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Effects of drying methods on the biochemical and antioxidant properties of *Volvariella volvacea* from Côte d'Ivoire

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Abstract:
The wild mushroom *Volvariella volvacea* is widely picked and consumed in Côte d'Ivoire. However, it is highly perishable due to its high moisture content. This study aimed to determine the effects of three drying methods on the biochemical and mineral composition, as well as antioxidant properties, of *V. volvacea* powders.
Three *V. volvacea* powders were obtained by sun drying, oven drying, and freeze-drying. Each powder was analyzed for its biochemical and mineral composition according to standard analytical methods. The powder methanolic extracts were analyzed for their antioxidant components by colorimetric methods or titration, while their antioxidant capacities were determined by using DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) scavenging and the ferric reducing antioxidant power.
The freeze-dried powder of *V. volvacea* had a lower moisture content than the oven-dried and sun-dried powders. The highest protein, ash, and fiber contents were also recorded in the freeze-dried powder. In addition, freeze-drying provided the highest contents of iron, magnesium, sodium, and potassium. Regarding the antioxidant components, the freeze-dried powder showed the highest levels of total phenolic compounds, flavonoids, and vitamin C. Similarly, freeze-drying provided the best antioxidant capacities in terms of DPPH scavenging and the ferric reducing antioxidant power.
Our study showed that freeze-drying ensured a better retention of essential nutrients and antioxidant components in the mushroom *V. volvacea*, while sun-drying led to greater losses of these compounds.

Keywords: Mushroom, *Volvariella volvacea*, drying methods, mushroom powders, biochemical and nutritional properties, antioxidant capacity

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INTRODUCTION

In Africa, as in several developing countries around the world, wild edible mushrooms have always been an important component of foodstuffs intended for human consumption [1–4]. Several studies have reported that edible mushrooms are valuable healthy and nutritious foods, low in calories and rich in vegetable proteins, vitamins, and minerals [5–9]. In addition to their food value, they play a role in traditional medicine. Indeed, certain species of mushrooms have, among other things, antioxidant, antimicrobial, and anticancerous properties [10–13]. During rainy seasons in Côte d'Ivoire, wild edible mushrooms are collected and sold by women and even men in rural and peri-urban areas [14].

According to a recent study, the species *Psathyrella tuberculata* ranks first in terms of importance, followed by *Volvariella volvacea* and *Termitomyces letestui* [15]. *V. volvacea* has been the subject of ecological, as well as biochemical and nutritional studies in Côte d'Ivoire [4, 8, 16]. This saprophytic species, which generally grows on the trunks of dead oil palms, is rich in proteins, carbohydrates, fibers, minerals, and natural antioxidants. However, it is highly perishable in the fresh state, like other species of mushrooms, due to a high water content (over 80%) which promotes bacterial proliferation. Moreover, the oxidation of phenolic compounds under the action of enzymes, such as polyphenol oxidases, causes browning that affects the quality [17].

In tropical Africa, mushrooms are traditionally sun-dried, which is a cheap and therefore accessible method [18]. Although this method has an undeniable advantage resulting from the conversion of ergosterol into vitamin D, its impact on the dried mushroom does not guarantee its quality in terms of health safety and nutrient retention [19]. Therefore, other methods such as oven-drying and freeze-drying seem appropriate to improve the quality of the dried mushrooms. Previous works have indicated satisfactory results for the drying of several species of mushrooms [20–22].

Thus, we aimed to analyze and compare three methods of drying the wild edible mushroom *V. volvacea* harvested in Côte d'Ivoire in terms of the chemical composition and antioxidant properties of the resulting products.

STUDY OBJECTS AND METHODS

***Volvariella volvacea* collection.** Fresh fruiting bodies of *V. volvacea* mushrooms were harvested from dead trunks of oil palms in the plantations of Dimbokro, the N'zi region (Côte d'Ivoire). Once harvested, the mushrooms were packaged in ventilated baskets and carefully transported on the same day to the laboratory for subsequent analyses.

Sampling. In the laboratory, the mushrooms were sorted and cleared of debris. Then, they were washed three times with tap water and rinsed with distilled water. Finally, the mushrooms were divided into three 200-g samples. Each of the samples was subsequently dried and ground into a powder.

Drying and obtaining *V. volvacea* powders. The first sample was placed on a table covered with aluminum foil and subjected to direct sunlight for 5 successive days. As soon as the sun set, the table was removed to the laboratory to avoid rehydration due to the humidity of the air. The second sample was dried in a ventilated oven (BOBASE, China) at 45°C for 48 h. The third sample was first frozen at –80°C, quickly transferred to a pre-cooled freeze-dryer (BIOBASE, China), and dried for 48 h. The freeze-dryer had a cold trap temperature of –80°C and a vacuum of 1 bar. After the application of these drying methods, the mushrooms of each sample were crushed with a flat-hammer grinding mill and sifted through a 60-mesh screen. The three powdered samples were packaged in labeled bottles, which were previously dried and hermetically sealed. These bottles were stored in a desiccator at 25°C until further use.

Biochemical and mineral composition. The moisture, ash, fat, and protein contents of the mushroom powders were determined according to the AOAC [23]. The moisture content was determined by drying a sample in an oven at 105°C to a constant weight. Fat contents were determined by continuous extraction in a Soxhlet apparatus for 4 h using hexane as a solvent. After evaporation of the solvent, the fat content was obtained by the gravimetric method. Ash was measured from the residual mass obtained after incinerating the samples at 550°C for 2 h in a muffle furnace. The protein content was calculated by nitrogen ×6.25. The contents of fibers and total carbohydrates were respectively determined gravimetrically and by difference. The energy value of each sample was estimated by multiplying protein, fat, and available carbohydrates (total carbohydrates minus fibers) by 4, 9, and 4, respectively. Total and reducing sugars were quantified using the methods of Chow & Landhäusser and Garriga *et al.*, respectively [24, 25]. To determine the contents of different mineral elements, the ash residue of each sample (1 g) was digested with a mixture of concentrated nitric acid (14.44 mol/L), sulfuric acid (18.01 mol/L), and perchloric acid (11.80 mol/L). After cooling, the samples were filtered through Whatman filter paper No. 4. Then, each sample solution was made up to a final volume of 25 mL with distilled water. An aliquot of each solution was used to determine the contents of Zn, Cu, Fe, Ca, Mg, Mn, and Na by measuring atomic absorption [26]. *P* was determined colorimetrically using the method of Taussky & Shorr [27].

Antinutritional factors. Oxalate contents in the *V. volvacea* powder were determined according to the method described by Day & Underwood using a potassium permanganate solution (0.05 M $KMnO_4$) [28]. Phytate contents were determined according to the method of Latta & Eskin using a Wade reagent [29].

The phenolic compounds of each *V. volvacea* powder were extracted with 80% (v/v) methanol. For this, 10 g of *V. volvacea* powder was extracted by stirring with 50 mL of 80 % (v/v) methanol at 25°C for 24 h and filtered through Whatman paper No. 4. The residue was then extracted with two additional 50 mL portions of methanol. The combined methanolic extracts were evaporated at 35°C in a Heildolph Laborota 4003 Control rotary evaporator (Schwabach, Germany) until the volume of 25 mL. The extracts obtained were used to estimate the contents of phenolic compounds.

The content of total phenolic compounds in each *V. volvacea* powder was determined using the Folin-Ciocalteu reagent as described by Singleton *et al.* [30]. The results were expressed as mg gallic acid equivalent (GAE)/100 g DW. The content of flavonoids was estimated by the method of Meda *et al.* using aluminum chloride [31]. The results were expressed as mg of quercetin equivalent (QE)/100 g DW. The tannin content was determined according to the method described by Bainbridge *et al.* using a vanillin reagent [32]. The results were expressed as mg of tannic acid equivalent (TAE)/100 g DW.

The vitamin C content in each powder was estimated by titration with 2,6-dichloroindophenol as reported by Pongracz *et al.* [33].

Antioxidant capacities. The capacity of the *V. volvacea* powders to scavenge DPPH radicals was monitored according to the method described by Hatano *et al.* [34]. For this, *V. volvacea* powder solutions (2.5 m) at various concentrations ranging from 0 to 100 mg/mL and a Trolox solution (standard reference of antioxidant) were added to 1 mL of a methanolic solution of DPPH (3 mM).

The mixture was shaken vigorously and left to stand for 30 min in the dark. The DPPH inhibition was determined by measuring absorbance at 517 nm. A check was made by also measuring the absorbance of the DPPH solution. The antioxidant activity expressed as the DPPH radical scavenging activity of each powder and Trolox was marked by the discoloration of the DPPH solution. It was calculated as a percentage of DPPH inhibition, % using the following equation:

$$\text{DPPH inhibition} = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times 100 \quad (1)$$

where A_{control} is the absorbance of the DPPH solution, A_{sample} is the absorbance of the solution with the sample extract.

The concentration of each powder solution causing 50% inhibition (EC_{50}) was estimated from the graph of the DPPH inhibition percentage against the powder solution concentration.

The ferric reducing antioxidant power of the methanolic solution of each of the *V. volvacea* powders or the Trolox methanolic solution was determined according to the method described by Barros *et al.* with slight modifications [35]. For this, 0.1 mL of the *V. volvacea* powder solution or the Trolox solution prepared at various concentrations (0 to 100 mg/mL) was mixed with 2.0 mL of phosphate buffer (0.2 M, pH 6.6) and then with 2 mL of 1% potassium hexacyanoferrate [$K_3Fe(CN)_6$] (w/v). The mixture was incubated at 50°C in a water bath for 20 min and then cooled. A volume of 2 mL of 10% (w/v) trichloroacetic acid was then added and the mixture was centrifuged at 3000 rpm for 10 min. Finally, 2 mL of the supernatant was mixed with 2 mL of distilled water and 0.4 mL of ferric chloride ($FeCl_3$). A blank without a powder was prepared under the same conditions. Absorbance was measured at 700 nm against the blank. Increased absorbance indicated higher reducing power. The concentration of each powder solution causing half maximal effective concentration (EC_{50}) was estimated from the graph of absorbance at 700 nm against the powder solution concentration.

Statistical analysis. All chemical analyses and assays were carried out in triplicate. The results were expressed as mean values ± standard deviation (SD). Analysis of variance (ANOVA) followed by Duncan's test was performed to test for differences between the means by employing Kyplot (version 2.0 beta 15, ©1997–2001, Koichi Yoshioka) statistical software. Significance of differences was defined at the 5% level ($p < 0.05$).

RESULTS AND DISCUSSION

The biochemical composition and energy values of the *Volvariella volvacea* powders obtained by sun drying, oven drying, and freeze-drying are presented in Table 1.

In terms of moisture, freeze-drying allowed better dehydration of the mushroom *V. volvacea* with a powder water content of 4.21%, compared to oven drying and sun drying with the water contents of 5.32 and 8.11%, respectively. It is well-known that dehydration by conventional drying methods is an important process in the food industry because it considerably reduces the water activity which affects the microbiological stability and the physicochemical deterioration reactions [21, 36].

Various studies dedicated to the drying of edible mushrooms have indicated that freeze-drying is the best form of dehydration since it transforms water into ice and then directly into water vapor, skipping the liquid phase [21, 22, 37]. On the other hand, oven drying, which uses a uniform temperature, resulted in a higher removal of moisture compared to sun drying [22, 38]. With regard to the retention of different nutrients, freeze-drying also gave better results than oven drying. This could be due to the fluctuation of temperature for efficient moisture removal with a good retention of proteins, total and reducing sugars, ash, and fibers.

The sun-dried *V. volvacea* powder presented the worst results for nutrient retention. Several reports have indicated a similar trend regarding the impact of the drying method on the protein content of mushrooms [21, 22, 39, 40]. The capacity of freeze-drying to ensure a better retention of proteins could be explained by the fact that drying with hot air (sun drying and oven drying) can cause denaturation of some proteins due to relatively high temperatures, resulting in a substantial protein

Table 1 Biochemical composition, % DW and energy values of *Volvariella volvacea* powders by different drying methods

Parameters	Volvariella volvacea powder obtained by		
	Sun-drying	Oven drying	Freeze-drying
Moisture, %	8.11 ± 0.01[a]	5.32 ± 0.04[b]	4.21 ± 0.01[c]
Proteins, %	24.43 ± 0.03[a]	27.25 ± 0.03[b]	30.10 ± 0.00[c]
Fat, %	1.40 ± 0.04[a]	1.47 ± 0.07[b]	1.50 ± 0.08[c]
Total carbohydrates, %	53.84 ± 0.02[a]	51.93 ± 0.01[b]	48.65 ± 0.02[c]
Total sugars, %	17.33 ± 0.14[a]	18.14 ± 0.11[b]	19.66 ± 0.03[c]
Reducing sugars, %	0.42 ± 0.09[a]	0.49 ± 0.02[b]	0.51 ± 0.07[c]
Ash, %	12.22 ± 0.11[a]	14.03 ± 0.05[b]	15.54 ± 0.04[c]
Fibers, %	13.67 ± 0.13[a]	14.87 ± 0.09[b]	15.50 ± 0.01[c]
Energy value, Kcal/100 g DW	271.20 ± 013[a]	270.47 ± 0.12[b]	266.50 ± 0.01[c]

n = 3; the means ± standard deviations with different letters on the same line are significantly different at $p < 0.05$ according to Duncan's test

loss [22, 41]. In addition, the low protein content of the sun-dried and oven-dried *V. volvacea* powders, compared to that of the freeze-dried powder, could be partly due to the leaching of soluble proteins by the washing water and losses during browning reactions (Maillard reactions) [41, 42].

The low total and reducing sugar contents of the sun-dried and oven-dried powders could be attributed to the fact that some sugars are consumed by heat-induced Maillard reactions [43]. The low content of fibers in the sun-dried *V. volvacea* powder could be explained by the fact that this method required a long duration, i.e., a long exposure to the sun rays, which resulted in a rupture of the cell walls, thus causing a decrease in fibers as a beta-glucan content [44, 45]. However, it is generally recognized that the method of drying does not affect the fiber content in mushrooms [20, 22].

The fat contents were quite low for the *V. volvacea* powders from the three drying methods, as previously reported [4, 8]. The few slight differences between the powders obtained by hot air drying and freeze-drying could be due to oxidation. The mushroom fat is mainly made up of unsaturated fatty acids which are very prone to oxidation when exposed to heat and ambient air [22, 38]. The good ash retention observed during the freeze-drying of the *V. volvacea* mushroom is in agreement with the results reported by Bashir *et al.* for the mushroom *Pleurotus florida* [21]. The considerable decrease in ash during the sun drying could be due to the diffusion of some minerals into the water which migrates out of the mushroom during the process [21, 45]. With respect to energy, the *V. volvacea* powder from sun drying recorded the highest value (271.20 ± 0.13 Kcal/100 g DW), followed by the oven-dried powder (270.47 ± 0.12 DW) and the freeze-dried powder (266.50 ± 0.01 Kcal/100 g DW). This resulted from the fact that the powder from freeze-drying has the lowest levels of available carbohydrates estimated by difference, as reported by Dunkwal *et al.* [46].

Oxalate and phytate are antinutritional factors, also called antinutrients, which interfere with the absorption of certain minerals (iron, calcium, zinc, etc.). Table 2 shows the contents of these two antinutritional factors in the *V. volvacea* powders.

The highest levels of oxalate and phytate were observed in the freeze-dried powder of *V. volvacea* with the respective values of 11.91 ± 0.12 and 8.50 ± 0.03 mg/100 g DW. The lowest contents of oxalate and phytate were recorded in the powder obtained by sun drying. It is well known that oven drying significantly reduces the antinutrient levels of vegetables, which could justify the fact that the oven-dried powder showed lower oxalate and phytate contents than the freeze-dried powder [47]. The report of Bello *et al.* indicated that drying oyster mushroom *Pleurotus sajur-caju* in the oven at 60°C considerably reduced the levels of antinutritional factors, including phytate and oxalate [48]. The low contents of these compounds in the sun-dried *V. volvacea* powder could be attributed to the fact that these two antinutrients are more or less soluble in water and an important amount of them could have migrated with the water that came out of the mushroom during drying. We found that the freeze-drying showed better retention of phytate and oxalate. However, the levels obtained were well below the limits reported by the WHO, which are 22.10 and 105.00 mg/100 g for phytate and oxalate, respectively [49].

The mineral composition of each *V. volvacea* powder was evaluated in terms of microelements and macroelements. Table 3 presents the microelement (zinc, copper, iron, and manganese) contents of the *V. volvacea* powders.

Overall, only the iron content varied significantly from one drying method to another. The powder from freeze-drying had the highest iron content of 4.850 ± 0.014 mg/100 g against 4.15 ± 0.10 and 3.41 ± 0.20 mg/100 g for the oven-dried and sun-dried powders, respectively. This result was comparable to that reported by Bashir *et al.* for the oyster mushroom *P. florida* [21]. In their study, the freeze-dried powder of this mushroom showed the best iron content of 5.10 mg/100 g compared to other methods. On the other hand, Maray *et al.* reported that the sun drying of *Pleurotus ostreatus* resulted in the highest iron content of 11.6 mg/100 g [45]. The other microelements did not show any significant differences depending on the drying method. The values were around 10.30, 1.32, and 2.45 mg/100 g for zinc, copper, and manganese, respectively.

The contents of the macroelements (magnesium, sodium, potassium, phosphorus, and calcium) are presented in Table 4. These contents showed significant differences. The highest contents of most of the macroelements

Table 2 Contents of antinutritional factors (oxalate and phytate) in *Volvariella volvacea* powders dried by different methods

Parameter	*Volvariella volvacea* powder obtained by		
	Sun-drying	Oven drying	Freeze-drying
Oxalate, mg/100 g DW	6.51 ± 0.02[a]	10.10 ± 0.21[b]	11.91 ± 0.12[c]
Phytate, mg/100 g DW	4.37 ± 0.05[a]	6.09 ± 0.09[b]	8.50 ± 0.03[c]

n = 3; the means ± standard deviations with different letters on the same line are significantly different at $p < 0.05$ according to Duncan's test

Table 3 Contents of microelements in *Volvariella volvacea* powders obtained by different drying

Microelements, mg/100g	*Volvariella volvacea* powder obtained by		
	Sun-drying	Oven drying	Freeze-drying
Zn	10.69 ± 0.04[a]	10.21 ± 0.05[a]	10.30 ± 0.05[a]
Cu	1.30 ± 0.15[a]	1.32 ± 0.02[a]	1.38 ± 0.10[a]
Fe	3.41 ± 0.20[a]	4.15 ± 0.10[b]	4.85 ± 0.01[c]
Mn	2.33 ± 0.11[a]	2.45 ± 0.03[a]	2.51 ± 0.09[a]

n = 3; the means ± standard deviations with different letters on the same line are significantly different at $p < 0.05$ according to Duncan's test

were obtained in the freeze-dried *V. volvacea* powder. Thus, freeze-drying allowed for a good retention of these minerals. This same trend was observed by Bashir *et al.* for the contents of magnesium, potassium, phosphorus, and calcium during the drying of the oyster mushroom *P. florida* [21].

In addition, potassium showed the highest content in each of the *V. volvacea* powders, while sodium showed the lowest content. Due to a high K/Na ratio, the *V. volvacea* powders may have an advantage for patients with hypertension and other cardiovascular diseases. Such a result was reported very recently for powders from the oyster mushrooms *P. sajor-caju* and *P. djamor* [50].

Total phenolic compounds, flavonoids, tannins and vitamin C. Table 5 shows the contents of total phenolic compounds, flavonoids, tannins, and vitamin C in the *V. volvacea* powders obtained by different drying methods.

The *V. volvacea* powder obtained by freeze-drying generated the highest contents of total phenolic compounds, flavonoids, tannins, and vitamin C compared to those obtained by oven drying and freeze-drying. These compounds are widely described as major antioxidant components of edible mushrooms [4, 51, 52]. Thus, we found that freeze-drying ensured a better retention of the antioxidant components in the mushroom *V. volvacea*. The findings reported by Tarafdar *et al.* indicated a good retention of vitamin C during the freeze-drying of the button mushroom *Agaricus bisporus* [53]. The decreased retention of these antioxidants in the sun-dried and oven-dried *V. volvacea* powders could be attributed to the fact that high temperatures are likely to degrade heat-sensitive components such as vitamin C and antioxidants [54, 55].

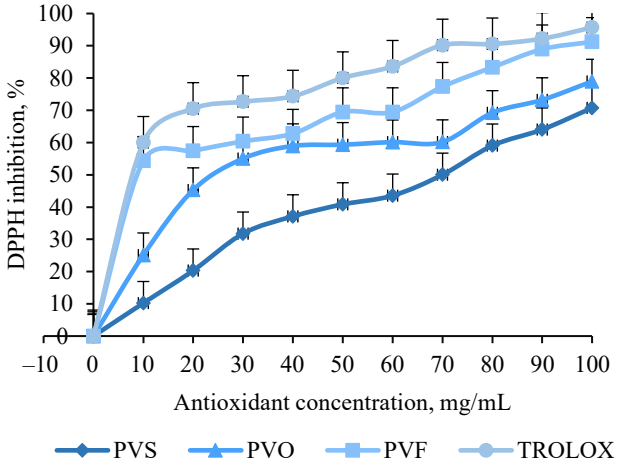
Antioxidant capacities. Two methods of *in vitro* assay of antioxidant activities were used to evaluate the *V. volvacea* powders, namely the DPPH scavenging and the ferric reducing antioxidant power. Figure 1 represents the percentage of DPPH inhibition as a function of the *V. volvacea* powder solution. We observed higher inhibition percentages with increased concentrations of *V. volvacea* powders in the following order: freeze-drying > oven drying > sun-drying (Fig. 1). Trolox used as a reference antioxidant showed the highest percentage of DPPH inhibition. At 100 mg/mL, the Trolox, freeze-dried, oven-dried, and sundried powders had DPPH inhibition percentages of 95.6, 91.2, 78.9, and 70.7%, respectively.

The graphically determined effective concentrations (EC_{50}) of the *V. volvacea* powders are presented in Table 6. As can be seen, the powders showed effective concentrations in the following increasing order: Trolox < freeze-drying < oven drying < sun-drying. The values of effective concentrations were 10.2 ± 0.1, 24.3 ± 0.2, and 69.8 ± 0.5 mg/mL for the *V. volvacea* powders obtained by freeze-drying, oven drying, and sun drying, respectively.

Table 4 Contents of macroelements in *Volvariella volvacea* powders from different drying methods

Macroelements, mg/100g	*Volvariella volvacea* powder obtained by		
	Sun-drying	Oven drying	Freeze-drying
Mg	79.43 ± 0.04[a]	82.64 ± 0.20[a]	86.50 ± 0.04[b]
Na	3.78 ± 0.02[a]	4.11 ± 0.12[b]	4.50 ± 0.01[c]
K	500.04 ± 0.13[a]	678.00 ± 0.16[b]	831.04 ± 0.03[c]
P	183.10 ± 0.17[b]	180.02 ± 0.10[b]	138.13 ± 0.05[a]
Ca	124.01 ± 0.14[b]	132.76 ± 0.03[c]	110.41 ± 0.01[a]

n = 3; the means ± standard deviations with different letters on the same line are significantly different at $p < 0.05$ according to Duncan's test



PVS, PVO, and PVF are *V. volvacea* powders obtained by sun-drying, oven drying, and freeze-drying, respectively

Figure 1 Antioxidant activities via DPPH radical scavenging as a function of *Volvariella volvacea* powders. Each value is expressed as mean ± standard deviation (n = 3)

Table 5 Contents of total phenolic compounds, flavonoids, tannins, and vitamin C in *Volvariella volvacea* powders obtained by different drying methods

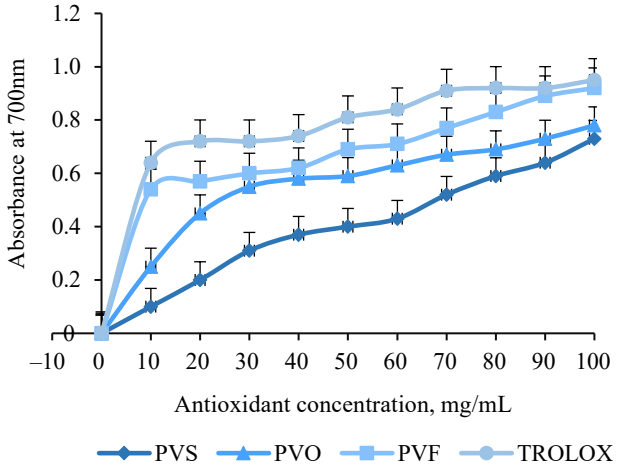
Parameter	*Volvariella volvacea* powder obtained by		
	Sun-drying	Oven drying	Freeze-drying
Total phenolic compounds, mg EG/A100 g	251.30 ± 0.02[a]	269.34 ± 0.03[b]	340.26 ± 0.17[c]
Flavonoids, mg EQ/100 g	50.22 ± 0.05[a]	79.30 ± 0.03[b]	92.66 ± 9.15[c]
Tannins, mg ETA/100 g	39.38 ± 0.07[a]	52.57 ± 0.17[b]	74.59 ± 0.11[c]
Vitamin C, mg/100 g	1.60 ± 0.01[a]	2.44 ± 0.03[b]	5.21 ± 0.02[c]

n = 3; the means ± standard deviations with different letters on the same line are significantly different at $p < 0.05$ according to Duncan's test

Table 6 Effective concentrations (EC_{50}) of *Volvariella volvacea* powders from freeze-drying, oven drying, and sun-drying for DPPH scavenging

Antioxidant	Effective concentrations EC_{50}, mg/mL
Trolox	9.4 ± 0.2^{d}
Freeze-dried powder	10.2 ± 0.1^{c}
Oven dried powder	22.3 ± 0.2^{b}
Sun-dried powder	698.0 ± 0.5^{a}

Each value is expressed as mean ± standard deviation (n = 3). The values with different letters within the same column are significantly different ($p < 0.05$)



PVS, PVO, and PVF are *V. volvacea* powders obtained by sun-drying, oven drying, and freeze-drying, respectively

Figure 2 Antioxidant activities of *Volvariella volvacea* powders via ferric ion reducing antioxidant power. Each value is expressed as mean ± standard deviation (n = 3)

According to the results, the freeze-dried powder of *V. volvacea* showed the best antioxidant capacity in terms of DPPH scavenging due to its lower effective concentration EC_{50}. The decrease in DPPH radical scavenging activity in the sun-dried and oven-dried powders could be the consequence of thermal degradation of vitamin C and some phenolic compounds, as reported by Bashir *et al.* [55]. Similar results were reported for the mushroom *Lentinus edodes*, with the lowest effective concentration obtained by its powder from freeze-drying [56].

With regard to the ferric reducing antioxidant power, Fig. 2 represents the absorbance at 700 nm as a function of the concentration of the *V. volvacea* powder solution. We found that the reducing power expressed by increased absorbance at 700 nm was higher with increased concentrations of the *V. volvacea* powders. Trolox showed the highest absorbances at all concentrations, followed respectively by the powders from freeze-drying, oven drying, and sun drying. At 100 mg/mL, the absorbances were 0.95, 0.92, 0.78, and 0.72 for Trolox, freeze-dried, oven-dried, and sun-dried powders, respectively.

Table 7 Effective concentrations (EC_{50}) of *Volvariella volvacea* powders for ferric reducing antioxidant power

Antioxidant	Effective concentration EC_{50}, mg/mL
Trolox	8.5 ± 0.2^{d}
Freeze-dried powder	10.1 ± 0.1^{c}
Oven dried powder	25.6 ± 0.4^{b}
Sun-dried powder	68.5 ± 0.3^{a}

Each value is expressed as mean ± standard deviation (n = 3). Values with different letters within the same column are significantly different ($p < 0.05$)

The effective concentrations (EC_{50}) for the ferric reducing antioxidant power (Table 7) followed the same trend as those for the DPPH trapping activities: Trolox < freeze-drying < oven drying < sun-drying. The values of effective concentrations were 10.1 ± 0.1, 25.6 ± 0.4, and 68.5 ± 0.3 mg/mL for the *V. volvacea* powders obtained by freeze-drying, oven drying, and sun drying, respectively.

Similar patterns were reported by some authors about the reducing power of mushroom powders from different drying methods [55]. Better antioxidant activity of the freeze-dried samples can be attributed to low temperature and vacuum used in the freeze-drying process which cause less thermal degradation and oxidation of phenolic compounds [56].

CONCLUSION

Our results clearly indicate that freeze-drying is the best method of drying the mushroom *Volvariella volvacea* from Côte d'Ivoire because it results in a better retention of nutrients and bioactive compounds responsible for antioxidant activities. This could promote the use of the freeze-dried powder of *V. volvacea* to formulate functional foods and fortify certain conventional foods.

CONTRIBUTION

E.J.P. Kouadio designed the research concept, provided the analysis tools, wrote the manuscript, and submitted it. B.B. Koffi, O.J. Gbotognon, and S. Soro were responsible for data collection and analysis.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding this publication.

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