Hindawi
Journal of Food Processing and Preservation
Volume 2023, Article ID 2518620, 12 pages
https://doi.org/10.1155/2023/2518620

Research Article

Assessment of the Quality Characteristics of *Stropharia rugosoannulata* Subjected to Five Different Drying Methods

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Received 9 September 2022; Revised 15 December 2022; Accepted 17 March 2023; Published 31 March 2023

Academic Editor: Yogesh Kumar

The effect of solar drying (SD), room-temperature shaded drying (RSD), hot-air drying (HD), vacuum freeze drying (VFD), and microwave drying (MD) was compared on the sensory quality, nutrient substances, bioactive constituents, and antioxidant activities of dried *Stropharia rugosoannulata*. The results revealed that, in comparison with SD, RSD, HD, and MD, VFD mushrooms exhibited a better appearance with less shrinkage and an ideal colour with lower a colour difference. Meanwhile, a significantly higher content ($p < 0.05$) of protein, carbohydrate, total sugar, and vitamin C was retained in VFD samples. The HD and VFD samples both had abundant total free amino acids and best met the ideal protein standard. Furthermore, VFD had advantages in terms of better preserving bioactive constituents and stronger antioxidant activities compared to other treatments. Therefore, the VFD-dried *S. rugosoannulata* obtained a better overall quality compared to the other four drying methods.

1. Introduction

Edible mushrooms are healthy foods, not only for their nutritional value with high contents of proteins, vitamins, amino acids, carbohydrates, dietary fibres, minerals, and low lipids but also for their medicinal value with rich bioactive components giving the mushrooms antimicrobial, antioxidant, antitumor, and antidiabetic effects [1, 2]. The excellent nutritional and medicinal value is in line with the needs of modern people for health care. Both edible mushrooms and health products made by combining edible mushrooms with daily food have a large market demand at this stage. *Stropharia rugosoannulata* (family: Strophariaceae), a kind of edible mushroom, was recommended to developing countries by the UN Food and Agriculture Organization and traded internationally [3, 4]. Some pharmacological activities of *S. rugosoannulata* including antitumor, antihyperglycemic, antibacterial, antioxidant, and coronary heart disease preventative effects have been reported by now [5, 6].

S. rugosoannulata is widely distributed in the northern temperature zones of the world. In China, it is mainly cultivated in the northeast (Heilongjiang and Jilin provinces), southwest (Sichuan and Yunnan provinces), central (Henan and Hubei provinces), and eastern (Shandong, Fujian, and Jiangxi provinces) regions. In central China, *S. rugosoannulata*, grown under the bamboo forests in Bo'ai County of Henan Province, has high quality, and its cultivation industry has achieved considerable economic and ecological benefits [7]. However, *S. rugosoannulata* is extremely susceptible to microbial spoilage and chemical deterioration due to its high content of moisture (85-95%) and polysaccharides; thus, the preservation period is limited to 2-3 days. Nowadays, *S. rugosoannulata* dehydration is the main disposal method used to inhibit this phenomenon. In addition, dried mushrooms can be used as an important ingredient in a broad range of food formulations such as stuffing, instant soup premix, snack seasoning, pizza, pasta, salad, and rice dishes [8]. The drying process may also improve the abundance of chemical ingredients and strengthen antibacterial

and antioxidant activities, for instance, the essential oil of air-dried *S. rugosoannulata* [9]. But, improper drying methods may result in quality changes such as loss of nutrients and aroma and degradation of bioactive components [10]. Therefore, the selection and exploitation of a suitable drying treatment for fresh *S. rugosoannulata* preservation are very important and meaningful.

Thermal processes are typical methods that can significantly retard the quality degradation of mushrooms by controlling storage temperature and water activity [11, 12]. Conventionally, mushroom drying is performed by room-temperature shaded drying (RSD), solar drying (SD), and hot-air drying (HD). However, the heat transfers slowly from the food's surface to the centre. Therefore, the drying processes require a long time, leading to quality degradation in the final products. Microwave drying (MD) is a rapid and uniform method, as well as space and energy efficient. It can prevent decomposition because the waves have a high capacity of penetration with heating not only on the surface but also inside the materials [13]. Vacuum freeze drying (VFD) could produce high-quality products on the basis of water sublimation, but the cost of energy and investment was higher [14]. In summary, each drying treatment has its own strengths and weaknesses, and the choice depends on the drying purpose such as retaining nutritional values, maintaining pharmacological activity, or keeping active ingredients from being degraded.

The effects of natural air drying, hot air drying, and vacuum freeze drying on the proximate composition and nonvolatile compounds of *S. rugosoannulata* cultivated in the Sichuan province (southwest of China) [15] have been reported, and it suggested that VFD was better to preserve the non-volatile compounds and HD would be a potential method to produce umami concentration in dried mushrooms. However, the influence of other drying methods on the quality characteristics such as sensory quality, nutritional substances, bioactive constituents, and pharmacological activities, especially for *S. rugosoannulata* grown under the bamboo forest in Bo'ai County of Henan Province, has not been described till now. Therefore, the purpose of this investigation was to determine the effects of five different drying methods (SD, RSD, HD, VFD, and MD) on the sensory quality, proximal composition, minerals, vitamins, amino acids, bioactive constituents, and antioxidant activities of *S. rugosoannulata* collected from the Bo'ai bamboo forest.

2. Materials and Methods

2.1. Chemicals and Reagents. 1,1-Diphenyl-2-picrylhydrazyl (DPPH), oleanolic acid, rutin, D-glucose, gallic acid, and ascorbic acid (Vc) were obtained from Sigma-Aldrich (St. Louis, MO, USA). High-performance liquid chromatography- (HPLC-) grade methanol, acetic acid, and phosphoric acid were purchased from Merck (Darmstadt, Germany). All other chemicals and reagents were of the highest commercial grade and obtained from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China).

2.2. Materials. Fresh *S. rugosoannulata* mushrooms were collected from the bamboo forest in Bo'ai County in May 2021. They were thoroughly washed with water, kept on filter papers to soak up excess water, and divided into five equal portions of 1 kg for each drying method.

2.3. Drying Treatments

2.3.1. Solar Drying (SD). Fresh mushrooms were placed on the stainless steel trays and sent into the SD chamber where ambient air could be heated by solar collectors through recirculation of the drying air. This process was kept for 10-14 days, and the temperature was set at about $40 \pm 5^{\circ}C$.

2.3.2. Room-Temperature Shaded Drying (RSD). Fresh mushrooms were placed dispersedly on the floor and dehydrated in a special room, not allowing the sun rays to reach onto the mushrooms directly, and the natural air can flow with the room temperature of 22-28°C. The drying time lasted for 18-21 days.

2.3.3. Hot-Air Drying (HD). This process was carried out in a hot air dryer (DGX-9143B-1, Shanghai Fuma Test Equipment Co., Ltd., Shanghai, China) operated by convection that was heated by electric resistors owning a control unit to adjust air velocity (1 m/s) and temperature (40°C). The drying time was 5-7 days.

2.3.4. Vacuum Freeze Drying (VFD). Fresh mushrooms were first cut into small slices about 0.2 cm thick, frozen overnight at -80°C in an ultralow temperature freezer (Premium U410, Eppendorf, Hamburg, Germany), and then freeze-dried for 4 days at 0.04 mbar and −58°C in a freeze-dryer (CTFD-18 T, Qingdao Creatrust Electronic Technology Co., Ltd., Qingdao, China).

2.3.5. Microwave Drying (MD). Fresh mushrooms were dried in a microwave oven (M1-230E, Guangdong Midea Kitchen Appliance Manufacturing Co., Ltd., Foshan, China) at an average power level (800 W) for a cumulative 30-40 min, during which they were turned over every 3-5 minutes in case of burning.

All drying processes lasted until the mushrooms reached a constant weight when the moisture content was at the equilibrium condition. The dried mushrooms were ground using a high-speed grinder (YF-1000, Yongli Pharmaceutical Machinery Co., Ltd., Wenzhou, China) and passed through a 60-mesh sieve. The powders were sealed in plastic bags and stored at 4°C for further investigation.

2.4. Appearance and Colour Measurement. The appearance of dried mushrooms was pictured by using a full-wavelength TLC scanner (KH3000Plus, Shanghai Kezhe Biochemistry Technology Co., Ltd., Shanghai, China), which is composed of a camera (DS126291, Canon, Taiwan, China), an illumination cabinet, and a computer to operate a white fluorescent simulator. The colour of fresh and dried mushrooms was tested using a portable colorimeter (WR10, Shenzhen WaveGD Photoelectric Technology Co., Shenzhen, China). This apparatus was calibrated by a

standard white tile, and L (lightness), a (green-red), and b (yellow-blue) colour scales were measured. The difference in colour (ΔE) between dried and fresh samples was used to describe the colour change and is defined as follows:

$$\Delta E = \sqrt{(L - L_f)^2 + (a - a_f)^2 + (b - b_f)^2}, \quad (1)$$

where L, a, and b refer to the lightness, redness, and yellowness of dried samples, respectively, while L_f, a_f, and b_f indicate those of fresh samples, respectively.

2.5. Proximal Composition. The contents of moisture, ash, crude protein, fat, crude fibre, total carbohydrate, and total sugar were tested based on the AOAC standard method [16]. The reducing sugar content was tested by the Somogyi-Nelson assay using a microtiter plate [17].

2.6. Mineral Composition. The mineral contents of the mushrooms dehydrated by different methods were assayed through inductively coupled plasma optical emission spectrometry (ICP-OES, Varian-Vista, Australia). About 5 g of the dried mushrooms were weighed into a porcelain crucible and ashed in a muffle furnace at 500°C overnight. The ash samples were digested in diluted nitric acid (7 mol/L), evaporated near dryness on a hot plate in a fuming hood, cooled, filtered, and then diluted up to the mark (100 mL) into a calibrated flask [18]. The resulting solution was then analyzed using ICP-OES calibrated with different concentrations of standard solutions of the minerals. Phosphorus (P) was measured through molybdenum blue spectrophotometry.

2.7. Vitamin Composition. Fat-soluble vitamins A, D, and E were tested in accordance with Chinese Standard GB 5009.82-2016 [19]. Quantitative determination of vitamin K_1 was performed using the method of GB 5009.158-2016 [20]. Vitamins B_1, B_2, and B_6 were determined according to GB 5009.84-2016 [21], 5009.85-2016 [22], and 5009.154-2016 [23], respectively. Pantothenic acid (vitamin B_5) [24] and nicotinic acid [25] were measured by HPLC. Vitamin B_{12} and folic acid were tested by reagent kit methods.

2.8. Amino Acid Composition. The compositions of amino acids were determined by a reversed-phase HPLC method according to the previous report [7]. Retention data were collected with a Waters ACQUITY chromatographic system (Waters, Milford, MA, USA) including a 2414 evaporative light scattering detector. The analyses were performed on a Phenomenex Gemini-NX C18 column (4.6 mm × 250 mm, 5 μm). A gradient elution process (Table 1) at 35°C was used, and the flow rate was 1 mL/min. The mobile phase included buffer A (0.05 mol/L sodium acetate, pH = 6.4 ± 0.05, 0.1% N, N-dimethylformamide) and buffer B (acetonitrile: deionized water = 1 : 1, V/V). 2,4-Dinitrofluorobenzene was used for precolumn derivation, and the detection wavelength was selected at 360 nm. The stock solutions (approximately 1 mmol/L) of individual amino acids were prepared in 0.1 mol/L HCl, but tryptophan was prepared in water.

Table 1: Gradient progress of the mobile phase.

Time/min	Percentage of mobile phase A	Percentage of mobile phase B
0-3	82%	18%
3-8	82%	18%
8-20	72%	28%
20-30	72%	28%
30-40	68%	32%
40-55	68%	32%
55-70	40%	60%
70	5%	95%

2.9. Bioactive Constituents

2.9.1. Quantification of Triterpenoids. The triterpenoid content was quantified on the basis of the protocol reported by Oludemi et al. [26]. Briefly, 100 μL of crude extract was mixed with 150 μL 5% vanillin-glacial acetic acid and 500 μL 70% perchloric acid. The mixture solution was placed in a hot water bath for 30 min at 70. Thereafter, it was cooled in an ice-water bath to room temperature, and 2.25 mL of glacial acetic acid was added. The absorbance was measured at 548 nm using an iMark™ microplate reader (Bio-Rad Laboratories, Hercules, California). Oleanolic acid was used as a standard. The results were expressed as mg/mL oleanolic acid equivalent.

2.9.2. Quantification of Flavonoids. The flavonoid content was determined according to the method of Hudz et al. with minor amendments [27]. Concisely, 100 μL of crude extract was dissolved in 300 μL methanol, and 20 μL of 10% aluminum chloride was added to the previous solution. Then, the mixture solution was added in with 20 μL of 1 mol/L sodium acetate, and distilled water was added to make up the volume to 1 mL. The mixture was incubated at room temperature for 30 min, and the absorbance was tested at 450 nm using an iMark™ microplate reader (Bio-Rad Laboratories, Hercules, California). Rutin was used as a standard. The flavonoid content was expressed as mg/mL rutin equivalent.

2.9.3. Quantification of Polysaccharides. The basic protocol of Dubois et al. [28] was followed, with the modifications indicated below. 0.6 mL of crude extract was mixed with 0.3 mL 1% phenol solution. Then, 1.5 mL of concentrated sulfuric acid was added slowly. After vortex-stirred, the mixture was incubated for 20 min at 80°C and finally cooled down to room temperature. The absorbances were read at 490 nm using an iMark™ microplate reader (Bio-Rad Laboratories, Hercules, California). D-glucose was used as a standard, and the polysaccharide content was expressed as mg/mL D-glucose equivalent.

2.9.4. Quantification of Phenols. The total phenol content was quantified following the Folin-Ciocalteu method [25] with slight modifications. In brief, 25 μL of crude extract was treated with 250 μL Folin-Ciocalteu's reagent for 5 min, and the reaction was stopped by adding 750 μL of

20% anhydrous sodium carbonate. Distilled water was added to make up the volume to 5 mL. The mixture was immediately incubated in the dark at room temperature for 2 h and the absorbance was measured at 760 nm with an iMark™ microplate reader (Bio-Rad Laboratories, Hercules, California). Gallic acid was used as a standard, and the phenol content was expressed as mg/mL gallic acid equivalent.

2.10. Antioxidant Activity

2.10.1. Aqueous and Ethanolic Extracts. The mushroom powders dried by five different methods (SD, RSD, HD, VFD, and MD) were named as SDSR, RSDSR, HDSR, VFDSR, and MDSR, respectively. They were used for ethanolic and aqueous extraction. Soxhlet's extraction was performed to prepare the ethanolic extract, and the powder soaked in 95% ethanol was heated at 75°C for 24 h. For the aqueous extract preparation, the powder macerated in water was boiled for 4 h. All extracts were filtered, dried, and stored at 4°C.

2.10.2. DPPH Radical Scavenging Activity. The spectrophotometric method [29] based on the use of free radical DPPH was used to evaluate the antioxidant activity. In brief, the reaction mixtures including 2.0 mL of extract (2, 4, 8, 16, and 32 mg/mL) and 2.0 mL of DPPH solution (0.05 mmol/L in ethanol) were incubated in a 25°C water bath for 30 min in the dark, and then the absorbance was read at 517 nm using an iMark™ microplate reader (Bio-Rad Laboratories, Hercules, California). Ascorbic acid (V_c, 0.1-0.5 mg/mL) was used as the positive control. The DPPH radical scavenging rate was calculated as follows:

$$\text{Scavenging}\,(\%) = \left[\frac{(A_0 - A_1)}{A_0}\right] \times 100, \tag{2}$$

where A_1 was the absorbance with sample and A_0 was the absorbance without sample.

2.10.3. Ferric Reducing Power (FRP). The FRP potential was determined using the method of Hu et al. [30]. 1.0 mL of extract in 0.2 M phosphate buffer and 1.0 mL of potassium ferricyanide solution (1.0%, *w*/*v*) were fully mixed and heated at 50°C for 20 min. Then the reaction was terminated by adding 1.0 mL of trifluoroacetic acid (10.0%, *w*/*v*), and the mixture was centrifuged at 1000 × g for 5 min. The supernatant was fully mixed with 1.0 mL ultrapure water and 0.5 mL ferric chloride (1.0%, *w*/*v*), and the mixture reacted for 10 min at room temperature. The absorbance was read at 700 nm using an iMark™ microplate reader (Bio-Rad Laboratories, Hercules, California). V_c (0.5-8 mg/mL) was used as the positive control.

2.11. Statistical Analysis. All assays were performed in triplicate. The results were expressed as mean value ± standard error (SE). Data differences between the two groups were analyzed using the Student *t*-test ($p < 0.05$) by the SPSS software (version 20.0, IBM SPSS Inc., Chicago, Illinois). *p* values below 0.05 were considered to be statistically significant.

3. Results and Discussion

3.1. Appearance and Colour. Appearance is one of the key indicators for the quality evaluation of dried mushrooms. The appearances of the fresh *S. rugosoannulata* and dried samples treated by SD, RSD, HD, VFD, and MD are presented in Figure 1. It can be seen that VFD mushrooms were round with a smooth surface and dense texture (Figure 1(b)), resembling fresh mushrooms (Figure 1(a)). They showed limited shrinkage, followed by that of MD, RSD, SD, and HD. VFD achieved the purpose of drying through water sublimation at a low temperature, thus building a rigid bulk structure and avoiding shrinkage and collapse of the parenchyma cells [31]. The shrinkage of MD mushroom was alleviated, as shown in Figure 1(e), which coincided with the study of Tian et al. [32]. It was reported that shiitake mushrooms dried by MD showed the lowest shrinkage ratio than that of microwave vacuum drying, vacuum drying, and HD. The preferential absorption of microwave energy by water molecules accelerates the evaporation of water within the sample, which was responsible for reducing shrinkage. Generally, the shrinkage rate is closely related to the changes in moisture under different heating transfer modes, and shrinkage is desirable when the volume reduction due to the removal of liquid water is less than the theoretical reduction [33]. Reversely, the volume of HD mushrooms (Figure 1(f)) was significantly reduced, and the shrinkage was more apparent due to the longer heating time and higher temperature.

Colour is an important quality parameter for dried mushrooms. Table 2 presented the results of colour measurements, and the data was plotted as a bar chart (Figure 2). The colour difference close to zero indicates that the colour of the dried sample is close to the fresh one, and both the caps and stipes showed a low colour difference could be considered as the ideal colour. The *L* value in the cap of VFD and RSD samples increased while that of the other three dried samples decreased. Similarly, the *L* value in the stipe of the VFD sample increased, but the other four decreased. Correspondingly, as shown in Figure 1, the colour of the cap and stipe became brown after being dried, except for VFD. This phenomenon was explained by nonenzymatic browning reactions due to the presence of carbohydrates and proteins in fresh samples [34]. It was found that the lowest *L* value was 18.42 from the HD sample. This finding was consistent with the results of other authors who have shown that HD products became darker due to prolonged heat exposure [35]. A statistically significant difference ($p > 0.05$) among the ΔE data of different drying groups was not observed, but the lowest $\Delta E'$ was owned by VFD and RSD samples. In fact, the concentration of oxygen is reduced in the vacuum drying chamber during FD, thus leading to less colour degradation of dried samples [32]. As for RSD, low temperatures may reduce the possibility of browning. To sum up, *S. rugosoannulata* dried by VFD

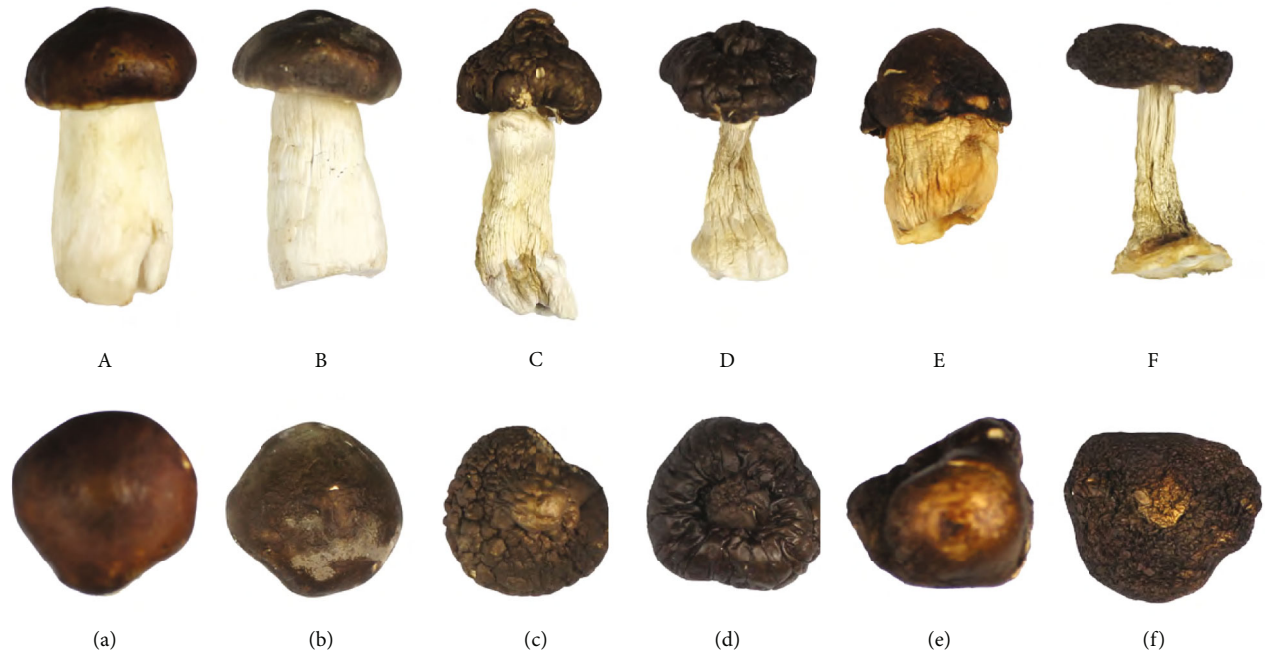

Figure 1: The appearance of *S. rugosoannulata* dried by different drying methods. (A–F) The overall images of fresh and five dried mushrooms (VFD, RSD, SD, MD, and HD), respectively. (a–f) Those of the corresponding image of the cap.

Table 2: The colour of the caps and stipes of *S. rugosoannulata* dehydrated by different drying methods.

	L	a	b	ΔE	L'	a'	b'	$\Delta E'$
Fresh	21.95 ± 0.87^{c}	20.86 ± 0.73^{a}	29.75 ± 0.74^{a}	0	74.07 ± 0.93^{b}	1.94 ± 0.15^{c}	11.06 ± 0.58^{c}	0
VFD	32.94 ± 0.93^{a}	8.83 ± 0.52^{bc}	10.94 ± 0.50^{c}	21.85 ± 1.16	85.03 ± 0.82^{a}	2.1 ± 0.25^{c}	11.33 ± 0.35^{c}	10.50 ± 0.66^{c}
RSD	26.01 ± 1.27^{b}	9.55 ± 0.45^{b}	24.12 ± 0.96^{b}	20.35 ± 0.88	67.71 ± 1.46^{c}	11.36 ± 0.80^{a}	16.55 ± 0.79^{b}	10.26 ± 0.40^{c}
SD	19.67 ± 1.03^{c}	6.9 ± 0.61^{c}	22.36 ± 0.49^{b}	19.13 ± 0.51	53.2 ± 3.57^{d}	5.5 ± 0.27^{b}	16.21 ± 0.46^{b}	34.09 ± 0.57^{a}
MD	19.43 ± 1.03^{c}	8.25 ± 0.51^{bc}	24.91 ± 0.60^{b}	19.00 ± 1.42	53.43 ± 0.50^{d}	6.31 ± 0.38^{b}	28.79 ± 0.91^{a}	32.53 ± 0.93^{a}
HD	15.70 ± 0.68^{d}	6.76 ± 0.33^{c}	30.78 ± 1.19^{a}	19.39 ± 1.04	51.83 ± 2.10^{d}	5.34 ± 0.58^{b}	17.94 ± 0.58^{b}	27.53 ± 0.94^{b}

Notes: results were expressed as means ± SE ($n = 3$). L, a, and b represented the lightness, redness, and yellowness of the cap of dried mushrooms, respectively. L', a', and b' represented those of the stipes, respectively. ΔE and $\Delta E'$ mean the colour difference between the dried and fresh samples in the caps and stipes, respectively. Different letters in the same column indicated significant differences at $p < 0.05$.

obtained a good appearance with minor shrinkage, a smooth surface, and a dense texture, as well as ideal colour.

3.2. Proximate Composition. Proximate compositions of *S. rugosoannulata* dried by five different methods are shown in Table 3. The final moisture contents of the dried samples were reduced to below 11.5 ± 2.0 g/100 g d.m., and HD showed the best dehydration rate (5.20 ± 0.28). The fat content of dried materials varied little, ranging from 1.11 g/100 g (MD) to 1.38 g/100 g (HD). Similarly, Zhao et al. reported that fat was relatively stable and not easy to change during the drying process [10]. The high ash content (6.82-8.51 g/100 g) showed that *S. rugosoannulata* was a good source of minerals. VFD was significantly better than the other methods in preserving protein, carbohydrates, and total sugar. It has been reported that many quality deteriorations almost stopped during freeze-drying [36]. The content of total protein, reducing sugar, and total sugar in MD and HD samples was the lowest, which was due to the Maillard reaction. The Maillard reaction is a nonenzymatic reaction between the carbonyl groups of reducing sugars and the free amino groups of a protein [37], and several factors, such as the reaction temperature, time, ratio of the amino groups and reducing sugars, water activity, and pH, influence the Maillard reaction [38]. In this study, the high temperature and long drying time of MD and HD may accelerate the reaction, leading to the reduction of protein, reducing sugar, and total sugar. The result was consistent with the previous report [10].

3.3. Mineral Composition. Table 4 showed the results of the effects of SD, RSD, HD, VFD, and MD on the mineral elements in *S. rugosoannulata*. It showed that all five kinds of dried samples contained K, Ca, Mg, Na, and P as major elements, and Fe, Zn, Mn, Cu, and Se as trace elements, which was in agreement with previous reports [7, 39]. K plays an

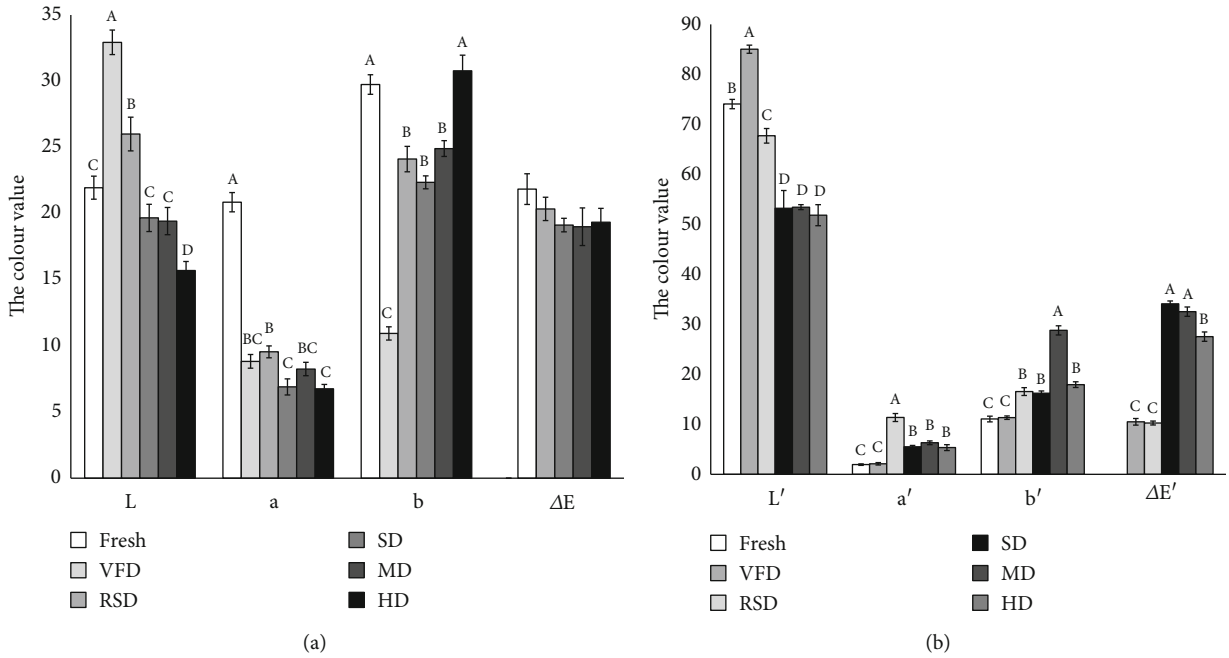

Figure 2: The colour variation of *S. rugosoannulata* dehydrated by different drying methods. (a, b) The colour variation of caps and stipes, respectively. L, a, and b represented the lightness, redness, and yellowness of the cap of the dried mushrooms, respectively. L', a', and b' represented those of the stipes, respectively. ΔE and $\Delta E'$ mean the colour difference between the dried mushrooms and the fresh samples in the caps and stipes, respectively. Each value is expressed as a mean with an error bar of SE ($n = 3$). Different letters in the same group indicated significant differences at $p < 0.05$.

Table 3: Proximate analysis of *S. rugosoannulata* dehydrated by different drying methods.

Parameters g/100 g d.m.	Drying methods				
	SD	RSD	HD	VFD	MD
Moisture	8.98 ± 0.23^{a}	9.25 ± 0.21^{a}	5.20 ± 0.28^{c}	6.72 ± 0.22^{b}	7.21 ± 0.25^{b}
Fat	1.18 ± 0.02^{bc}	1.12 ± 0.01^{c}	1.38 ± 0.01^{a}	1.25 ± 0.03^{b}	1.11 ± 0.03^{c}
Ash	8.51 ± 0.11^{a}	7.74 ± 0.11^{b}	8.37 ± 0.15^{a}	6.82 ± 0.24^{c}	7.92 ± 0.25^{ab}
Crude protein	38.45 ± 1.25	39.61 ± 2.42	36.49 ± 1.37	41.35 ± 2.76	37.94 ± 1.94
Crude fibre	5.47 ± 0.18^{b}	5.94 ± 0.31^{b}	7.29 ± 0.26^{a}	5.84 ± 0.15^{b}	5.51 ± 0.22^{b}
Reducing sugar	3.81 ± 0.14	3.74 ± 0.19	3.68 ± 0.27	3.95 ± 0.21	3.74 ± 0.18
Carbohydrate	38.90 ± 1.98^{b}	40.31 ± 1.25^{b}	43.67 ± 1.91^{ab}	48.44 ± 3.16^{a}	44.89 ± 2.04^{ab}
Total sugar	33.12 ± 1.15^{b}	35.81 ± 1.81^{ab}	32.45 ± 1.01^{b}	38.01 ± 1.38^{a}	31.85 ± 1.20^{b}

Notes: results were expressed as means ± SE ($n = 3$). "d.m." represented dry matter. Different letters in the same row indicated significant differences at $p < 0.05$.

important role in maintaining fluid balance and controlling blood pressure in the human body [40]. Ca is known to be a musculoskeletal material that aids in the formation of strong bones and teeth [41]. Particularly, Se deficiency in human bodies has been proven to be connected with some diseases including cancer, cardiovascular diseases, and abnormalities in immune and thyroid function. It is an essential micronutrient for humans [42]. The results showed that the drying process caused no significant changes ($p > 0.05$) in Zn content, while fluctuations in Fe, K, and Mg content ($p < 0.05$). As for Fe, Mn, Se, Na, K, and Mg, the contents of these elements in dried *S. rugosoannulata* by HD were significantly higher than others. The contents of Ca and P were highest in the MD and RSD samples, respectively. The significant differences in mineral content among *S. rugosoannulata* dried by different methods may not be the effect of the drying process, but due to the heterogeneous distribution of the minerals in the analyzed samples [43]. Anyway, dried *S. rugosoannulata* was a good source of minerals that are essential for numerous body processes by serving as important cofactors for many enzymes.

3.4. Vitamin Composition. The results of vitamins A, B-group, C, D, E, K_1, folic acid, and nicotinic acid are shown in Table 5. Vitamins A, B_1, D, E, and K_1 cannot be detected. Vitamin C (ascorbic acid) could be detected only in RSD

Table 4: Mineral analysis of *S. rugosoannulata* dehydrated by different drying methods.

Elements mg/kg d.m.	Drying methods				
	SD	RSD	HD	VFD	MD
Fe*	187.33 ± 5.49^{cd}	204.33 ± 3.18^{bc}	224.33 ± 9.53^{a}	164.83 ± 7.42^{d}	221.33 ± 10.11^{ab}
Mn*	20.83 ± 0.45^{b}	20.10 ± 1.05^{a}	23.20 ± 1.40^{a}	14.30 ± 0.90^{ab}	21.77 ± 0.55^{ab}
Zn*	48.73 ± 1.18	52.47 ± 0.61	53.33 ± 1.24	50.07 ± 1.01	51.67 ± 1.30
Cu*	21.00 ± 0.81^{ab}	20.81 ± 0.27^{ab}	21.25 ± 0.51^{a}	19.47 ± 0.13^{b}	19.73 ± 0.32^{ab}
Se*	1.97 ± 0.08^{bc}	2.10 ± 0.12^{ab}	2.52 ± 0.11^{a}	1.60 ± 0.22^{c}	2.37 ± 0.09^{ab}
Na#	988.67 ± 25.12^{c}	925.67 ± 14.15^{d}	1221.33 ± 19.64^{a}	820.33 ± 6.64^{e}	1102.33 ± 23.96^{b}
K#	38300.00 ± 115.47^{c}	37200.00 ± 230.94^{d}	42100.00 ± 288.67^{a}	32200.00 ± 115.47^{e}	40500.00 ± 230.94^{b}
Ca#	1206.67 ± 30.31^{ab}	1195.33 ± 25.12^{ab}	1232.33 ± 12.41^{a}	1139.00 ± 18.48^{b}	1257.33 ± 12.99^{a}
P#	856.67 ± 12.41^{b}	970.33 ± 19.34^{a}	803.33 ± 8.37^{c}	817.67 ± 7.80^{bc}	833.67 ± 14.15^{bc}
Mg#	1089.67 ± 8.95^{bc}	1030.00 ± 16.74^{c}	1260.33 ± 28.58^{a}	822.33 ± 8.37^{d}	1120.33 ± 30.89^{b}

Notes: results were expressed as means ± SE ($n = 3$). "d.m." represented dry matter. *Microelement. #Macroelement. "Fe" represented iron. "Mn" represented manganese. "Zn" represented zinc. "Cu" represented copper. "Se" represented selenium. "Na" represented natrium. "K" represented potassium. "Ca" represented calcium. "P" represented phosphorus. "Mg" represented magnesium. Different letters in the same row indicated significant differences at $p < 0.05$.

Table 5: Vitamin analysis of *S. rugosoannulata* dehydrated by different drying methods.

Vitamins	Drying methods				
	SD	RSD	HD	VFD	MD
Vitamin A*	ND (<10)	ND (<10)	ND (<10)	ND (<10)	ND (<10)
Vitamin C**	ND (<0.5)	11.11 ± 0.57	ND (<0.5)	9.99 ± 0.85	ND (<0.5)
Vitamin D*	ND (<0.7)	ND (<0.7)	ND (<0.7)	ND (<0.7)	ND (<0.7)
Vitamin E**	ND (<0.04)	ND (<0.04)	ND (<0.04)	ND (<0.04)	ND (<0.04)
Vitamin K_1**	ND (<1.5)	ND (<1.5)	ND (<1.5)	ND (<1.5)	ND (<1.5)
Vitamin B_1**	ND (<0.03)	ND (<0.03)	ND (<0.03)	ND (<0.03)	ND (<0.03)
Vitamin B_2**	1.78 ± 0.05^{a}	1.60 ± 0.09^{b}	1.82 ± 0.02^{a}	1.72 ± 0.03^{ab}	1.69 ± 0.050^{ab}
Vitamin B_5**	12.86 ± 0.07^{b}	12.38 ± 0.22^{b}	13.62 ± 0.27^{ab}	10.48 ± 0.53^{c}	14.97 ± 1.00^{a}
Vitamin B_6**	0.23 ± 0.01	0.19 ± 0.01	0.21 ± 0.00	0.18 ± 0.02	0.19 ± 0.01
Vitamin B_{12}*	0.49 ± 0.01^{ab}	0.31 ± 0.03^{d}	0.56 ± 0.01^{a}	0.44 ± 0.02^{bc}	0.38 ± 0.04^{cd}
Folic acid**	47.85 ± 0.78^{c}	55.82 ± 1.06^{a}	53.45 ± 1.29^{ab}	40.67 ± 1.33^{d}	49.11 ± 2.21^{bc}
Nicotinic acid**	330.19 ± 8.69^{b}	364.87 ± 13.24^{a}	340.15 ± 11.88^{ab}	327.87 ± 5.50^{b}	312.54 ± 6.91^{b}

Notes: results were expressed as means ± SE ($n = 3$). "ND" represented it was not detected. * μg/100 g dry matter. **mg/100 g dry matter. Different letters in the same row indicated significant differences at $p < 0.05$.

(11.11 ± 0.57 mg/100 g) and VFD (9.99 ± 0.85 mg/100 g) samples, possibly due to the low temperature. It is disclosed that the higher temperature or lower relative humidity of the drying air can cause a higher loss of vitamin C in the dried fruits [38]. The data revealed that the contents of vitamins B_2, B_5, B_6, and B_{12} in the HD samples were maintained at high levels. B-group vitamins are the most important bioactive substances due to their involvement in the biosynthesis of proteins and their functional role in the central cardiovascular, gastrointestinal, and nervous systems [44, 45]. However, they cannot be synthesized in the human body and must be obtained from additional supplements. In this perspective, the mushrooms dried by HD were suitable for the bodies needing B-group vitamin supplements. The contents of folic acid (55.82 ± 1.06 mg/100 g) and nicotinic acid (364.87 ± 13.24 mg/100 g) in RSD mushrooms were the highest, followed by HD. Folate is essential for optimal brain function and a suitable intake during pregnancy, and a common genetic variant in folate metabolism is associated with an increased risk of neural tube defects and other neurodevelopmental disorders such as autism spectrum disorder and schizophrenia [46, 47]. Therefore, women in the periconceptional period are encouraged to consume supplements of folic acid (a synthetic form of folate) at more than 400 μg per day. So *S. rugosoannulata* mushroom, particularly dried by RSD and HD, was a suitable food material for a periconceptional mother. Nicotinic acid, as one of the naturally occurring B_3 vitamins, acts as the precursor of NAD^+/NADH and $NADP^+$/NADPH and participates in some important biochemical processes such as glycolysis,

Table 6: Composition and content of amino acids of *S. rugosoannulata* dehydrated by different drying methods.

Amino acids g/100 g d.m.	Drying methods				
	SD	RSD	HD	VFD	MD
Ile*	1.37 ± 0.03^{a}	0.91 ± 0.02^{c}	1.26 ± 0.00^{b}	1.20 ± 0.05^{b}	1.15 ± 0.04^{b}
Leu*	1.87 ± 0.01^{c}	1.58 ± 0.01^{b}	2.14 ± 0.07^{a}	2.02 ± 0.03^{a}	2.11 ± 0.04^{a}
Lys*	1.74 ± 0.02^{b}	1.52 ± 0.07^{c}	1.96 ± 0.05^{a}	1.88 ± 0.10^{ab}	1.89 ± 0.03^{ab}
Met*	0.35 ± 0.01^{ab}	0.32 ± 0.00^{c}	0.37 ± 0.01^{a}	0.32 ± 0.01^{bc}	0.34 ± 0.01^{bc}
Phe*	1.47 ± 0.03^{ab}	1.18 ± 0.06^{d}	1.56 ± 0.04^{a}	1.40 ± 0.04^{bc}	1.31 ± 0.00^{c}
Thr*	1.54 ± 0.04	1.38 ± 0.11	1.58 ± 0.02	1.45 ± 0.07	1.49 ± 0.13
Trp*	0.51 ± 0.01^{bc}	0.48 ± 0.01^{c}	0.56 ± 0.02^{ab}	0.58 ± 0.02^{a}	0.55 ± 0.01^{ab}
Val*	1.48 ± 0.07^{a}	1.24 ± 0.02^{b}	1.66 ± 0.10^{a}	1.57 ± 0.07^{a}	1.69 ± 0.03^{a}
Asp**	2.50 ± 0.14	2.48 ± 0.05	2.52 ± 0.10	2.52 ± 0.05	2.47 ± 0.08
Arg**	1.29 ± 0.07^{bc}	1.64 ± 0.09^{a}	1.12 ± 0.03^{c}	1.45 ± 0.07^{ab}	1.51 ± 0.03^{a}
Ala**	2.09 ± 0.12^{a}	1.32 ± 0.04^{b}	1.98 ± 0.12^{a}	2.25 ± 0.12^{a}	2.14 ± 0.04^{a}
Cys**	0.12 ± 0.01^{ab}	0.08 ± 0.01^{b}	0.14 ± 0.01^{a}	0.10 ± 0.01^{ab}	0.12 ± 0.02^{ab}
Glu**	6.89 ± 0.14^{a}	7.15 ± 0.03^{a}	6.07 ± 0.16^{c}	4.82 ± 0.08^{d}	6.54 ± 0.07^{b}
Gly**	1.39 ± 0.03^{a}	1.10 ± 0.05^{b}	1.52 ± 0.03^{a}	1.34 ± 0.13^{a}	1.48 ± 0.05^{a}
His**	0.71 ± 0.05	0.70 ± 0.03	0.78 ± 0.02	0.73 ± 0.03	0.75 ± 0.04
Pro**	1.37 ± 0.03^{b}	0.99 ± 0.00^{c}	1.49 ± 0.05^{a}	1.38 ± 0.02^{ab}	1.45 ± 0.05^{ab}
Ser**	1.25 ± 0.04	1.24 ± 0.01	1.28 ± 0.02	1.31 ± 0.04	1.28 ± 0.05
Tyr**	0.72 ± 0.03^{ab}	0.63 ± 0.01^{bc}	0.68 ± 0.04^{abc}	0.77 ± 0.01^{a}	0.61 ± 0.04^{c}
TFAA	28.67 ± 0.85^{a}	25.93 ± 0.61^{b}	28.65 ± 0.85^{a}	28.12 ± 0.86^{a}	28.89 ± 0.75^{a}
EAA	10.33 ± 0.22^{a}	8.61 ± 0.30^{b}	11.08 ± 0.32^{a}	10.43 ± 0.38^{a}	10.53 ± 0.29^{a}
NEAA	18.33 ± 0.63	17.33 ± 0.31	17.57 ± 0.53	16.69 ± 0.49	18.36 ± 0.46
E/T	36.03	33.20	38.67	38.46	36.45
E/N	56.36	49.68	63.06	62.49	57.35

Notes: results were expressed as means ± SE ($n = 3$). "d.m." represented dry matter. *Essential amino acid to the human body. **Nonessential amino acid to the human body. "Ile" represented isoleucine. "Leu" represented leucine. "Lys" represented lysine. "Met" represented methionine. "Phe" represented phenylalanine. "Thr" represented threonine. "Trp" represented tryptophan. "Val" represented valine. "Asp" represented aspartic acid. "Arg" represented arginine. "Ala" represented alanine. "Cys" represented cystine. "Glu" represented glutamic acid. "Gly" represented glycine. "His" represented histidine. "Pro" represented proline. "Ser" represented serine. "Tyr" represented tyrosine acid. "TFAA" represented total free amino acid. "EAA" represented essential amino acid. "NEAA" represented nonessential amino acid. "E/T" represented the proportion of essential amino acids to total free amino acids. "E/N" represented the proportion of essential amino acids to nonessential amino acids. Different letters in the same row indicated significant differences at $p < 0.05$.

respiration, lipid metabolism, and tissue oxidation [48]. Therefore, the influence of drying methods on vitamins was different, and the proper drying method should be selected depending on the actual vitamin requirements.

3.5. Amino Acids Composition. Free amino acids (FAA) exist in a free state in foods as a single amino acid molecule and can be directly absorbed and utilized. Table 6 exhibited the free amino acid composition and content of five kinds of dried mushrooms. The total amount of FAA was between 25.93 and 28.89 g/100 g, and no significant difference was found among the MD, SD, HD, and VFD samples. As for essential amino acids (EAA), leucine, lysine, and threonine were the most abundant, accounting for 18.0-20.0%, 17.2-18.0%, and 13.6-17.5% of total EAA, respectively. Among nonessential amino acids (NEAA), glutamic acid had the highest content from 4.82 to 7.15 g/100 g. Similar results were found in the investigation of Hu et al., who reported that the predominant amino acids were threonine (6.65-19.35 g/100 g), glutamic acid (2.35-10.40 g/100 g), and lysine (1.36-3.52 g/100 g) [15]. Other than threonine, aspartic acid, histidine, and serine, the contents of other amino acids were statistically different among different drying methods. The difference may be due to the complexity of drying systems that generated different types of reactions during the process, which hinders the prediction of some amino acids' final content [12, 49]. According to the essential amino acid model of protein nutritional value proposed by the World Health Organization (WHO) and the United Nations Food and Agriculture Organization (FAO) in 1973, the EAA/(EAA + NEAA) value in an ideal protein should reach about 40%, and the EAA/NEAA value should be above 60% [50]. The value of EAA/(EAA + NEAA) was between 33.20% and 38.67%, and the value of EAA/NEAA was 49.68-

Table 7: Effect of different drying methods on bioactive compound contents in *S. rugosoannulata*.

Bioactive constituent content g/100 g d.m.	Drying methods				
	SD	RSD	HD	VFD	MD
Total flavonoids	0.21 ± 0.01^{b}	0.15 ± 0.01^{bc}	0.13 ± 0.02^{c}	0.39 ± 0.03^{a}	0.19 ± 0.01^{bc}
Total polysaccharides	10.21 ± 0.35^{b}	12.02 ± 0.44^{a}	9.44 ± 0.36^{b}	11.63 ± 0.29^{a}	9.87 ± 0.18^{b}
Total phenols	2.73 ± 0.07^{c}	3.28 ± 0.08^{b}	2.90 ± 0.15^{c}	4.26 ± 0.11^{a}	2.77 ± 0.13^{c}
Total triterpenoids	1.48 ± 0.02^{c}	1.85 ± 0.02^{b}	1.32 ± 0.01^{d}	1.98 ± 0.05^{a}	1.50 ± 0.03^{c}

Notes: results were expressed as means ± SE ($n = 3$). "d.m." represented dry matter. Different letters in the same row indicated significant differences at $p < 0.05$.

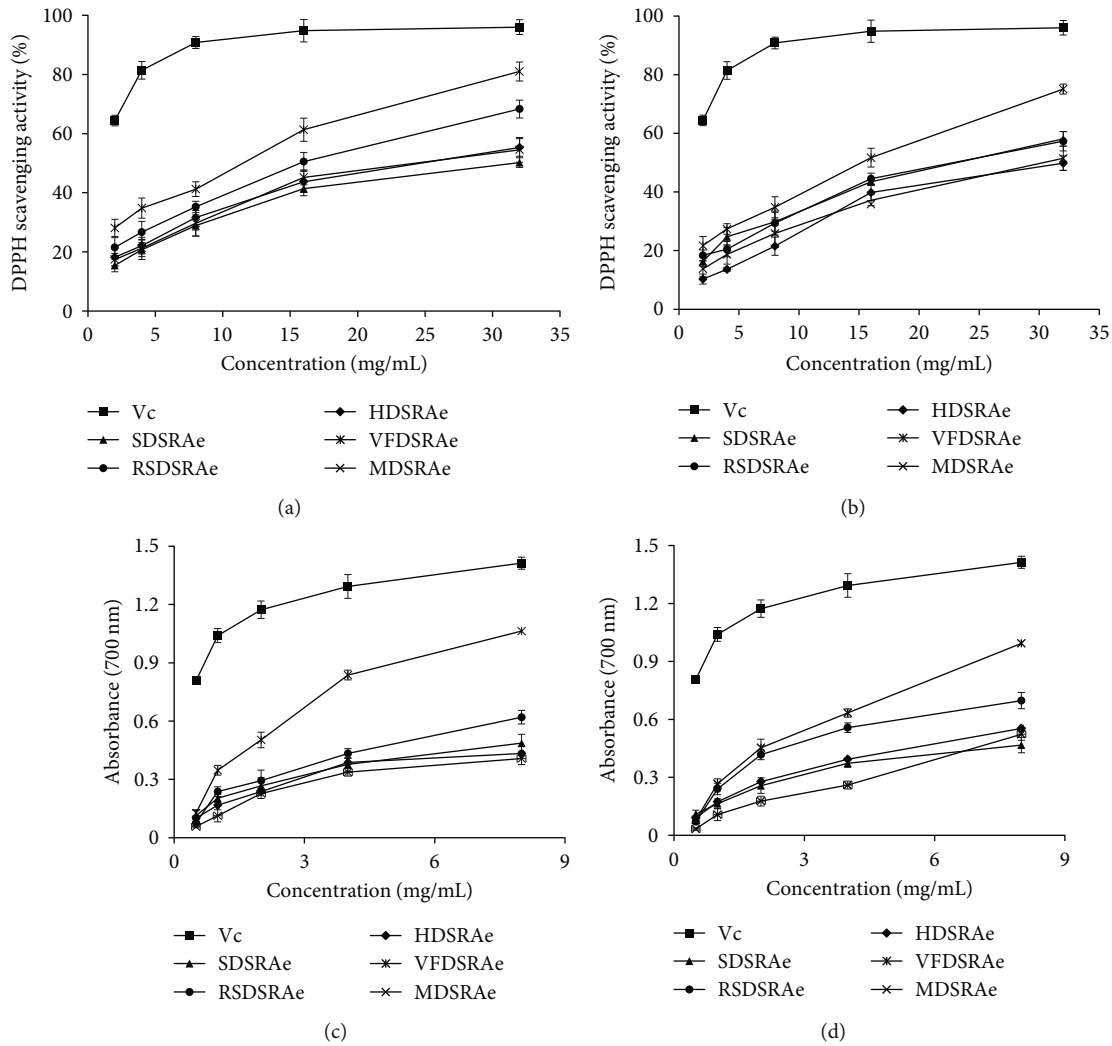

Figure 3: Antioxidant activity of aqueous and ethanolic extracts of SDSR, RSDSR, HDSR, VFDSR, and MDSR. (a) DPPH radical scavenging activity of aqueous extracts. (b) DPPH radical scavenging activity of ethanolic extracts. (c) Reducing the power of aqueous extracts. (d) Reducing the power of ethanolic extracts. SDSRAe was an aqueous extract of SDSR. RSDSRAe was an aqueous extract of RSDSR. HDSRAe was an aqueous extract of HDSR. VFDSRAe was an aqueous extract of VFDSR. MDSRAe was an aqueous extract of MDSR. SDSREe was ethanolic extract of SDSR. RSDSREe was the ethanolic extract of RSDSR. HDSREe was the ethanolic extract of HDSR. VFDSREe was the ethanolic extract of VFDSR. MDSREe was ethanolic extract of MDSR.

63.06%. In contrast, the HD (38.67 of E/T and 63.06 of E/N) and VFD (38.46 of E/T and 62.49 of E/N) samples best met the ideal protein standard.

3.6. Bioactive Constituents. In addition to being considered a nutritious food, mushrooms are also an important source of bioactive constituents. They have been found to have

many pharmacological functions such as antitumor, antiallergic, immunomodulating, anti-inflammatory, and anti-atherogenic activities [51]. In general, those bioactive compounds mainly include flavonoids, polysaccharides, phenols, and triterpenoids. The contents of the four types of compounds in five dried *S. rugosoannulata* are represented in Table 7. The results showed that there was a statistical difference in the contents of bioactive constituents among different methods, but the contents of flavonoids (0.39 g/100 g), polysaccharides (11.63 g/100 g), phenols (4.26 g/100 g), and triterpenoids (1.98 g/100 g) in VFD mushrooms were the highest. Lu et al. also confirmed that the retention of active constituents was best under free drying [52]. Some factors such as drying rate, drying temperature, and oxygen could influence the preservation of active constituents in the sample. The much lower content of phenols in the SD sample (2.73 g/100 g) may be affected by enzymatic processes that occurred during drying. SD does not immediately inactivate degradative enzymes such as polyphenol oxidases, so they can degrade phenolic compounds before the materials are completely dried [53]. The loss of flavonoids was found to be greatest in HD (0.13 g/100 g), and this loss may be due to drying time and temperature. Heating may disrupt some phytochemicals that affect cell wall integrity and lead to the migration of some flavonoid components. In addition, the loss may be related to breakdown or leakage by chemical reactions including oxygen, enzymes, and light [54]. Similarly, as for HD and MD, polysaccharides may be degraded and some were converted to melanoid and oligosaccharides because of the Maillard and caramelization reactions [37]. Therefore, VFD was a suitable technique with less damage to bioactive compounds.

3.7. Antioxidant Activity. The research on antioxidants has become a hotspot in the pharmaceutical and food industries. Natural antioxidants from foods are preferred because they not only play an important role in the prevention and adjuvant treatment of diseases but also can avoid adverse reactions to human health [55]. Two types of tests were performed to determine the antioxidant activities of aqueous and ethanolic extracts of mushrooms dried by five treatments, including free radical scavenging ability and reducing power. The results are presented in Figure 3.

Different drying methods were able to affect the antioxidant capacity of the extracts of dried materials. In a study of white button mushrooms, it was found that freeze-dried sample had a higher content of phenolic compounds than hot air and sun drying, and the antioxidant capacity was better [53]. The bioactive constituents of the fresh bitter water rose flower were better kept by freeze-drying treatment than HAD, and correspondingly, the DPPH scavenging ability was stronger [56]. In the present study, as shown in Figures 3(a) and 3(b), ten extracts (aqueous and ethanolic extracts of *S. rugosoannulata* dehydrated by five drying methods) scavenged the DPPH radicals in a dose-dependent manner within the test concentration range (2-32 mg/mL). Overall, the extracts of dried samples showed strong scavenging ability against DPPH free radicals. When the concentrations were 32 mg/mL, the scavenging rates of SDSRAe, RSDSRAe, HDSRAe, VFDSRAe, MDSRAe, SDSREe, RSDSREe, HDSREe, VFDSREe, and MDSREe reached to 50.2, 68.3, 55.3, 81.0, 54.5, 58.1, 57.3, 49.8, 75.1, and 51.5%, respectively. It can be seen that both aqueous and ethanolic extracts of the VFDSR had the greatest effect. Similarly, the reducing power of each group (Figures 3(c) and 3(d)) increased concentration-dependently in the measured concentration range (0.5 to 8 mg/mL). When the concentration was 8 mg/mL, extracts from the VFD sample had relatively strong reducing power, followed by RSD, HD, MD, and SD samples. So, as far as antioxidant activities are concerned, VFD is proposed as an appropriate drying method.

4. Conclusions

S. rugosoannulata is mainly traded in the international market in the form of drying and it is of great practical significance to select suitable drying methods for the production of high-quality mushrooms. SD, RSD, HD, VFD, and MD are conventional thermal processes for preserving medicinal and aromatic mushrooms. This study described the influence of these five drying methods on the appearance, colour, nutrient substance, bioactive constituent, and antioxidant activity of *S. rugosoannulata*. The VFD mushroom obtained a good appearance with minor shrinkage, a smooth surface, and a dense texture, as well as an ideal colour. It also allowed better preservation of protein, carbohydrate, total sugar, and vitamin C than those of other methods. The HD sample can maintain B-group vitamins at high levels. The HD and VFD samples had abundant total free amino acids and best met the ideal protein standard. Moreover, VFD had advantages in terms of higher retention of bioactive constituents and stronger antioxidant activities than SD, RSD, HD, and MD. Overall, considering good sensory quality, high retention of nutrients, rich bioactive constituents, and strong antioxidant capacity, VFD is a potential drying method for fresh *S. rugosoannulata*.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors' Contributions

Lei Wei and Wei Wang contributed equally to this work.

Acknowledgments

This study was financially supported by the Henan Science and Technology Research Project (code: 222102310288), Outstanding Young Talents Training Program of Henan Academy of Sciences (code: 220413009), and Special Project of Introducing Foreign Intelligence in Henan Province (211213004).

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