high crude protein value of black fonio confirmed that it's an effective nutritional carrier for diets and capable of tackling PEM in rural agrarian households (Ayo *et al.*, 2020). In contrary, *D. exilis* allocates most of their metabolite towards total carbohydrate thus indicating its potential for providing great calorie value. Both species have low equilibrium moisture content that would offer tremendous physiological benefits, in preventing microbial invasion and enzymatic deterioration, thus maintaining stability of the product for extended storage and long shelf life without needing sophisticated storage facilities.

4.2 Mineral and Vitamin Composition

The element analysis of the two fonio samples under consideration yielded measurable levels of the following essential macro and micro-minerals: Calcium (Ca), Magnesium (Mg), Sodium (Na), Iron (Fe), Zinc (Zn) and Phosphorus (P). Majority of the mineral element levels, especially calcium and magnesium were found to be comparatively higher in *Digitaria iburua* than in *D. exilis*. Calcium and magnesium are physiological relevant minerals responsible for bone integrity, electrolyte balance, neuromuscular activities, activation of enzymes, among other physiological functions crucial to human well-being. The comparatively high level of the elements in black fonio further supports its nutritionally relevant value as a valuable indigenous cereal that could significantly contribute to the provision of dietary mineral nutrients, thus alleviating the burden of micronutrient deficiencies in many developing countries (Aremuet *al.*, 2006; Jideani & Jideani, 2011).

Vitamins, especially vitamins A, C, E, and the B-complex vitamins are essential compounds that equally demonstrate the nutritional and functional value of these underutilized cereals. Vitamins are indispensable to normal physiological functions, such as immune system enhancement, antioxidant effects, metabolic activities and repair processes. Coupled with mineral elements the presence of these vitamins adds further support to the emerging appreciation of fonio as a nutritionally dense functional food and a candidate for food security and nutritional intervention programs for the promotion of indigenous diets in sub-Saharan Africa (NRC, 1996; Vodouh *et al.*, 2006).

4.3 Phytochemical Profile and Anti-nutritional profile

Phytochemical screening, qualitatively and quantitatively reveal several classes of compounds in the sample including flavonoids, tannins, alkaloids, steroids, glycosides, total phenolic content. These compounds, referred to as secondary metabolites in plants, are vital in plant protection and exhibit remarkable ability in radicals scavenging, antimicrobial and anti-inflammatory functions in plants when

consumed. The relatively high quantity of the total flavonoids and the polyphenolic fractions quantified in a large number of anatomical structures in *D. Iburua* show its higher antioxidant capacity than in *D. exilis*, and therefore, *D. iburua* represents a significant nutraceutical and therapeutic candidate with great potential in dietary intervention of metabolic diseases such as type 2 diabetes through adequate nutrition. (Jideani & Jideani, 2011).

The negative aspect in terms of anti-nutritional compounds like oxalates and phytates present was mitigated by other nutritional profiles. Oxalates and phytates serves as antioxidant and are good for other health benefits, but the elevated total minerals present with a high amount of carbohydrate and protein could suggest easy bio-available nutrient after appropriate processing treatments (fermentation, de-husking, germination etc.) are performed

5. Conclusion

In conclusion, this comparative analysis affirms the suitability of *Digitaria exilis* and *D. iburua* as very hardy, bio-active and nutritious indigenous cereals, tailor-made for incorporation into agro-systems under semi-arid conditions for sustainable utilization. Their low moisture demands and strong phytochemical arsenal coupled with good nutritional properties for macronutrients and micronutrients places them as climate smart orphan crops for sustained usage. By improving their cultivation and industrial value addition, these short-seasoned millets represent a plausible way for improving aggregate food security, rural livelihood generation, and sustainable dietary diversity in semi-arid environments. Increased cultivation, conservation, genetic improvement, and value addition of fonio should therefore be encouraged to enhance sustainable agricultural production and rural livelihoods in Nigeria and across West Africa.

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References

Abdullahi, D. and Luka, D. (2003). The status of Acha (*Digitaria exilis*) production in Bauchi Stateof Nigeria: Report of the Crop Area Yield (CAY) for year 2003.Presented at the1st National Acha Stakeholders workshop in Jos. Submission of Bauchi State Agricultural Development Program, Bauchi

Achigan-Dako, E. G., Sogbohossou, O. E., &Maundu, P. (2014). Current knowledge on *Gynandropsisgynandra* (L.) Briq. (Cleomaceae): A roadmap for research and development of an underutilized vegetable crop. *Genetic Resources and Crop Evolution*, *61*(1), 177–187. https://doi.org/10.1007/s10722-013-0022-2

Adoukonou-Sagbadja, H., Wagner, C., Dansi, A., Ahlemeyer, J., Daïnou, O., Akpagana, K., Ordon, F., &Friedt, W. (2006). Genetic diversity and population differentiation of traditional fonio

millet (*Digitaria* spp.) landraces from different agro-ecological zones of West Africa. *Theoretical and Applied Genetics*, *115*(7), 917–931. https://doi.org/10.1007/s00122-007-0620-1

Adoukonou-Sagbadja, H., Wagner, C., Dansi, A., Ahlemeyer, J., Dutreux, F., &Friedt, W. (2007). Genetic diversity and population structure of Guinea fonio (*Digitariaexilis*Kipp. Stapf) landraces revealed by AFLP markers. *Genetic Resources and Crop Evolution*, *54*(4), 819–832. https://doi.org/10.1007/s10722-006-9146-x

Andrieu, N., Howland, F., Acosta-Alba, I., Le Coq, J. F., Osorio-García, A. M., Martínez-Barón, D., &Speelman, E. (2015). The role of agroecology in climate-smart agriculture. *Agronomy for Sustainable Development*, *35*(4), 1239–1252. https://doi.org/10.1007/s13593-015-0325-4

Animasaun, D. A., Morakinyo, J. A., & Mustapha, O. T. (2014). Assessment of genetic variability in Nigerian fonio millet (*Digitariaexilis* and *Digitariaiburua*). *Nigerian Journal of Genetics*, *28*(2), 45–52. https://doi.org/10.1016/j.njg.2014.11.002

Association of Official Analytical Chemists (AOAC). (2010). *Official methods of analysis* (18th ed.). Association of Official Analytical Chemists.

Atwater, W. O., & Rosa, E. B. (1899). *Description of a new respiration calorimeter and experiments on the conservation of energy in the human body* (Bulletin No. 63). U.S. Department of Agriculture, Office of Experiment Stations. Government Printing Office.

FAO (2003) *(Anchors the standard calculation of carbohydrates by difference)*

Food and Agriculture Organization of the United Nations (FAO). (2003). *Food energy: Methods of analysis and conversion factors* (FAO Food and Nutrition Paper No. 77). Food and Agriculture Organization of the United Nations.

Ayo, J. A., Ayo, V. I., & Johnson, R. G. (2020). Chemical composition, physical and sensory qualities of acha-guava flour blend biscuits. *FUOYE Journal of Agriculture and Human Ecology*, *3*(2), 114–125. https://doi.org/10.62923/fuojahe.v3i2.114

Ayenan, M. A. T., Ofori, K., Ahoton, L. E., &Danquah, E. Y. (2017). Utilization and farmers' knowledge on fonio (*Digitaria* spp.) production in West Africa. *Journal of Ethnic Foods*, *4*(2), 87–96. https://doi.org/10.1016/j.jef.2017.05.006

Ballogou, V. Y., Soumanou, M. M., Toukourou, F., &Hounhouigan, J. D. (2013). Evaluation of agronomic performance of fonio (*Digitariaexilis* and *Digitariaiburua*) in West Africa. *African Journal of Agricultural Research*, *8*(29), 3921–3928. https://doi.org/10.5897/AJAR2013.7219

Causse, S., Kaczmarek, T., Dubois, C., Achigan-Dako, E. G., Adjebeng-Danquah, J., Agyaree, R. Y., Akanvou, L., Bakasso, Y., Barry, M. B., Diop, B. M., Gueye, M. C., Ibrahim Bio Yerima, A. R., Oselebe, H. O., Idil, S. S., Uyoh, E. A., Vancoppenolle, S., Barnaud, A., Billot, C., Ramie, J. F., & Leclerc, C. (2025). A fast and effective method to distinguish cultivated fonio species: Conservation and evaluation perspectives. *Journal of Plant Breeding and Crop Science*, *17*(3), 88–99.

Cruz, J. F. (2011). Fonio: A small grain with potential. *LEISA Magazine*, *27*(1), 16–17.

Cruz, J. F., Béavogui, F., &Dramé, D. (2016). *Fonio: An African cereal*. Quae, CTA, Presses Agronomiques de Gembloux.

Daichi, S.N., Mamza, W.S. and Bakare, S.O. (2017). Growth and yield of Acha (*Digiteria exilis* Kippis Stapf) as influence by sowing methods and nitrogen rates in the Guinea

savanna areaof Nigeria. *Journal of science and technology*. 3(2): 33-37.

Dansi, A., Vodouhè, R., Azokpota, P., Yedomonhan, H., Assogba, P., Adjatin, A., Loko, Y. L., Dossou-Aminon, I., &Akpagana, K. (2010). Diversity of the neglected and underutilized crop species of importance in Benin. *Scientific Research and Essays*, *7*(4), 319–339.

Duncan, D. B. (1955). Multiple range and multiple *F* tests. *Biometrics*, *11*(1), 1–42. https://doi.org/10.2307/3001478

Ebere, C., &Godswill, A. C. (2016). Nutritional and health benefits of fonio (*Digitaria* spp.): A review. *International Journal of Advanced Academic Research*, *2*(11), 15–23.

Enyiukwu, D. N., &Bassey, S. U. (2020). Fonio millet in Africa: Nutritional value, production constraints, and prospects for improvement. *Asian Journal of Research in Crop Science*, *5*(3), 1–15. https://doi.org/10.9734/ajrcs/2020/v5i330099

FMnEnv. (2014). Federal Ministry of Environment. *United Nations Framework Convention on Climate Change (UNFCCC): Second National Communication of the Federal Republic of Nigeria*. Federal Ministry of Environment.

Field, A. (2013). *Discovering statistics using IBM SPSS statistics* (4th ed.). SAGE Publications.

Garba , D. S., & Sabo, M. U. (2025).Effect of seed sowing type and seed rate on the productivity of fonio (*Digitaria exilis* L.) in Bogoro, Bauchi State, Nigeria. *Nigerian Journal of Agriculture and Agricultural Technology (NJAAT)* 5, (1A): 2811-1885; ISSN (Online): 2811-1893

Garí, J. A. (2002). Review of the African millet diversity. *International Journal of Food Sciences and Nutrition*, *53*(5), 419–426. https://doi.org/10.1080/09637480220138096

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed.). John Wiley & Sons.

Ibrahim, A., Mohammed, S., & Yusuf, A. (2020). Morphological characterization of fonio millet (*Digitaria* spp.) in northern Nigeria. *Nigerian Journal of Crop Science*, *7*(1), 55–63.

IPGRI. (2004). International Plant Genetic Resources Institute. *Descriptors for fonio (Digitariaexilis and Digitariaiburua)*. IPGRI.

Isa, S., Mohammed, A. A., Adamu, A, Z., & Jauhar, S. J. (2024). Analysis of agromorphological characteristics, nutritional values and phytochemical constituents of two fonio species in Gombe State, Nigeria towards enhancing national food security. *Journal of Natural Science Review*, *2*(Special Issue), 109–129.

Jideani, I. A. (2012). *Digitaria exilis* (acha/fonio), *Digitaria iburua* (iburu/fonio): Underutilized cereal grains with potentials. *Nutrition Reviews*, *70*(12), 681–692. https://doi.org/10.1111/j.1753-4887.2012.00541 x

Jideani, I. A., & Jideani, V. A. (2011). Developments on the cereal grains *Digitaria exilis* (acha) and *Digitariaiburua* (iburu). *Journal of Food Science and Technology*, *48*(3), 251–259. https://doi.org/10.1007/s13197-010-0208-9

Jones, D. B. (1941). *Factors for converting percentages of nitrogen in foods and feeds into percentages of proteins* (Circular No. 183). U.S. Department of Agriculture.

Kwon, C.-W., Musdalifah, M., & Park, J.-H. (2021). Agronomic characterization and growth performance of underutilized millets: A review of phenological tracking methods. *Journal of Crop Science and Biotechnology*,

24(4), 365–378. https://doi.org/10.1007/s12892-021-00102-x

Laheri, F., & Soon, J. M. (2018). Applications of fonio (*Digitaria* spp.) in food products and human nutrition. *Journal of Cereal Science*, *83*, 166–172. https://doi.org/10.1016/j.jcs.2018.07.009

Luke, J., &Abdullahi, M. B. (2013). Phytochemical constituents of some Nigerian vegetable plants. *Jewel Journal of Scientific Research*, *1*(Maiden Edition), 81–85.

Mbosso, C., Bouharmont, P., &Mergeai, G. (2020). Fonio (*Digitariaexilis*): A neglected cereal with high potential for food security in Africa. *Biotechnology, Agronomy, Society and Environment*, *24*(2), 91–101. https://doi.org/10.25518/1780-4507.18525

Merrill, A. L., & Watt, B. K. (1973). *Energy value of foods: Basis and derivation* (Agriculture Handbook No. 74). Human Nutrition Research Division, Agricultural Research Service, U.S. Department of Agriculture.

National Research Council (NRC). (1996). *Lost crops of Africa: Volume I: Grains*. The National Academies Press. https://doi.org/10.17226/5135

Nimyel, D. N., Mwanse, D. D., &Gyang, J. D. (2020). Analysis of rainfall and temperature trends over Bauchi State, Nigeria. *Journal of Atmospheric and Earth Sciences*, *4*(1), 12–25.

Ojanuga, A. G. (2006). *Agroecological zones of Nigeria*. National Special Programme for Food Security, Federal Ministry of Agriculture and Rural Development.

Pucher, A., Sy, O., Angarawai, I., &Zangre, R. (2015). Agro-morphological characterization of fonio millet (*Digitaria* spp.) accessions from West Africa. *Plant Genetic Resources*, *13*(1), 45–54. https://doi.org/10.1017/S147926211400061X

Radford, P. J. (1967). Growth analysis formulae—their use and abuse. *Crop Science*, *7*(3), 171–175. https://doi.org/10.2135/cropsci1967.0011183X000700030001x

Schippers, R. R. (2000). *African indigenous vegetables: An overview of the cultivated species*. Natural Resources Institute/ACP-EU Technical Centre for Agricultural and Rural Cooperation.

Sekloka, E. (2015). Traditional cultivation practices and constraints in fonio production systems in West Africa. *African Journal of Agricultural Research*, *10*(8), 789–798. https://doi.org/10.5897/AJAR2014.9392

Sofowora, A. (1996). *Medicinal plants and traditional medicine in Africa* (2nd ed.). Spectrum Books Limited.

Trease, G. E., & Evans, W. C. (2002). *Pharmacognosy* (15th ed.). W.B. Saunders.

Upadhyaya, H. D., Pundir, R. P. S., Dwivedi, S. L., Gowda, C. L. L., Reddy, V. G., & Singh, S. (2008). Developing a core collection of pearl millet [*Pennisetumglaucum* (L.) R. Br.] germplasm using macro-demographic and geographic data. *Crop Science*, *48*(5), 1913–1922. https://doi.org/10.2135/cropsci2007.11.0649

Zhu, F. (2020). Fonio grains: Nutritional composition, functional properties, and food applications. *Food Chemistry*, *319*, Article 126564. https://doi.org/10.1016/j.foodchem.2020.126564