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Analysis of Pretreatment Effect on the Chemical Composition of Tender and Matured Fronds of Vegetable Fern (*Diplazium esculentum*) in Nigeria

Nsidibe Nduenie Umodioh & Aniekpeno Isaac Elijah, PhD
Department of Food Science and Technology, Faculty of Agriculture
University of Uyo, Uyo, Akwa Ibom State, Nigeria
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Abstract

This study evaluated the effect of pretreatment on the chemical composition of tender and matured vegetable fern fronds in Nigeria. Fresh tender and matured fronds of vegetable fern were obtained from Mkpat Enin Local Government Area, Akwa Ibom State. The plant was identified in the herbarium, Department of Pharmacognosy and Natural Medicine, Faculty of Pharmacy, University of Uyo. The study adopted experimental research design to systematically analyze the effect of pretreatment on the proximate, mineral, vitamin and energy value of vegetable fern fronds. Results indicated that fresh fronds (untreated sample) of both tender and matured samples had significantly ($P < 0.05$) higher proximate, mineral and vitamin compositions than pretreated samples. The protein, ash, fibre as well as mineral contents of matured fronds (both treated and untreated) were significantly higher than that of the tender sample. Blanched samples significantly ($P < 0.05$) had highest fibre contents in tender (16.44%) and matured (18.11%) fronds. However, the vitamin composition of tender fronds (both treated and untreated) was significantly ($P < 0.05$) higher than that of matured sample. The control sample (fresh vegetable fern fronds) was not significantly ($p < 0.05$) different from shade dried sample (13.39 mg/100g) but had a significantly ($p < 0.05$) higher vitamin A content than hot water blanched (12.66 mg/100g), sun dried (12.64 mg/100g) and oven dried (12.06 mg/100g) samples which were not significantly different from one another. From the findings of the study, fresh tender vegetable fern fronds is recommended for consumption for maximum nutrient benefit. Shade drying should be employed in the pretreatment of vegetable fern to ensure its availability both in and out of season.

Keywords: *Pretreatment, Chemical Composition, Fronds, Vegetable Fern (Diplazium esculentum), Nutritional Analysis, Nigeria*

Introduction

There are numerous plant species that grow naturally and are consumed or even sold locally, yet are not cultivated. These are known as wild edible plants (Beluhan et al., 2010). One such highly nutritious edible plant is the vegetable fern (Diplazium esculentum), often referred to as "nyama idim" in Ibibio or "water fern" and "edible fern" in English. This pteridophyte is widely consumed in tropical and subtropical regions across the globe (Kumar, Singh, & Devi, 2023; Adediran, Ibrahim, & Okonkwo, 2023). The vegetable fern belongs to the Athyriaceae family and is commonly found in regions with sufficient moisture, such as India, China, Cambodia,

Laos, Vietnam, Nigeria, and Malaysia (Schuettpelz et al., 2016; Greeshma, Sridhar & Pavithra, 2018). The taxonomy of D. esculentum is classified under Kingdom Plantae, Division Tracheophyta, Class Polypodiopsida, Order Polypodiales, Family Athyriaceae, Genus Diplazium, and Species esculentum (USDA, 2018).

These vegetables provide significant nutritional benefits, including vitamins, phosphorus, calcium, iron, and bioactive compounds, making them vital for food security, nutrition, and medicinal purposes (Tharmabalan, 2023; Rahman, Choudhury, & Banu, 2024). The fronds, stems, rhizomes, and shoots of the vegetable fern are typically consumed fresh, boiled, blanched, in salads, stir-fried, or even pickled (Duncan, 2012). Additionally, vegetable fern has been noted for its traditional medicinal uses, particularly in treating conditions such as fever, dermatitis, measles, dysentery, glandular swellings, indigestion, diarrhea, and various skin infections (Abe et al., 2013; Zakiyyah & Sumardjo, 2016; Zannah et al., 2017).

The chemical composition of *Diplazium esculentum* differs considerably between tender and mature fronds due to the physiological and biochemical changes that occur during their growth and development (Borah et al., 2022; Sharma & Pandey, 2023). Research indicates that tender fronds are typically higher in moisture, vitamin C, and polyphenols, making them more prone to enzymatic degradation, whereas mature fronds have a higher fiber content and contain specific phytochemicals that offer health benefits such as enhanced digestion and cholesterol reduction (Singh, Sharma & Kumar, 2023; Rahman, Choudhury, & Banu, 2024). While tender fronds may be bitter or tasteless, they are the most affordable and easily accessible sources of vitamins and minerals (Mensah et al., 2008). The Adi tribe in the Dehang-Dehang Biosphere Reserve of Arunachal Pradesh, India, uses boiled tender fronds with boiled rice as a laxative (Kagyung et al., 2010). Furthermore, these plants do not carry the harmful effects associated with the fertilizers and pesticides commonly used in agricultural fields.

The nutritional importance of *Diplazium esculentum* goes beyond its basic macronutrient content to include several bioactive compounds with antioxidant, anti-inflammatory, and antimicrobial effects (Akter et al., 2014; Choudhury et al., 2017). The vegetable fern also contains flavonoids, phenolics, and carotenoids, all of which contribute to its health-promoting benefits (Tongco et al., 2014). However, like many leafy greens, *D. esculentum* also contains anti-nutritional factors such as tannins, oxalates, and phytates (Yusuff et al., 2023). These anti-nutritional compounds can impair the bioavailability of essential nutrients, making it necessary to apply appropriate pretreatment techniques to enhance its nutritional value (Jain & Bhardwaj, 2022). Understanding these variations is crucial for identifying the most effective pretreatment methods to optimize the nutritional potential of *D. esculentum*.

Studies suggest that pretreatment can improve the digestibility and safety of ferns while preserving their bioactive compounds (Adediran et al., 2023; Chen et al., 2023). Methods such as blanching, drying, controlled fermentation, and soaking in acidic solutions have been shown to lower oxalate and tannin levels, thereby enhancing digestibility and the bioavailability of minerals (Ramakrishna & Sulochana, 2023; Akinwale, Adegbite, & Eze, 2023; Mondal et al., 2023; Singh et al., 2023). For example, blanching helps reduce enzymatic activity and microbial load while maintaining key nutrients, though excessive heat exposure may result in the loss of vitamins (Okonkwo & Akinwumi, 2023; Akinwale et al., 2023). Fermentation, meanwhile, has been found to increase the bioavailability of minerals by decreasing the concentrations of phytates and oxalates, making essential nutrients more available for absorption (Jain & Bhardwaj, 2022). Soaking and drying are also commonly employed to extend shelf life and enhance sensory properties.

In Nigeria, the consumption of vegetable fern is restricted due to its seasonal availability, perishability, and the presence of anti-nutritional factors that can hinder nutrient absorption (Okonkwo & Akinwumi, 2023). The impact of various processing methods on the nutrient retention of both tender and matured fronds has not been thoroughly explored in Nigeria (Adediran, Ibrahim, & Okonkwo, 2023). Traditional processing techniques such as boiling, sun drying, and fermentation are used by local communities to enhance edibility, but their effects on the chemical composition of the fern remain insufficiently studied (Oladimeji et al., 2022; Yusuff, Adeoye, & Omole, 2023). This lack of documentation has led to the underutilization of *D. esculentum* in both household and commercial food systems, limiting its potential contribution to food security and economic empowerment in Nigeria.

Factors such as low awareness of its nutritional and economic advantages, the absence of standardized processing methods, and the presence of anti-nutritional factors contribute to the underutilization of *D. esculentum* in Nigeria (Olawale & Adeyemi, 2024). Olawale and Adeyemi (2024) further note that the lack of standardized processing techniques that can optimize its consumption and shelf life presents another challenge. Existing studies tend to focus on the general nutrient composition of *D. esculentum* rather than the specific effects of different pretreatment methods on the chemical properties of the fronds. The absence of comprehensive comparative studies on tender and matured fronds also limits the ability to optimize processing techniques for maximum nutritional benefit (Singh et al., 2023).

Therefore, the rising demand for indigenous vegetables with high nutritional value necessitates scientific validation of traditional processing methods (Oladimeji et al., 2022). Expanding the knowledge base on *D. esculentum* through empirical research will not only promote its inclusion in diets but also contribute to food security and sustainable nutrition strategies (Mondal et al., 2023; Singh et al., 2023). This study seeks to provide empirical insights into the effects of various pretreatment methods on the chemical composition of both tender and matured fronds of *Diplazium esculentum* in Nigeria.

Objectives of the Study

The specific objectives are to:

1. determine at effect of pretreatment on the proximate composition and energy value of vegetable fern fronds.
2. examine the effect of pretreatment on mineral composition of vegetable fern fronds.
3. assess the effect of pretreatment on vitamin content of vegetable fern fronds.

MATERIALS AND METHODS

1. Sample Collection and Preparation

This study adopted experimental research design. Fresh tender and matured fronds of vegetable fern were collected from Mkpat Enin Local Government Area, Akwa Ibom State, and identified at the University of Uyo Herbarium, (UUPH A10 (a). The fronds were cleaned, washed with distilled water, and cut into pieces. A total of 1.5kg of fresh fronds (tender and matured) was used, divided into five portions of 300g each. One portion served as the control sample, while the remaining portions were treated as outlined below.

i. **Oven dried**: 300g of vegetable fern fronds were oven-dried at 60°C for 48 hours using a Blast Air Oven (KX350A, Kenixin, China) and then stored in an airtight container.

ii. **Sun dried**: 300g of fronds were sun-dried at an ambient temperature of 35-41°C from 10:30 am to 5:30 pm daily for 5 days until constant weight was reached, then stored in an airtight container.
iii. **Hot water blanched**: 300g of fronds were blanched in hot water at 70°C for 2 minutes, then cooled with cold running water and drained.
iv. **Shade dried**: 300g of fronds were dried under shade with good ventilation, low humidity, and no direct sunlight exposure, similar to sun drying.

2. Determination of Proximate Composition Analysis

The proximate composition (moisture, crude protein, crude fat, ash, crude fibre, carbohydrate and total energy) of the treated and untreated vegetable fern samples were analysed following the method described in AOAC (2006).

i. **Determination of Moisture Content:** Cleaned Petri dishes were dried in hot air oven at 100^{o}C for 1 h, weighed and then cooled in a desiccator. Two (2) g of each of the samples was then weighed into the different Petri dishes and dried at 100^{o}C until a constant weight was obtained as calculated in Equation 1:

$$\% \text{ Moisture content} = \frac{w_2 - w_3}{w_2 - w_1} \times 100 \qquad \text{Equation 1}$$

Where: w_1 = Initial weight of the empty petri dish, w_2 = Weight of the dish + sample before drying, w_3 = Weight of the dish + sample after drying.

ii. **Determination of Crude Protein:** The micro-Kjeldahl method was used for determination. One gram of sample was weighed into a 100 ml Kjeldahl flask, and 2.5 g anhydrous Na2SO4, 0.5 g CuSO4, and 5 ml concentrated H2SO4 were added and allowed to stand for 2-3 hours. The flask was heated gently in a flame chamber, initially boiling until fumes appeared, then heated intensively until the solution became clear. After cooling, the content was transferred into a 100 ml volumetric flask and made up to the mark with distilled water. A 5 ml aliquot of the sample digest was mixed with 5 ml boric acid indicator and 3 drops of methyl red in a 100 ml conical flask, then steam distilled into a conical flask using 100 ml of 60% NaOH for 5 minutes until the color changed from purple to green. About 5 ml of the distillate was titrated against 0.01N HCl to a purple endpoint, as calculated in Equations 2 and 3:

$$\% \text{ Crude protein} = \% \text{ Nitrogen} \times \text{N - Protein factor} \qquad \text{Equation 2}$$

$$\text{While, } \% \text{ Nitrogen} = \frac{T \times 14.01 \times 0.01 \times 20 \times 100}{1.0 \times 100} \qquad \text{Equation 3}$$

Where; Titre value = T, Weight of sample = 1.0 g, Dilution factor = 20, Normality of HCL = 0.01, Atomic mass of Nitrogen = 14.01, Conversion factor of protein = 6.25.

iii. **Determination of Crude Fat:** Two grams of the sample were placed in a labeled thimble. A Soxhlet extractor with a reflux condenser and a 500 ml round-bottom flask was set up. The flask was filled with 300 ml petroleum ether, and the thimble was sealed with cotton wool. The apparatus was allowed to reflux for 6 hours, after which the thimble was removed. Petroleum ether was collected, and the solvent was evaporated by drying the sample at 105°C for 1 hour, then cooling in a desiccator and weighing, as calculated in Equation 4:

$$\% \text{ Fat content} = \frac{w_2 - w_1}{w_3} \times 100 \qquad \text{Equation 4}$$

Where: w_1 = Empty thimble, w_2 = Thimble with sample, w_3 = Weight of sample.

iv. **Determination of Ash:** Two grams of the sample were weighed into a preheated shallow ashing dish (crucible), cooled in a desiccator, and weighed. The crucible and its contents were transferred to a muffle furnace (Nabertherm L1/12, Lilienthal, Germany) set at 550°C for 8 hours. After ashing, the crucible was removed, moistened to expose un-ashed carbon, dried at 100°C for 4 hours in an oven (KX3050A Kenixin International Co. Ltd, China), and re-ashed at 550°C for 1 hour. The crucible was then cooled in a desiccator and weighed. The percentage ash was calculated using Equation 5:

$$\% \text{ Ash} = \left[\frac{\text{weight of ash}}{\text{weight of sample used}} \times 100 \right] \qquad \text{Equation 5}$$

v. **Determination of Crude Fibre:** Two grams of the sample were placed in 200 ml of 1.25% H2SO4 and boiled for 30 minutes. The solution was filtered through muslin cloth, washed with boiling water until acid-free, then returned to 200 ml NaOH and boiled for another 30 minutes. After further washing with boiling water, the residue was transferred to a silica ash crucible, dried in an oven for 30 minutes, cooled in a desiccator, and weighed. The result was calculated using Equation 6:

$$\% \text{ Crude fibre} = \frac{\text{loss in weight on ignition}}{\text{weight of food sample}} \times 100 \qquad \text{Equation 6}$$

vi. **Determination of Carbohydrate Content (by difference):** The total carbohydrate content was estimated as the difference between 100 and the total sum of moisture, crude fat, crude protein, crude fibre and ash as calculated in Equation 7:

% Carbohydrate = 100% - % moisture + % crude fat + % crude protein + crude fibre + % ash content. Equation 7

vii. **Determination of Total Energy:** The total energy of the pretreated samples of tender and matured fronds of *Vegetable fern* was estimated by calculation using the Atwater quantification factors of 4, 9, and 4 kcal/g for protein, fat and carbohydrate respectively as calculated Equation 8:

Total energy (kcal/g) = [(% fat × 9) + (% protein × 4) + (% carbohydrate × 4)] Equation 8

3. Determination of Mineral Composition

The determination of mineral composition in Phosphorus (P), Potassium (K), Iron (Fe), Magnesium (Mg), Sodium (Na), and Calcium (Ca), was carried out using the AOAC (2006) method. Initially, 1g of each sample was weighed and placed into a 250 ml crucible. To digest the samples, a mixture of hydrochloric acid (HCl) and nitric acid (HNO3) in a 3:1 ratio (referred to as regia) was added to the crucible. The samples were heated on an electric hotplate (85-1 Laboratory Stirrer, China) at 130°C for 30 minutes to break down the sample matrix and release the minerals into solution.

After digestion, the mixture was filtered, and the filtrate was transferred to a 100 ml volumetric flask. The final volume was adjusted to 100 ml with distilled water, ensuring that the digested

solution was adequately prepared for analysis. The standard solutions for each mineral were prepared to calibrate the Atomic Absorption Spectrophotometer (AAS), which was used for the mineral analysis. These standards were essential for creating a calibration curve for the AAS measurements.

The AAS (model: Varian Spectra 100, Australia) was preheated for 10 minutes before use. The calibration curve was established by injecting standard metal solutions into the AAS using acetylene gas. This allowed for the proper calibration of the instrument to ensure accurate readings of mineral concentrations. After calibration, an aliquot of the digested sample solution was injected into the AAS for analysis. The mineral concentrations were obtained from the AAS by measuring the absorbance at specific wavelengths corresponding to each metal (P, K, Fe, Mg, Na, and Ca). The concentrations of each mineral in the samples were calculated by comparing the absorbance values of the samples to the calibration curve created from the standard solutions. This methodology provided accurate and reliable data for the mineral composition of the samples.

4. Determination of Vitamin Composition

i. Determination of Vitamin A (Retinol): Vitamin A was determined using the AOAC (2006) method. A 1g sample was weighed, and proteins were precipitated with 3 ml of absolute ethanol. Vitamin A was extracted by adding 5 ml of heptane, and the mixture was shaken for 5 minutes. After standing, 3 ml of the heptane layer was transferred to a cuvette and read at 450 nm using a UV spectrophotometer (L7 Double Beam, Shanghai, China), with heptane as the blank. A standard was prepared and also read at 450 nm. Vitamin A was calculated using Equation 15:

$$\text{Vitamin A} = \frac{100}{W} \times \frac{Au}{As} \times C \qquad \text{Equation 15}$$

Where; Au = Absorbance of Sample, W = weight of sample, AS = Absorbance of Standard, C = Concentration of Vitamin.

ii. Determination of Vitamin B_1 (Thiamine): Thiamine was determined using the AOAC (2006) method. Two grams of the sample were mixed with 75 ml of 0.2 N HCl and boiled in a water bath (Precisterm spectra, JP Selecta, Spain). After cooling, 5 ml of phosphatase enzyme solution was added, and the mixture was incubated at 37°C overnight. The solution was transferred to a 100 ml volumetric flask, made up to volume with distilled water, and filtered. The filtrate was purified by passing through a silicate column.

To 25 ml of the filtrate, 5 ml of acidic KCl eluate, 3 ml of alkaline ferricyanide solution, and 15 ml of isobutanol were added and shaken for 2 minutes. After separation, the alcohol layer was collected and treated with 3 g of anhydrous sodium sulfate. A 5 ml aliquot of thiamine solution was treated similarly, with the same oxidation and extraction procedures. For the blank, 3 ml of 15% NaOH was used instead of alkaline ferricyanide. The prepared blank and samples were analyzed using a UV spectrophotometer (L7 Double Beam, Shanghai, China). Absorbance readings were taken, and thiamine concentrations were determined based on the readings, following the procedure outlined in Equation 16:

$$\%\ \text{thiamine} = \frac{X}{Y} \times \frac{1}{5} \times \frac{25}{V} \times \frac{100}{W} \qquad \text{Equation 16}$$

Where; W = weight of sample, X = reading of sample - reading of blank, Y = reading of thiamin standard - reading of blank standard, V = volume of solution used for test on the column.

iii. **Determination of Vitamin C (Ascorbic Acid):** Ascorbic acid was determined using the 2, 6-dichlorophenol titrimetric method (AOAC, 2006). Two grams of the sample were homogenized with acetic acid solution for extraction. A standard vitamin C solution was prepared by dissolving 50 mg of ascorbic acid in a 100 ml volumetric flask with distilled water. The solution was filtered, and 10 ml of the clear filtrate was collected into a spectrophotometer reading tube. The absorbance was measured using a UV spectrophotometer (L7 Double Beam, Shanghai, China), and ascorbic acid concentration was calculated using Equation 17:

$$\text{Ascorbic acid (mg/g)} = \frac{100}{W} \times \frac{Au}{As} \times C \qquad \text{Equation 17}$$

Where: Au = Absorbance of sample, W = Weight of sample, As = Absorbance of standard, C = Concentration of vitamin

iv. **Determination of Vitamin E (Tocopherol):** Vitamin E was determined using the AOAC (2006) method. One gram of the sample was weighed, and proteins were precipitated with 3 ml of absolute ethanol. Vitamin E was extracted with 5 ml of heptane, and the test tube was shaken for 5 minutes. Three milliliters from the heptane layer were transferred to a cuvette and read at 450 nm against a heptane blank. The standard was prepared and also read at 450 nm using a UV spectrophotometer (L7 Double Beam, Shanghai, China), with the results calculated using Equation 18:

$$\text{Vitamin E} = \frac{100}{W} \times \frac{Au}{As} \times C \qquad \text{Equation 18}$$

Where; Au = Absorbance of Sample, W = weight of sample, AS = Absorbance of standard, C = Concentration of vitamin.

Method of Data Analysis

Statistical analysis was performed using SPSS (version 21). A one-way ANOVA was conducted to determine significant differences at $p < 0.05$. Where significant differences were found, a post hoc Duncan multiple range test was used. A student t-test was also applied to compare differences between tender and matured fronds of vegetable fern. Data are presented as means ± standard deviation (SD) of three replicate determinations.

RESULTS AND DISCUSSION OF FINDINGS

1. Effect of Pretreatment on Proximate Composition and Energy value of Vegetable Fern Fronds.

Table 1: Effect of Pretreatment on proximate composition and energy value of vegetable fern fronds (on dry matter basis).

Samples	Moisture (%)		Protein (%)		Fat (%)		Ash (%)		Fibre (%)	
	Tender	Matured	Tender	Matured	Tender	Matured	Tender	Matured	Tender	Matured
FDE (Control)	$51.48 \pm 0.01^{a\,A}$	$37.81 \pm 0.00^{a\,B}$	$8.62 \pm 0.01^{a\,A}$	$7.99 \pm 0.02^{a\,B}$	$4.67 \pm 0.01^{a\,A}$	$3.10 \pm 0.01^{a\,B}$	$2.97 \pm 0.01^{a\,B}$	$5.02 \pm 0.01^{a\,A}$	$18.98 \pm 0.01^{a\,A}$	$18.60 \pm 0.01^{a\,B}$
ODE	$2.72 \pm 0.01^{e\,A}$	$1.98 \pm 0.01^{c\,B}$	$3.02 \pm 0.02^{d\,B}$	$4.21 \pm 0.01^{d\,A}$	$1.55 \pm 0.02^{d\,A}$	$0.99 \pm 0.01^{e\,B}$	$2.45 \pm 0.02^{b\,B}$	$4.38 \pm 0.00^{c\,A}$	$12.23 \pm 0.01^{d\,B}$	$13.63 \pm 0.01^{d\,A}$
HBD	$3.84 \pm 0.01^{c\,A}$	$2.63 \pm 0.00^{b\,B}$	$2.51 \pm 0.01^{e\,B}$	$3.87 \pm 0.00^{e\,A}$	$1.96 \pm 0.01^{c\,A}$	$1.18 \pm 0.01^{d\,B}$	$1.78 \pm 0.01^{c\,B}$	$4.24 \pm 0.00^{d\,A}$	$16.44 \pm 0.02^{b\,B}$	$18.11 \pm 0.01^{b\,A}$
SDE	$2.94 \pm 0.02^{d\,A}$	$1.66 \pm 0.01^{d\,B}$	$3.54 \pm 0.02^{c\,B}$	$4.58 \pm 0.02^{c\,A}$	$1.60 \pm 0.01^{d\,A}$	$1.43 \pm 0.00^{c\,B}$	$2.50 \pm 0.01^{b\,B}$	$4.36 \pm 0.00^{c\,A}$	$10.66 \pm 0.01^{e\,B}$	$11.44 \pm 0.00^{e\,A}$
SHD	$5.80 \pm 0.01^{b\,A}$	$1.03 \pm 0.01^{e\,B}$	$4.62 \pm 0.01^{b\,B}$	$5.43 \pm 0.00^{b\,A}$	$2.65 \pm 0.02^{b\,A}$	$1.76 \pm 0.01^{b\,B}$	$2.94 \pm 0.02^{a\,B}$	$4.85 \pm 0.01^{b\,A}$	$14.27 \pm 0.02^{c\,B}$	$15.86 \pm 0.00^{c\,A}$

Samples	Carbohydrate (%)		Energy Value (Kcal/100g)	
	Tender	Matured	Tender	Matured
FDE (Control)	79.76 ± 0.04$^{a\ A}$	78.02 ± 0.05$^{a\ B}$	395.55 ± 0.33$^{a\ A}$	371.94 ± 0.37$^{a\ B}$
ODE	78.04 ± 0.07$^{b\ A}$	74.68 ± 0.03$^{c\ B}$	339.09 ± 0.45$^{c\ A}$	324.47 ± 0.25$^{c\ B}$
HBD	74.81 ± 0.06$^{c\ A}$	69.38 ± 0.02$^{e\ B}$	324.92 ± 0.37$^{e\ A}$	303.62 ± 0.17$^{e\ B}$
SDE	79.67 ± 0.08$^{a\ A}$	77.29 ± 0.03$^{b\ B}$	347.33 ± 0.58$^{b\ A}$	340.35 ± 0.20$^{b\ B}$
SHD	73.62 ± 0.07$^{d\ A}$	71.10 ± 0.03$^{d\ B}$	336.81 ± 0.38$^{d\ A}$	321.96 ± 0.21$^{d\ B}$

Values are means ± SD of triplicate determination. Means in the same column with different superscript (lower case) are significantly ($p < 0.05$) different, while mean in the same row with different superscript (upper case) are significant ($p < 0.05$) different. FDE = Fresh vegetable fern fronds; ODE = Oven dried vegetable fern fronds; HBD = Hot water blanched vegetable fern fronds; SDE = Sun dried vegetable fern fronds; SHD = Shade dried vegetable fern fronds.

Table 1 presents the effect of pretreatment and maturity on the proximate composition and energy value (dry matter basis) of vegetable fern fronds. Pretreatment significantly ($p < 0.05$) affected the proximate composition and energy values. The protein content of the control (fresh vegetable fern fronds) was significantly higher ($p < 0.05$) than that of the pretreated samples. Shade dried, sun dried, oven dried, and hot water blanched fronds had protein contents of 5.43%, 4.58%, 4.21%, and 3.87%, respectively, with significant ($p < 0.05$) differences. In tender vegetable fern fronds, the control had the highest protein content (8.62%), followed by shade dried (4.62%), sun dried (3.54%), oven dried (3.02%), and hot water blanched (2.51%) samples. Protein content in matured fronds was significantly ($p < 0.05$) affected by pretreatment. The protein content of fresh tender fronds (8.62%) was higher than that reported by Veena and Christopher (2017) at 3.6%. Except in the control, where protein content of tender fronds was significantly ($p < 0.05$) higher, matured fronds had higher protein content than tender fronds in all pretreated samples.

Fat content in tender vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatment. The control (fresh fronds) had the highest fat content, significantly higher than the pretreated samples. Shade dried and hot water blanched fronds had fat contents of 2.65% and 1.96%, respectively, while sun dried and oven dried fronds had fat contents of 1.60% and 1.55%, which were not significantly ($p < 0.05$) different. For matured fronds, pretreatment significantly ($p < 0.05$) affected fat content, with the control (fresh fronds) having significantly higher fat content. Shade dried, hot water blanched, sun dried, and oven dried fronds had fat contents of 1.76%, 1.43%, 1.18%, and 0.99%, respectively, with significant ($p < 0.05$) differences in decreasing order. Generally, fat content in tender fronds was significantly ($p < 0.05$) higher than in matured fronds.

Ash content in tender vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatment. The control sample (2.97%) and shade dried fronds (2.94%) had significantly higher ash contents, but were not significantly ($p < 0.05$) different from each other. Oven dried (2.45%) and sun dried (2.50%) fronds had significantly ($p < 0.05$) lower ash contents but were not significantly ($p < 0.05$) different from each other. Hot water blanched fronds had the lowest ash content. For matured fronds, pretreatment significantly ($p < 0.05$) affected ash content, with the control (5.02%) having the highest. This was followed by shade dried fronds (4.85%), oven dried (4.38%) and sun dried (4.36%) fronds, which were not significantly ($p < 0.05$) different. Hot water blanched fronds had the lowest (4.24%). Ash content in matured fronds was significantly ($p < 0.05$) higher than in tender fronds, regardless of treatment. Ash content increased with dehydration, as moisture was reduced, and fresh matured fronds had higher ash content than tender ones

Fibre content in tender vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatments. The control sample (fresh fronds) had the highest fibre content, followed by hot water blanched (16.44%), shade dried (14.27%), oven dried (12.23%), and sun dried (10.66%) fronds. Similarly, matured fronds had significantly ($p < 0.05$) higher fibre content in the control sample (18.60%) compared to pretreated samples, with hot water blanched (18.11%), shade dried (15.86%), oven dried (13.63%), and sun dried (11.44%) fronds. Except for the control, fibre content in matured fronds was higher than in tender fronds. Blanching increased fibre content by washing away soluble components. The fibre content of fresh matured fronds (18.60%) was higher than reported by Sanjay et al. (2020) at 17.44%, and lower than Saha et al. (2015) at 18.32%. Crude fibre aids bowel movement and reduces the risk of colon cancer (Devinder et al., 2012; Dawczynski et al., 2007).

Carbohydrate content in tender vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatment. The control sample (79.76%) and sun dried (79.67%) fronds had higher but not significantly different carbohydrate contents. Oven dried, hot water blanched, and shade dried fronds had progressively lower carbohydrate contents. Similarly, carbohydrate content in matured fronds was significantly ($p < 0.05$) affected by pretreatment, with the control sample having the highest (79.76%), followed by sun dried (77.29%), oven dried (74.68%), shade dried (71.10%), and hot water blanched (69.38%) fronds. Carbohydrate contents of tender fronds were significantly ($p < 0.05$) higher than those of matured fronds. Sun dried fronds had the highest carbohydrate and energy values, possibly due to energy absorbed from sunlight. Carbohydrate deficiency can lead to poor mental function and fatigue (Udousoro et al., 2013).

Energy value of tender vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatment. The control sample had the highest energy value, followed by sun dried (347.33%), oven dried (339.09%), shade dried (336.81%), and hot water blanched (324.92%) fronds, all significantly ($p < 0.05$) different. Similarly, energy value of matured fronds was significantly ($p < 0.05$) affected by pretreatment, with the control sample having the highest energy value. Sun dried (340.35%), oven dried (324.47%), shade dried (321.96%), and hot water blanched (303.62%) fronds showed decreasing values. Energy values of tender fronds were significantly higher than those of matured fronds. Variations in results were attributed to treatment differences, with shade drying possibly retaining more nutrients.

2. Effect of Pretreatment on the Mineral Composition of Vegetable Fern Fronds

Table 2: Effect of pretreatment on the mineral composition of vegetable fern fronds

Samples (mg/100 g)	Phosphorus (P)		Potassium (K)		Iron (Fe)		Magnesium (Mg)	
	Tender	Matured	Tender	Matured	Tender	Matured	Tender	Matured
FDE (Control)	$7.73 \pm 0.01^{a\,B}$	$8.51 \pm 0.02^{a\,A}$	$46.10 \pm 0.01^{a\,A}$	$48.62 \pm 0.02^{a\,B}$	$49.02 \pm 0.01^{a\,B}$	$54.38 \pm 0.00^{a\,A}$	$28.14 \pm 0.01^{a\,B}$	$31.73 \pm 0.01^{a\,A}$
ODE	$5.58 \pm 0.01^{c\,B}$	$7.97 \pm 0.01^{c\,A}$	$41.51 \pm 0.00^{b\,A}$	$41.86 \pm 0.00^{b\,A}$	$30.42 \pm 0.01^{d\,B}$	$32.44 \pm 0.00^{d\,A}$	$23.85 \pm 0.01^{c\,B}$	$26.17 \pm 0.02^{c\,A}$
HBD	$2.02 \pm 0.01^{d\,B}$	$4.63 \pm 0.00^{e\,A}$	$36.04 \pm 0.01^{d\,B}$	$38.36 \pm 0.01^{d\,A}$	$29.04 \pm 0.01^{e\,A}$	$29.20 \pm 0.01^{e\,A}$	$16.64 \pm 0.01^{e\,B}$	$19.32 \pm 0.02^{e\,A}$
SDE	$5.46 \pm 0.00^{c\,B}$	$6.77 \pm 0.00^{d\,A}$	$33.20 \pm 0.00^{e\,B}$	$35.53 \pm 0.01^{e\,A}$	$31.96 \pm 0.01^{c\,B}$	$35.76 \pm 0.01^{c\,A}$	$25.09 \pm 0.01^{b\,B}$	$29.08 \pm 0.00^{b\,A}$
SHD	$6.49 \pm 0.02^{b\,B}$	$8.01 \pm 0.01^{b\,A}$	$40.18 \pm 0.01^{c\,B}$	$40.73 \pm 0.01^{c\,A}$	$33.28 \pm 0.01^{b\,B}$	$39.26 \pm 0.00^{b\,A}$	$18.28 \pm 0.01^{d\,B}$	$21.23 \pm 0.02^{d\,A}$

Samples (mg/100 g)	Sodium (Na)		Calcium (Ca)	
	Tender	Matured	Tender	Matured
FDE (Control)	$46.01 \pm 0.01^{a\,B}$	$50.52 \pm 0.01^{a\,A}$	$30.01 \pm 0.01^{a\,A}$	$35.93 \pm 0.02^{a\,A}$
ODE	$24.19 \pm 0.01^{d\,B}$	$35.72 \pm 0.01^{d\,A}$	$20.26 \pm 0.01^{e\,B}$	$26.04 \pm 0.01^{d\,A}$
HBD	$19.02 \pm 0.01^{e\,B}$	$27.83 \pm 0.00^{e\,A}$	$23.92 \pm 0.01^{d\,B}$	$24.79 \pm 0.01^{e\,A}$
SDE	$30.45 \pm 0.01^{c\,B}$	$39.27 \pm 0.02^{c\,A}$	$25.04 \pm 0.01^{c\,B}$	$29.28 \pm 0.01^{c\,A}$
SHD	$34.42 \pm 0.01^{b\,B}$	$43.13 \pm 0.01^{b\,A}$	$26.43 \pm 0.02^{b\,B}$	$32.39 \pm 0.00^{b\,A}$

Values are means ± SD of triplicate determination. Means in the same column with different superscript (lower case) are significantly ($p < 0.05$) different, while mean in the same row with different superscript (upper case) are significant ($p < 0.05$) different. FDE = Fresh vegetable fern fronds; ODE = Oven dried vegetable fern fronds; HBD

= Hot water blanched vegetable fern fronds; SDE = Sun dried vegetable fern fronds; SHD = Shade dried vegetable fern fronds

Pretreatment significantly ($p < 0.05$) affected the mineral composition of both tender and matured vegetable fern fronds. Hot water blanched samples had the lowest mineral values, likely due to leaching and thermal destruction. For tender fronds, phosphorus content was highest in the control sample (fresh fronds) and significantly ($p < 0.05$) higher than the pretreated samples. The phosphorus contents of shade dried (6.49 mg/100g), oven dried (5.58 mg/100g), and sun dried (5.46 mg/100g) samples were not significantly different, while hot water blanched samples had the lowest content (2.02 mg/100g). For matured fronds, the control had the highest phosphorus content, followed by shade dried (8.01 mg/100g), oven dried (7.97 mg/100g), sun dried (6.77 mg/100g), and hot water blanched samples (4.63 mg/100g), all significantly ($p < 0.05$) different. Generally, phosphorus content was significantly ($p < 0.05$) higher in matured than in tender fronds.

Potassium content in tender vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatment. The control sample (fresh fronds) had the highest potassium content, followed by oven dried (41.51 mg/100g), shade dried (40.18 mg/100g), hot water blanched (36.04 mg/100g), and sun dried (33.20 mg/100g) samples, all significantly different ($p < 0.05$). For matured fronds, the control had the highest potassium content, followed by oven dried (41.86 mg/100g), shade dried (40.73 mg/100g), hot water blanched (38.36 mg/100g), and sun dried (35.53 mg/100g) samples, all significantly different ($p < 0.05$). Overall, potassium content was significantly ($p < 0.05$) higher in matured than in tender fronds. Potassium is essential for water balance, nervous system function, and blood pressure regulation (Ranhotra et al., 1998).

Pretreatment significantly ($p < 0.05$) affected the iron content of tender vegetable fern fronds. The control (fresh fronds) had the highest iron content, followed by shade dried (33.28 mg/100g), sun dried (31.96 mg/100g), oven dried (30.42 mg/100g), and hot water blanched (29.04 mg/100g) samples, all significantly different ($p < 0.05$). Similarly, for matured fronds, the control had the highest iron content, followed by shade dried (39.26 mg/100g), sun dried (35.76 mg/100g), oven dried (32.44 mg/100g), and hot water blanched (29.20 mg/100g) samples, all significantly different ($p < 0.05$). Iron is crucial for hemoglobin, neurotransmitter synthesis, and brain development (Tan et al., 2006). The iron content of fresh tender fronds (49.02 mg/100g) was higher than reports from Smriti et al. (2018) and Sanjay et al. (2020). The WHO/FAO recommended daily allowance for iron is 4-18 mg/day for children and 22-33 mg/day for adults.

Magnesium content of tender vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatment. The control (fresh fronds) had the highest magnesium content, followed by sun dried (25.09 mg/100g), oven dried (23.85 mg/100g), shade dried (18.28 mg/100g), and hot water blanched (16.64 mg/100g) samples, all significantly different ($p < 0.05$). Similarly, for matured fronds, the control had the highest magnesium content, followed by sun dried (29.08 mg/100g), oven dried (26.17 mg/100g), shade dried (21.23 mg/100g), and hot water blanched (19.32 mg/100g) samples, all significantly different ($p < 0.05$). Magnesium content was higher in matured than tender fronds, regardless of treatment. The magnesium content of fresh tender fronds (28.14 mg/100g) was higher than the 9.56 mg/100g reported by Smriti et al. (2018). The variation may be due to environmental mineral availability. The WHO/FAO recommended daily allowance for magnesium is 60-220 mg/day for children and 230-260 mg/day for adults. Magnesium is crucial for numerous body reactions (Grosvernor & Smolin, 2002).

Sodium content of tender vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatments. The control (fresh fronds) had the highest sodium content, followed by shade dried (34.42 mg/100g), sun dried (30.45 mg/100g), oven dried (24.19 mg/100g), and hot water

blanched (19.02 mg/100g) samples, all significantly different ($p < 0.05$). For matured fronds, the control had the highest sodium content, followed by shade dried (43.13 mg/100g), sun dried (39.27 mg/100g), oven dried (35.72 mg/100g), and hot water blanched (27.83 mg/100g) samples, all significantly different ($p < 0.05$). Sodium content was higher in matured than tender fronds, regardless of treatment. The sodium content of fresh tender fronds (46.01 mg/100g) was higher than the 0.50 mg/100g reported by Smriti et al. (2018), and the sodium content of fresh matured fronds (50.52 mg/100g) was higher than the 1.18 mg/100g reported by Sanjay et al. (2020). Sodium helps regulate blood pressure, blood volume, and nerve impulse transmission, and plays a vital role in glucose and amino acid transport (Asuquo et al., 2004)

Pretreatment significantly ($p < 0.05$) affected the calcium content of tender vegetable fern fronds. The control (fresh fronds) had the highest calcium content, followed by shade dried (26.43 mg/100g), sun dried (25.04 mg/100g), hot water blanched (23.92 mg/100g), and oven dried (20.26 mg/100g) samples, all significantly different ($p < 0.05$). For matured fronds, the control had the highest calcium content, followed by shade dried (32.39 mg/100g), sun dried (29.28 mg/100g), oven dried (26.04 mg/100g), and hot water blanched (24.79 mg/100g) samples, all significantly different ($p < 0.05$). Calcium content was higher in matured than tender fronds, regardless of treatment. The calcium content of fresh matured fronds (35.93 mg/100g) was higher than the 12.25 mg/100g reported by Sanjay et al. (2020). Calcium is important for bone and teeth health, muscle, nerve, and heart function (Lilly et al., 2017). The WHO/FAO recommended daily allowance (RDA) for calcium is 500-700 mg/day for children and 1000-1300 mg/day for adults.

3. Effect of Pretreatment on Vitamin Composition of Vegetable Fern Fronds

Table 3: Effect of pretreatment on vitamin composition of vegetable fern fronds

Samples (mg/100 g)	Vitamin A		Vitamin B1		Vitamin C		Vitamin E	
	Tender	Matured	Tender	Matured	Tender	Matured	Tender	Matured
FDE (Control)	$13.37 \pm 0.02^{a\,A}$	$8.44 \pm 0.00^{a\,B}$	$3.16 \pm 0.02^{a\,A}$	$1.93 \pm 0.02^{a\,B}$	$19.26 \pm 0.02^{a\,A}$	$12.47 \pm 0.01^{a\,B}$	$24.15 \pm 0.00^{a\,A}$	$15.97 \pm 0.02^{a\,B}$
ODE	$12.61 \pm 0.01^{b\,A}$	$7.69 \pm 0.01^{b\,B}$	$1.62 \pm 0.01^{c\,A}$	$0.87 \pm 0.01^{c\,B}$	$16.25 \pm 0.03^{c\,A}$	$8.21 \pm 0.03^{c\,B}$	$12.88 \pm 0.01^{c\,A}$	$9.72 \pm 0.01^{c\,B}$
HBD	$12.66 \pm 0.02^{b\,A}$	$7.66 \pm 0.01^{b\,B}$	$1.15 \pm 0.00^{d\,A}$	$0.31 \pm 0.01^{d\,B}$	$14.16 \pm 0.02^{e\,A}$	$4.30 \pm 0.01^{e\,B}$	$7.85 \pm 0.00^{e\,A}$	$2.85 \pm 0.01^{e\,B}$
SDE	$12.64 \pm 0.01^{b\,A}$	$7.71 \pm 0.00^{b\,B}$	$1.65 \pm 0.00^{c\,A}$	$0.99 \pm 0.02^{c\,B}$	$15.69 \pm 0.02^{d\,A}$	$7.87 \pm 0.00^{d\,B}$	$10.08 \pm 0.01^{d\,A}$	$6.94 \pm 0.02^{d\,B}$
SHD	$13.39 \pm 0.02^{a\,A}$	$5.90 \pm 0.02^{c\,B}$	$2.32 \pm 0.01^{b\,A}$	$1.02 \pm 0.02^{b\,B}$	$18.19 \pm 0.02^{b\,A}$	$10.51 \pm 0.01^{b\,B}$	$18.46 \pm 0.01^{b\,A}$	$12.31 \pm 0.01^{b\,B}$

Values are means ± SD of triplicate determination. Means in the same column with different superscript (lower case) are significantly ($p < 0.05$) different, while mean in the same row with different superscript (upper case) are significant ($p < 0.05$) different. FDE = Fresh vegetable fern fronds; ODE = Oven dried vegetable fern fronds; HBD = Hot water blanched vegetable fern fronds; SDE = Sun dried vegetable fern fronds; SHD = Shade dried vegetable fern fronds.

Pretreatment significantly ($p < 0.05$) affected the vitamin composition of tender and matured vegetable fern fronds. The vitamin A content of tender fronds was highest in the control (fresh) sample, followed by shade dried (13.39 mg/100g). Hot water blanched (12.66 mg/100g), sun dried (12.64 mg/100g), and oven dried (12.06 mg/100g) samples had significantly lower but similar values. For matured fronds, the control had the highest vitamin A content, followed by sun dried (7.71 mg/100g), oven dried (7.69 mg/100g), and hot water blanched (7.66 mg/100g) samples, which were similar. Shade dried fronds had the lowest vitamin A content (5.90 mg/100g). Generally, tender fronds had significantly higher vitamin A than matured ones, regardless of pretreatment. Vitamin A is essential for the visual system, growth, immune function, and reproduction (Gilbert, 2013). The WHO/FAO recommended Daily Allowance (RDA) for vitamin A is 400-500 µRE/day for children and 600 µRE/day for adults.

Vitamin B1 content of tender vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatment. The control sample had the highest vitamin B1 content, followed by shade dried (2.32 mg/100g), sun dried (1.65 mg/100g), oven dried (1.62 mg/100g), and hot water blanched (1.15 mg/100g) samples, which were significantly different. For matured fronds, the control had the highest vitamin B1 content, followed by shade dried (1.02 mg/100g), sun dried (0.99 mg/100g), oven dried (0.87 mg/100g), and hot water blanched (0.31 mg/100g) samples, with significant differences. Overall, tender fronds had significantly higher vitamin B1 than matured fronds. Vitamin B1 (thiamine) is essential for energy use from carbohydrates and supports the nervous system, muscles, and heart. The FAO recommends a daily intake of 1.2 mg/100g for males and 1.1 mg/100g for females.

Vitamin C content of tender vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatment. The control sample (fresh fronds) had the highest vitamin C content, followed by shade dried (18.19 mg/100g), oven dried (16.25 mg/100g), sun dried (15.69 mg/100g), and hot water blanched (14.16 mg/100g) samples. For matured fronds, the control also had the highest vitamin C content, followed by shade dried (10.51 mg/100g), oven dried (8.21 mg/100g), sun dried (7.87 mg/100g), and hot water blanched (4.30 mg/100g) samples. Tender fronds consistently had higher vitamin C than matured fronds. Vitamin C (ascorbic acid) is water-soluble and decreases with heat treatment. The vitamin C content of fresh fronds in this study (higher than 0.94 mg/100g reported by Okwu, 2004) was consistent with previous studies, showing better retention in oven-dried samples than sun-dried ones.

Ascorbic acid is highly sensitive to oxygen, light, and temperature, and like vitamin E, it aids iron absorption and stabilizes folate. Vitamin C maintains iron in its reduced form (FAO/WHO, 2001). The RDA for vitamin C is 30-40 mg/day for children and 45 mg/day for adults. Processing methods like blanching help preserve vitamin C by inactivating ascorbate oxidase. Excessive vitamin C can lead to hyperoxaluria.

Vitamin E content in matured vegetable fern fronds was significantly ($p < 0.05$) affected by pretreatment. The control (fresh fronds) had the highest vitamin E content (12.31 mg/100g), followed by shade dried (9.72 mg/100g), oven dried (6.94 mg/100g), and hot water blanched (2.85 mg/100g) samples. Vitamin E in tender fronds was also significantly ($p < 0.05$) higher, with shade dried (18.46 mg/100g), oven dried (12.88 mg/100g), sun dried (10.08 mg/100g), and hot water blanched (7.85 mg/100g) samples showing significant differences. Vitamin E is a fat-soluble antioxidant that helps form red blood cells and prevents clotting in blood vessels. The fresh vegetable fern fronds in this study had higher vitamin E (18.46 mg/100g) compared to previous reports (0.28 mg/100g, Patric et al., 2003). The RDA for vitamin E is 5-7.5 mg/day for children and 10 mg/day for adults.

The treatments (fresh, oven dried, hot water blanched, sun dried, and shade dried vegetable fern fronds) significantly ($p < 0.05$) reduced the contents of vitamins A, B1, C, and E in both tender and matured fronds. Hot water blanching caused the highest loss of vitamin B1, C, and E, likely due to the heat sensitivity of these vitamins. In contrast, shade drying resulted in better retention of vitamins, possibly due to the absence of heat treatment.

Conclusion

This study provides empirical evidence on the effects of different pretreatment methods on the chemical composition of tender and matured fronds of *Diplazium esculentum*, a widely consumed but underutilized vegetable in Nigeria. By examining its proximate composition, mineral content, vitamins, phytochemicals, and anti-nutritional factors, the research identifies

the most effective pretreatment techniques to enhance nutrient retention and minimize anti-nutritional compounds. The findings will help optimize processing methods to ensure that *D. esculentum* remains a highly nutritious and safe dietary component, particularly for communities relying on indigenous vegetables for food security and micronutrient intake. Moreover, the study contributes to sustainable food processing practices, offering improved preservation methods that can reduce post-harvest losses and increase the shelf-life of this valuable vegetable.

The outcomes of this research have broader implications for nutrition policy, food technology, and dietary recommendations in Nigeria. The data generated will serve as a valuable resource for food scientists, nutritionists, agricultural policymakers, and local food processors, enabling them to enhance the utilization of indigenous vegetables. By bridging knowledge gaps on the effects of pretreatment, the study will support evidence-based recommendations for optimal processing techniques, ultimately improving the availability and nutritional quality of *D. esculentum* in Nigerian diets. The findings will be shared through academic publications, policy briefs, and stakeholder workshops, ensuring their integration into food security strategies and public health initiatives aimed at combating micronutrient deficiencies and promoting sustainable nutrition.

Recommendations

1. Food processors and local farmers should adopt shade drying as a preferred method of preserving *Diplazium esculentum* due to its superior retention of essential vitamins, particularly Vitamin C, compared to other heat-based pretreatments.
2. Policymakers and regulatory bodies should promote the development and implementation of guidelines for the optimal processing and preservation of indigenous vegetables like *D. esculentum* to enhance food security and improve nutritional quality.
3. Nutritional programs in Nigeria should integrate *Diplazium esculentum* as a key component for combating micronutrient deficiencies, particularly in rural communities where access to diverse nutrient-rich foods may be limited.
4. Local food processors should be trained on sustainable processing methods that minimize nutrient loss, such as blanching techniques with controlled heat, to ensure the highest nutritional value is maintained in processed *D. esculentum* products.
5. Government bodies should support the establishment of a certification system for value-added products derived from *D. esculentum*, ensuring that these products meet the nutritional standards and safety guidelines for local and international markets.
6. Nutritionists and dieticians should encourage the consumption of *D. esculentum* as part of a balanced diet, especially for populations in need of affordable sources of vitamins and minerals, highlighting its potential role in addressing nutrient deficiencies.
7. Agricultural extension services should promote the cultivation of *Diplazium esculentum* among local farmers, providing training on improved farming practices and post-harvest handling to maximize the nutritional value of the vegetable.
8. Research institutions should collaborate with local food industries to scale up the application of the study's findings, developing low-cost, nutrient-dense products based on *D. esculentum* for local consumption and export.
9. Community-based nutrition education programs should be established to raise awareness about the health benefits of consuming *D. esculentum* and the importance of proper processing techniques for preserving its nutritional content, particularly in underserved populations

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