International Journal of Computational Research in Science and Technology
E-ISSN: 3108-0871, Volume 2 Issue 1
Jan-Feb 2026, PP 77-92

Physicochemical and Toxicological Characterization of Five Mushroom Species and Their Potential Application in the Bioremediation of Trace Metal Contaminated Soils

Umudi Ese Queen[1], Odimgbe Ezekiel Izudike[2], Anyanwu Chidinma Gogo[3], Andrew Ogheneovo Onofuevure[4], Ikechukwu Sampson Chikwe[5], Ndego Chukwudi. Charles[6], Onwugbuta Godpower Chukwuemeka[7], Abubakar Abdulkarim[8], Wilson joseph joseph[9], Erienu Kennedy Obruche[10]

[1]Department of Chemical Science, University of Delta, Agbor, Nigeria

[2]Department of Industrial Chemistry, Ebonyi State University, Abakaliki

[3]Department of Chemical Science, University of Agriculture and environmental science, Umusgwo, [4]Department of Industrial Chemistry, Dennis Osadebay University, Asaba

[5]Department of Science Laboratory Technology, Imo State Polytechnic, Omuma

[6]Department of SLT, Federal University of Petroleum Resource, Effurun

[7]Department of Biochemistry/Chemistry Technology, University of Port Harcourt, River State

[8]Department of Chemical Engineering, University of Maiduguri, Nigeria

[9]Department of Microbiology, Ignatius Ajuru University of Education, Port Harcourt

[10]Department of Chemistry, Delta State College of Education, Mosogar

Abstract. Five mushroom species—Termitomyces robustus, Agaricus bisporus, Pleurotus tuber-regium, Amanita phalaoides, and Amanita verosa—were collected from eleven locations in Anambra State, Nigeria, between 2024 and 2025. The mushrooms were identified, dried at 75°C for 4 hours, and stored for chemical analysis. Some were cultivated by scrapping mature mushroom seeds into substrates from their natural habitats and refuse dumps. After 14 days of cultivation, mushrooms were harvested, cleaned, and dried for further analysis. The chemical analysis revealed that moisture content ranged from 81.79% to 97.84%, with Amanita phalaoides showing the highest. Dry matter ranged from 2.63% to 18.36%, indicating high roughage content. Crude protein ranged from 8.16% to 24.67%, comparable to seeds and legumes. Ash content ranged from 3.26% to 14.33%, indicating high mineral presence, while lipids were low (1.00% to 6.68%), making the mushrooms suitable for diabetic and heart disease diets. Carbohydrates were between 32.00% and 35.40%. Vitamin C levels were low (0.01-0.37 mg/100g). Heavy metal concentrations like Na, K, Ca, Mg, and Fe were within WHO guidelines, while trace metals such as Cd, Co, Cu, and Zn showed significant differences between wild and cultivated mushrooms. Bioaccumulation factors for metals were higher than acceptable limits, particularly for Cd and Ni, indicating potential risks from polluted substrates.

International Journal of Computational Research in Science and Technology
E-ISSN: 3108-0871, Volume 2 Issue 1
Jan-Feb 2026, PP 77-92

Keywords: Physicochemical, Toxicological, Mushroom, Bioremediation, Trace Metal, Soils.

I. Introduction

The environment faces growing challenges as human activities release a wide range of pollutants into ecosystems, particularly in developing countries like Nigeria (Obruche et al., 2025). Among these pollutants, trace metals—such as lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and mercury (Hg)—are of significant concern due to their potential to harm both environmental and human health. These metals are persistent, toxic, and often bioaccumulate in the food chain, leading to detrimental long-term effects on biodiversity and human well-being (Akpaja et al., 2003). The contamination of soil with these trace metals is particularly alarming, as it threatens agricultural productivity, food security, and ecosystem health. In recent years, bioremediation has emerged as a promising and cost-effective approach to mitigating the impact of trace metal pollution.

Bioremediation relies on biological processes to degrade, transform, or immobilize contaminants, with the potential to restore polluted environments (Itodo et al., 2021). Among the various organisms capable of bioremediation, fungi have attracted significant attention due to their remarkable ability to tolerate and detoxify environmental pollutants. Fungi, particularly mushrooms, have evolved intricate biochemical mechanisms that enable them to survive in contaminated environments, making them ideal candidates for use in bioremediation efforts (Erienu et al., 2022). Mushrooms, the fruiting bodies of macrofungi, possess unique properties that contribute to their efficiency in environmental cleanup.

These include their extensive mycelial networks, which can penetrate soil and absorb nutrients, and their ability to produce a variety of extracellular enzymes capable of breaking down organic pollutants (Umudi et al., 2025). More importantly, many species of mushrooms can accumulate trace metals from their surrounding environments, sequestering them in a non-toxic form and reducing the availability of these metals to other organisms. The potential of mushrooms to remediate polluted soils depends not only on their ability to uptake trace metals but also on their physico-chemical characteristics and toxicological profiles, which determine their overall viability and safety for use in environmental cleanup (Adebayo et al., 2009). In Anambra State, Nigeria, where agricultural activities are a major economic driver, soil pollution with trace metals has become an increasing concern due to industrial and mining activities.

This region, like many others in Nigeria, faces significant challenges with environmental contamination, particularly from the improper disposal of industrial waste and the use of harmful chemicals in agriculture (Ekpo et al., 2025). The local mushroom species present in Anambra State could hold significant potential for bioremediation, but their ability to remediate polluted soil, their interaction with trace metals, and their potential toxicity remain largely understudied. It is therefore crucial to examine the physicochemical characteristics, toxicological profiles, and bioremediation potential of locally available mushroom species in this region (Obruche et al., 2018).

International Journal of Statistics and Mathematical Research Trends
E-ISSN: 3108-0871, Volume 2 Issue 1
Jan-Feb 2026, PP 77-92

This study aims to investigate the physico-chemical and toxicological profiles of five species of mushrooms found in Anambra State, Nigeria, and evaluate their potential for the bioremediation of trace metal-polluted soils.

II. Materials and Method

Study area

The study was conducted in towns and villages situated within the Idemili North, Idemili South, Nnewi North, and Ekwusigo local government areas (L.G.As) of Anambra State, located in South-East Nigeria, as illustrated in Figure 1. Anambra State is positioned between the longitudes of 6037'E and 7027'E, and the latitudes of 6048'E and 6040'N. The specific towns and villages involved in the research include Uke, Abatete, Ideani, Nnobi, Nnewi, and Ozubulu, during the timeframe of July to October, spanning the years 2024 to 2025 (Umudi et al., 2025).

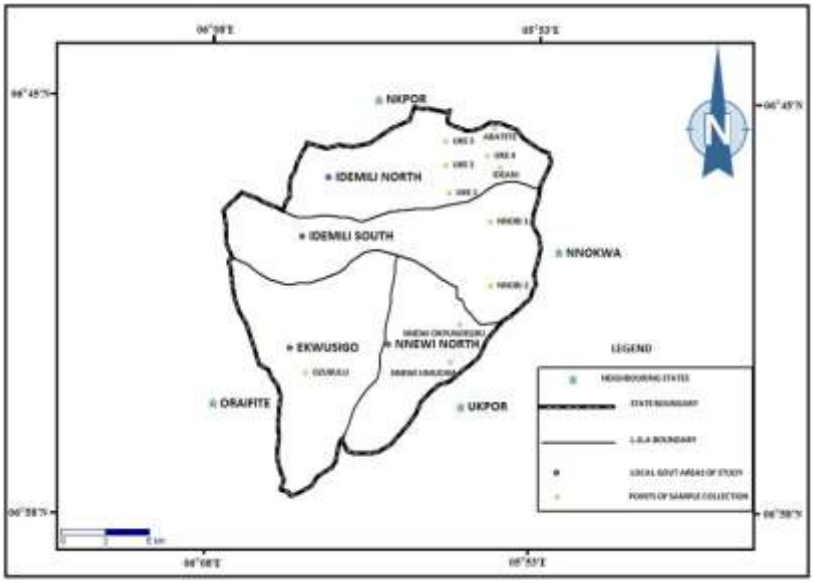

Figure1: Anambra Map showing the Study Area

Collection of samples

The sample collection was based on the procedures outlined by (Ugochukwu et al., 2025; Umudi et al., 2025). Mushroom species were gathered from various towns and villages situated in Idemili North, Idemili South, Nnewi North, and Ekwusigo Local Government Areas. Five species of wild mushrooms, specifically: Termitomyces robustus, Agaricus bisporus, Pleurotus tuber-regium, Amanita phalloides, and Amanita verosa, were collected from Uke, Abatete, Ideani, Nnobi, Nnewi, and Ozubulu during the period from July to October, spanning the years 2024 to 2025. The identification of the mushroom samples was conducted by a taxonomist from the Centre for Ethnomedicine and Drug Development, Bioresources Development and Conservation Programme, located in Nsukka, Enugu State. The wild mushroom samples were collected along with the soil or substrates on which they were found. The mushrooms were promptly transported to the laboratory and stored in a refrigerator at 4 ˚C.

Cultivation of Mushrooms

Preparation of Substrates for Spawn Production

Nutrient preparation adhered to the methodologies outlined by Osemwegie et al (2006). Four distinct substrates were created. The fifth substrate consisted of soil gathered from the respective sites. These substrates were finely ground into powder and placed into wide-mouthed bottles, which were then sealed with cotton wool and aluminum foil. The bottles underwent autoclaving at a temperature of 125 °C and a pressure of 15 psi for a duration of one hour, after which they were allowed to cool to room temperature and subsequently spread onto petri dishes for the purpose of Spawn Production.

Production of Spawn

Mycelia were scraped from the tops of mature mushrooms and permitted to fall onto the surface of the substrates within the petri dishes. The spawns that germinated were allowed to develop into mycelial cultures over a period of 4 to 5 days prior to the planting of the fruiting bodies (Okhuoya & Okogbo, 1991).

Planting of Fruiting Bodies of Mushrooms

The autoclaved substrates were placed into clean, colorless, wide-mouthed bottles and allowed to cool to room temperature. The cultured mycelia were transferred by taking approximately 2 cm^2 of substrate along with the mycelia and positioning it on the surface of the cooled substrate to facilitate the development of fruiting bodies (mature mushrooms), which occurs within a span of 21 days. The spawn bottles were subjected to daily visual inspections to monitor for increases in length, the emergence of caps, signs of off-sectoring, discoloration, infection, and the disappearance of smaller mushrooms as the larger ones matured, as illustrated in Table 1. Off-sectoring is defined as any mycelial growth that exhibits differences in appearance, growth rate, and color compared to the typical characteristics of the mycelia obtained (Festus-Amadi et al., 2021).

Table 1: Compounded Substrates for Spawn Cultivation

S/No.	Substrates	Quantity (g)	Mushroom SP
1	Elephant grass	400	*Agaricus bisporus*
	Chicken manure	120	
	Rice bran	20	
	Brewer's waste	22	
	Urea	6	
	Soya bean meal	5	
2	Elephant grass	500	*Amanita verosa*
	Cassava leaves	500	
	Chicken manure	400	
	Spent grain	72	
	Urea	14.5	
3	Saw dust	800	*Amanita phalaiodes*
	Urea	20	
4	Rice straw	300	*Termitomyces robustus*
	Chicken manure	150	

	Wheat bran	12.5	
5	Soil from sites 1,5,8,10 and 11		*Amanita verosa, amanita phalaiodes, termi-*

Production of Fruiting Bodies Utilizing the Sclerotium or Underground Tuber of Pleurotus tuber-regium (Ero-Osu)

The sclerotium or underground tuber of Pleurotus tuber-regium underwent conditioning by being immersed in water until its moisture content increased by 65%. Subsequently, it was enclosed in a polyethylene bag and stored until pinhead-like structures emerged. Following this, the polyethylene bag was opened, and the tuber was lightly watered once daily until the development of fruiting bodies occurred (Abeokuta et al., 2025).

Bioremediation Process

The bioremediation method employed was based on the procedure outlined by (Erienu et al., 2022). Soil samples were collected from Uke (site 1), Abatete (site 5), Nnobi (site 8), Nnewi Umudim (site 10), and Ozubulu (site 11). Compounded substrates, as formulated, were also employed for each mushroom species. The soil samples were combined with the specified substrate and placed into wide-mouthed glass bottles with lids. These were autoclaved at 125 °C for 2 hours at a pressure of 15 psi. After cooling to room temperature, seeds from mature mushrooms were scraped into the glass bottles and allowed to germinate over a period of 4-5 days. The germinated seeds (mycelia) were then transferred by cutting approximately 2 cm² of soil/substrate/mycelia and placing it on the surface of the cooled substrate to develop into fruiting bodies, which matured within 14 days. The soil/substrates and mushroom samples underwent chemical analysis. The bioaccumulation factors were calculated as follows;

$$Bioaccumulation\ Factor = \frac{\text{metal concentration in mushroom}}{\text{metal concentration in } \frac{\text{soil}}{\text{substrates}}}$$

Proximate Analyses of Investigated Mushroom Samples

Sample Preparation

Mushroom samples were dried in an oven at 75 °C, ground, and stored in polythene containers. Soil/substrate samples were dried in an oven at 105 °C until they reached constant weights. The dried samples were then pulverized and stored in treated polyethylene containers.

Determination of Moisture Content, Dry Matter, Ash Content, crude protein content, total lipids, Crude Fibre Content, Ethanol Soluble Sugar and vitamin C content

The assessment of Moisture Content, Dry Matter, Ash Content, crude protein content, total lipids, Crude Fibre Content, Ethanol Soluble Sugar, and vitamin C content was performed according to the methods established by Obruche et al. (2019), and Umudi et al. (2205) with slight modifications.

Determination of Anti-Nutritional (Non-Metallic Toxicants) Factors in the Mushroom Samples: phytate content, Cyanide Content and Tannin Content

The methods for determining Anti-Nutritional (Non-Metallic Toxicants) Factors in the **Mushroom Samples:** phytate content, Cyanide Content, and Tannin Content were similar to those outlined by Ekpo et al. (2023), with some minor adjustments.

Preparation of Samples for Metals Determinations

Ashing of Mushroom Samples

Porcelain crucibles with lids were cleaned and dried at 450 °C for 30 minutes and then placed inside the muffle furnace. The dishes were allowed to cool and weighed. This process was repeated until consistent weights were obtained. 2.0 g of dried ground mushroom samples were precisely weighed into the crucibles, and 1 mL of concentrated HNO3 was added and left overnight. The sample underwent charring (carbonization) using a Bunsen burner flame to facilitate gas escape, and was subsequently placed in a muffle furnace at 450 °C for duration of 4 hours, with periodic checks to ensure complete ashing, indicated by the appearance of a whitish residue. Once the ashing process was complete, the furnace was turned off, allowing the residue to cool. The ashed samples were then extracted and stored in a desiccator.

Solution of the Mushroom Samples

A precise volume of 5 mL of 10% HCl solution was introduced to the ash and heated in a water bath to ensure complete dissolution. Additionally, 5 mL of 10% nitric acid was incorporated and boiled in the water bath for thorough dissolution. The resultant sample solution was quantitatively transferred using a stirring rod through a funnel lined with acid-treated filter paper into a clean, dry 50 mL standard flask, with the volume adjusted using de-ionized water after rinsing both the crucible and filter paper. This solution was subsequently utilized for analysis via flame photometry or atomic absorption spectrophotometry.

Digestion of Substrates and Soil Samples

A precisely measured 1.0 g of dried substrate was digested in a 500 mL flask using a mixture of concentrated nitric acid and perchloric acid in a 4:1 ratio for 1 hour on an electric hot plate. The resulting residue was re-dissolved in 0.1 M HNO3 and filtered through 0.1 M HCl pre-washed filter paper. The filtrate was then adjusted to the 50 mL mark in a volumetric flask with de-ionized water (Umanah et al., 2025).

Analysis of Trace Metals by AAS

Preparation/Digestion of Mushroom Sample Solutions

A precise amount of 2.0 g of dried and ground mushroom samples was ashed in a glazed crucible after undergoing pre-burning (charring) over a Bunsen flame within a fume chamber. The ashing process was conducted at 450 °C for 4 hours in a muffle furnace. Following cooling, the ash was transferred into a 50 mL beaker by dissolving it in 10 mL of concentrated HNO3 and rinsing with 10 mL of concentrated HCl. The solution was covered with watch glass and gently warmed for 10 minutes. Subsequently, the solution was cooled, decanted into a 100 mL volumetric flask, and adjusted to the mark with de-ionized water.

Statistical Analysis

The data collected were analyzed using analysis of variance (ANOVA) with the Statistical Package for Social Scientists (SPSS) version 16.0. Significantly different means were identified through Duncan's multiple range tests.

International Journal of Statistics and Mathematical Research Trends
E-ISSN: 3108-0871, Volume 2 Issue 1
Jan-Feb 2026, PP 77-92

III. Results and Discussion

The proximate compositions, vitamin C content and anti-nutritional profiles of the examined wild mushrooms are displayed in Table 2, while those of the cultivated mushrooms are shown in Table 3. The moisture content (MC) varied from 81.79% to 97.84%, with the highest value attributed to Amanita Phalaoides and the lowest to Agaricus bisporus. These findings are consistent with the values reported by Jonathan (2006) in his evaluation of the nutritional values of various wild Nigerian mushrooms. The dry matter (DM) content ranged from 2.63% to 18.36%, indicating a high level of roughage present in the mushrooms.

The crude protein (CP) content ranged from 8.16% to 24.67%, which is comparable to the following seeds and legumes: cowpea (19.06%), Treculia Abrilana (19.31%), bean seed (20.80%), colocy cilrullus (22.00%), and groundnut (23.05%). The ash content of mushrooms ranged from 3.26% to 14.33%, indicating a high mineral content. These findings are consistent with various literature reports. The lipid content, which varied from 1.00% to 6.68%, suggests that mushrooms serve as an excellent dietary option for individuals with diabetes and coronary heart disease. The crude fiber (CF) content in wild mushrooms was found to be between 2.62% and 11.37%, whereas cultivated mushrooms exhibited a range of 8.31% to 15.37%. T

hese figures align closely with data reported by Kalac (2009) regarding certain European mushrooms. Additionally, the values for ethanol soluble sugar (ESS), carbohydrates (CH2O)n, and vitamin C were similar, indicating no significant differences ($p > 0.05$) between wild and cultivated mushrooms. The anti-nutritional factors measured (mg/100 g) included cyanide (0.02-0.21), tannins (0.12-0.55), and phytic acid (0.01-0.70) in wild mushrooms, while cultivated mushrooms showed values of cyanide (0.04-0.31), tannins (0.01-0.67), and phytic acid (0.01-0.70). All these values were below the 1.00 mg/100 g threshold established by WHO guidelines for these toxicants in food. Similarly, a study conducted by Urgun et al. (2006) indicated that the levels of heavy metals (Pb, Ni, Mn, Cd, and Zn) in water from a nearby area were significantly above the recommended thresholds.

Table 2: Mean Proximate Compositions, Vitamin C and Anti-nutritional Profiles of Wild Mushrooms (%/100 g)

Mushroom Species	Moisture Content	Dry Mattter Content	Crude Protein	Crude Fibre	Ash	Lipid	Ethanol Soluble Sugar	Carbohydrate	Vitamin C	Cyanide	Tannins	Phytic acid
Termitorobustus	88.8 ±0.0	7.55 ±0.0	23.0 ±0.0	7.9 ±0.0	13.4	5.4 ±0.0	11.93 ±0.3	38.45 ±0.37	0.0	0.0 ±	0.0	0.0
Agaricus bisporus	81.2 ±0.2	18.7 ±0.1	24.0 ±0.0	9.0 ±	11.0 ±0	0.7 ±0.0	11.93 ±0.1	22.38± 0.2	0.0 ±0	0.0 ±	0.0	0.3 ±
Pleuotus tuber-re-	89.00 ±0.0	11.00 ±0.1	15.60 ±0.0	10.80 ±0.0	14.60 ±0	2.90 ±0.0	10.50 ±0.0	21.70±	0.10 ±0	0.02 ± 0.0	0.03 ± 0.0	0.05 ±

Amanita	97.1	2.90	8.5	2.2	3.8	2.9	10.50	69.	0.	0.	0.	0.7
phalaoid	±0.1	±0.0	±0.	±0.	±0	±0.	±0.0	90 ±0.10	±0	0.	0.	±
					3							
Amanta verosa	84.09 ±0.06	15.93 ±0.47	10.38 ±0.18	11.43 ±0.59	13.80 ±0.7	2.20 ±0.700	7.80 ±0.2 3	35.40 ±0.09	0.12±0.002	0.04 ± 0.01	0.12 ± 0.06	0.15 ± 0.04
Range	81.23 – 97.10	2.90 – 18.78	8.50 – 24.18	2.20 – 11.43	3.80± 14.6	0.70 ± 5.95	9.80 – 11.93	21.70 – 69.90	0.10 ± 0.15	0.02- 0.21	0.12- 0.55	0.01 – 0.70

Table 3: Mean Proximate Compostions, Vitamin C and Anti-nutritional Profiles of Cultivated Mushrooms (%/100 g)

Mushroom Species	Mois-ture Con-	Dry Mattter Con-	Crude Pro-tein	Crude Fibre	Ash	Lipid	Ethanol Soluble Sugar	Carbo hy-drate	Vitamin C	Cya-nide	Tan-nins	Phytic
**Termito-myce s ro-*	-	-	-	-	-	-	-	-	-	-	-	-
Agaricus	86.8	13.	31.	13.	13.	3.6	8.85	18.	0.37	0.14	0.67	0.0
bisporus	±0.1	±0.	±0.	±	±0.	±0.	±0.10	00	±0.0	0.01	0.20	±
Pleuotus	83.0	17.	12.	11.	11.	0.7	0.60	20.	0.16	0.04	0.01	0.3
tuber-re-	±0.0	±0.	±0.	±0.	±0.	±0.	±0.10	00	0.00	0.02	0.01	0.0
Amanita	94.0	6.0	18.	14.	14.	1.3	9.10	45.	0.17	0.31	0.55	0.7
phalaoides	±0.0	±0.	±0.	±0.	±0.	±0.	±0.70	00	±0.2	0.06	0.14	0.2
Amanta	94.6	5.3	13.	8.9	15.	2.6	6.10	32.	2±	0.14	0.01	0.0
verosa	±0.1	±0.	±0.	±0.	±0.	±0.	±0.11	00	1	0.04	0.01	0.0
Range	83.0	5.3	12 –	8.9	11.	0.7	0.60	18.	0.16	0.04-	0.01	0.0
	94.6	17.	31.	14.	15.	±3.	9.10	00 —		0.31	0.67	0.7

*Not planted

Table 4 presents the average concentrations of essential metals found in both wild and cultivated mushrooms. The data for these two categories of mushrooms are similar at $p>0.05$ and align with the values documented for fruits and vegetables by Obruche et al. (2009) as well as for mushrooms by Ogwuche and Obruche (2020).. However, it is noteworthy that some edible mushrooms from South Eastern Nigeria exhibited higher concentrations. The mean values recorded for Na, Ca, and K were in accordance with the WHO guideline levels, whereas the values for Mg and Fe were found to be elevated in mushrooms.

International Journal of Statistics and Mathematical Research Trends
E-ISSN: 3108-0871, Volume 2 Issue 1
Jan-Feb 2026, PP 77-92

Table 4: Mean Concentrations (mg/kg) of Essential Metals in Wild and Cultivated Mushrooms

Mushroom species	Wild					Cultivated				
	Na	K	Ca	Mg	Fe	Na	K	Ca	Mg	Fe
Tr	370.99 ± 0.27	886.32 ±0.14	83.64 ±0.15	686.76 ±0.04	213.09 ±0.19	-	-	-	-	-
Ab	474.64 ±0.33	714.88 ±2.15	252.67 ±0.80	476.57 ± 0.97	268.11 ±0.19	668.49 ±0.33	844.23 ±4.33	588.61 ±2.20	549.66 ±1.11	446.19 ±0.72
Ptr	152.36 ±0.14	678.39 0.27	399.76 ±0.84	601.83 ±0.44	154.68 ±0.15	332.77 ±1.59	698.17 ±0.63	801.19 ±1.20	899.10 ±3.11	401.66 ±0.92
Aph	777.42 6.27	933.81 ±2.14	545.00 ±0.64	1,191.00 ±2.04	404.32 ±1.19	1,061.13 ±7.33	701.99 ±0.28	1,841.00 ±0.14	1,566.11 ±0.81	772.01 ±3.12
Av	669.59 ±0.84	166.88 ±0.16	111.40 ±0.77	1,178.00 ±1.85	684.74 ±0.55	698.60 ±0.89	196.39± 0.93	219.69 ±1.20	1,279.00 ±2.11	777.18 ±1.12
Range	152.36-777.42	66.88-933.81	83.64-545.0	476.57-1,191.0	154.68-684.74	332.77-1,061.13	196.39-844.23	219.67-1841.00	549.66-1,566.11	401.66-777.18
WHO	1500	4700	1300	420	18	1500	4700	1300	420	18

Tr-Termitomyces robustus, Ab- Agaricus bisporus, Ptr-Pleurotus tuber-regium, Aph-Amanit phalaoides, Av-Amanita verosa

Table 5: Mean Concentrations (mg/kg) of Trace Metals in Wild and Cultivated Mushrooms.

Mushroom spe-	Wild								Cultivated							
	Cu	Co	Pb	Zn	Cd	Ni	Mn	Cr	Cu	Co	Pb	Zn	Cd	Ni	Mn	Cr
Tr*	0.12	0.59	5.03	50.88	4.48	16.85	24.42	BDL	-	-	-	-	-	-	-	-
	±0.	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0									
Ab	0.39	1.21	4.56	28.72	4.41	1.40	15.20	BDL	0.09	2.03	6.33	68.56	9.15	2.19	21.72	BDL
	±0.	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0		±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	±0.0	
Ptr	0.22	0.48	3.60	25.00	4.30	3.04	13.60	BDL	0.01	0.49	3.68	45.48	4.40	3.08	13.60	BDL
	±0.	±0.6	±1.0	±6.0	±0.9	±1.0	±3.0		±0.0	±0.0	±1.2	±0.0	±1.3	±1.0	±2.0	
Aph	0.72	1.52	4.62	34.02	3.88	4.77	16.60	BDL	0.22	6.04	5.55	48.33	4.99	6.89	18.80	BDL
	±0.	±0.2	±0.0	±5.0	±1.0	±1.6	±2.0		±0.0	±0.8	±1.0	±7.0	±1.0	±0.9	±0.7	

Av	0.66	0.63	3.83	61.17	6.68	15.07	8.25	BDL	0.36	4.83	4.89	9.33	9.88	22.05	11.60	BDL
	±0.	±0.0	±0.0	±0.0	±1.0	±3.0	±1.0		±0.0	±0.7	±0.8	±0.8	±1.0	±2.0	±0.9	
Range	0.12-0.72	0.48-1.52	3.60-5.03	25-61.1	3.88-6.68	1.40-16.8	8.25-24.4	BDL	0.01-0.36	0.49-6.04	3.68-6.33	9.33-68.5	4.99-9.88	2.19-22.0	11.60-21.7	BDL
WHO 2004	0.90	0.29	0.63	11	0.59	0.50	2.3	0.95	0.90	0.29	0.63	11	0.59	0.50	2.3	0.95
CODEX 1995	3	0.01-0.1	0.05	17	0.1	0.4	0.13-0.26	0.1	3	0.01-0.1	0.05	17	0.1	0.4	0.13-0.26	0.1

*Not Ccultivated., Tr-Termitomyces robustus,Ab-Agaricus bisporus,Ptr-Pleurotus tuber-regium,Aph-Amanita phalaoides,Av-Amanita verosa

Chromium was undetectable in all mushroom samples, whereas copper levels in every mushroom sample were below the concentrations recommended by the WHO for food. The remaining metals exhibited concentrations exceeding the WHO guideline levels in all samples analyzed, including both wild and cultivated mushrooms.
Contains average concentrations of trace metals found in soils and substrates from which wild mushroom samples were obtained.

Table 6: Mean Concentrations (mg/kg) (n=3) of Trace Metals in Soils and Substrates from where Wild Mushroom Samples were collected.

Soil/sub	Cd	Co	Cr	Cu	Fe	M	Ni	Pb	Zn
Garden soil	6.04	1.1	2.09	10.6	11	2.6	8.6	66.	18.83
	±0.44	±0.	±0.1	±1.0	±1.	±0.	±0.	±0	±0.10
Decayed wood	5.15	BD	30.1	10.1	20	40.	18.	4.2	16.35
	±0.44	-	±0.7	±1.7	±2.	±0.	±0.	±0	±0.72
Farmland soil	10.55	10.	8.89	10.7	10	10.	23.	6.0	80.83
	±2.33	±1.	±0.7	±0.9	±2.	±0.	±0.	±0	±2.55
Farmland soil	3.38	2.0	0.19	2.08	34	1.3	8.1	4.7	4.77
	±0.98	±0.	±0.0	±0.7	±2.	±0.	±0.	±0	±0.70
Decayed wood	30.30	1.8	0.04	1.39	44	1.3	6.6	16.	10.04
	±2.86	±0.	±0.0	±0.2	±0.	±0.	±0.	±0	±0.25
Farmland soil	6.04	1.1	2.09	10.6	20	2.6	8.6	66.	18.83
	±1.29	±0.	±0.1	±1.6	±0.	±0.	±1.	±2	±1.22
Refuse soil	17.65	4.4	6.44	15.7	60	7.8	18.	10	22.44
	±1.59	±0.	±0.9	±1.7	±6.	±0.	±1.	±4	±1.3
Sub(leaf litters)	3.18	2.0	0.03	2.08	10	1.3	2.1	1.7	1.89
	±0.19	±0.	±0.0	±0.7	±2.	±0.	±0.	±0	±0.44
WHO agric	0.05-	2-	0.10	20.0	400-	50-	20.	20.	100
WHO Pol-	3-	5-	4-	50-	400-	50-	75-	50-	300-

All soil samples exhibited contamination with cadmium (Cd) and chromium (Cr), while 40% were found to be contaminated with lead (Pb), which also displayed increased

levels in other samples. Additionally, nickel (Ni) levels were elevated across all samples. The remaining metals were found to be below the guideline levels established by the World Health Organization (WHO). Notably, chromium was undetectable in all species of both wild and cultivated mushrooms. Overall, bioaccumulation factors were notably low, despite the fact that many mushroom species contained metal concentrations exceeding the WHO guideline values for food.

Table 7: Bioaccumulation of Trace Metals in Wild and Cultivated Mushrooms

Mush Species	BIOACCUMULATION FACTORS																	
	Wild									Cultivated								
	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Tr*	0.74	0.54	--	0.01	1.79	9.25	1.95	0.08	2.70	--	--	--	--	--	--	--	--	--
Ab	0.86	0.28	--	0.04	1.30	0.38	0.08	1.08	1.76	1.78	0.47	--	0.01	2.16	0.54	0.12	1.50	4.19
Av	0.63	0.06	--	0.06	1.45	0.78	0.65	0.63	0.76	0.94	0.44	--	0.03	2.22	1.10	0.95	0.79	6.12
Aph	1.15	0.76	--	0.35	1.17	11.94	0.58	0.97	7.13	1.48	3.01	--	0.11	1.27	13.53	0.84	1.16	10.13
Ptr	0.14	0.26	--	0.12	1.54	9.78	0.46	0.21	2.49	0.15	0.26	--	0.01	1.77	9.78	0.46	0.22	4.53

IV. Discussion

Proximate Compositions, Vitamin C, and Anti-nutritional Factors of Mushroom Samples. Proximate composition, vitamin C, and mineral content serve as indicators of nutritional quality. The values obtained from the analyzed mushrooms clearly demonstrate that these mushrooms possess high nutritional qualities, albeit with low anti-nutritional factors that remains below the permissible limits set by WHO for food (Table 2&3). The crude protein (CP) levels, ranging from 8.50% to 24.18%, are relatively comparable to those found in legumes (Cowpea 19.06%, Beans 20.80%, Groundnut 23.05%) and meat muscle (22.00%). The ash content, which varies from 3.26% to 14.33%, indicates a high mineral content in mushrooms. The low lipid (fat/oil) content, ranging from 1.00% to 6.68%, suggests that mushrooms are an excellent dietary option for individuals with diabetes and coronary heart disease.

Based on the analytical data obtained, it is reasonable to conclude that the studied mushroom species, namely Termitomyces robustus, Agaricus bisporus, Amanita phalaoides, Amanita verosa, and Pleurotus tuber-regium, hold significant potential in addressing the protein supply deficiency prevalent in several developing countries in Africa, including Nigeria. The low carbohydrate content, ranging from 32.00% to 35.40%, explains why certain mushroom species are locally utilized as binders, bulking agents (in melon cake—a local snack), and thickeners in soups or infant formulas. This suggests that mushrooms can effectively function in low-fat diets, which are particularly beneficial for patients with cardiovascular diseases, obesity, and diabetes. The vitamin C content was detectable at levels between 0.01 and 0.37 mg/100 g. However, the determined values of vitamin C indicate that these mushroom species are not reliable sources of vitamin C, although they may still contribute significantly to the diet.

The low levels of anti-nutritional factors indicate that consumers are unlikely to experience the toxic effects of these substances, as cooking further degrades them. Similar values of 0.36 mg/100 g for phytates have been documented in certain mushrooms and cowpea (0.36 mg/100 g). The average phytic acid content of 0.26 mg/100 g is comparable to the levels found in both wild and cultivated mushrooms, which are at 1.00 mg/100 g according to WHO guidelines from 1995. Phytates have the ability to chelate essential minerals such as calcium, magnesium, iron, and zinc, making these minerals less available for absorption.

Additionally, phytates inhibit the activity of digestive enzymes, including amylase, pepsin, and pancreatic enzymes. The average cyanide content of 0.16 mg/100 g in these mushroom species is low compared to the 0.36 mg/100 g reported in the literature and WHO guidelines. This cyanide content can be reduced through blanching and cooking before consumption. The mean tannin value of 0.31 mg/100 g is slightly below the maximum permissible levels set by WHO, which may lead to health issues when mushrooms are consumed in large quantities. These findings were statistically close ($p>0.05$) and comparable to values reported for fruits and vegetables; however, higher levels were noted in some edible mushrooms from South Eastern Nigeria (Umudi et al., 2025).

Concentrations of Essential Metals in Studied Mushroom Samples

The concentrations of essential metals presented in Table 4 indicate that these mushroom species are excellent sources of these elements, potentially providing up to 50% of the recommended daily allowances. The mean values obtained from the studied mushrooms were also higher than those found in existing literature. For instance, the mean sodium concentration in the studied mushrooms was 777.42 mg/kg, compared to 277.33 mg/kg in cowpea and 252.67 mg/kg in vegetables.

The concentration of sodium differs across various parts of species, which aligns with findings documented in existing literature. Sodium and potassium serve as systemic electrolytes and play a crucial role in the co-regulation of ATP. ATP, or Adenosine triphosphate, is a nucleotide with the chemical formula $C10H16N5O13P3$, consisting of adenosine and three phosphate groups, which releases energy upon hydrolysis to ADP. It is found in all cells, where it functions to store and transport the energy necessary for biochemical reactions.

Mitochondria in both plant and animal cells contain ATP, which is a primary energy source for cellular reactions, with energy being released during the conversion of ATP to ADP. The observed values were greater than those reported for vegetables. The nutritional advantages of ATP include its necessity for muscle development, support for the heart and digestive system, bone formation, and the proper functioning of blood cells. Iron (Fe) is essential for the synthesis of various proteins and enzymes, particularly hemoglobin, to avert anemia. Based on the data collected, the mushrooms examined can be regarded as excellent sources of iron and magnesium. Magnesium is vital for the optimal functioning of ATP and for bone development (Itodo et al., 2021).

Trace Metal Concentrations in Soils and Substrates.

Table 6 clearly indicates that the soils and substrates from which the studied mushrooms were harvested exhibited concentrations of cadmium (Cd), chromium (Cr),

nickel (Ni), and lead (Pb) that exceeded the guideline values set by the WHO, while the concentrations of other metals remained within acceptable limits.

Concentrations and Bioaccumulation of Trace Metals.
Among the trace metals analyzed, copper was the only metal whose concentration fell below the WHO guideline levels for food. In contrast, other trace metals displayed concentrations that surpassed the WHO guideline values in food. This finding reinforces the assertion that, under natural conditions, the concentrations of heavy metals in certain mushroom species can be elevated, even when the level of soil pollution is minimal. Furthermore, the brief cropping cycle of 10-14 days suggests that these mushroom species possess a significant capacity for trace metal uptake and accumulation, which could be harnessed for the bioremediation of soils contaminated with trace metals.

Potential of the Investigated Mushrooms for the Removal of Trace Metals from Contaminated Soils.
Bioaccumulation factors serve as indicators of the extent to which living organisms acquire or retain persistent contaminants in relation to the concentrations of these contaminants present in the ecosystem. The bioaccumulation factors determined in this study are predominantly low, despite the fact that the concentrations of metals, with the exception of Cu and Cr, in the analyzed samples surpassed the levels recommended by the WHO. In comparison, Mn and Zn exhibited notable bioaccumulation factor levels. Specifically, Mn has a bioaccumulation factor ranging from 11.94 to 13.53 in Amanita phalaoides; 9.78 in Pleurotus tuber-regium; and 9.25 in Termitomyces robustus, while Zn has a range of 7.13 to 10.13 in Amanita phalaoides and 6.12 in Amanita verosa.

The mushrooms examined in this study can effectively extract Mn and Zn from metal-contaminated soils. Mushrooms offer several advantages over other bioremediation agents: they have a shorter lifespan, a greater capacity for accumulation, and the ease of biomass removal. The short cropping cycle of mushrooms, lasting 10-14 days, is beneficial as it allows for multiple cropping sessions within a single season. Consequently, Amanita phalaoides demonstrates significant potential for the removal of Mn and Zn, while Pleurotus tuber-regium and Termitomyces robustus are effective for Mn, and Amanita verosa is effective for Zn (Umudi et al., 2025).

V. Conclusion

Mushrooms, recognized as a favored culinary delicacy in contemporary society, have garnered increasing interest in the fields of bioremediation and biotechnology. The mushrooms examined were all determined to be edible, exhibiting high nutritional values and low levels of anti-nutritional factors that fall below the permissible limits set by the WHO for food and vegetables. They serve as excellent sources of essential metals, including Na, K, Ca, Mg, and Fe. Additionally, they act as accumulators of toxic metals such as Cd, Co, Mn, Ni, Pb, and Zn. Notably, all detected levels of these toxic metals exceeded WHO guideline values, which may compromise their edibility. In terms of bioremediation, Amanita phalaoides demonstrates significant potential for the removal of Mn and Zn, while Termitomyces robustus and Pleurotus tuber-regium are effective for Mn, and Amanita verosa is suitable for Zn extraction from trace metal-contaminated soils, as inferred from their accumulation capabilities for these metals. Achieving safe concentrations of Mn and Zn in contaminated soils can be facilitated by

leveraging their short cropping cycles and the possibility of multiple plantings within a single season. The successful cultivation of Amanita phalaoides, Pleurotus tuber-regium, Amanita verosa, and Agaricus bisporus has been accomplished. In conclusion, the research findings indicate that all examined mushrooms are edible, although their safety may be compromised if cultivated or harvested from contaminated soils. The study has revealed that, in comparison to international standards, the investigated areas are indeed polluted with Mn, Zn, Cd, and Pb.

References

1. Abeokuta, O.J, Uriri, S.A, Obruche, E.K, Okurame, O (2025). Hydrochemical Assessment of Borehole Water Quality in Eku, Delta State, Nigeria. Journal of Science, Technology and Environmental Studies,1(2):17-25
2. Adebayo, J.G., Banjo, N.O., Abikoye, E.T. (2009). Evaluation of Yield of Oyster Mushroom (Pleurotus pulmonarius) Grown on Cotton Waste and Cassava Peel. African Journal of Biotechnology, 8(2), 215-218.
3. Akpaja, E. O., Isikhuemhen, O. S., Okhuoya, J. A. (2003). Ethnomycology and Usage of Edible and Medicinal Mushrooms among the Igbo People of Nigeria. International Journal of Medicinal Mushrooms, 5, 313-319.
4. Ekpo Ekokodu Rose, Erienu Obruche Kennedy, and Abiye Clement. Marcus (2025). Spatial and Temporal Variations in the Concentrations of Polycyclic Aromatic Hydrocarbon, in Ambient Air From Three Different Locations in River State, Nigeria. International Journal of New Chemistry, 12 (4), 567-580
5. Erienu Obruche Kennedy, Itodo Adams, Wuana Raymond and Sesugh Ande (2022). Polycyclic Aromatic Hydrocarbons in Harvested Rainwater in Warri and Agbarho, Nigeria. Bulletin of chemical society of Ethiopia, 36(4): 27-35.
6. Festus-Amadi, I. R, Erhabor, O. D, Ogwuche Christiana E, and Obruche E. K. (2021). Characterization of Contaminated Sediments Containing Polycyclic Hydrocarbons from Three Rivers in the Niger Delta Region of Nigeria. Chemistry Research Journal, 6(3):1-12
7. Itodo, A. U., Wuana, R. A. Erhabor, O. D., Obruche, E. K. and Agbendeh, Z. M.(2021). Evaluating the Effects of Roofing Materials on Physicochemical Properties of Harvested Rainwater in Warri, Delta State, Nigeria. Chemical Society of Nigeria Journal, Kano, 12(1): 234-245
8. Obruche E. K, Emakunu S.O, Ugochukwau G. C (2025). Rainwater Harvesting: Microbial and Chemical Water Quality Assessment in Warri District. Mosogar Journal of Science Education,10(1):36-45
9. Osemwegie, O.O., Eriyaremu, E.G., Abdulmalik, J. (2006). A survey of macrofungi in Edo/Delta Region of Nigeria, their Morphology and Uses. Global Journal of Pure and Applied Science, 12 (2), 149-157.
10. Obruche E. k, Erhabor O.D, Itodo A.U and Itopa S.T (2019). Spectrophotometric determination of iron in some commercial iron containinig tablets/capsule. International journal of advanced trends in computer applications, 1(1): 231-235
11. Okhuoya, J.A., Okogbo, F.O. (1991). Cultivation of Pleurotus Tuber-Regium (FR) singer) on Various Farm Wastes. Proceedings of the Oklahoma Academy of Sci., 17, 1-3.
12. Obruche E. K, Ogwuche C.E, Erhabor O.D and Mkurzurum.C (2018). Evaluation of the inhibitive effect of African Marigold (Tagetes erectal L.) Flower Extracts

on the Corrosion of Aluminium in Hydrochloric Acid. International Journal of Advances in Scientific Research and Engineering, 4 (12): 167-177

13. Ogwuche C.E and Obruche E.K. (2020). Physio-chemical analysis of palm oils (elaeis guineensis) obtained from major markets in agbarho, unenurhie, opete, ughelli and evwreni town, Delta state, Nigeria. International journal of trend in scientific research and development,4(2):56-60
14. Obruche E. K, Ogwuche C.E, Erhabor O.D and Mkurzurum.C (2019).Investigating Corrosion Inhibition Effects of Tagetes Erecta L. Leaf Extrac on Aluminium in Acidic Medium. Global Scientific Journals, 7 (1): 1-17
15. R.E. Ekpo, A.C. Marcus and E.K. Obruche (2023). Spartial and Temporal Variations in the Concentration of Particulate Matter in Ambient Air from three Different Locations in River State, Nigeria. International Journal of Scientific Research in Chemical Science,10(4):32-38
16. Umudi E. Q., Obruche E. K., Sani M. I., Onwugbuta G. C., Aghemwenhio I.S., Ikechukwu S. C., Clark P. D., Essiet A.G., Eresanya O.I., Ibe M.C. & Hashimu. A. (2025). Evaluation of Polycyclic Aromatic Hydrocarbons (PAHs) Contents of Fishes, Waters and Sediments of Rivers Niger: Human Health Risk Assessment. Journal of Basics and Applied Sciences Research,3(5),187-199. https://dx.doi.org/10.4314/jobasr.v3i5.20
17. Umanah F. I ; Oyibo R. U ; Rita C. N; Bashir M. A, Ibebuike U. O. & Obruche E. K. (2025). Self-Concept, Self-Efficacy and Parental Involvement as Predictors of Academic Achievement of Junior Secondary School Students in Delta South Senatorial District. Journal of Education Research and Library Practice,9(8):51-65
18. Umudi Ese Queen, Ese Ekanem , Sani Mamman Ibrahim, Onwugbuta Godpower Chukwuemeka , Suleiman Abdulmajid, Magashi Luper, Udo Idongesit , Ikechukwu Chikwe Odontimi Nimighaye , Essiet Gordon , Chinedu Okechukwu, Brown Amieye Bright and Erienu Obruche Kennedy.(2025) Degradation Efficiencies of the Total Petroleum Hydrocarbons (TPHs) in the Soil Amended with Palm Bunch Ash and Tween 80 in Ibenomo L.G.A, Akwa Ibom State. International Journal of Chemistry and Chemical Processes,11(5):1-20 10.56201/ijccp.vol.11.no5.2025.pg1.21
19. Ugochukwu Gladys Chioma, Ataine Theresa Ifeyinwa and Erienu Kennedy Obruche (2025). Determination of the Physicochemical Properties of Soil Amended with Cassava Mill Effluent in Mosogar Area of Delta State. Mosogar Journal of Science Education,10(1):81-89
20. Umudi Ese Queen, Odontimi Nimighaye, Sani Mamman Ibrahim, Chidi Henry, Onwugbuta Godpower Chukwuemeka, Odejobi BabajideMichael, Jemimah Wakawa Ronald Winfred Abhulimen , Abiodun Emmanuel Adams , Ikechukwu Chikwe and Erienu Obruche Kennedy. (2025). Assessment of the Seasonal Variations in Heavy Metals Concentration in the Ughelli Central Market River, Delta State, Nigeria. International Journal of Applied Science and Mathematical Theory,11(6),78-88 https//doi.org/10.56201/ijasmt.vol.11.no6.2025.pg78.88
21. Urgun, M., Demirtas, B.S., Pagilla, K. (2006). Uses of genetically engineered micro-organisms (GEMs) for the bioremediation of contaminants. Critical Review in Biotechnology, 26 (3), 145- 164.
22. Umudi Ese Queen; Ese Ekanem; Idongesit O. Ekpenyong; Sani Mamman Ibrahim; Onwugbuta Godpower Chukwuemeka; Suleiman Abdulmajid; Ikechukwu Chikwe; Chidi Henry; Chidi Victory; and Erienu Obruche Kennedy.(2025). Seasonal Assessment of Heavy Metals Concentrations in Sediment of the Sapele

River, Nigeria Journal of Science Innovation & Technology Research, 9(9),124 – 139

23. WHO (1995). Forty fourth report of WHO expert committee on food additives. Evaluation of certain food additives and contaminants. Geneva Pub., 1 (2), 32-34.
24. WHO(2010).Guidelines for Safe Recreational Water Environments. Coastal and Fresh waters.[www.who.org/media/media_2722 8.html], (accessed 27/12/2016).