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Research Article

Nutritional Profile of Some Wild Edible Mushrooms, Cultivated in Cameroon and Democratic Republic of Congo

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Abstract

Wild edible mushrooms (WEM) are non-wood forest products that are widely used in the diets of many people in tropical Africa. In order to improve local diets and make the most of these natural resources, the nutritional quality of 28 wild and domesticated species in Cameroon and the Democratic Republic of Congo was analyzed. Measurements were taken of ash, water, carbohydrate, crude fiber, lipid, protein and energy content. The results indicate that these mushrooms are rich in lipids (11.75 g/100 g DM), proteins (25.89 g/100 g DM), crude fiber (13.91 g/100 g DM), water (86.82 g/100 g FM), ash (6.51 g/100 g DM), carbohydrates (27.57 g/100 g DM) and energy (324.13 kcal/100 g). Highly significant differences ($P < 0.05$) were observed between species. For example, *Termitomyces* sp.$_5$ (28.78 g/100 g DM) is rich in ash, while *P. pulmonarius* (28.52 g/100 g DM) stands out for its high lipid content and *T. griseiumbo* (49.38 g/100 g DM) has a remarkable level of protein. In terms of carbohydrates, *P. ostreatus* (55.51 g/100 g DM) stands out, while *P. tuber-regium* (26.79 g/100 g DM) has a notable proportion of crude fiber. In terms of energy, *P. pulmonarius* (459.76 kcal/100 g DM) still stands out. These results demonstrate the significant nutritional potential of these mushrooms, which are using to reduce nutritional deficiencies and facilitate intestinal transit thanks to their fiber content. Domestication of these mushrooms would also ensure continuous availability throughout the year, thereby reducing dependence on natural resources.

Keywords

Domestication, Non-timber Forest Products, Nutritional Deficiencies, Proximal Composition, Wild Edible Mushrooms

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1. Introduction

Over the last 20 years, the study of edible fungi has developed rapidly throughout the world and in Africa. Once regarded as foods of little nutritional value, edible mushrooms are now attracting particular interest [1]. Global production has risen steadily from 2,182,000 t/year in 1986 to 10,378,163 t/year in 2016; and is expected to reach 20.84 million tons by 2026 [1-4]. Africa's share of production was around 21,185 t/year [5]. Given that 48.5% of the population of Central Africa suffers from malnutrition, affecting 14.4 million Cameroonians [6, 7], the integration of edible mushrooms is already recognized as a key element of the modern diet and a potential resource for boosting food security in developing countries [8]. This strategy could significantly improve living conditions. According to Black *et al* [9], famine is the main or underlying cause of death for almost 11 million children under the age of 5, who die as a direct or indirect result of famine and malnutrition. Millions more suffer from diseases caused by nutritional deficiencies in vitamins, minerals and trace elements nutrients essential to their health and physical development. Faced with this public health challenge, the exploitation of natural resources appears a promising avenue. Mushrooms, like medicinal plants, are recognized for their therapeutic properties in cardiology, parasitology, tumors, viral diseases and in the field of antibiotics [10-12], and for their nutritional qualities [13-16]. Their exploitation could help mitigate the devastating effects of malnutrition and improve the quality of life of the most vulnerable populations.

The nutritional value of mushrooms is comparable to that of meat, eggs and milk [17, 18]. They are rich in protein, vitamins, minerals and fiber; they are low in fat and provide very little energy, making them a low-calorie food [19, 20]. As such, they serve as an important accompaniment to meals and a supplement to the human diet, especially in rural areas, and have an excellent nutritional value comparable to that of many vegetables. This has draw the attention of researchers to their mineral content [2, 21]. On the one hand, mushrooms help improve diet quality by providing high-quality protein; on the other, they combat poverty when marketed [22].

In tropical Africa, very little is known about the diversity and use of medicinal and edible mushrooms. This is surprising, given the scattered studies by Malaisse *et al*. [23] and Degreef *et al*. [8] in Burundi, the Central African Republic and Rwanda; by Ogundana & Fagade [24], Ijioma *et al*. [25] and Nwoko *et al*. [26] in Nigeria; and by Oba *et al*. [27], Metsebing [28] and Tsigain *et al*. [29] in Cameroon. Yet few investigations have focused on the nutritional properties of edible mushrooms from Central Africa particularly those from Cameroon [13, 14, 16]. This gap is notable, considering the mycoflora's diversity and the undeniable role of edible mushrooms in local diets: around 1.1-1.4 kg per person in Cameroon [30], 30 kg per person in the Democratic Republic of Congo [31], almost all production consumed in Gabon [32], and 9% of the total harvest in south-west Burundi [33].

A study of the biochemical properties would provide a better understanding of the nutritional value of the samples analyzed, so that local edible mushrooms produced by mushrooms farmers could be better exploited. Cameroon produces 52 tons of mushrooms per year and imports more than 200 tons [34]. In view of their number and recognized potential, such as the presence of all the essential amino acids in their composition, their richness in protein, fiber, ash, water, lipid, energy and their medical importance [35, 36], edible mushrooms could provide a nutritional palliative to the food deficit experienced by populations in tropical Africa in particular, and in Cameroon and the Democratic Republic of Congo as a result of internal conflicts.

It was with this in mind that this study was initiated. Its general objective is to assess the nutritional composition of a number of edible mushroom species found in Cameroon and the Democratic Republic of Congo and consumed by local populations.

2. Materials and Methods

2.1. Materials

2.1.1. Biological Material

The biological material used in this study consists of twenty-eight (28) species of edible fungi. In Cameroon 24 samples were used (23 samples were collected and 01 was purchased) and 04 samples were collected in Congo (DRC) (Table 1). They were collected between March and December 2022-2023 in three regions of Cameroon: the Centre region (University of Yaounde I campus, city supermarket, Mont Eloundem and Cryptogamy laboratory), West region (Santchou forest reserve, Bandjoun market, Kamna and Mbouda markets), and the North-West region (Bamenda University campus and Bambui market). In the Democratic Republic of Congo, samples were collected in the provinces of Kongo-Central (Tshela market), Haut-Katanga (Lubumbashi market) and Matadi (Kisantu market).

2.1.2. Technical Material

The technical equipment consisted of a camera for taking photos of the samples, a machete and a penknife for harvesting. After harvesting, paper bags were used to place samples for storage. A home-made or and electric dryer was used for drying at 60°C for around 24 hours. The identification of samples was done in the Cryptogamy laboratory in the Department of Plant Biology, Faculty of Science at the University of Yaounde I and the laboratory herbarium.

Table 1. Edible mushrooms studied with their different substrate types and collection sites.

Order Number	Species	Family	Type of substrate	Sample collection site
1	*Cantharellus* sp.	Cantharellaceae	Lignicolous	D. R. Congo (Lubumbashi)
2	*Pleurotus tuber-regium*	Pleurotaceae	Sclerotium	D. R. Congo (Tshela)
3	*Pleurotus citrinopileatus*	Pleurotaceae	Lignicolous	Cameroon (Yaoundé)
4	*Pleurotus pulmonarius*	Pleurotaceae	Lignicolous	Cameroon (Mount Eloundem)
5	*Volvariella volvacea*	Plutaceae	Lignicolous	Cameroon (UY1 Campus)
6	*Termitomyces* sp.1	Lyophyllaceae	Meules	Cameroon (Bandjoun)
7	*Tricholomopsis aurea*	Tricholomataceae	Lignicolous	Cameroon (Bambui)
8	*Termitomyces fombapei*	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Santchou)
9	*Pleurotus ostreatus*	Pleurotaceae	Lignicolous	Cameroon (Bamenda)
10	*Termitomyces* sp. 4	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Santchou)
11	*Termitomyces mboukouina*	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Santchou)
12	*Termitomyces melongii*	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Santchou)
13	*Termitomyces* sp. 2	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Santchou)
14	*Termitomyces* aff. *clypeatus*	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Santchou)
15	*Termitomyces mbongonensis*	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Santchou)
16	*Termitomyces* sp. 3	Lyophyllaceae	Terricole (grinding stones)	D. R. Congo (Kisantu)
17	*Auricularia judae*	Auricullariaceae	Lignicolous	Cameroon (Yaoundé
18	*Termitomyces* sp. 5	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Santchou)
19	*Pleurotus sajor-caju*	Pleurotaceae	Lignicolous	Cameroon (Mount Eloundem)
20	*Pleurotus pulmonarius* (cultivated)	Pleurotaceae	Corncobs	Cameroon (Cryptogamy Lab.)
21	*Termitomyces reticulatus*	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Kamna)
22	*Termitomyces letestui* (form, 1)	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Mount Eloundem)
23	*Termitomyces meduis*	Lyophyllaceae	Terricole (grinding stones)	Cameroon (U. Y1 Campus)
24	*Termitomyces congolensis*	Lyophyllaceae	Terricole (grinding stones)	D. R. Congo (Lubumbashi)
25	*Termitomyces letestui* (form, 2)	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Mbouda)
26	*Agaricus bisporus* (cultivated)	Agaricaceae	Horse exchange	Cameroon (Bought in Yaoundé super market)
27	*Pleurotus sajor-caju* (cultivated)	Pleurotaceae	Corncobs	Cameroon (Cryptogamy Lab.)
28	*Termitomyces griseiumbo*	Lyophyllaceae	Terricole (grinding stones)	Cameroon (Makénéné)

2.2. Methods

2.2.1. Collection and Identification of Samples

Samples were collected in the field using the opportunistic method. This consists of (randomly) scouring the collection site in search of specimens or taxa visible to the naked eye [37]. It was then possible to identify the fungi using conventional taxonomy. Macroscopically, the characters visible to the naked eye (shape and size of the stalk, cap, odor, flavor, any ornamentation, etc.) on the specimens were described and the colors were specified using the colour chart, "Metheun Handbook of Color" by Kornerup & Wansher [38].

Microscopically, structures invisible to the naked eye were observed and described (cystids, basidia, spores, etc. were described) using an OLYMPUS CH2 photonic microscope

with a micrometric eyepiece and solvents such as 12% glycerin, 10% KOH, Phloxine B and immersion oil. After observing these characteristics, we compared them with the contents of monographs, existing determination keys, documents, articles and various available literature [27-29, 39, 40].

2.2.2. Determination of Proximate Composition of Edible Mushrooms

To carry out the analyses, the previously dried samples were crushed into pieces and ground in a blender. The water, dry matter, protein, lipid, ash and crude fiber contents were determined, along with the carbohydrates and energy contents. All parameters (water content, protein, lipid, carbohydrate, ash, crude fiber) were expressed in g/100g of fresh matter (FM) or dry matter (DM) and energy in Kcal/100g of dry matter.

(i). Determination of Water Content

The water content was determined using the method described by AFNOR [41]. The principle is based on the loss of mass of the sample until a constant mass is obtained at 105 ℃ for 24 hours. To do this, 1g of sample powder is weighed and introduced into aluminum crucibles that have been cleaned and sterilized beforehand, and the empty weight (P_0) is noted. The weight (P_1) measured and noted corresponds to the weight of the empty crucible plus that of the sample. Once the sample has been removed from the oven, the weight (P_2) is measured and noted.

This weight is then used to calculate the water content (W.C) according to the following formula:

$$W.C\ (g/100g\ FM) = (P_2 - P_0) / (P_1 - P_0) \times 100$$

Where:

P_0: the empty weight of the crucibles,

P_1: weight of crucibles + test sample before treatment,

P_2: the weight of the crucibles + test sample after treatment.

(ii). Determination of Protein Content

Protein content was determined using the Dumas method [42], which involves catalytic combustion with a nitrogen elemental analyzer (Vario Micro Cube, Elementar, Frankfurt, Germany). Briefly, the samples are injected into a furnace at 1080 °C under a flow of oxygen and helium. The gas mixture generated then passes through the reduction tube at 850 °C, where the gases are purified. The nitrogen content obtained was multiplied by 5.7 to obtain the protein content.

(iii). Determination of Lipid Content

To determine lipid content (L.C), 1 g of sample was weighed and the method described by Bourely [43] was used. This method is based on the use of Soxhlet as an extractor and hexane as a solvent for 12 hours. After vaporizing the solvent and drying the filter papers in an oven at 105 °C for 30 minutes, the difference in weight gives the lipid content of the sample.

This can be calculated using the following formula:

$$L.C\ (g/100g\ DM) = (P_1 - P) / (P_1 - P_2) \times 100$$

Where:

P_1: the weight of the full bag containing the test sample before processing,

P: the weight of the full bag containing the test sample after oil extraction,

P_2: the weight of the empty filter paper bag.

(iv). Determination of Ash Content

The method used to determine ash is that described by AFNOR [44]. It consists of incinerating 1g of sample powder in a furnace at 550 °C for 24 h until white ash is obtained. This is done by measuring the weight P_0 of the aluminum crucibles, the weight P_1 of the crucibles plus the sample and 24 hours later the weight P_2.

The formula below was used to calculate the ash content (A.C):

$$A.C\ (g/100g\ DM) = (P_2 - P_0) / (P_1 - P_0) \times 100$$

Where:

P_0: weight of empty crucibles,

P_1: the weight of the crucibles containing the test sample before treatment,

P_2: the weight of the crucibles containing the test sample after treatment.

(v). Determination of Crude Fiber Content

The crude fiber content was obtained by the method described by the AOAC [45], which consists of weighing 1g (P_e) of delipidated sample and introducing it into a beaker containing sulphuric acid (0.26N H2SO4). The mixture obtained was then boiled for 30 min and filtered. Sodium hydroxide (0.23N NaOH) was added to the residue and the mixture was again boiled for 30 minutes. After filtration, the residue was washed 3 times with hot distilled water and 2 times with acetone. The insoluble residue obtained was dried at 105 °C for 8 hours and weighed (P_1). This dry residue was incinerated at 550 °C for 3 hours and the ash obtained was weighed (P_2). The crude fiber content (C.F.C.) is determined by the following formula:

$$C.F.C\ (g/100g\ DM) = (100 - H)\ (P_1 - P_2) / P_e$$

With:

H: lipid content,

Pe: test sample,

P_1: the weight obtained after digestion,

P_2: the weight obtained after incineration.

(vi). Determination of Carbohydrate Content

The simple carbohydrate content was determined using the AOAC method [45], which states that the dry weight of the sample is the difference between the sum of the weights of protein, fat, ash and crude fiber. The following formula is used to calculate the carbohydrate content:

Carbohydrate (g/100g DM) = W.C (g/100g FM) - (Protein + Fat + Ash + Crude Fiber) g/100g DM.

(vii). Calculation of Energy Content

The energy value is calculated according to the Atwater and Rosa protocol [46], which stipulates that:

Energy (Kcal/100g DM) = 4 x (protein content + carbohydrate content) + 9 x (lipid content).

2.3. Statistical Analysis

The data obtained were subjected to an analysis of variance (ANOVA). Means were compared using Duncan's test at the 5% threshold. A dendrogram was then produced to classify the samples into groups according to their nutrient content, using a Euclidean distance model. These analyses were carried out using R software version 4.1.3.

3. Results and Discussion

3.1. Identification of Mushrooms

Each of the mushrooms studied in this work belongs to the order Agaricales. Based on laboratory observations, information from local populations and the existing literature, we can confirm that all 28 samples are edible [27-29, 39, 40].

The mushroom samples were all identified both generically and specifically. At the end of this work, twenty-two (22) fungi out of a total of twenty-eight (28) were identified specifically, including eleven (11) samples belonging to the genus *Termitomyces*, seven (07) to the genus *Pleurotus* and the remaining four (04) samples related to the genera *Volvariella* (01), *Tricholomopsis* (01), *Agaricus* (01) and *Auricularia* (01). Of the twenty-two (22) mushrooms identified, six (06) are new samples recently described and therefore nutritional analysis has never been done, thus enriching the existing wide range of edible mushrooms. Six (06) other samples were identified at the generic level, the vast majority (05) being *Termitomyces*.

Nevertheless, of the twenty-eight (28) edible fungi studied, sixteen (16) were of the genus *Termitomyces*, underlining the predominance of this genus in tropical Africa. These results confirm the work of Batra and Batra, [47], Tibuhwa, [48] and Essouman, [49], who consider that fungi of the genus *Termitomyces* are more prevalent in many countries of South-East Asia and tropical Africa. However, it should be remembered that production of these fungi is subject to seasonal variations and climatic hazards, resulting in high variability from one season to the next. Similar observations have been reported by Dijk *et al*. [30] and De Kesel *et al*. [50], showing that environmental fluctuations have a direct influence on the abundance and availability of these fungal resources.

3.2. Nutrients Compositions of Edible Mushrooms Analyzed

3.2.1. Water Content

The water content of the samples varied from 81.59±0.17 g/100g DM for *Cantharellus* sp. to 93.68±0.31 g/100g DM for *Termitomyces reticulatus*. Dry matter content ranged from 6.32±0.31 g/100g DM to 18.41±0.17 g/100g DM for the same species (Table 2). The high water content of mushrooms is explained by the essential role this element plays in maintaining their structure, supporting their metabolism and facilitating their internal exchanges. In addition, this high water content contributes to their high perishability, making it imperative for them to be rapidly dehydrated before storage or refrigeration. The differences observed in the water content of mushrooms could be attributed to environmental factors linked to growth, storage or the genetic make-up of each species. These results are within the range of water contents reported by other authors [1, 13, 16].

3.2.2. Protein Content

The protein content of the mushrooms varied according to species. It ranged from 5.68±0.52 g/100 g DM for *Auricularia judae* to 49.38±1.25 g/100 g DM for *Termitomyces griseiumbo* (Table 2). However, *Termitomyces* species had protein contents ranging from 24.10 to 49.38 g/100 g DM, while *Pleurotus* species had values ranging from 12 to 31.09 g/100 g DM.

The results confirm that most of the fungi studied are rich in protein, an essential element for growth, digestive enzyme production and defense, which explains their high protein concentration. The variations observed between species could be attributed to the levels of nitrogen present in their substrate, as well as to their genetic composition [51, 52]. These results are in agreement with those reported by Yu *et al*. [53] and Ouali *et al*. [54]. Similar values for the *Termitomyces* genus have also been reported by Parent and Thoen [31], Kansci *et al*. [13] and Teke *et al*. [16], attesting to the high protein content of these species.

Compared with staple foods, *Termitomyces* contain more protein than certain foods such as rice (7.3%), maize (9.4%) and potatoes (2%), and four times more than tomatoes. However, this content is still lower than that of soya (35%) and common beans (20-30%) [55]. In comparison with animal products, they also contain more protein than milk (3.5%), but less than eggs (13.3%), beef (19.9%), pork (13.2%) and chicken (19.3%). However, they are considered an alternative

to meat, as they contain all nine essential amino acids [56, 57].

Mushroom proteins could therefore be a valuable alternative for populations with limited access to animal proteins. In particular, it is recommended to consume 3 to 4 fresh edible mushrooms, such as *Termitomyces letestui* or *Agaricus bisporus*, in order to cover the nutritional protein requirements of a 60 kg individual.

3.2.3. Lipid Content

The lipid content of twenty-eight (28) mushrooms, of which twenty-five (25) were wild and three (03) cultivated, showed wide variations between the species studied. These lipids, which are essential for life, show very contrasting values: *Termitomyces* sp.$_5$ has the lowest content (1.83±0.24 g/100 g DM) while *Pleurotus pulmonarius* has the highest (28.52±0.73 g/100 g DM). Furthermore, lignicolous fungi have twice the lipid content of their terricolous counterparts. This difference seems to be linked to metabolic adaptation to the substrates on which they grow [58].

According to Aletor [59] and Bernaś *et al*. [51], the variations observed could be due to the stage of development of the basidiocarps. The mean lipid content obtained in all the specimens in this study, 11.97±0.38 g/100 g DM, is significantly higher than the values reported by several other authors in similar studies [60-62].

In addition, the lipid contents of some of the mushrooms studied differ from those reported by Kouame *et al*. [1], Kansci *et al*. [13], Omer & Alfaig [63], Agbagwa *et al*. [64] and Manjunathan and Kaviyarasan [65], which were low.

1. *Volvariella volvacea*: 16.79±0.12 g/100 g DM,
2. *Termitomyces letestui* (form 1): 15.63±0.07 g/100 g DM,
3. *Agaricus bisporus* (cultivated): 16.56±0.32 g/100 g DM,
4. *Auricularia judae*: 23.97±1.16 g/100 g DM,
5. *Pleurotus tuber-regium*: 15.29±0.28 g/100 g DM.

These differences are thought to be partly due to the nature of the extraction solvent used and the protocols employed.

3.2.4. Ash Content

The mushrooms analyzed had average ash (mineral salt) contents ranging, for example, from 0.79±0.29 g/100 g DM for *Auricularia judae* to 26.78±0.30 g/100 g DM for *Termitomyces* sp.$_5$, with an average of around 6.51±0.30 g/100 g DM (Table 2). This mean value is in line with nutritional recommendations for individuals aged 11 years and over. Although these mineral salts are not directly involved in the body's metabolism like proteins, lipids or carbohydrates, they play a crucial role in bone formation, muscle contraction and the transmission of nerve signals.

The results obtained in this study exceed those reported by Kansci *et al*. [13] and Teke *et al*. [16] in the nutritional analysis of edible mushrooms from Cameroon, which indicated ash contents of between 5.17 and 14.39 g/100 g DM and between 7.74 and 14.10 g/100 g DM respectively. According to Magginioni *et al*. [66], these differences can be explained by the specific biological characteristics of each mushroom species.

Furthermore, the average ash content of the mushrooms studied per 100 g dry matter exceeds that observed in other foods such as free-range chicken thighs (3.1%), backyard chickens (3.4%) in Cameroon [67] and soya (3-6.5%) [68]. Because of their ability to efficiently absorb low molecular weight organic acids, fungi absorb more major elements and trace elements than plants. They are therefore an excellent source of mineral salts and could be used to enrich traditional dishes, partially replacing meat and fish.

3.2.5. Crude Fiber Content

The mushrooms analyzed had a high crude fiber content. In *T. letestui* (form, 2), this content is 6.52±0.21 g/100 g DM, while it reaches 26.79±0.29 g/100 g DM in *P. tuber-regium*, with an average of approximately 13.91±0.24 g/100 g DM (Table 2). These values indicate the presence of soluble and insoluble fibers.

For the genus *Termitomyces*, the fiber content varied from 6.52 to 23.57 g/100 g DM (mean 13.88±5.25 g/100 g DM), while for the genus *Pleurotus*, it ranged from 8.36 to 26.79 g/100 g DM (mean 14.28±6.63 g/100 g DM).

The high fiber content is explained by its essential role in the structure and protection of mushrooms. For the human body, these fibers promote intestinal transit by acting as a prebiotic, retaining beneficial bacteria in the colon by absorbing water as they pass through the digestive system, which facilitates defecation [69, 70].

According to Rop *et al*. [71], the differences observed between species could be linked to the quantity and type of saccharides present in their cell walls.

In addition, the crude fiber content of samples from the *Termitomyces* genus is comparable to that reported by Kansci *et al*. [13] and Teke *et al*. [16], indicating the richness of these species. In addition, the values obtained for *P. tuber-regium* (26.79±0.55 g/100 g DM), *P. ostreatus* (10.55±0.24 g/100 g DM), *Auricularia judae* (22.60±0.20 g/100 g DM) and *Agaricus bisporus* (cultivated) (19.76±0.44 g/100 g DM) are higher than those reported by Ijioma *et al*. [25] for *P. tuber-regium*, by Titilawo *et al*. [72] and Agbagwa *et al*. [64] for *Auricularia judae*, and by Omer & Alfaig [63] for *Agaricus bisporus* (cultivated). These differences can be explained by the nature of the sample growth substrates, the solvents used and the analysis protocols employed.

However, the fiber content of these fungi is significantly higher than that of certain vegetables and plants, such as tomato (0.20±0.01%), red onion (0.37±0.03%), broccoli (0.16±0.01%), lettuce (0.06±0.01%), carrot (1.60±0.02%) and potato (0.84±0.01%) [73]. Consequently, these fibers could be particularly beneficial for diabetics by reducing glucose absorption and delaying gastric emptying, which is why Kouadio *et al*. [69] and Yu *et al*. [53] reported that fibers are considered to be "intestinal traps".

3.2.6. Carbohydrates Content

The carbohydrate content of the mushrooms ranged from 11.77±0.09 g/100 g DM for *Volvariella volvacea* to 55.51±0.31 g/100 g DM for *Pleurotus ostreatus* (Table 2). Compared with their wild counterparts, cultivated edible mushrooms of the genus *Pleurotus* have a lower carbohydrate content (30.04±1.13 g/100 g DM). On the other hand, edible *Pleurotus* mushrooms (36.10±0.45 g/100 g DM) have a higher average carbohydrate content than *Termitomyces* mushrooms (23.23±0.83 g/100 g DM). It should be noted that locally cultivated species (*Pleurotus sajor-caju* and *Pleurotus pulmonarius*) have much higher carbohydrate contents than *Agaricus bisporus* (cultivated). According to these observations, this macronutrient is the most abundant among edible mushrooms and can vary enormously from one mushroom to another.

Bernaś *et al.* [51] believe that the differences observed between the samples can be explained by the presence in them of carbohydrate compounds in the form of polysaccharides of different sizes and by the nature of the substrate on which they grow.

Furthermore, Zakhary *et al.* [74]; Samsudin & Abdullah [75] consider that these polysaccharides are mainly composed of digestible carbohydrates (starch, glycogen and trehalose) and non-digestible carbohydrates (chitin, mannans and cellulose). *V. volvacea*, *Auricularia judae*, *Pleurotus ostreatus*, and *Pleurotus tuber-regium* have low carbohydrate contents compared to those obtained by Omer & Alfaig [63]; Jacinto-Azevedo *et al.* [76]; Kadnikova *et al.* [77]; Titilawo *et al.* [72] with 49.98 ±0.01 g/100g DM; 66.1 ±4.0 g/100g DM; 79.3 ±0.14 g/100g DM; and 55.91 ±0.64 g/100g DM, respectively.

Table 2. *Nutrient contents of 28 samples of edible mushrooms encountered in Cameroon and DR Congo.*

Order number	Herbarium number	Species	Ashes (g/100g DM)	Lipids (g/100g DM)	Water content (g/100g MF)	Dry matter (g/100g DM)
1	DM 1801	*Cantharellus* sp.	13,78±0,43^{b}	23,82±0,79^{cd}	81,59±0,17^{o*}	18,41±0,17^{a**}
2	DM 1825	*Pleurotus tuber-regium*	2,12±0,07^{op}	15,29±0,28^{i}	86,28±0,22^{jk}	13,72±0,22^{de}
3	DM 888	*Pleurotus citrinopileatus*	6,21±0,55^{j}	17,32±0,03^{f}	87,17±0,02^{ij}	12,83±0,02^{efg}
4	DM 1288	*Pleurotus pulmonarius*	1,27±0,02^{q}	28,52±0,73^{a**}	90,55±0,31^{bc}	9,45±0,31^{lm}
5	DM 1743	*Volvariella volvacea*	9,55±0,42^{ef}	16,79±0,12^{fg}	82,07±0,10^{no}	17,93±0,10^{a}
6	DM 1578	*Termitomyces* sp.1	4,87±0,28^{k}	21,32±0,45^{e}	84,35±0,50^{l}	15,65±0,50^{c}
7	DM 1867	*Tricholomopsis aurea*	4,79±0,09^{k}	16,01±0,46^{ghi}	85,93±0,60^{k}	14,07±0,60^{d}
8	DM 1282	*Termitomyces fombapei*	3,74±0,36^{lm}	4,52±0,67^{m}	83,29±0,86^{lm}	16,71±0,86^{bc}
9	DM 966	*Pleurotus ostreatus*	4,69±0,43^{k}	2,28±0,00^{no}	85,99±0,72^{k}	14,01±0,72^{d}
10	DM 1781	*Termitomyces* sp. 4	2,26±0,19^{op}	2,54±0,64^{no}	89,02±0,63^{def}	10,98±0,63^{ijk}
11	DM 1272	*Termitomyces mboukouina*	1,59±0,07^{pq}	3,06±0,08^{n}	87,71±0,72^{ghi}	12,29±0,72^{fgh}
12	DM 1728	*Termitomyces melongii*	0,83±0,00^{q}	2,86±0,28^{no}	82,49±0,70^{mno}	17,51±0,70^{ab}
13	DM 1292	*Termitomyces* sp. 2	8,78±0,30^{fg}	2,32±0,03^{no}	82,16±0,50^{no}	17,84±0,50^{a}
14	DM 1294	*Termitomyces.* aff. *clypeatus*	4,35±0,31^{kl}	3,33±0,21^{n}	86,36±0,50^{jk}	13,64±0,50^{de}
15	DM 1290	*Termitomyces mbongonensis*	8,79±0,28^{fg}	2,54±0,65^{no}	85,68±0,80^{k}	14,32±0,80^{d}
16	DM 1268	*Termitomyces* sp. 3	8,48±0,16^{g}	2,94±0,07^{n}	85,50±0,70^{efg}	11,50±0,70^{hij}
17	DM 1866	*Auricularia judae*	0,79±0,29^{q*}	23,97±1,16^{c}	86,63±0,38^{ijk}	13,37±0,38^{def}
18	DM 1720	*Termitomyces* sp. 5	26,78±0,30^{a**}	1,83±0,24^{o*}	84,14±0,50^{l}	15,86±0,50^{c}
19	DM 895	*Pleurotus sajor-caju*	2,71±0,24^{no}	16,00±0,28^{ghi}	89,75±0,35^{cd}	10,25±0,35^{kl}
20	DM1782	*Pleurotus pulmonarius* (cultivated)	3,18±0,25^{mn}	22,92±0,63^{d}	89,55±0,48^{cde}	10,45±0,48^{jkl}
21	DM 1700	*Termitomyces reticulatus*	1,23±0,13^{q}	16,56±0,32^{fgh}	93,68±0,31^{a**}	6,32±0,31^{n*}
22	DM 213	*Termitomyces letestui* (form, 2)	10,23±1,03^{e}	15,17±0,13^{i}	87,34±0,37^{hij}	12,66±0,37^{efg}
23	DM 372	*Termitomyces meduis*	12,80±0,96^{c}	16,71±0,18^{fg}	87,15±0,07^{ij}	12,85±0,07^{efg}
24	DM 1702	*Termitomyces congolensis*	6,63±0,12^{ij}	12,53±0,34^{j}	82,72±0,48^{mn}	17,28±0,48^{ab}

Order number	Herbari-umnumber	Species	Ashes (g/100g DM)	Lipids (g/100g DM)	Water content (g/100g MF)	Dry matter (g/100g DM)
25	DM 150G	*Termitomyces letestui* (form, 1)	7,58±0,15^{h}	15,63±0,07^{hi}	84,22±0,38^{l}	15,78±0,38^{c}
26	DM 1707	*Agaricus bisporus* (cultivated)	11,43±0,13^{d}	13,15±0,92^{j}	90,46±0,61^{bc}	9,54±0,61^{lm}
27	DM 215	*Pleurotus sajor-caju* (cultivated)	3,27±0,00^{mn}	10,01±0,67^{k}	91,42±0,12^{b}	8,58±0,12^{m}
28	DM 224	*Termitomyces griseiumbo*	8,88±0,31^{fg}	5,60±0,28^{l}	90,96±0,35^{b}	9,04±0,35^{m}
Average ± σ			6,48±0,28%	11,97±0,38%	86,68±0,44%	13,31±0,44%

Table 2. *Continued.*

Order number	Herbari-umnumber	Species	Proteins (g/100g DM)	Carbohydrates (g/100g DM)	Crude fibers (g/100g MS)	Energies (Kcal/100g MS)
1	DM 1801	*Cantharellus* sp.	19,30±0,15^{n}	18,05±0,09^{jklm}	6,55±0,63 ^{p}	364,14±7,12^{efg}
2	DM 1825	*Pleurotus tuber-regium*	12,00±0,35^{q}	30,06±0,50^{fg}	26,79±0,29^{a**}	305,93±2,54^{mn}
3	DM 888	*Pleurotus citrinopileatus*	23,21±0,34^{m}	31,92±0,34^{ef}	8,36±0,12^{n}	377,04±0,31^{d}
4	DM 1288	*Pleurotus pulmonarius*	18,03±0,95^{no}	32,95±0,88^{e}	8,49±0,01^{n}	459,76±15,10^{a**}
5	DM 1743	*Volvariella volvacea*	33,31±0,44^{cd}	11,77±0,09^{o*}	8,20±0,27^{n}	331,43±1,08^{jk}
6	DM 1578	*Termitomyces* sp.$_{1}$	24,43±1,19^{lm}	19,76±1,24^{ij}	14,44±0,14^{h}	366,80±4,13^{def}
7	DM 1867	*Tricholomopsis aurea*	15,96±2,10^{p}	39,44±2,41^{c}	10,43±0,61^{m}	362,89±4,20^{efg}
8	DM 1282	*Termitomyces fombapei*	27,00±0,43^{jk}	35,29±0,21^{d}	12,97±0,02^{i}	288,96±6,04^{op}
9	DM 966	*Pleurotus ostreatus*	12,94±0,22^{q}	55,51±0,31^{a**}	10,55±0,24^{lm}	294,44±0,06^{no}
10	DM 1781	*Termitomyces* sp. $_{4}$	34,72±0,34^{bc}	30,01±0,42^{fg}	19,58±0,00^{ef}	281,46±5,79^{p}
11	DM 1272	*Termitomyces mboukouina*	30,54±0,76^{fgh}	28,57±0,84^{g}	23,67±0,55^{b}	266,18±2,29^{q}
12	DM 1728	*Termitomyces melongii*	35,61±0,37^{b}	32,02±0,24^{ef}	11,16±0,06^{kl}	295,40±2,54^{no}
13	DM 1292	*Termitomyces* sp. $_{2}$	33,32±0,23^{cd}	16,76±0,26^{m}	21,06±0,00^{d}	220,92±0,31^{s}
14	DM 1294	*Termitomyces.* aff. *clypeatus*	32,98±0,77^{cde}	29,84±1,07^{fg}	15,77±0,23^{g}	281,61±1,90^{p}
15	DM 1290	*Termitomyces mbongonensis*	32,26±0,53^{def}	21,01±0,73^{hi}	21,14±0,00^{d}	235,70±5,85^{r}
16	DM 1268	*Termitomyces* sp. $_{3}$	27,78±0,18^{ij}	31,78±2,44^{ij}	15,62±0,02^{g}	264,68±10,13^{q}
17	DM 1866	*Auricularia judae*	5,68±0,52^{r*}	33,39±0,55^{de}	22,60±0,20^{c}	372,85±10,50^{de}
18	DM 1720	*Termitomyces* sp. $_{5}$	25,48±2,38^{kl}	19,14±2,07^{ijkl}	11,99±0,62^{j}	190,63±2,16^{t*}
19	DM 895	*Pleurotus sajor-caju*	13,47±0,50^{q}	38,69±0,60^{c}	19,03±0,33^{f}	352,04±2,54^{gh}
20	DM1782	*Pleurotus pulmonarius* (cultivated)	31,09±0,03^{efgh}	19,63±0,04^{ijk}	12,72±0,24^{i}	408,75±5,09^{c}
21	DM 1700	*Termitomyces reticulatus*	24,10±1,80^{lm}	43,41±1,26^{b}	7, 47±0,19^{o}	422,72±2,92^{b}
22	DM 213	*Termitomyces letestui* (form, 2)	32,28±3,37^{def}	21,20±0,48^{hi}	6,52±0,21^{p*}	358,25±1,20^{fgh}
23	DM 372	*Termitomyces meduis*	36,13±0,36^{b}	14,33±0,50^{n}	7,18±0,05^{op}	352,23±1,65^{gh}
24	DM 1702	*Termitomyces congolensis*	29,11±0,14^{hi}	22,80±0,17^{h}	11,60±0,56^{jk}	320,65±3,11^{kl}
25	DM 150G	*Termitomyces letestui* (form, 1)	31,66±0,57^{defg}	17,46±0,33^{klm}	11,58±0,50^{jk}	338,39±0,63^{ij}
26	DM 1707	*Agaricus bisporus* (cultivated)	29,95± 0,24^{gh}	16,11±0,31^{mn}	19,76±0,44^{e}	302,87±8,33^{mn}
27	DM 215	*Pleurotus sajor-caju* (cultivated)	19,74±0,81^{n}	43,97±0,51^{b}	14,00±0,00^{h}	346,65±6,10^{hi}
28	DM 224	*Termitomyces griseiumbo*	49,38±1,25^{a**}	16,99±1,56^{lm}	10,44±0,18^{m}	314,56±2,54^{lm}

Order number	Herbari-umnumber	Species	Proteins (g/100g DM)	Carbohydrates (g/100g DM)	Crude fibers (g/100g MS)	Energies (Kcal/100g MS)
Average ± σ			26,48±0,76%	27,57±0,73%	13,91±0,24%	324,13±4,15%

*Contents with different letters on the same column are significantly different at the 5% threshold
N = 3 repetitions
DM = Dry matter,
MF = Fresh material,
*: Small content,
**: High content

3.2.7. Energy Content

By taking into account the carbohydrate, lipid and protein contents, it was possible to calculate the energy content, which is highly variable (Figure 1). Depending on the species, the energy content varies from 190.63±2.16 kcal/100g DM for *Termitomyces* sp.5 which corresponds to 8.66% of the daily energy intake for a woman aged between 20 and 40 and 7.06% for a man in the same age group, to 459.76±15.10 kcal/100g DM for *Pleurotus pulmonarius* which corresponds to 20.89% of the daily energy intake for a woman aged between 20 and 40 and 17.02% for a man in the same age group. However, the average energy content of all edible mushrooms is 324.13±4.15 kcal/100g DM, which would correspond to 14.73% and 12% of daily energy intake respectively for a woman and a man in the same age bracket, namely 20-40 years.

This average content is higher than that of certain meats such as beef (125.4 kcal/100 g), chicken (117.1 kcal/100 g), prawns (101 kcal/100 g), eggs (143.16 kcal/100 g) and certain local dishes based on plantain (136.47 kcal/100 g) and yam (120.21 kcal/100 g) (FAO [78]; Januškevičius *et al*. [73]. However, it is very close to that of cereals (millet 314 kcal/100 g, maize 349 kcal/100 g, wheat flour 357.79 kcal/100 g and soya 447.8 kcal/100 g) [79, 80]. Given their intermediate caloric value, mushrooms can be used for weight control or as part of low-calorie diets [81].

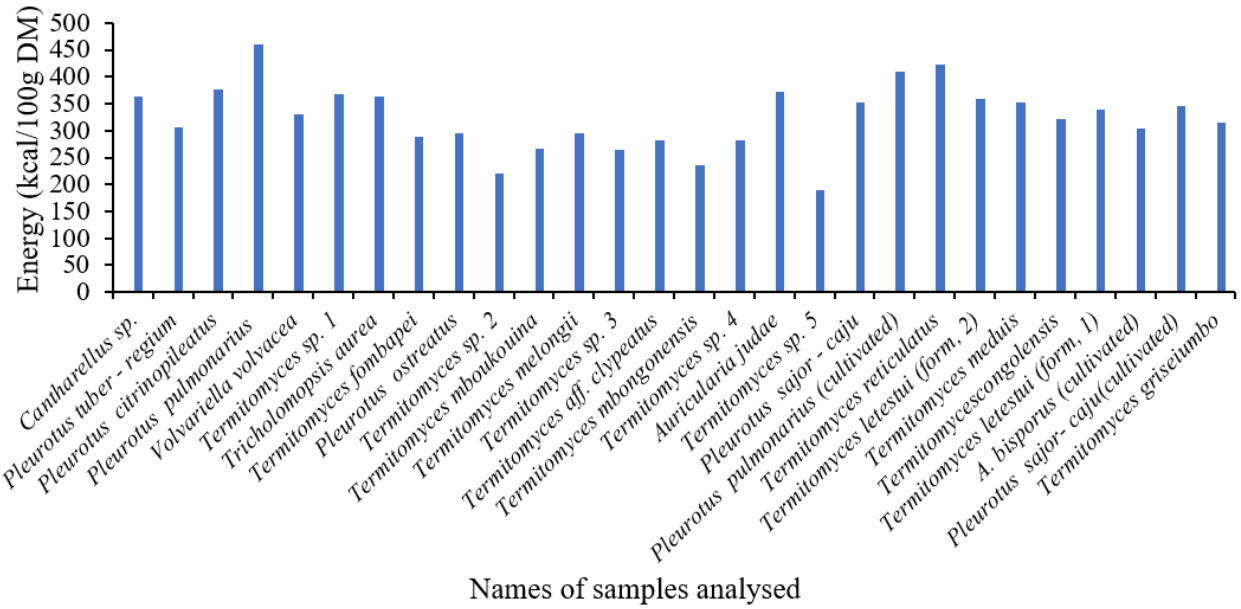

Figure 1. *Variation in energy content according to the samples analyzed.*

3.3. Principal Component Analysis

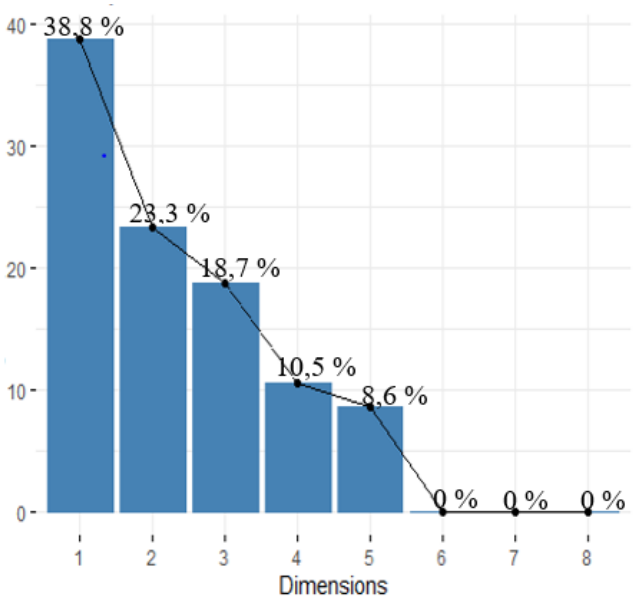

Figure 2. *Percentage of explanatory variation between the different components.*

Principal component analysis enabled us to visualize the discriminating parameters relating to the nutritional value of the samples (Figure 2). The factorial design (Dim 1-Dim 2) summarizes the cumulative variations at nearly 62.10%. The first component (Dim 1) explains 38.80% of the total variance. In this dimension, energy shows a strong contribution to the variance (45%), followed by the variables water (42%), carbohydrates (34%) and lipids (31%), which show a positive and significant correlation. The second component (Dim 2) accounts for 23.3% of the explanatory variance. In this dimension, the lipid content variables show a contribution of 53%, which is strongly and positively correlated with energy, which shows a contribution to the variance of 42%, followed by the ash and dry matter variables, which respectively show a contribution to the variance of 22%. On the other hand, variables such as crude fibre and carbohydrates show a negative contribution to variance and a high correlation. However, observation of the different axes (Figure 3) revealed a high fibre content in *P. tuber-regium* and *T. mboukouina*, a high protein content in *Termitomyces reticulatus* and *Termitomyces* sp.2 and *T. medius* and a high carbohydrate content in *T. melongii*. In contrast, *Termitomyces* sp.1, 5, *P. pulmonarius* (cultivated) and *P. ostreatus* are rich in protein and lipids; protein and ash; lipids and energy; fiber and carbohydrates, respectively. However, *Termitomyces* sp.3, *T. fombapei*, *T. griseiumbo*, *T. mboukouina*, *T.* aff. *clypeatus* and *T. mbongonensis* are high in protein, carbohydrates and crude fibre. *Pleurotus citrinopileatus*, *P. pulmonarius*, *Tricholomopsis aurea*, *Auricularia judae*; *Termitomyces congolensis*; *Cantharellus* sp., *Volvariella volvaceae* and *Pleurotus sajor-caju* and *P. sajor-caju* (cultivated) are respectively rich in lipids, carbohydrates and energy; proteins, carbohydrates and ash; lipids, ash and energy; carbohydrates, crude fibre and energy. We also note that *Termitomyces letestui* (form, 1 & 2) and *Agaricus bisporus* (cultivated) are respectively rich in ash, lipids, proteins, energy and lipids, crude fibre, ash and proteins.

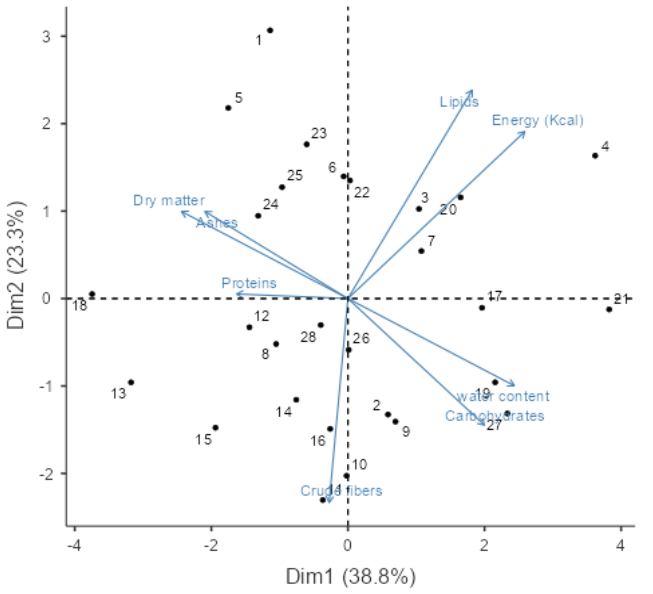

Figure 3. *Representation of the results of the Principal Component Analysis.*

Legend: 1- Cantharellus sp., 2- Pleurotus tuber-regium, 3- Pleurotus citrinopileatus, 4- Pleurotus pulmonarius, 5- Volvariella volvaceae, 6- Termitomyces sp.1, 7- Tricholomopsis aurea, 8- Termitomyces fombapei, 9- Pleurotus ostreatus, 10- Termitomyces sp.4, 11- Termitomyces mboukouina, 12- Termitomyces melongii, 13- Termitomyces sp.2, 14- Termitomyces aff. clypeatus, 15- Termitomyces mbongonensis, 16- Termitomyces sp.3, 17- Auricularia judae, 18- Termitomyces sp.5, 19- Pleurotus sajor-caju, 20- Pleurotus pulmonarius (cultivated), 21- Termitomyces reticulatus, 22- T. letestui (form, 2), 23- Termitomyces medius, 24- Termitomyces congolensis, 25- T. letestui (form, 1), 26- Agaricus bisporus (cultivated), 27- P. sajor-caju (cultivated), 28-Termitomyces griseiumbo.

3.4. Hierarchical Analysis of Mushrooms Nutrients

The fungi studied were grouped according to their similarities or dissimilarities in terms of nutrients, mineral elements and substrates using the dendrogram (Figure 4). This grouping takes into account more than 62.10% of the differences between the samples and divides them into three (03) large groups, attesting to the existence of differences. The vast majority of these groups correspond to terricolous and lignicolous species respectively, with a few exceptions. In the first group, colored red, there are seven (07) samples including *Pleurotus pulmonarius*, *P. tuber - regium*, *P. sajor - caju*

and *Termitomyces* sp.$_5$, *T. griseiumbo*, *T. melongii*, *T. letestui* (form, 1), which are low in carbohydrates and fibre but high in lipids, ash, proteins and energy. The second group, green in colour, comprises twelve (12) samples. It is largely made up of lignicolous fungi including *Pleurotus citrinopileatus*, *P. sajor-caju* (cultivated), *Cantharellus* sp., *Volvariella volvaceae*, *Tricholomopsis aurea*, *Auricularia judae*, *Agaricus bisporus* (cultivated) and those of the *Termitomyces* genus, including *Termitomyces* sp.$_1$ *T. reticulatus*, *T. letestui* (form, 2), *T. medius*, *T. congolensis*. They are essentially rich in lipids, crude fibre, carbohydrates and energy, but low in protein and ash. The third group, blue in colour, contains nine (09) samples and is essentially made up of soil samples, more specifically those of the *Termitomyces* genus, namely *Termitomyces* sp.$_4$, sp.$_2$, sp.$_3$, *T. fombapei*, *T. mboukouina*, *T.* aff. *clypeatus*, *T. mbongonensis* and *Pleurotus pulmonarius* (cultivated), *P. ostreatus*. They are rich in ash, fibre and protein, but low in lipids, carbohydrates and energy. The differences in content recorded in terms of nutritional parameters could be due in part to the assimilation capacities of the various nutrients and minerals, which depend on the nature of the species, their age, the growing conditions and the substrates on which they grow, thus confirming the studies carried out by Demirbaş [82]; Mattila *et al*. [83] and Titilawo *et al*. [72]. This analysis also shows that there are dietary links between the mushroom species analyzed, regardless of their substrate, texture or palatability. For example, in group II, *Termitomyces medius* and *Auricularia judae* (edible and fleshy) are strongly linked, even though they come from different substrates. This link could be due to their richness in macronutrients, namely carbohydrates, fibre and energy. On the other hand, the link between the samples in group III is due to their abundance of nutrients (ash, protein and crude fibre) as well as their substrates, which are millstones. Similarly, in group I, the link between the fungi could be due to a lesser extent to their substrates and their low lipid, ash, protein and energy content. What's more, this is the very first study of its kind to take into account more than twenty species, including 15 new ones whose nutritional profile had never been established before.

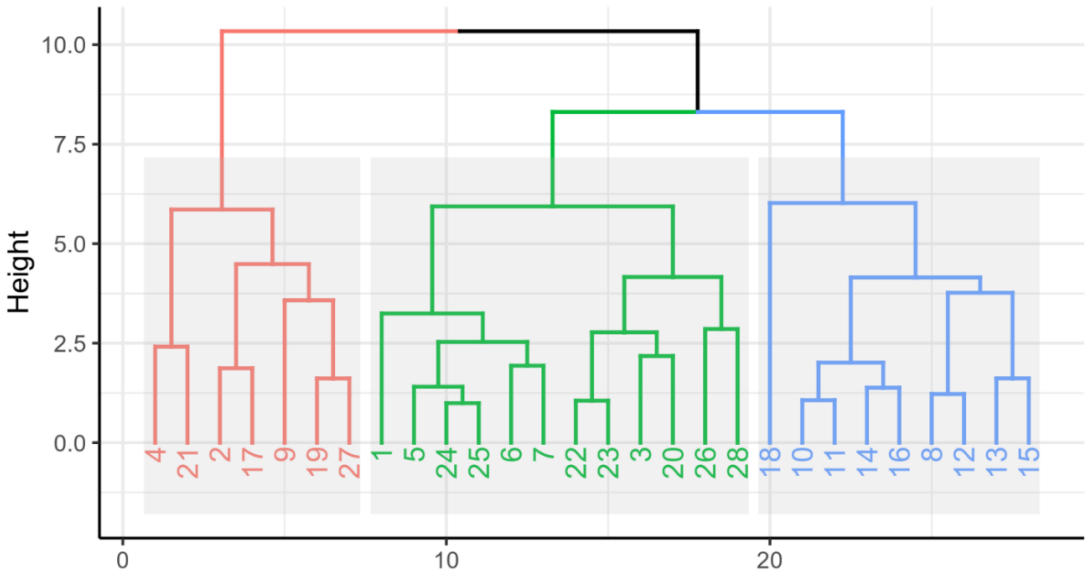

Figure 4. *Hierarchical classification of the different samples.*

Legend: 1- Cantharellus sp., 2- Pleurotus tuber-regium, 3- Pleurotus citrinopileatus, 4- Pleurotus pulmonarius, 5- Volvariella volvaceae, 6- Termitomyces sp.$_1$, 7- Tricholomopsis aurea, 8- Termitomyces fombapei, 9- Pleurotus ostreatus, 10- Termitomyces sp.$_4$, 11- Termitomyces mboukouina, 12- Termitomyces melongii, 13- Termitomyces sp.$_2$, 14- Termitomyces aff. clypeatus, 15- Termitomyces mbongonensis, 16- Termitomyces sp.$_3$, 17- Auricularia judae, 18- Termitomyces sp.$_5$, 19- Pleurotus sajor-caju, 20- Pleurotus pulmonarius (cultivated), 21- Termitomyces reticulatus, 22- Termitomyces letestui (form, 2), 23- Termitomyces medius, 24- Termitomyces congolensis, 25- Termitomyces letestui (form, 1), 26- Agaricus bisporus (cultivated), 27- Pleurotus sajor-caju (cultivated), 28-Termitomyces griseiumbo.

4. Conclusion

The analysis of the nutritional composition of edible mushrooms from Cameroon and the Democratic Republic of Congo (DRC) carried out in this study shows that the 28 samples analyzed can be used as food supplements in several populations. It appears that *Termitomyces* sp. $_2$, $_5$, *T. mbongonensis*, *T. griseiumbo*, *T. congolensis* and *Agaricus bisporus* (cultivated) would be recommended to people wishing to enrich their diet with mineral salts or to follow low-calorie diets, as they are rich in proteins and mineral salts but low in carbohydrates and energy. On the other hand, *Pleurotus*

pulmonarius, *P. pulmonarius* (cultivated), *P. sajor-caju*, *P. sajor-caju* (cultivated), *P. citrinopileatus*, *P. ostreatus*, *P. tuber-regium*, *Termitomyces* sp. 1, 3, 4, *T. letestui* (form, 1 & 2), *T. medius*, *T. mboukouina*, *T.* aff. *clypeatus*, *T. fombapei*, *T. melongii* and *T. reticulatus* are recommended for people wishing to enrich their diet with mineral salts or follow a low-calorie diet. However, *Cantharellus* sp., *Volvariella volvaceae*, *Auricularia judae* and *Tricholomopsis aurea* are recommended for people suffering from protein-energy disorders, as they are rich in lipids, energy, protein, crude fibre and carbohydrates. Domestication efforts are needed to make edible *Termitomyces* mushrooms accessible to the public at all times, as they are rich in protein, carbohydrates and crude fibre. The data thus presented could help to enrich African food composition tables with a view to solving the problems of malnutrition, particularly among the most vulnerable populations in developing countries.

Abbreviations

AFNOR	Association Française de Normalisation
AOAC	Association of Official Analytical Chemists
A C	Ash Content
DM	Dry Matter
FM	Fresh Matter
L.C	Lipid Content
P.	*Pleurotus*
T.	*Termitomyces*
WEM	Wild Edible Mushrooms
F AO	Food and Agriculture Organisation
FAOSTAT	Food and Agriculture Organisation Statistics

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Gabriel Medoua Nama: Formal analysis, Methodology

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Dominique Claude Mossebo: Conceptualization

Zachée Ambang: Conceptualization, Supervision, Validation, writing review, Revision, Project administration

Conflicts of Interest

The authors declare no conflicts of interest.

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