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Analysis of Agromorphological Characteristics, Nutritional Values and Phytochemical Constituents of Two Fonio Species in Gombe State, Nigeria towards the Enhancing Afghanistan National Food Security

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ABSTRACT

Fonio is a traditional African cereal grain that is poorly studied, as revealed in the literature. It has the potential to contribute significantly to whole grain diets, wellness, and economic status improvement and play an essential role in food security in developing economies. A comprehensive study compared the agromorphological characteristics and nutritional values of *Digitaria exilis* and *Digitaria iburua* (black and white fonio, respectively), both of West African origin. The parameters measured for morphological and physiological screening included the number of leaves, leaf area, number of tillers, number of spikes, spike length, number of seeds per spikelet, days to flowering, and thousand-seed weight. Nutritional values such as crude protein, crude fat, crude fiber, carbohydrate, moisture, and ash content were determined. Minerals, including sodium and potassium, were measured using flame photometry, while zinc, iron, and calcium were determined using atomic absorption spectrometry. Qualitative and quantitative analyses were carried out to assess the presence and quantities of bioactive compounds in the grains using methanol as the solvent for extraction. The results revealed that black fonio had the highest number of leaves (19), a shorter lifecycle (56 days to flowering), and a higher number of seeds with greater weight (0.84g). They were found to be more nutritious than white fonio in terms of proximate composition: moisture (3.81%), ash (1.69%), crude protein (12.3%), ether extract (2.81%), crude fiber (1.37%), carbohydrate (77.97%), and mineral composition. Additionally, black fonio contains many bioactive compounds, including flavonoids, tannins, steroids, and glycosides in all plant parts. At the same time, alkaloids and anthraquinones were present only in its roots. Therefore, black fonio (Digitaria iburua) is suggested as a viable candidate for breeding programs aimed at crop and yield improvement.

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Introduction

Fonio is one of the oldest cereal crops domesticated by farmers in West Africa, with cultivation believed to have begun approximately 7000 years ago (Garí, 2002). It refers to two cultivated grasses in the genus *Digitaria*, *D. exilis* and *D. iburua*, demonstrating a high drought tolerance, flooding, and diseases. Due to its hardy nature, fonio is considered a priority crop in West Africa. Fonio grains, a small-seeded cereal native to Western Africa, are crucial for food security (Zhu, 2020). It is an ancient, underutilized cereal cultivated by resource-poor farmers in arid and semi-arid regions of West Africa, who have conserved and used this cereal for nutrition and income generation. Subsistence farmers are the primary cultivators of fonio, and it serves as a staple cereal for over 95% of households in northern Nigeria, Burkina Faso, Guinea, and Mali (Jideani & Jideani, 2011).

Fonio plants exhibit high resistance to drought and adapt well to climate change. Germination is rapid, and the young plants are highly drought-resistant, enabling fonio to grow in harsh conditions. A key trait of fonio is its resilience to drought and climate adaptability, attributed to its C_4 metabolism, allowing it to thrive under local soil and climatic conditions (Cruz et al., 2011; 2016). Fonio plays a critical role in food and nutrition security for millions in the region, particularly during food shortages due to its short life cycle (Adoukonou-Sagbadja et al., 2006). Some varieties mature so quickly that they are ready for harvest long before other grains. During critical months each year, fonio becomes a "grain of life," as it is perhaps the world's fastest-maturing cereal, producing grain just six to eight weeks after planting. Without such fonio types, the annual hunger season in West Africa would be much more severe. These varieties provide early-season food when the main crops are immature and last year's reserves have been exhausted.

Other fonio varieties mature more slowly, typically in 165-180 days. By planting a mix of fast- and slow-growing varieties, farmers can ensure a continuous grain supply throughout the year. This approach enhances food security under unpredictable growing conditions (NRC, 1996).

Due to limited research, fonio, also called "hungry rice," remains agronomically primitive and is characterized by small seeds, low yields, and some seed shattering. The plant responds to fertilizers, though excessive application may cause the plants to become top-heavy and susceptible to lodging. Thus, agromorphological characterization of local germplasm is crucial for understanding diversity, facilitating targeted genetic breeding, and potentially linking this information to genotypic data (Pucher et al., 2015). Traditionally, morphological traits have been used to assess genetic diversity and classify germplasm, although this method is relatively primary.

As a novel food, fonio has attracted global attention due to its favorable nutritional properties (e.g., whole grain and gluten-free) and potential applications in food products. Fonio, a small-sized cereal in the genus *Digitaria*, is a traditional crop grown in West Africa (Ayenan et al., 2017). Compared to major cereals like wheat and rice, fonio is an underutilized grain with promising food applications (Mbosso et al., 2020). It has attracted interest in various regions for its potential in food products (Jideani, 2012; Laheri & Soon, 2018; Abrouk et al., 2020). Industrial applications in the confectionery and pharmaceutical sectors have also been reported (Jideani, 2012).

Despite issues of food insecurity, malnutrition in children, diabetes, and high healthcare costs, there has been limited research on fonio production and improvement in Gombe State, Nigeria. The crop has not been prominent in local agricultural improvement initiatives. Although Fonio has significant potential, only about 19 research articles have been published over the past 20 years. Unlike other crops, fonio's comprehensive nutritional profile is absent from major databases like the USDA (Enyiukwu et al., 2020).

Food insecurity remains a pressing issue in Africa, where hunger threatens peace and stability. This situation is partially due to the neglect of native crops like fonio that have sustained the continent for thousands of years (Cruz, 2011; Sekloka, 2015). Despite fonio's significance in traditional farming, research to improve it has been minimal. Fonio (acha) faces challenges such as inadequate crop management and the absence of improved varieties, limiting productivity. Additionally, the lack of research attention has hindered the crop's genetic potential. Fonio is a staple crop for small-scale farmers, offering numerous nutritional benefits and requiring minimal inputs, making it an accessible source of income and food security for rural communities. Crops are crucial to food security, especially during hunger when household food reserves are low (Dansi, 2010). To improve fonio, research is needed to identify genetic diversity among landraces and existing germplasm. Traditional practices, such as broadcasting seeds at undefined rates based on availability and farmer expertise, often lead to low yields and require refinement (Sekloka, 2015).

Tolerant to drought, flooding, and pathogens (Ballougou et al., 2013), fonio is well-suited to the local growing conditions in Nigeria's Plateau, Niger, Nasarawa, Bauchi, Kebbi, Abuja, and Kaduna states, where warm, arid climates dominate most of the year (Animasaun et al., 2014). Fonio's adaptability to varied climates and soil types makes it an invaluable crop for local agriculture (NRC, 1996). Fonio's drought resilience during early growth stages and low greenhouse gas emissions make it a potential climate-smart crop for semi-arid regions (Andrieu et al., 2015). It plays a critical role in food and nutrition security for millions, especially during food shortages caused by its short lifecycle (Adoukonou-Sagbadja et al., 2006).

This cereal grain with excellent nutritional properties should be encouraged, considering the challenging cost of health care if the growing population is to experience the full benefits of fonio (*acha*) for an active, healthy life (Ebere and Godswill, 2016). Moreover, health reports identified iodine, iron, vitamin A, and zinc deficiencies among the world's most serious health factors. All these, put together, make the crop an inviting specimen for both classical and biotechnological attention ranging from its agronomy, seed size enhancement, plant health management, antilodging, anti-nutrients and nutritional profile, health benefits, pharmaceutical properties, value chains and scientific validation of its phyto-therapeutic activities and mycotoxins inhibitors (Enyiuku and Bassey, 2020). Hence, there is a need for this research to help address food insecurity in Nigeria and Afghanistan, as this is a bedeviling phenomenon that has spread across the globe. This will help attain the sustainable development goal (SDG) in Afghanistan. This study aimed to determine the possibility of growing fonio in diverse Afghanistan land to increase food security by comparing agromorphological characteristics and the nutritional values of *Digitaria exilis* and *Digitaria iburua* (black and white fonio, respectively).

Materials and Methods

Study Area

This study was conducted at the Botanical Garden and the Gombe State University, Nigeria laboratory, located at latitude 10 18′20′′N and longitude 11 10′30′′E.

Sample Collection and Identification of Plant Materials

The two fonio (white and black) seeds (Plate 1A and 1B) were collected from the National Cereal Research Institute (NCRI) Badeggi, Niger State. The plant species were identified by a Taxonomist at the Herbarium of Gombe State University with the voucher numbers GSUH 379 for the white fonio and GSU 354 for the black fonio.

Soil Preparation and plantation

Humus and topsoil were used in this study and obtained from the botanical garden of Gombe State University.

A nursery bed of 3 by 2 square meters was prepared for each species. The seeds were planted using the broadcasting method; a spoonful of each fonio species was mixed with sand and broadcasted. The soil was roughly loosened before planting; the seeds were then lightly dug into the soil or covered using a stick and allowed to germinate.

Cultural practice

Watering. Rainwater was adopted during the rainy season (late July to early October 2021). Where there was drought, the plants were subjected to irrigation for healthy growth by applying water in the morning and evening.

Weed control . Weeds were managed by hand due to the delicate nature of the plants throughout the period.

Harvesting

Harvesting of the fonio plants started at 10 weeks and 12 weeks for the black and white fonio, respectively. Hands carried out the harvesting process due to the delicate nature of the plants.

Dehusking

The removal of the hulls of the paddy fonio was traditionally done by pounding the grains with a pestle in a mortar to crack the hulls and then winnowing successively to separate the grain from the hulls.

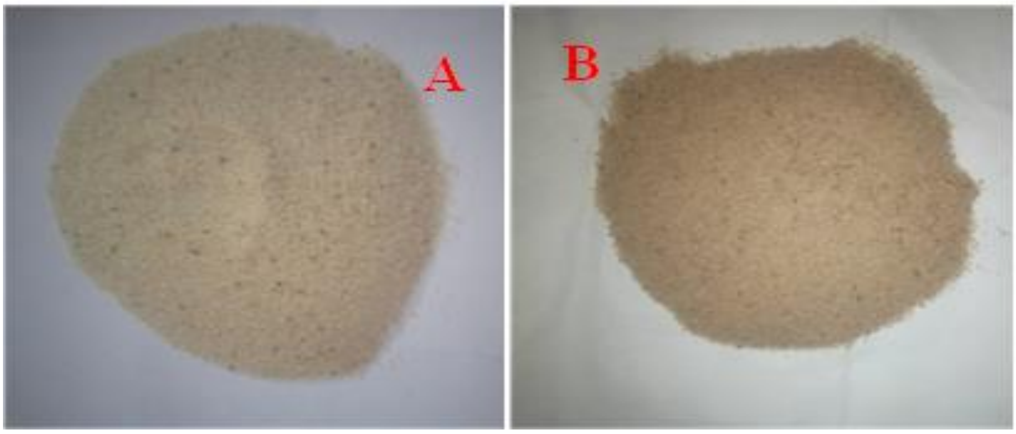


Figure 1: Two varieties of fonio grains after dehusking. Plate A displays the white fonio, and Plate B is the black fonio.

Data Collection

The data were collected twice a week for both varieties. All quantitative traits (vegetative and reproductive), plant height, leaf area, and spike length were measured using a meter rule. The number of leaves borne on each plant, number of tillers, days to flowering, number of spikes and seeds per spikelet were counted. Thousand 1000 seeds were counted, and the weight was determined using a digital weighing balance adopted by Ibrahim *et al*. (2020).

Agromorphological Characterization

The phenotypic characteristics of the plants at various stages were critically observed, from the vegetative to the reproductive stage, to determine the growth and development of the plants.

Samples Preparation

The samples (black and white fonio grains) were dehusked, destined, washed with distilled water, and allowed to air dry in the laboratory. They were then ground into fine powder using mortar, pestle, and an electric blender (Plate A and 2). The powder was stored in an air-tight sterile polythene bag for the proximate and mineral analysis.

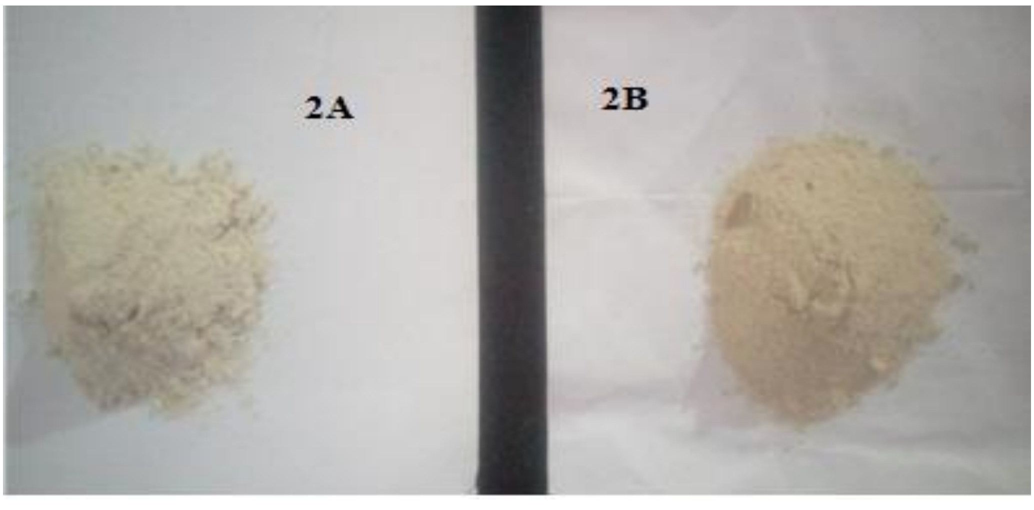
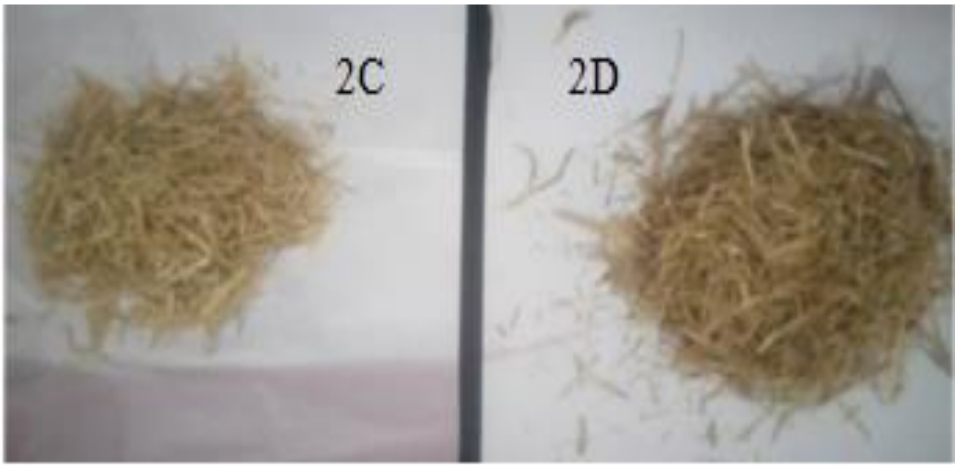


Figure 1: Powder forms of the two fonio varieties. Plate 2A is a white fonio powder, and Plate 2B is a black fonio powder

Preparation of Extract

The harvested plant materials were carefully washed under running tap water, followed by sterilized distilled water, and were air dried at room temperature in the laboratory for 21 days. These dried plant materials (Plate 2A & 2B) were then homogenized to a fine, coarse powder using an electric blender and stored in air-tight containers until further use. The grinded plant parts were extracted in the Gombe State University Biochemistry department using the method adopted by Sofowora (1996).



Nutritional Analysis

Standard analysis methods were used to analyze both grains' proximate and mineral composition. The nutritional values such as crude protein, crude fat, crude fiber, carbohydrate, moisture, and ash content were determined as adopted by AOAC (2010).

Determination of Moisture Content. Procedures: Six empty dishes were heated in an ovum at about 100^{o}C until a constant weight was attained (W_1). About 2g of the sample was put into each empty dish and weighed (W_2). The dishes in which the sample was put were heated at a temperature of about 100^{o}C in an oven for a day (24 hours), after which it was weighed and then reweighted after another 3 hours to obtain a constant weight (W_3). The moisture content was calculated as follows;

$$\%\,moisture = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where:

W_1= empty dish weight.W_2= dish weight + sample weight before drying. W_3= dish weight + sample weight after drying (AOAC, 2010).

Determination of Ash Content. Procedures: The ash content was determined using the AOAC (2010) method. About six (6) crucibles were dried in an ovum, and a desiccator was used to cool them. The crucible with the samples was introduced into the furnace, set at 6000C, and ignited for about eight hours. The crucibles with the ash were taken out, cooled in a desiccator, and weighed (W_3).

% ash content was calculated as follows;

$$\% \, ash = \frac{weight \ of \ ash}{weight \ of \ sample} \times 100$$

Determination of Protein. Total protein was determined using the Kjedahl method. 0.5g of the sample was weighed in triplicate into a filter paper and put into a Kjedahl flask, 8 to 10cm^3 of concentrated H_2SO_4 were added and then digested in a fume cupboard until the solution became green. Distillation was carried out with about 10cm^3 of 40% NaOH solution. The condenser tip was dipped into a conical flask containing 5cm^3 of 2% boric acid in a mixed indicator till the boric acid solution turned green. Titration was done in the receiver flask with 0.01M HCl until the solution turned red (AOAC, 2010).

Determination of Crude Fiber. The weight (W1) of the chaff from the extraction was recorded and transferred to a beaker. Water and NaOH were added and boiled for 30 minutes, filtered, and the residue acidified in a beaker, boiled for 30 minutes, filtered again, and the residue generated was transferred into a crucible and weighed (W2). This new weight (W2) was oven-dried at 105^{o}C. The residue was moved into a furnace and ash at 550^{o}C. The weight of the crucible and the content were taken and recorded (AOAC, 2010).

$$\% \, ash = \frac{W3 - W2}{W1} \times 100$$

Determination of Crude Fat. Few granules that prevent bumping were added to Six (6) cleaned round flasks, and Petroleum ether with B.P 40- 600^{o}C of about 300mls was put into each flask and then fixed in the soxholer extraction units. The thimbles for Extraction were weighed and 20 milliliters of the samples was put into the weighed thimble (W1). The thimble was put into the Soxhler extraction unit, including the forceps and the circulation of the cold water was turned on. The heating mantle was turned on, and the refluxing solution was set at a constant pace. The Extraction was performed for about eight hours. The thimble was taken out, dried at 70^{o}C to a constant weight, and weighed (W2). The calculation of extractable fat (AOAC, 2010) was as follows;

$$\% \, crude \ fat = \frac{W3 - W1}{W2 - W1} \times 100$$

Carbohydrate Determination . The carbohydrate content was calculated using the following formula:

Available carbohydrate (%), = 100 – [protein (%) + Moisture (%) + Ash (%) + Fibre (%) + Crude Fat (%)] (AOAC, 2010).

Energy Calculation. The percent of black and white Fonio calories were calculated from the crude protein, fat, and carbohydrate values obtained in this experiment. First, crude protein and carbohydrate percentages were multiplied by 4, crude fat multiplied by 9, and all the values obtained were added. The calculation was done as follows;

Energy (Kcal/100g) = [% C.P × 4] + [% carbohydrate × 4] + [% C.F × 9] where: C.P is Crude Protein and C.F is Crude Fat.

Determination of Anti-nutrients. Determination of phytate content: This was carried out according to AOAC, (2010). Two grams (2.0 g) of the sample was weighed using electronic balance. The sample was extracted using 0.2N HCl (aq), then 0.5 ml of the extract was pipetted into a test tube fitted with glass stopper. One milliliter (1ml) of the solution was added in the tube and covered with stopper, which was fixed with a clip. The tube was heated in a boiling water bath for 30 minutes and the tube was covered very well with the stopper for the first 15 minutes. Then the test tube cooled in ice water for 15 minutes and allowed to adjust to room temperature. Then the content of the test tube was mixed very well and centrifuged for 30 minutes. One ml of the supernatant was transferred into another test tube and 1.5 ml of the solution was added. The absorbance at 519 nm against distilled water was measured as follows:.

% Phytate = Au x C x 100 x Vf as W VA

Where: Au = absorbance of test sample, As = Absorbance of standard solution C, = concentration of standard solution, W = Weight of sample used, Vf = Total volume of extract and Va = Volume of extract.

Mineral Analysis

Minerals such as sodium and potassium were determined using flame photometry; zinc, iron, and calcium were determined using atomic absorption spectrometry, according to AOAC (2010).

Phytochemical Analysis

The method of Sofowora (1996) was employed for the qualitative screening to test the presence of the phytochemical constituents such as alkaloids, flavonoids, saponins, tannins, steroids, anthraquinones in the two fonio species using methanol solvent.

Quantitative Determination of Phytochemicals

The phytochemicals observed from the qualitative screening were further quantified using shoot, root, and seed extracts as Trease and Evans (2002) adopted.

Statistical analysis

All measurements were conducted in replicates. Measurements and are results presented as Mean ± SEM. Data obtained were inputted and compiled using Microsoft Excel 2013 and Jamovi software version 2.1.13. The data were subjected to analysis of variance (ANOVA) to ascertain whether there was a significant difference in the values obtained for the two varieties using Graph Pad Prism Software (Graph Pad Inc., San Diego, CA, USA) (*6*) at $p<0.05$.

Results

Physiological Screening

The physiological parameters of the two varieties, as presented in Table 1, showed a significant ($p \leq 0.05$) difference between the black and white fonio varieties. The plant height at week 4 (29.9 cm ± 0.86 and 29.9 cm ± 0.47), week 6 (51.2^{ab}cm ± 1.06 and 49.6^{ab}cm ± 1.10), and week 7 (57.3^{ab}cm ± 0.41 and 57.3^{ab}cm ± 0.41) were observed not to be significantly different between the fonio varieties whereas, highly significant values ($p < 0.001$) were observed in weeks 5 (40.3^{ab}cm ± 1.51 and 36.7^{ac}cm ± 1.11), 8 (60.1^{ab}cm ± 0.22 and 56.9^{ac}cm ± 1.60), 9 (64.3^{ab}cm ± 0.81 and 56.3^{ac}cm ± 1.39) and 10 (77.8^{ab}cm ± 1.97 and 56.3^{ac}cm ± 1.39) between the varieties. On the other hand, a highly significant ($p< 0.001$) difference was observed between the numbers of leaves where the black fonio variety produced a higher number of leaves from weeks 4 (6.8^{ab}± 0.81), 5 (13.2^{ab}± 0.87), 6 (16.4^{ab}± 1.3) to week 8 (19^{ab}± 0.87) as compared with the white fonio variety. Regarding leaf area index, the white fonio showed increased leaf area from week 8 ($12.8^{ab}$$cm^2$± 0.89) to week 9, compared to the black fonio. Increased numbers of tillers have been observed in white fonio from week 6 (3^{ab} ± 0.26) to week 8 (5.6^{ab} ± 0.16), whereas the black fonio started tillering at week 4 (2.5^{ab} ± 0.30) and reached its maximum at week 5 (5^{ab} ± 0.70).

Table 1: Varietal Comparison in Physiological Parameters of the Fonio Plants

Fonio Varieties	No. of Weeks	Plant Height(cm)	No. of Leaves	Leaf Area(cm^2)	No. of Tillers
White Fonio	4	29.9 ± 0.86	5.3^{ab} ± 0.50	0.97^{ab}± 0.19	0^{ab}± 0.00
	5	40.3^{ab} ± 1.51	6.6^{ab} ± 0.34	2.65^{ab} ± 0.18	0^{ab} ± 0.00
	6	51.2^{ab} ± 1.06	8^{ab} ± 0.21	7.48^{ab} ± 0.67	3^{ab}± 0.26
	7	57.3^{ab} ± 0.41	9.3^{ab}± 0.21	9.94^{ab} ± 0.45	4.6^{ab} ± 0.16
	8	60.1^{ab} ± 0.22	9.9^{ab} ± 0.23	12.8^{ab} ± 0.89	5.6^{ab}± 0.16
	9	64.3^{ab} ± 0.81	12.7^{ab}± 0.40	14.1^{ab} ± 0.91	5.6^{ab} ± 0.16
	10	77.8^{ab} ± 1.97	13.4^{ab}± 0.16	14.4^{ab} ± 0.97	5.6^{ab} ± 0.16
Black Fonio	4	29.9 ± 0.47	6.8^{ac}± 0.81	2.09^{cd} ± 0.22	2.5^{cd} ± 0.30
	5	36.7^{ac} ± 1.11	13.2^{cd}± 0.87	3.83^{ac} ± 0.40	5^{cd} ± 0.70
	6	49.6^{ac} ± 1.10	16.4^{cd}± 1.3	7.84^{ab} ± 0.99	5^{ab}± 0.70
	7	57.3^{ab} ± 0.41	18.4^{cd}± 0.90	10.8^{ac} ± 0.68	5^{ab} ± 0.70
	8	56.9^{ac} ± 1.60	19^{cd} ± 0.87	$11.^{ab}$ ± 0.75	5^{ab} ± 0.70

9	$56.3^{ac} \pm 1.39$	$18.4^{ac} \pm 1.02$	$11.1^{ac} \pm 0.75$	$5^{ab} \pm 0.70$
10	$56.3^{ac} \pm 1.39$	$18.4^{ac} \pm 1.02$	$11.1^{ac} \pm 0.75$	$5^{ab} \pm 0.70$

Table 2 presents the mean values of reproductive parameters of the fonio plants where the number of spikes exhibited per plant showed no significant difference between the two fonio species. However, spike length index recorded significant ($p \leq 0.05$) difference between the two fonio species. Highly significant ($p < 0.001$) variations were observed from the black fonio variety in terms of seeds number (130.4± 8.01).

Table 2: Varietal Comparison in Reproductive Parameters of the Fonio Plants

	Fonio Varieties	Mean ± STD.
Spike length(cm)	White Fonio	$12.42^{b} \pm 0.47$
	Black Fonio	$12.72^{a} \pm 0.07$
Number of seeds/spikelet	White Fonio	$88.3^{b} \pm 20.3$
	Black Fonio	$130.4^{a} \pm 8.01$
Number of spikelet	White Fonio	$8^{a} \pm 0.67$
	Black Fonio	$8^{a} \pm 1.28$

Values with different superscripts differ significantly at $p < 0.05$ for a parameter.

Phonology of the white and black fonio

The phonology of the fonio varieties is shown in Figure 1. The result shows a mean difference in the number of days to flowering, where the white fonio had a high number of days to flower (73), while the black fonio had a lower number of days to flower (58).

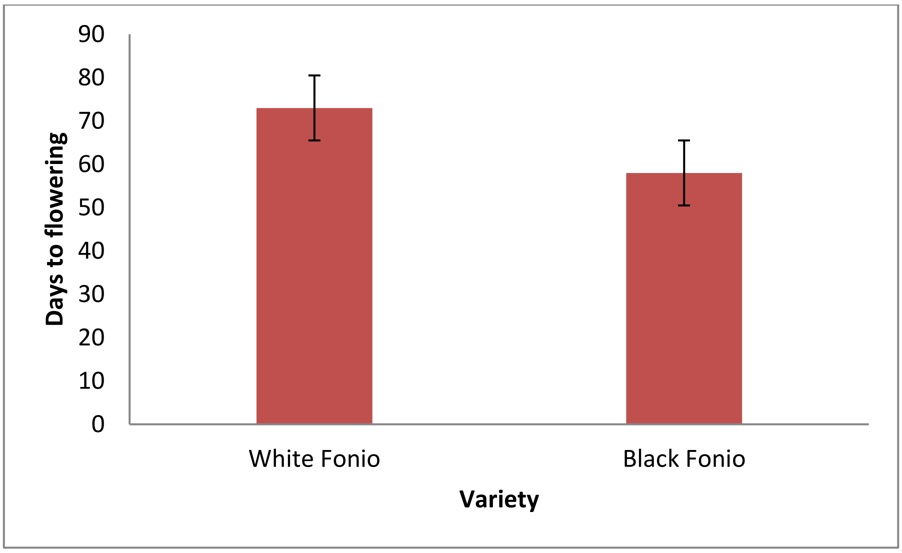


Figure 1: Phonology of white and black fonio

Weight of Thousand (1000) Seeds

The black fonio recorded the highest 1000seeds weight (0.84g) while the white fonio recorded the least (0.62g), as shown below in Figure 2:

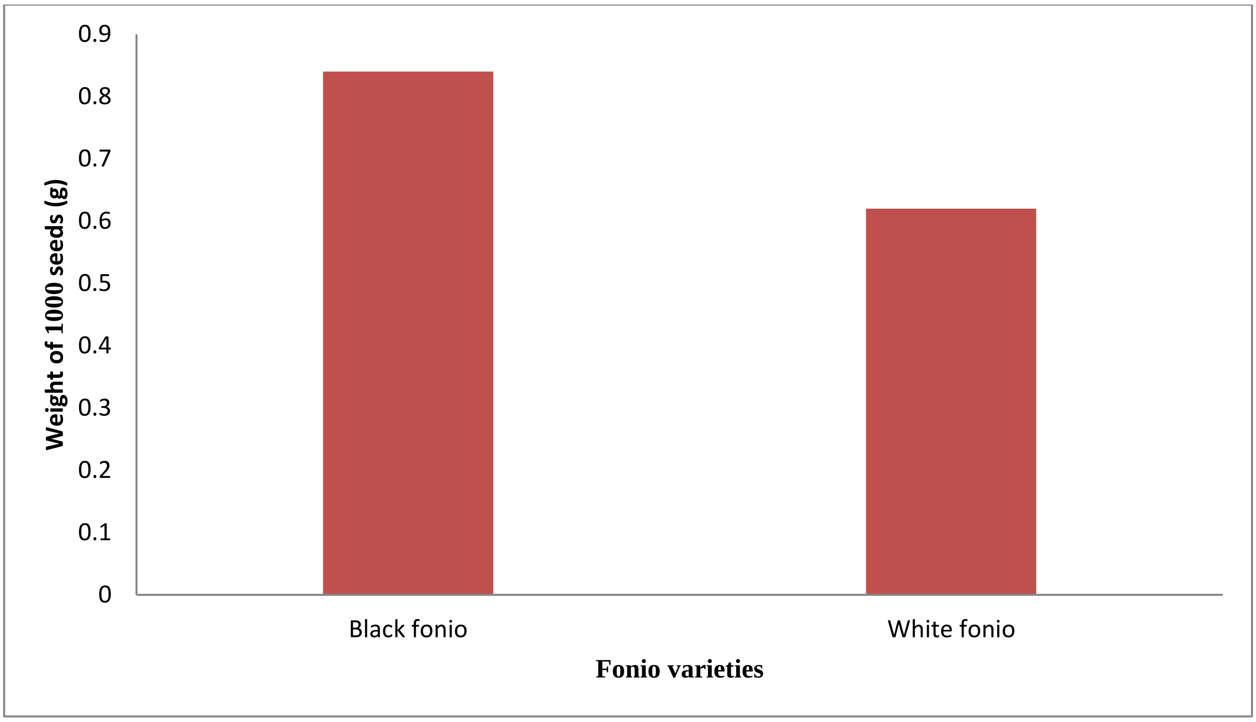


Figure 2: 1000seeds weight

Proximate Analysis

The nutritional, minerals, and phytochemical analyses of the two fonio species, Black (*Digitaria iburua)* and White (*Digitaria exilis*), were comparatively investigated in this study. The results of the proximate composition (moisture, ash, protein, fat, and carbohydrate) and mineral composition are presented in Table 3.

Moisture content was found to be 3.81 % and 3.83 % in black and white fonio, respectively. The statistical result shows no significant difference between the two fonio analyzed at $p<0.05$. The ash content was 1.69 % and 1.54 % in black and white fonio, respectively, and statistical results show no significant difference between the two fonio varieties analyzed at $p<0.05$.

However, crude protein was found to be 12.3% black fonio and 9.14% white fonio. The statistical result showed a significant difference between the two fonio varieties analyzed at $p<0.05$. Black fonio recorded a higher value of 2.81 % than white fonio, which recorded 2.26 % for ether extract (fat content) analysis. At $p<0.05$, there was a significant difference between the two varieties.

On the other hand, Crude fiber for black fonio was found to be 1.37% and 1.10% for the white fonio. Statistical results showed a significant difference between the black and white fonio at $p<0.05$. Carbohydrate content in white fonio was 82.16% and 77.97% in black fonio. Statistical results of the two varieties of fonio showed significant differences at $p<0.05$.

Table 3: Proximate Composition of White (Digitaria exilis) and Black (Digitaria iburua) fonio

Proximate Composition (%)

Samples	Moisture content	Ash content	Crude Protein	Ether Extract	Crude Fibre	Carbohydrate	Energy (Kcal/100g)
D. exilis	3.83^{a}±0.07	1.54^{a}±0.01	9.14^{a}±0.02	2.26^{a}±0.02	1.10^{a}±0.02	82.16^{a} ± 0.02	385.46^{a}±0.30
D. iburua	3.81^{a}±0.00	1.69^{a}±0.01	12.37^{b}±0.04	2.81^{b}±0.01	1.37^{b}±0.01	77.97^{b} ± 0.04	386.59^{a}±0.08

Values are expressed as Mean ± Standard Error of Mean of replicate readings.

Mineral elements analysis

Both the white fonio (*Digitaria exilis*) and black fonio (*Digitaria iburua*) showed significant amounts of the minerals analyzed, as shown in Table 4.

The Sodium concentration was 40.5 mg/100 g for white fonio and 56.5 mg/100 g for black fonio. At $p<0.05$, there was a significant difference between the two varieties of fonio analyzed in this study. Relatively lower values were obtained for potassium; white fonio recorded a higher value of 9.35 mg/100 g when compared with black fonio, which recorded 6.10 mg/100 g. The statistical result shows no significant difference between the two varieties of fonio analyzed in this study at $p<0.05$.

Conversely, black fonio recorded a relatively higher calcium concentration of 520 mg/100 g and 220 mg/100 g for white fonio. The statistical result shows no significant difference between the two varieties of fonio at $p<0.05$. The magnesium content obtained for the black fonio was 440 mg/100 g and 139 mg/100 g for the white fonio, which showed a highly significant difference at $p<0.05$ between the two varieties studied.

However, zinc concentration was 0.69 mg/100 g in black fonio and 0.44 mg/100 g in white fonio. Statistical results showed no significant difference at $p<0.05$ between the two varieties. Black fonio recorded 3.0 mg/100 g and white fonio 1.90 mg/100 g of iron concentration, where statistical results showed no significant difference at $p<0.05$ between the varieties.

Table 4: Mineral Composition of White Fonio (Digitaria exilis) and Black Fonio (Digitaria iburua)

Samples	Mineral Composition (mg/100 g)					
	Sodium	**Potassium**	**Calcium**	**Magnesium**	**Zinc**	**Iron**
D. exilis	40.5^{b} ± 0.35	9.35^{a} ± 0.18	220.0^{b} ± 0.00	139.0^{b}± 1.41	0.44^{a}± 0.01	1.90^{b}± 0.00
D. iburua	56.5^{a} ± 1.77	6.10^{b} ± 0.07	520.0^{a} ± 2.12	440.5^{a}± 3.18	0.69^{a} ± 0.01	3.00^{a} ± 0.14

Values are expressed as Mean ± Standard Error of Mean of replicate readings.

Phytochemical screening

The qualitative phytochemical screening for secondary metabolites, as shown in Table 5, revealed the presence of various phytochemicals in a shoot, seeds, and roots of white fonio (*Digitaria exilis*) and black fonio (*Digitalia iburua*). Flavonoids, tannins, steroids, and glycosides were present in all parts of the two varieties of the two fonio studied. Alkaloids were only present in the shoots and roots of both fonios and absent in both flowers. Conversely, saponin was found in the flowers of all the samples while anthraquinone was found in only the roots of both samples.

Table 5: Qualitative Phytochemical Screening of White Fonio (Digitaria exilis) and Black Fonio (Digitaria iburua)

Samples	Alkaloids	Flavonoids	Saponins	Tannins	Steroids	Glycosides	Anthraquinones
Shoot *D. iburua*	+	+	-	+	+	+	-
Seed *D. iburua*	-	+	+	+	+	+	-
Root *D. iburua*	+	+	-	+	+	+	+
Shoot *D. exilis*	+	+	-	+	+	+	-
Seed *D. exilis*	-	+	+	+	+	+	-
Root *D. exilis*	+	+	-	+	+	+	+

Key: + = Present; - = Absent; *D. = Digitaria*

Phytochemical Quantification analysis

The shoot of white fonio recorded the highest amount of alkaloids at 152.9 mg/kg, while the root of black fonio recorded 71.2mg/kg as the least. Flavonoid contents ranged between 69.2 - 183.51mg/kg in black fonio and 62.53 – 149.39mg/kg in white fonio, where the shoot of both white and black fonio recorded the highest amounts. Saponins recorded 91.6mg/kg in black fonio, while the white was beyond the detection limit. For steroids, the seed and root of black fonio recorded 118mg/kg and 121mg/kg, respectively, while the shoot and root of white fonio recorded 147mg/kg and 92mg/kg, respectively. Significant amounts of total phenolics were recorded in all samples: 235.5mg/kg, 122.52mg/kg, and 96.71mg/kg in the root, shoot, and seed of black fonio (*D. iburua)*, while 203.7mg/kg and 119.33mg/kg was recorded for root and seed of white fonio (*D. exilis)* respectively. The phytate concentration ranged from 180.95 mg/kg in the seed of *D. exilis* to 15.41mg/kg in *D. iburua* (Table 6).

Table 6: Quantitative Phytochemical Compositions of White Fonio (Digitaria exilis) and Black Fonio (Digitaria iburua)

Samples	Phytochemical Compositions(mg/kg)						
	Alkaloids	**Flavonoids**	**Saponins**	**Tannins**	**Steroids**	**Total phenolic**	**Phytate**
Shoot *D. iburua*	118	183.51	B.D.L	138	149	122.52	92.69
Seed *D. iburua*	B.D.L	69.2	91.6	20.28	118	96.71	15.41
Root D. iburua	71.2	101.8	B.D.L	164.35	121	235.5	126.2
Shoot D. exilis	152.9	149.39	B.D.L	39	147	B.D.L	B.D.L
Seed D. exilis	B.D.L	62.53	48.6	104	109	119.33	24.13
Root D. exilis	123.15	85.25	B.D.L	110.22	92	203.7	180.95

Key: B.D.L = Beyond Detection Limit (Absent); *D. = Digitaria*

Discussion

As the name implies, Fonio is mainly grown in Central and West Africa and is regarded as a small seed with a big promise on many occasions. It provides food in the early season when other crops are yet to mature for harvest (Ibrahim, 2001). The fonio grains have been confirmed to have been the most nutritious and tasty of all grains ever.

The agro-morphological characterization is essential for providing information for plant breeding programs (Nascimento *et al.*, 2011). A crop's morphological and agronomic characterization is important in managing genetic diversity. It is also a prerequisite for selecting improved varieties (Sekloka *et al.*, 2016).

In this study, the result of plant height showed a highly significant difference ($p< 0.001$) between the two varieties, which revealed that the white fonio variety produced taller plants with a longer lifecycle (84 days) as compared with the black fonio variety which produced shorter plants with a shorter life cycle (70 days). This agrees with the findings of the National Research Council (NRC, 1996), which reported that certain fonio varieties mature so quickly that they are ready to harvest long before all other grains. For a few critical months of most years, these become a "grain of life." They are perhaps the world's fastest maturing cereal, producing grain just 6 or 8 weeks after planting. It is also similar to the findings of Addai *et al*. (2022), who recorded mean plant height for the Kpenteke fonio variety (72.66 cm), which is among the commonly cultivated accessions in Ghana slightly lower than what was obtained in this study.

Moreover, the results also complement the findings of Nura *et al*. (2017), who reported that colchicines-treated seeds of white fonio produced taller mutants (79-83.93cm), which was slightly higher than what was obtained (77.8cm) in this study. However, the height difference observed suggests that the varieties might be genetically diverse and respond differently to the environment. Therefore, the plant height obtained in this study is in tandem with the findings of Cruz *et al*. (2011), who reported that Fonio reached a height of about 30 cm to 80 cm at maturity.

The number of leaves per plant showed a highly significant difference between the white and black fonio varieties. In contrast, the black fonio variety recorded more leaves (18) per plant. This is in contrast with the findings of Addai *et al*. (2022), who reported that the late maturing accessions registered the highest mean number of leaves (10 leaves) per plant compared to the early maturing accessions (7 leaves). Number of leaves borne by each plant is one of the visual key traits (phenotype) describing its development and growth; therefore, this study justifies and agrees with the findings of Dobrescu *et al*. (2017). Number of leaves produced by plants enables growth rate estimation and is related to the health status of the plant and its yield potential (Telfer *et al*., 1997; Walter and Schurr, 1999).

Conversely, a statistically significant difference was observed between the two fonio varieties where the white fonio leaf area recorded the largest leaf area compared to that of the black fonio. Morphologically, the black fonio showed shorter and broader leaves, while the white fonio showed longer and narrower leaves. Perhaps this study is in contrast with the findings of Addai *et al*. (2022). This suggests that the expression of fonio growth potential concerning leaf area depends on the genotypes and environmental factors.

The results of several tillers differ slightly, where the white fonio produced more tillers than the black fonio. This finding does not support the report of Dachi *et al.* (2017), where significant variation among black Fonio (*Digitaria iburua*) accessions for several tillers per plant was established in northern Nigeria. Similarly, Clottey *et al*. (2006) reported various tillers per plant, averaging 8 tillers in thirteen Fonio landraces assembled in Ghana. The results suggest that tillering in Fonio might depend on the location and the accession's genetic potential.

The number of days to flowering for both varieties disagrees with the findings of Skeloka *et al.* (2016), who reported extra-early accessions of less than 90 days and late accessions of more than 100 days. However, similar results regarding the earliness of Fonio were also found in Niger by Saidou *et al*. (2014). Identifying early accessions is of great agronomic importance for varietal breeding of fonio in the current context where climatic variations are becoming recurrent (Skeloka *et al.*, 2016). Early maturing fonio with higher grain yield are candidates for yield improvement and development of fonio lines with enhanced lodging resistance (Ibrahim *et al*., 2020).

The weight of a thousand seeds was fortunately found to be higher than that reported by Nyam *et al*. (2017) and Hammad *et al*. (2013), who obtained 0.51g and 0.75g, and also Ibrahim *et al*. (2020) who reported 0.76g, 0.68g, and 0.59g for their fonio accessions. These diversities observed among the fonio genotypes can be exploited by selecting genotypes with superior grain weight for improvement.

Proximate composition analysis of fonio research by Sadiq *et al*. (2015) reported a higher moisture value of 7% for both black and white varieties than in this study. Moisture content is an important index in food analysis as it indicates food stability. Hence, high moisture content predisposes food to bacterial and fungal attack, whereas low content indicates that food could be stored for a long time (Onwuka, 2005). Similarly, a relatively higher ash value of 2.31 % and 2.13 % for the black and white fonio was reported by Sadiq *et al*. (2015). Ash content is an important marker in food analysis as it's generally taken to measure the mineral content in the sample (Onwuka, 2015). Crude protein values obtained in this study are higher than those of Sadiq et al. (2015), who reported 8.75% and 7.11% for the black and white fonio, respectively. Proteins in the diet primarily build and maintain cells, but their chemical breakdown also provides energy, yielding nearly the same four (4) calories per gram as carbohydrates . Besides proteins functioning in synthesizing new cells and repairing worn-out tissues, enzymes, hormones, antibodies, and other substances, proteins are also required for healthy functioning and development of the body and its protection . The values obtained for fat content were relatively lower than those reported by Sadiq *et al*. (2015), which were 4% and 3% for the black and white fonio, respectively. Fats and oils in food serve as energy storage in the body, and they play a role in maintaining healthy skin and hair, insulating body organs against shock, maintaining body temperature, and promoting healthy cell function (Food Safety and Standards). Crude fiber for black fonio was higher than the values reported by Sadiq *et al*. (2015) of 1.03% and 0.79% for black and white fonio, respectively. Crude fiber speeds the passage of food through the digestive system, facilitating regularity. They also regulate blood sugar, possibly reducing the onset risk or symptoms of metabolic syndrome and diabetes (Food Safety and Standards Authority of India).

Carbohydrate content in Carbohydrates serves as the storage form of energy (glycogen) to meet the immediate energy demands of the body, provide necessary calories in the diet, promote the utilization of dietary fats, and reduce wastage of proteins (Balogun and Olatidoye, 2012). The energy value obtained is associated with the carbohydrate content, and thus, this makes fonio a valuable source of energy.

Minerals are inorganic nutrients that the human body needs in small amounts. Human beings require macro elements in amounts > 50mg/day, while trace elements are also essential but required in concentrations < 50mg/day (Belitz *et al*., 2009). Both white fonio (*Digitaria exilis*) and black fonio (*Digitaria iburua*) show significant amounts of the analyzed minerals, indicating that fonio can be regarded as good sources of essential minerals. The mineral elements analyzed in this study were sodium, potassium, calcium, magnesium, zinc, and iron.

The qualitative phytochemical screening for secondary metabolites revealed the presence of various phytochemicals in the shoot, seeds, and roots of white (*Digitaria exilis*) and black (*Digitaria iburua*) fonio which comprised flavonoids, tannins, steroids, and glycosides were found to be present in all parts of the two varieties of fonio studied. The presence of these bioactive substances (photochemical) in fonio is an indicator that fonio could serve as a potential source of natural antioxidants that could serve as therapeutic, anti-inflammatory, anti-analgesic, and anti-hyperlipidemic agents (Usunubon *et al*., 2015).

Phytate was revealed in all parts of white fonio (*D. exilis*) and black fonio (*D. iburua*) except the shoot of *D. exilis.* Generally, looking at the anti-nutritional indices investigated and the relatively low values obtained in both white fonio (*D. exilis*) and black fonio (*D. iburua*), it thus infers that the grain could be utilized effectively as there would likely be no interference with the nutritional markers or minerals.

Conclusion

This research was conducted to determine and compare the geomorphological variations, nutritional values, and qualitative and quantitative phytochemical constituents of *Digitaria exilis* (white fonio) and *Digitaria iburua* (black fonio). The results revealed that the most discriminating parameters were plant height, number of leaves, and number of seeds/spikelets. The black fonio variety was more vegetative with thicker and broader leaf area, earliest maturing with a shorter lifecycle, and the highest yielding variety with higher weight. It was more palatable regarding proximate and mineral composition than the white fonio (*Digitaria exilis*) and had a more comprehensive range of bioactive compounds.

Digitaria iburua (black fonio) is the best candidate, having the desirable traits for crop improvement, higher nutritional value, and constituting a wider range of bioactive compounds. The black fonio was more nutritive in terms of proximate and mineral composition than the white fonio (*Digitaria exilis*), where it contained significant amounts of minerals, thereby indicating that fonio can be regarded as a good source of essential minerals and the anti-nutritional indices investigated were relatively low and thus, infer that the grain could be utilized effectively as there would be likely no interference with the nutritional markers or minerals. Also, the bioactive compounds (phytochemicals) present indicate that the black fonio could serve as a potential source of natural antioxidants that could serve as therapeutic, anti-inflammatory, anti-analgesic, and anti-hyperlipidemic agents.

The black fonio (Digitaria iburua) can be a good candidate for crop and yield improvement and can cure diabetes and malnutrition in children. Therefore, this study will greatly improve crop, food, health, and nutritional security.

Recommendations

- Commercial farmers in Afghanistan should engage in black fonio cultivation to meet the demand for functional foods due to its shorter lifecycle and drought tolerance for food security.
- Although subject to environmental variations, plant genetic resources managers should not neglect these parameters since they have always been important in farmers' environments. They constitute important criteria for mass selection in crop improvement.
- The black fonio should be used for diabetic cure and prevention and for malnourished children due to its higher nutritional profile.
- A collaborative effort of the government, academia, and the food industry is required to assist in funding the development of equipment (dehusking machines) that would make it possible to mechanize grain production, which remains the major challenge to fonio production.
- Further studies should be conducted to improve the seed size for higher yield.
- Fonio shoots should be further investigated to be used as an alternative source of antibiotics.

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