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EFFECTS OF DRYING METHODS ON THE PHYSICAL AND CHEMICAL PROPERTIES OF STRAW MUSHROOMS

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ABSTRACT

Straw mushrooms are not only sumptuous in nutrients, but also scrumptious for the tastes and antioxidants as well as ergothioneine, several proteins, amino acids, beta-glucagon, amino acids, cod liver oil, calcium and vitamin D, and conjugated linoleum acid, low cholesterol and carbohydrates which increases body mechanism as diabetes, supports the prevention of cancer oust cells in breast and prostate glands. Fresh Mushrooms have a high moisture content and are difficult to store, so they need to be dried to extend their shelf life. Vacuum Freeze Drying (VFD), Hot air drying (HAD), Infrared drying (ID) and Vacuum drying (VD) are used to conduct this study. The purpose of the study is to the effects of different drying methods to increase the nutritional value, sensory as well as antioxidant activity to improve the technological properties of Straw Mushrooms. We choosed fresh straw mushrooms as raw materials, and used mushroom dry moisture, drying speed, re-hydration coefficient, sensory judgment difference, texture, micro structure and specific energy consumption as indicators of four different drying methods on dried mushroom products. We used uni-variate and Orthogonal test methods. The result shows that dried straw mushrooms dried by VFD have the best chemical, re-hydration, moderate firmness, vibrant color, low energy consumption, the highest sensory score as well as high antioxidant activities; followed by ID, VD and HAD. In HAD mushrooms shrinkage more, and brightness loss is high and hard compared to all other drying methods. In the antioxidant activities HAD mushrooms were a low score; on the other hand, VFD had the best antioxidant activities. Hence, VFD will be the best drying process for Straw mushrooms to achieve an optimal mushroom drying process and improve the dried products' quality.

KEYWORDS: Straw mushroom, Vacuum freeze drying, Physico-chemical characteristic, Antioxidant properties.

1. INTRODUCTION

Due to rising temperatures and carbon dioxide levels, a shortage of water and cultivable land, and low productivity, changes in the global climate have a significant influence on conventional cereal-based food resources. Mushrooms are a unique species of macroscopic fungus. Edible mushrooms, including straw mushrooms (Volvarella volvacea), are commonly farmed in tropical countries including China, Thailand, and Vietnam.[1,2] Mushrooms are abundant in protein, lipids, amino acids, glycogen, vitamins, and minerals, according to research.[1] Mushrooms have a higher mineral salt concentration than meat and fish and are approximately twice as salty as the most popular vegetables. Straw mushrooms account for 38% of global mushroom output.[3] In 2020, the mushroom farming industry is expected to be worth USD 16.7 billion. According to the China Business Research Institute, China was the world's top producer of edible mushrooms in 2017, with an estimated annual production of 38.42 million tons. This accounted for almost 75% of total global production. According to the China Edible Fungi Association's data, China's total edible mushroom output was 38.42 million tons in 2018, accounting for 27.15 percent of overall Chinese edible mushroom production. According to figures from China's Ministry of Commerce, China exported 153961.8 65 tons of mushrooms in 2018, up 5.5% year over year, with a value of US $2319.55 million, up 13.6%year over year.

Mushrooms degrade within a day of harvest; hence, to increase their shelf life for off-season use, pick them quickly. Mushrooms may help overcome protein deficits, especially in developing nations.[4] Mushrooms can only last a few days at room temperature due to mould and bacteria; therefore, have a short shelf life, making fresh distribution and use difficult.[5] As a result, extending the shelf life of mushrooms is an ongoing pursuit for the mushroom industry and supply chain.[6] Mushrooms lose quality during post-harvest storage, including weight loss,

shrinkage, elongation and thinning of stripe, opening of cap, decay, reduction in protein, sugar, and soluble solid contents, unwanted odour, colour changes (darkening, browning, etc.), texture changes (softening, toughening, etc.), and microbial infections, which often result in significant economic losses and reduce mushroom commercial value.[7] Thus, mushroom shelf life and quality depend on post-harvest storage. Always prioritise quality and nutrition while preserving mushrooms. To increase the shelf life and maintain the post harvest quality of mushrooms, various drying procedures are used.[8] Approximately 40%–50% of edible mushrooms produced worldwide are consumed fresh, with the remainder being processed (drying, canned, etc.).

Drying is used to preserve mushrooms that are more than consumed during the peak season of production. Temperature, mushroom thickness, drying method, and moisture diffusivity affect drying rate.[9] Low-temperature storage of horticultural crops, notably mushrooms, is known to reduce losses, maintain quality, and increase shelf life.[10,11] Mushrooms must be dried to a specific moisture level (about 12 percent) before being kept properly. Drying mushrooms slows enzyme activity, microbial growth, and water loss, maintaining quality and shelf life.[12] The drying procedure affects dried mushroom quality. Most mushrooms are dried by HAD, natural air drying, VD, microwave drying, sun drying, fluidized bed drying, ID, and freeze drying.[13] Like other mushrooms, straw mushrooms, are perishable and lose quality fast if not properly stored. Consumers prioritise mushroom quality and nutrients. Thus, studying how drying techniques affect straw mushroom quality and nutrition is important. This study examined how drying methods influenced straw mushroom quality and nutrition after harvest (Volvariella volvacea).

2. MATERIALS AND METHODS

2.1. Experimental Materials

The straw mushrooms (fruiting bodies) were collected from local marketplaces in Hefei, Anhui, China. Before testing, all mushroom samples were transferred to the laboratory and kept at 4 ± 0.5°C with 95% relative humidity in a refrigerator. The mushroom's average cap dimensions were 74.3 ± 2.5mm on the main axis and 65.1± 3.3 mm on the minor axis. The average length from crown to stem was 78.4 ± 5.6 mm. The moisture content was 88.1 ± 1.6% at the start (wet basis). They were cleaned and sliced into halves to eliminate any remaining compost. All additional chemicals and reagents were acquired from local sources for the analytical grade. All of the samples utilized in the drying process were from the same batch.

2.2. Experimental Method

Mushrooms can be dried to preserve them and extend their shelf life. Drying inhibits enzyme activity and many moisture-mediated processes, preventing the development of spoilage bacteria.[14] Dried mushrooms have higher levels of several minerals, such as vitamin D_2, than fresh mushrooms.[15] The umami flavor of dried shiitake mushrooms is superior to that of meat, cheese, and other mushrooms. This taste is created when proteins are broken down into amino acids during the drying process.[16] As a result, employing the best drying methods will increase mushroom quality. However, there are a variety of different techniques for extending the shelf life of mushrooms. Four drying processes were used in this study: (1) Hot air drying (HAD) (2) Vacuum drying(VD) (3)Vacuum freeze drying (VFD) and (4) Infrared drying (ID).

2.3. Processing before Drying

Fresh Mushrooms → Peeling → Cutting → Blanching →Color protection → Clean → Dry.

2.3.1. Hot air Drying

Mushrooms were dried through HAD at 65° C with airflow rates of 1.0 ± 0.05 m/s. nearly 5 to 6 hours. Material loaded on the tray was continuously weighed. Air was heated electrically before entering the dryer. HAD Method Experiment starts at 35° C and increases by 5 ° every hour to 60 ° - 65 ° C.

2.3.2. Vacuum drying

A VD oven with a cavity dimension of 345 X 370 X 415 mm was used for vacuum drying (Shanghai Yiheng Technology Co., Ltd. Shanghai, China). The samples were spread out in a single layer on a glassy culture plate and dried in 90k Pa at 60°- 65° C for 15 hours until the moisture content of the samples was decreased to 13%. (wet basis).

2.3.3. Infrared Drying

Setting up the ID is much easier than other types of dryers. Adjust its temperature to 50°C. Drying is 2 times faster than in convective devices, where the process takes place due to the Infrared ray.

2.3.4. Vacuum Freeze Drying

VFD experiment is conducted by freezing the mushrooms in a freezer at -20°C for 12 hours. The freezer must be switched on 30 minutes before the start of the experiment. Customize 1.5 KPa Degree - 50°C Vacuum freeze drying is a high-tech technology that uses the principle of sublimation of ice to dry materials at low temperatures which are mainly used in fruits, vegetables and meat. VFD preserves colour, form, and nutrition. It is lightweight, re-hydrates well, and stores easily. VFD preserves colour, form, and nutrition as well as it's lightweight, re-hydrates well, and stores easily.

2.4. Study on Color Protection Technology before Drying

We used 80g of chopped mushrooms in 400 ml of water and a time of 30 min. Under 34° C. Measurements (%) items are (a) Lemon acid: 0.1%, 0.2%, 0.3%, 0.4%, 0.5%; (b)Ascorbic acid: 0.12%, 0.14%, 0.16%, 0.18%, 0.20%; (c) EDTA-2Na: 0.1%, 0.2%, 0.3%, 0.4%, 0.5%.

2.4.1. Blanching

Blanching also scalds short-term processing of the product with boiling water or steam. To preserve the color, remove the bitterness and specific smell from the product of some vegetables. It also improves the taste. In the process of Blanching Boil Water Up to 95°C for two and a half minutes. After blanching, the product is usually washed with cold water to lower the temperature.

2.5. Study on the Nutritional Components in Different Drying

2.5.1. Measure protein content

Measure Protein Content (Coomassie Brilliant Blue G-250): Coomassie brilliant blue G-250: Dissolve 250 mg / 100 mg in 50 ml of 95% ethanol, then add 100 ml of 85% sulfuric acid and dilute to 1 L with distilled water to obtain a standard solution G-250. Mixed 10 mg bovine serum albumin + 100 ml distilled water to make the 0.1 mg/ml solution.

Work steps: A 500 mg sample was triturated with 20 ml of distilled water and centrifuged at 10,000 rpm for 10 minutes, 20ml of distilled water was added to the residue, centrifuged at 10,000 rpm for 10 minutes, and the supernatant was combined to obtain a solution sample (40 ml). After that take 1ml of sample solution and mix 5ml of G-250 standard solution, use a UV spectrophotometer to measure the standard solution, and neutralize the sample solution.

Determination of the total sugar content of edible mushrooms: Concentrated hydrochloric acid: P = 1.18 g /ml; Concentrated sulfuric acid: P = 1.84 g /ml.; Benzene percentage solution 60 g /L: Weigh 6g of phenol, dissolve in a 100 ml volumetric flask with water, shake and transfer to a brown flask after constant volume, and store in a refrigerator at 4°C in the dark. Standard glucose solution 100 mg /L. Dry glucose at constant temperature and 105°C to constant weight, weigh about 0.1 g of glucose (accurate to 0.000g), dissolve it in a 1000ml volumetric flask with water, and shake. Store in a refrigerator at 4°C, protected from light, and valid for two weeks. Weigh a sample of about 0.25 g to the nearest 0.001 g.

Hydrolysis: Pour the sample into a 250ml conical flask, add 50ml of water and 15 ml of concentrated hydrochloric acid, hydrolyze it in a water bath at 100°C for 3 hours, cool to room temperature and filter, then rinse the residue on the filter with distilled water, combine filtrate and wash. Liquid and dilute with water to 250ml. This solution is a sample test solution. (0.2 ml, make up 1ml).

Formulation of Standard Lines: Pipette out 0.2ml, 0.4ml, 0.6ml, 0.8ml, and 1.0ml glucose standard solution into a 10ml tube and add up to 1.0ml distilled water. Add 1.0ml of 6% phenol solution to the test solution, then quickly add 5.0ml sulfuric acid and let the reaction solution stand for 10 minutes. Then place the test tube in a water-soluble pot at 30°C and react for 20 minutes, absorbing at 4% mm. Use abscissa mass concentration and ordinate absorbance to construct a standard curve.

2.5.2. Vc content

For Vc content the materials were used: Reagent, Oxalic acid ($C_2H_2O_4$), Sodium bicarbonate ($NaHCO_3$); 2,6-Dichloroindophenol (sodium salt), 2,6-dichloroindophenol, ($C_{12}H_6C_{l2}NNaO_2$) and white clay (or kaolin) (no adsorption of ascorbic acid).

We weigh 2.5g and add 2.5 ml of 2% oxalic acid. After grinding, pour it into a volumetric flask, rinse, and filter evenly (50 ml of constant volume). Using a micro burette, make each standard solution of ascorbic acid 0.1 mg/ml (1.0ml, split into two 100ml Erlenmeyer flasks, add 9.0ml of 1% oxalic acid). Titrate with indigo 2, 6-dichlorophenol till bright crimson and finish at 155 with 10 ml oxalic acid. Calculated value (how many mg VC is equivalent to 1ml of dye)

$$T = \frac{c \times v}{V_1 - V_0}$$

Titration of the sample solution: Put 10 ml of the sample solution into a 100 ml conical flask, the titration method is the same as before.

$$\mathrm{m} = \frac{\mathrm{VT}}{m_0} \times 100$$

Where, m- 100g mass Vc in the sample (mg);
V-volume of the dye used in the titration;
T-mean value
m_0-sample weight (g);

Reagent

2% oxalic acid solution: 2g of oxalic acid is dissolved in 100ml of distilled water.

1% oxalic acid solution: We put 1g dissolved in 100ml distilled water Standard solution of ascorbic acid in a brown bottle (0.1 mg/ml): 50mg acerbate + 1% oxalic acid, and diluted to 500ml.

0.1% 2,6-dioxoindophenol: liquid of 50mg with 0.05g, 2.6 chlorindophenol in 300ml (containing 0.104 g, hot water NaHCO3). After cooling, add water to dilute to 500ml. After that filter off insoluble matter and store it in a brown bottle to cool.

2.5.3. Amino Acid Analysis

Mushrooms contain most amino acids, including sulfur-containing amino acids.[17] An amino acid analyser was modified to measure the samples' free amino acids.[18] We took Amino acid analysis 0.1g and sample (dried sample) attach with 10ml 6mol/L HCL. Concentrated hydrochloric acid: Water = 1: 1. Add to hydrolysis tube Shake well and fill with N_2. Heat in an oven at 165°C for 1 hour. Cool and stir Filtration through an open tube. After the 0.22 μm membrane is heated, remove the hydrolysis tube and filter to remove impurities. Volume up to 50ml Rinse the hydrolysis tubes several times (3

times) and then pour it into the flushing liquid for filtration. Take 1 to 10ml of hydrolysate and place it in a beaker and put in an oven at 60°-65°C to dry the moisture. After that add 3ml 0.02mol/L HCL solution 0.22μm used. Water membrane filtration and machine test 6ml/L HCL concentrated hydrochloric acid concentration is 12mol/L. Mixed standard amino acids with turbine standard were analyzed before sampling. The amino acids were identified and quantified by comparing the peak profiles of the mushroom samples with standard amino acid profiles. The results were expressed as the milligrams of amino acid per gram dry weight (mg/g).

2.5.4. Flavonoids

Flavonoids have been intimately connected with the plant kingdom for decades, particularly with land plants.[19,20] and flavonoids are chemicals produced by plants' secondary metabolism from precursors obtained from two major metabolic pathways: phenylpropanoid derivatives and malonyl-CoA. Flavonoid biosynthesis is now regarded as a classic example of a pathway that developed through time by genetic modification. The ability of mushrooms to absorb numerous nutrients and chemicals from the substrate where they grow or from neighboring plants by spreading their hyphae or developing mycorrhizae might explain the abundance of flavonoids in mushrooms. Some plants produce flavonoids to control these symbiotic plant-microbe interactions, determining which species are allowed to grow on their roots.[21] Although ingesting these chemicals may inhibit fungal development, they have been widely reported as antifungal substances since flavonoids are commonly generated by plants as a defense against fungal infections.[21]

The preparation of the sample solution: accurately weigh 2.0g of Dendrobium dry powder (60 mesh sieve), place it in a Soxhlet extractor, add 120ml of 80% ethanol, reflux for 1 hour and then filter it. Light to remove chlorophyll, and dilute to 250ml with 80% ethanol. Determination of the total flavonoids content in the sample: accurately draw 1.0ml of the sample solution, place it in a 10ml volumetric flask, operate according to the standard curve item, measure each sample in parallel three times, and substitute the measured absorbance into the rutin standard curve equation to calculate the content of total flavonoids in Dendrobium.

2.6. Study on Sensory Indexes in Different Drying Methods

Following the GB 8859-1988 standard, the quality of the Mushrooms after drying is assessed in five aspects: appearance, color, texture, hardness, and aroma. We selected 15 people who have been trained in assessment to form an assessment group.

2.6.1. Color Difference

The color difference meter is used to measure characteristic spatial parameters. Luminance index L; 0 means black, 100 means white: red-green gloss index "a" and yellow-blue gloss index "b"; "L" the larger the color, the closer to white, the higher the "b" value, the closer the color is to pure yellow. Use measured L, a, and b to calculate the formula for calculating ΔE as-

$$\Delta E = \sqrt{\left(L_0^* - L^*\right)^2 + \left(a_0^* - a^*\right)^2 + \left(b_0^* - b^*\right)^2}$$

In this experiment, 4 samples were taken from the groups and each sample was chosen differently (2 times for the upper, middle, and lower parts.). Each drying group was tested 3 times, and finally, the average value was taken as the color difference value of this group.

2.6.2. Shrinkage

The shrinkage was estimated under various circumstances to determine the reduction in storage space required. Shrinkage with a greater value is better for storage since it reduces the volume required for storage. On the other hand, shrinkage should be minimal in terms of product quality. Because, with less shrinking, mushroom slices are more likely to revert to their former shape. For the shrinkage, we need filler (glass slag) and measuring objects. First, take a beaker of a suitable container and fill the whole beaker with glass slag. After that pour out the millet, and place the test object in the beaker. Fill the beaker with a small bottle while shaking. Take the remaining millet volume V(ml) with a graduated cylinder to measure the volume of the object. A displacement technique was used to calculate the shrinkage ratio.[22] As a substitute medium, glass beads (0.1mm, USA Scientific Inc., Orlando, FL, USA) were employed. The shrinkage ratio of dried slices was determined using the following formula:

$$Shrinkage = \frac{V_0 - V_k}{V_0}$$

Where, V_k - Sample volume after drying

V_0 - Sample volume before drying

2.6.3. Rehydration ability

One slice of straw mushrooms to moisten it. Under tap water at 60°C for a total of 120 minutes at 60° C - Then take it out and dry it to absorb moisture from the surface of the mushroom slice.

$R = M_2 / M_1$

Where, R - Coefficient of rehydration

M_1 - the quality of straw mushroom before rehydration

M_2 is the quality of the straw mushroom after rehydration.

Repeat the measurement 5 times for each group and take the average value of the results.

2.6.4. Scanning electron microscope

An ecological scanning electron microscope was used to observe the microstructure of the mushrooms after drying. Select a sample of the Mushroom after drying in a variety of ways and select the inner gills of the dried product after it is broken from the middle, cut it into

small round pieces (length and width 3mm), and stick it on the conductive glue. After spraying with the ion spray film forging tool for about 2 minutes, zoom in to 2000x.

2.7. Study on Antioxidant Activity in Different Drying Methods

2.7.1. ABTS

The scavenging activity of ABTS radical action of mushroom crude extracts was evaluated by an improved method.[23] In brief, 2,2'-azinobis (3-ethylbenzothiazoline -6 -sulfonic acid) diammonium salt (ABTS) was dissolved in 10ml of distilled water to a concentration of 7mM. ABTS radical cation (ABTS+) was produced by reacting the prepared ABTS solution with 176µl of 2.45mM potassium persulfate (final concentration), and the mixture was allowed to stand in the dark at room temperature for 12-16 hours before use. This stock solution was then diluted with 95% ethanol until the absorbance fell within the range of 0.700 ± 0.020 at 734nm. An aliquot of l0µl of mushroom extracts with various concentrations (1.0, 1.5, 2.0, 2.5, 3.0, 3.5 mg/ml) or Trolox standards (0-2.5mM) dissolved in ethanol was added to 1ml of the reagent solution. To obtain a working solution ABTS. 200 Ul 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 mg/ml sample solution plus 4ml ABTS Working fluid with stir well. After that Keep away from light 15min to make 734nm ODAi. The percentage of inhibition was measured by absorbance at 734nm and was calculated according to the equation

ABTS scavenging activity

$$(\%) = \frac{A_0 - (A_1 - A_2)}{A_0} \times 100$$

Where, A_0 = is the absorbance of measured at 734nni (water + sample),

A_1 = is the absorbance of the test sample mixed with ABTS solution and

A_2 = is the absorbance of the sample without ABTS solution.

2.7.2. DPPH

The scavenging activity of mushroom crude extracts on DPPH radicals was examined according to a previous method with some modifications. An aliquot of 1ml of 0.lm DPPH radicals in methanol was added to a test tube containing 1ml of methanol or water mushroom crude extract of different concentrations (0.75-6 mg/ml). Methanol or water was added instead of mushroom extracts as a negative control. The reaction mixture was mixed thoroughly and allowed to stand in the dark for 30 minutes. The absorbance readings were then determined by measuring at 517nm with a UV-vis spectrophotometer (Genesys S, 105 Spectronic Instruments, USA). TBHQ (1.5 mg/ml) was used as the positive control. The inhibition percentage on DPPH radicals was calculated below equation-

DPPH Scavenging activity (%) = $[(A_0-A_1)/A_0] \times 100$

Where A_0=is the absorbance of DPPH solution without sample;

A_1= is the absorbance of the test sample mixed with DPPH solution and

A_2= is the absorbance of the sample without DPPH solution.

2.7.3. Iron reduction capacity

The Iron reduction effect was carried out according to the method of Dinis et al.[24] For the test Fe^{2+} for extra abilities1.0ml sample, Join in order 0.05ml, 2mmol /L from $FeCL_2$, 0.2ml, 5mmd/L 2.75ml Deionized water, Shake well to react at room temperature 10min. Participate in distilled water 562nm Measure the absorption value at wavelength. Use photo-ionized water as an empty control., EDTA-2Na Make a positive comparison.

Fe^{2+} Extra capacity (%) = $(A_0 - A_1)\ A_0 \times 100\%$

Where, A_0 = Absorption of the empty control group，

A_1 = Optical density of the measured solution

A_2 = Deionized water instead of absorbing the reagent.

2.7.4. Hydroxyl radicals

Hydroxyl radical-scavenging activity was measured using a previously described method[25] with some modifications. The reaction mixture, containing 0.34–3.46 mg m/L of the sample, was incubated with 2 mMEDTA-Fe (0.5mL), 3% H_2O_2(1mL), and 360 lg m/L 1crocusin 4.5mL of sodium phosphate buffer (150mM, pH 7.4) for 30 min at 37°C, and hydroxyl radicals were detected by monitoring the absorbance at 510nm. In the control reaction, the sample was substituted with distilled water, while $H_2O_2$was substituted with sodium phosphate buffer. Hydroxyl radical scavenging activity was calculated by using the following equation:

Exclusion rate （%）= $(A_0 - A_1) / A_0 \times 100\%$

where

A_0= the absorbance of the control reaction;

A_1= the absorbance of the test sample mixed with the reaction solution.

2.7.5. Statistical analysis

The total phenolic content and antioxidant activities of mushroom methanol and water crude extracts were represented as mean and standard deviation. One-way analysis of variance (One-Way ANOVA) was used to compare total phenolic content and antioxidant activity in the same crude extract of various mushrooms. Pearson correlation coefficients were used to investigate bivariate relationships between mushroom crude extract content and antioxidant activities (ABTS radical cation scavenging, DPPH radical scavenging, Iron reduction, Antioxidant Power test, and hydroxyl radical scavenging). The Pearson correlation coefficient indicated bivariate connections between antioxidant activity and total phenolic content. IBM SPSS version 21 performed to calculate all statistical analyses.

3. RESULTS AND DISCUSSION

Straw mushrooms, an organic food product, have a complex drying behaviour that depends on the raw material, yield after drying, blanching testing, and other factors. Slicing and cleaning mushrooms pre-treated and dried it. Since moisture change was important, mushroom moisture was monitored before and after drying. Since this study aims to determine straw mushroom drying features, four drying curves have been given to compare and show moisture change during drying and match drying characteristics. Dried mushrooms were compared to identify the which approach was the best.

3.1. Optimization of color protection technology before drying

The color values of the samples obtained at pre-determined specific intervals during the drying process were measured using the color measuring equipment during the research in which the drying process was carried out to examine the influence of the straw mushrooms on color change (Hunter Associates Laboratory, Model: MiniScan XE, the USA). The L value in the Hunter L, a, b color coordinate system stands for lightness, and its range is 0 to 100. When the a value is positive, it conveys the color red; when it is negative, it expresses the color green. Hunter a and b values are color coordinates that do not have a specific range of measurement. When the Hunter b value is positive, the color yellow is displayed, and when it is negative, the color blue is displayed. To conduct the test used 80 grams of chopped mushrooms, 400 ML of water, and a time of 30 min under 34°C. Measurements: Lemon acid/ citric acid (0.1% 0.2% 0.3% 0.4% 0.5%); Ascorbic acid: (0.12% 0.14% 0.16% 0.18% 0.20); EDTA-2Na: (0.1% 0.2% 0.3% 0.4% 0.5%).

3.1.1. Single-factor experiment

Figure-1of the single factor of the experiment results with citric acid, below concentration and on the left side values L tables. In (I) Citric Acid single factor experiment, the highest value in 0.2, 0.3 and then 0.4 concentration. Looking towards L 0.2 and 0.3 more than 60 Even closer to 65; And 0.4 less than 60. In (II) Ascorbic Acid single factor experiment, the highest is 0.18 followed by 0.16 and 0.20 concentrations. Looking towards L 0.16 and 0.18 values are more than 60 and even closer to 65. And 0.20 less than 60. In (III) EDTA-2Na Acid single factor experiment, the highest value are approximately same at the point 0.2, 0.3, 0.4 concentration. Looking towards L 0.2; 0.3; 0.4 Reach 65.

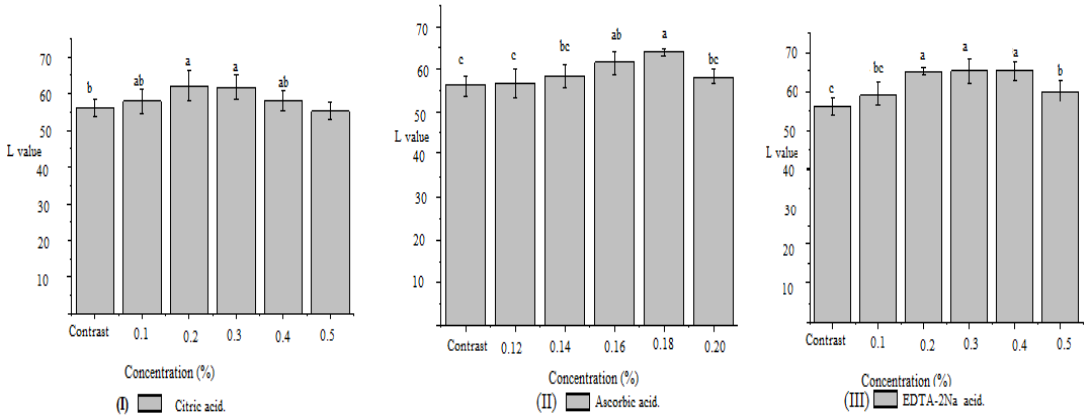


Figure - 1: Single Factor of the Experiment Result with (I) Citric Acid, (II) Ascorbic Acid and (III) EDTA-2Na Acid.

3.1.2. Orthogonal experiment

Orthogonal experiments were created from single-factor experiments to design is multifactor, multilevel research. This method employed orthogonality to choose representative points from a full test and then examined the results along with speeds up experimentation.[26,27] According to this orthogonal table, four tests may understand the full condition of eight tests since this orthogonal test is a three-factor two-level exam $L_4(2^3)$.[28] In the table-1, the combinations of trials and test results are displayed. The orthogonal to the experiment is here in table -1 with the highest concentration percentages. Ascorbic acid (0.16; 0.18; 0.20) Citric acid (0.2;0.3;0.4) EDTA (0.2; 0.3; 0.4).

Table - 1: Orthogonal to the experiment.

Experiment number	Ascorbic acid (%)	Citric acid z(%)	EDTA-2Na (%)	L*
1	0.16	0.2	0.2	
2	0.18	0.3	0.3	
3	0.20	0.4	0.4	
1	1	1	1	62.14
2	2	1	2	62.41

3	3	1	3	63.29
4	1	2	1	65.08
5	2	2	2	60.85
6	3	2	3	60.74
7	1	3	1	61.57
8	2	3	2	65.33
9	3	3	3	55.90
K1	62.93	62.61	62.63	
K2	62.86	60.55	62.86	
K3	59.97	60.93	59.99	
R	2.96	2.06	2.87	

Orthogonal experiments (Ascorbic acid, Citric acid and EDTA-2Na) a total of 9 experiments were performed, the best being the 8th. From the table, the results of "L" shows the highest value which is 65.33, which represents (Ascorbic acid 0.18, Citric acid 0.4; EDTA-2Na 0.3) the orthogonality. Down the table, K_1 represents the first concentration, K_2 the second. K_3 is the third concentration and R represents the maximum and minimum results of K_1-K_2-K_3.

3.2. Quality Analysis in Different Drying Methods

3.2.1. Nutritional Analysis

Table-2 shows the nutritional analyses of the four mushroom drying processes. VFD loses the least protein in mushrooms, followed by ID. Mushrooms lose protein more from HAD where HAD and VD are similar ($p < 0.05$). VD mushrooms lose the least amino acids compared to HAD VC.

Table-2: Effect of four drying methods on chemical properties.

Drying method	Protein content (mg/g)	VC content (mg/100g)	Sugar content (µg/g)
Hot air Drying (HD)	32.05 ± 0.38c	90.00 ± 11.55d	103.76 ± 1.4c
Vacuum Drying(VD)	35.93 ± 0.58b	125.00 ± 19.15c	105.63 ± 2.5c
Vacuum Freeze-Drying (VFD)	45.11 ± 2.00a	285.00 ± 25.00a	159.65 ± 1.3a
Infrared Drying (IFD)	37.66 ± 0.72b	170.00 ± 11.55b	146.57 ± 1.7b

Where, ($p < 0.05$).

They differ greatly ($p < 0.05$). Thus, ID and VFD have little influence on mushroom's chemical characteristics and operate effectively. Dried VFD products (straw mushrooms) lose the least sugar, whereas hot-air-dried mushrooms lose the most where as VD and HAD differ a little. VFD & ID difference is significant ($p < 0.05$). Thus, based on protein, VC, and sugar content, "VFD > ID > VD > HAD".

Amino Acid Content

Straw mushrooms contain various amino acids. The variations in the content and quantity of free amino acids before and after drying using various drying techniques are shown in Table 3. The samples had greater levels of glutamic acid (Glu), histidine (His), and alanine (Ala). These findings were consistent with previous studies that Glu and Asp were the most prevalent non-essential amino acid components in its aqueous extracts.[29,30] Fresh samples had a total free amino acid content of 37.07 mg/g dry weight. The fresh mushrooms were found to have a 15.64 mg/g dry weight of total free amino acids, which was not comparable to the results.[18] The total free amino acid content of the dried samples rose substantially ($p < 0.05$) after drying.

Table 3: Effect of four drying methods on Amino Acid Content.

Amino acid	Hot air drying (100g)	Vacuum drying (100g)	Vacuum freezing drying (100g)	Infrared drying (100g)
Asp	41.06	42.00	29.65	55.46
Thr	16.71	20.35	14.37	27.14
Ser	23.28	22.57	16.14	29.83
Glu	46.13	48.88	34.11	63.84
Gly	18.32	18.57	13.06	14.92
Ala	31.75	32.70	21.96	41.16
Val	12.26	20.15	12.64	26.93
Met	3.90	36.92	2.90	4.71
Leu	24.46	31.16	2190	41.93
Tyr	10.93	10.30	8.56	14.57
Phe	16.69	20.01	14.17	26.81
His	46.90	37.03	26.02	42.13

Lys	23.20	26.89	19.56	35.15
Arg	15.54	19.26	14.06	24.72
Ile	---	15.93	---	22.26

Through ID, the total free amino acid content reached a maximum of 60.91 mg/g dry weight (ID). This increase was less when VD and HAD were used (56.14 and 55.39 dry weight, respectively), and it was the smallest when VFD was used (47.09 mg/g dry weight). Zhang et al[31] found that shade-dried or hot air-dried shitake mushroom caps and stipes contained more free amino acids than freeze-dried mushrooms. These data supported protein content and suggested that high drying temperatures may promote proteolysis.

Essential amino acids were greatest in ID-treated samples and lowest in VFD-treated ones. Aspartic acid (Asp), Glutamine acid (Glu), and Histidine (His) were significantly higher in fresh straw mushrooms than in ID, VD, or HD-dried samples ($p < 0.05$). Komata.[7] described many groups of free amino acids based on their taste properties (Table -3). Monosodium glutamate-like (MSGlike) components were Asp and Glu. They supplied the most typical mushroom flavor, the umami flavor or pleasant flavor that MSG and 50-nucleotides were known for. Similar findings have been observed in other studies.[29,30,32] Mau, J.[33] discovered that both the MSG-like and sweet components in common mushrooms were umami taste-active amino acids that were responsible for flavor enhancement and sweetness. This showed that ID efficiency increased taste-active amino acid retention.

Flavonoid Content

The results showed that drying affects mushroom flavonoid content. Plants' polyphenolic flavonoid compounds are antimutagenic and anticancer.[34,35] White straw mushroom active component concentration was significantly affected by drying during phytochemical screening. High-temperature drying might damage the active substance's structure.[34,35] Fresh preparations may have less flavonoids than dry preparations because they include more freshwater, which dilutes the active ingredients. VFD sample extracts had the most flavonoid (figure -2), while low-oxygen and low-temperature HAD medium successfully minimized flavonoid losses. This is supported by Toor and Savage's.[36] that microwave radiation's permeability destroys tissue's biological components, making flavonoids easier to extract. Due to its shorter heating time, microwave drying preserves flavonoid better than hot air drying.

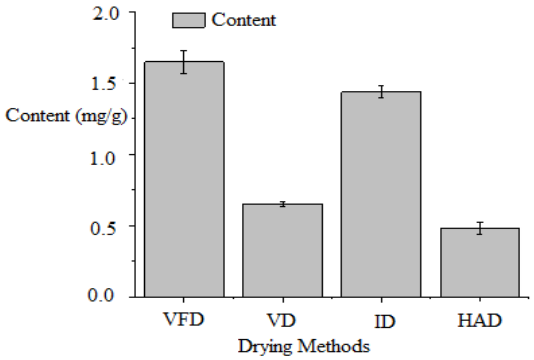


Figure 2: Single factor of the experiment result with Flavonoid Content.

Our findings were comparable to those of Wolfe and Liu.[37] Dehydration removes bonded phytochemicals from the matrix, making them easier to extract. A large percentage of phenolic compounds are related to cellular structures, according to Wojdyo et al.[38] VFD is the best way to save temperature-sensitive molecules since ice crystals formed inside the organic phase might damage the cell structure and release cellular components.[39] In this study, VFD maintained total phenolic, tannin, and flavonoid concentrations better than other drying methods.

3.2.2. Sensory index analysis

Color: Table-4 illustrates that HAD, VD, ID, and VFD drying procedures impact product colour and quality. Where, Brightness (L), Red and green (a) Yellow-blue (b) and significant (**ΔE).** The findings showed sublimation quality, due to vacuum-drying fresh frozen food, VFD produces the brightest mushroom light. Liquid removal preserves mushroom nutrients up to 95%. These nutrients keep trace elements, vitamins, taste, colour, and fragrance intact for a long time. Other dryers lose brightness in high temperatures (from VFD dryers). Thus, "VFD > ID >HAD > VD".

Table- 4: Influence of four drying methods on color and physical properties.

	Hot air drying	Vacuum drying	VFD drying	Infrared drying
L*	65.30±1.26b	61.50±2.11c	81.08±2.09a	67.97±2.48b
a*	10.70±1.17a	12.51±2.11a	4.98±2.79b	10.42±1.24a
b*	23.81±1.82a	23.73±4.28a	1095±1.19b	23.61±1.65a
ΔE*	28.76±1.69ab	31.41±4.07a	8.15±1.24b	26.59±2.37c
Shrinkage	90.53±0.36a	76.41±0.74b	22.16±0.66c	65.73±0.04b
Hardness	780.73±117.89c	2016.81±372.93b	2977.23±364.38a	1836.3±285.19b
Brittleness	7588.38±308.41b	7546.54±327.19b	10705.14±759.49a	9730.45±1001.51a

Where, VFD=Vacuum freeze-drying L=Brightness, **a*=** Red- green **b*=**Yellow-blue and **ΔE*** =significant**.**($p < 0.05$).

Shrinkage: Table-4 shows straw mushroom shrinkage data and how drying procedures effect product quality as discovered in the lab trial. Table -4 demonstrates that the VFD drier has the best mushroom shrinkage and quality. Rehydration hardness and shrinkage temperature are lowest. HAD mushrooms, however, shrank the most. Because shrinking is big but rehydration is minimal and brittleness and hardness after rehydration are huge. HAD mushrooms are denser, shrink more, and rehydrate worse because moisture seeps from the centre to the exterior and drying time rises. The feelings revealed that HAD mushrooms were overly dry compared to other dried mushrooms. Drying mushrooms with hot air takes time. Hot air hardens and crusts the mushroom surface, drying it off. The VFD immediately sublimates ice to keep colour, form, and flavour. Porous FD mushrooms rehydrate well. Rehydrated shiitakes are soft. These approaches shrink: "HAD > VD >ID > VFD".

Rehydration: The experiment was carried out under tap water at a temperature of 60°C with a Maximum of 180 minutes. Figure-3 illustrates mushroom straw rehydration using HAD, VD, ID, and VFD drying techniques. Rehydration curves rise and stabilize, because dried mushrooms rehydrate faster. After a while, it reaches optimum rehydration and steady water absorption, where the VFD is ideal. Dried mushrooms' delicate structure may explain this. Thus, it helps rehydrate. VFD dryers recover quicker because cell wall structure is broken soon. Hence Porous FD mushrooms rehydrate well. Rehydrated shiitakes are soft. These approaches shrink: "VFD > ID > HAD > VD".

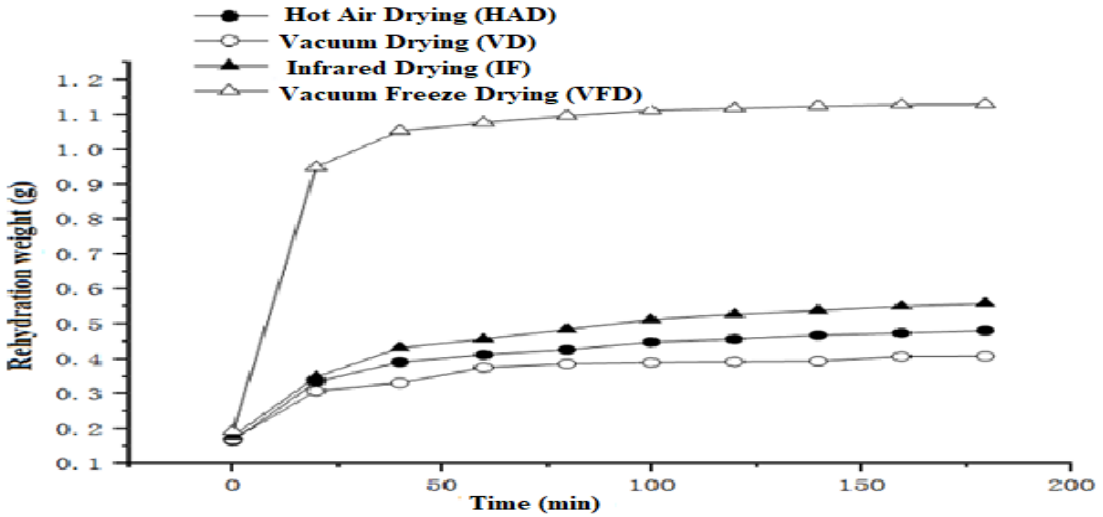


Figure - 3: Changes in the rehydration coefficient of mushrooms in four drying methods.

Texture: Table 4 compares the mushrooms' hardness and brightness in HAD, VD, ID, and VFD drying procedures with the significance level ($p < 0.05$) in addition to shows that different drying methods affect mushrooms' texture. The VFD is the best option and the best product of fungus. The hardness after rehydration is lesser. HAD mushrooms are of poor quality. Rehydration makes it harder and more fragile. HAD mushrooms become denser as moisture flows from the interior out during hot air drying. Thus, heated air hardens, crusts, and severely dries mushrooms. Dehydration creates a hard shell that inhibits fungus from losing moisture and shrinks unevenly. To preserve colour, form, and flavour, during the VFD immediately sublimates are ice. VFD-dried mushrooms are porous and have good rehydration properties. The hardness of shiitake mushrooms after rehydration is low. Hence,
Hardness: "VFD > VD >ID > HAD" and Fragility: "VFD > ID >HAD > VD".

Microstructure

Electron micrograph of four types of dried mushrooms: Fungi's cellular structures are affected by drying procedures. Fresh samples have dense, homogeneous cell walls with moderate thickness and plenty of cytoplasm. Vacuoles are more equally distributed than in dry materials and fill the product's cell walls. VFD's density and thickness are comparable to other species. The cells have fewer vacuoles, but the surface is smooth. Goods dried by infrared radiation have more cytoplasm than VFD products and slightly less than fresh samples. The cells' shrinking edges have a few vacuoles. The cell wall was thicker and denser than the rest of the species, with shrinkage, increased fibre lignifications, and cell adhesion. The cells deform after drying in the far infrared range, HAD, and VFD. With water evaporation, the total amount of cytoplasm decreases during drying. Cytoplasmic content loss is reduced by drying processes.

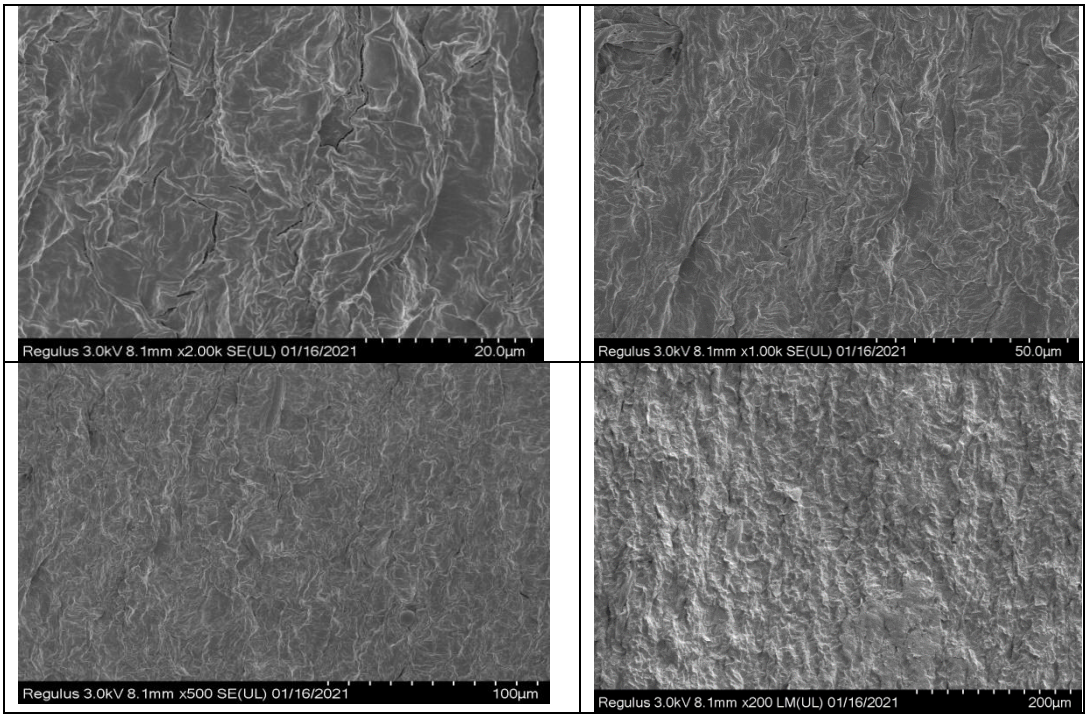


Figure - 4: Vacuum drying.

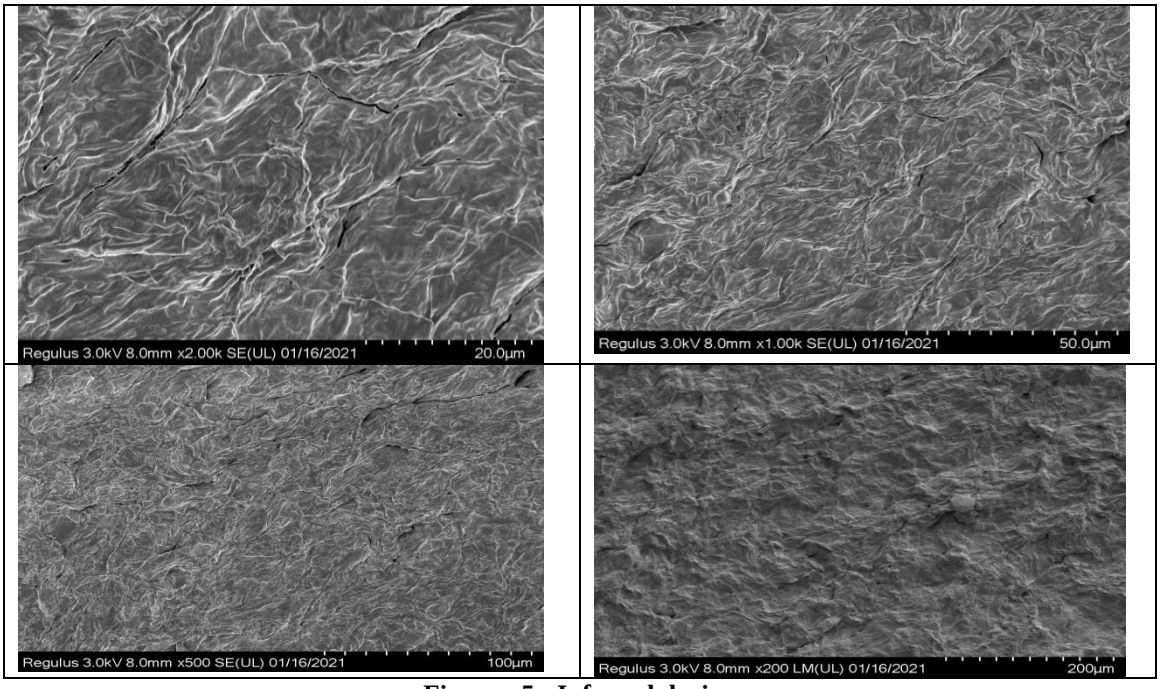
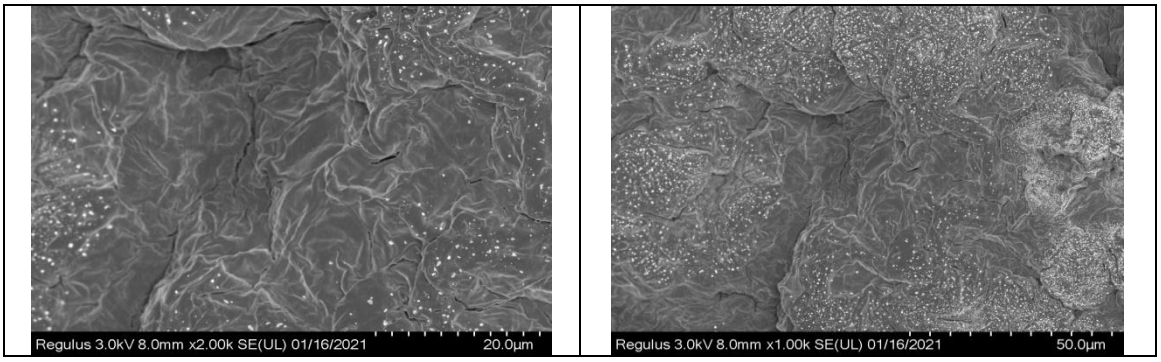


Figure - 5 : Infrared drying



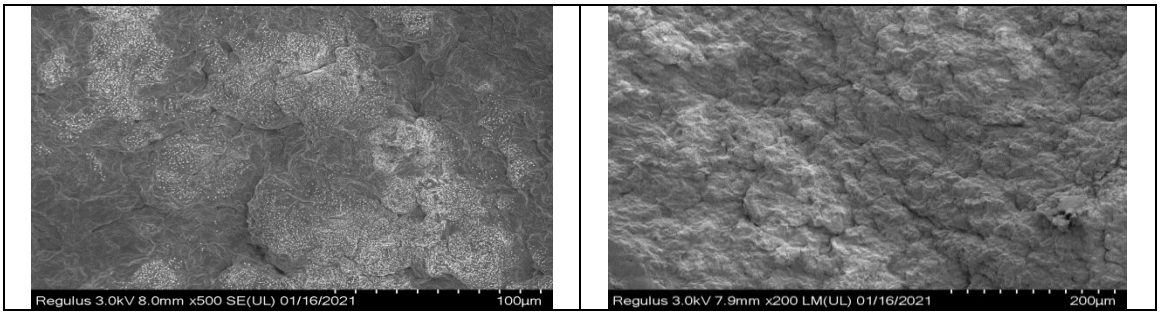


Figure - 6: Hot air drying.

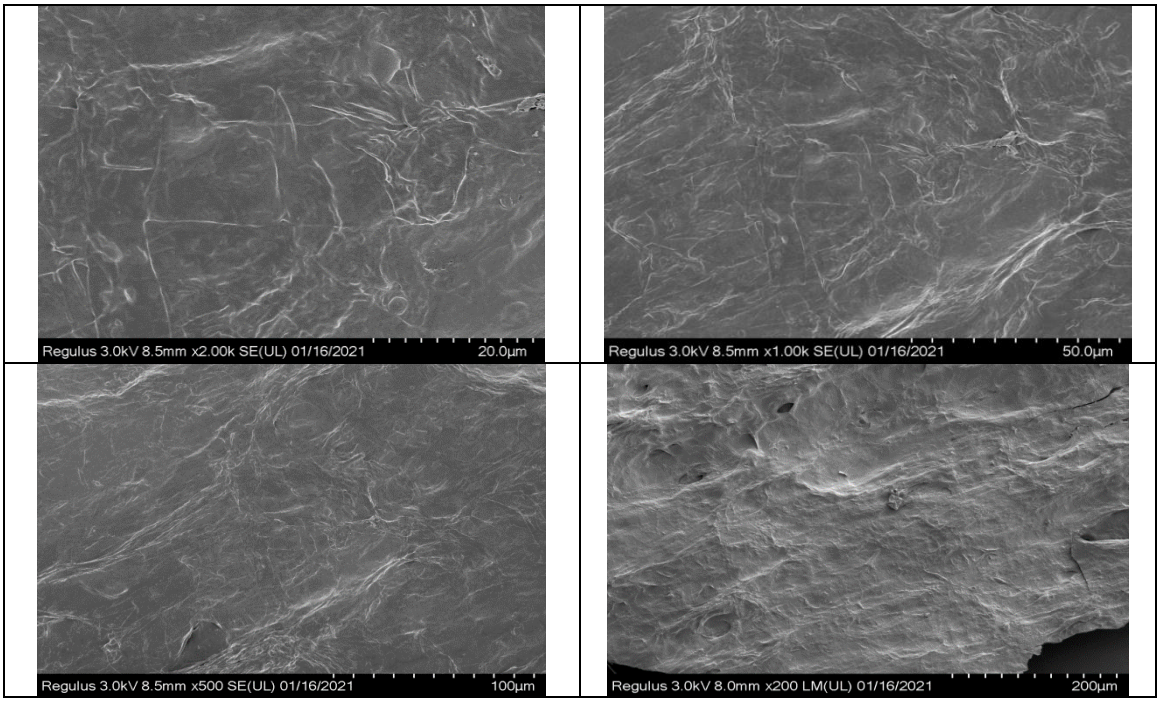


Figure -7: Vacuum freeze-drying.

Sensory Evaluation: The sensory qualities of the Straw mushrooms were tested for sensory characteristics such as appearance, shape, color, hard shell, crispiness, aroma, and overall acceptability at different pretreatments and drying techniques. The results in Table 5 revealed that VFD had the best overall acceptance, followed by VD, ID, and HAD.

Table 5: Sensory evaluation of dried mushrooms at different drying methods.

Drying method	Shape	Color	Hardshell	Crispy	Aroma	Sensory score
Hot air drying	8	10	8	8	19	53%
Vacuum drying	10	15	15	15	15	70%
VFD drying	20	20	20	20	18	98%
Infrared drying	10	11	15	15	18	69%

VFD= Vacuum freeze-drying.

In comparison to the other samples, the blanched samples dried by HAD showed the lowest organoleptic features. Previous research[40] has shown similar results. Before drying, soaking in citric acid enhanced color, texture, fragrance, and reconstitution characteristics[41] were evaluated. In addition,[42] discovered that dehydrated mushroom samples steeped in citric acid (0.25%) solution and VFD had a major impact on sensory characteristics.

Table 6: Antioxidant activities of dried mushrooms at different drying methods.

	(g/ml)	Freeze drying	Hot drying	Vacuum drying	Infrared drying
ABTS	0.10	27.73%	24.71%	23.28%	26.13%
	0.15	29.88%	26.89%	25.60%	28.50%
	0.20	34.26%	26.09%	26.60%	30.75%
	0.25	33.66%	24.99%	26.10%	29.00%
	0.30	36.43%	26.51%	26.65%	30.95%
	0.35	35.71%	27.80%	29.10%	31.97%
DPPH	0.10	35.37%	25.29%	25.29%	28.91%
	0.15	48.14%	29.11%	39.40%	44.78%
	0.20	60.61%	30.07%	50.13%	61.50%
	0.25	58.47%	37.85%	49.60%	56.17%
	0.30	74.17%	42.98%	58.51%	73.20%
	0.35	81.39%	44.88%	62.71%	74.04%
Iron Reduction Capacity	0.10	22.75%	16.87%	18.41%	17.35%
	0.15	30.53%	17.46%	21.91%	17.94%
	0.20	40.60%	21.49%	28.03%	22.17%
	0.25	43.54%	26.59%	35.03%	26.80%
	0.30	54.30%	29.00%	36.70%	28.21%
	0.35	56.42%	34.82%	39.47%	33.59%
Hydroxyl Radical.	0.10	25.79%	17.13%	18.61%	22.45%
	0.15	28.06%	17.32%	21.13%	29.41%
	0.20	38.55%	21.56%	24.76%	34.97%
	0.25	38.43%	22.83%	26.07%	33.07%
	0.30	45.53%	23.49%	28.47%	35.02%
	0.35	45.71%	34.40%	33.22%	35.20%

3.2.3. Antioxidant activity analysis

Antioxidant qualities are an essential aspect of plant food. Mushroom antioxidant activity involves adjusting the indirect chain reaction with free radicals, hydrogen donation, chelating catalytic ions, and peroxide elimination.[43] No single methodology can provide a complete antioxidant profile. This study included ABTS radical scavenging activity, DPPH, iron reducibility, and the Hydroxyl radical test to measure antioxidant capacity because a single analysis is insufficient (Table -6). Table-6 shows antioxidant activity values.

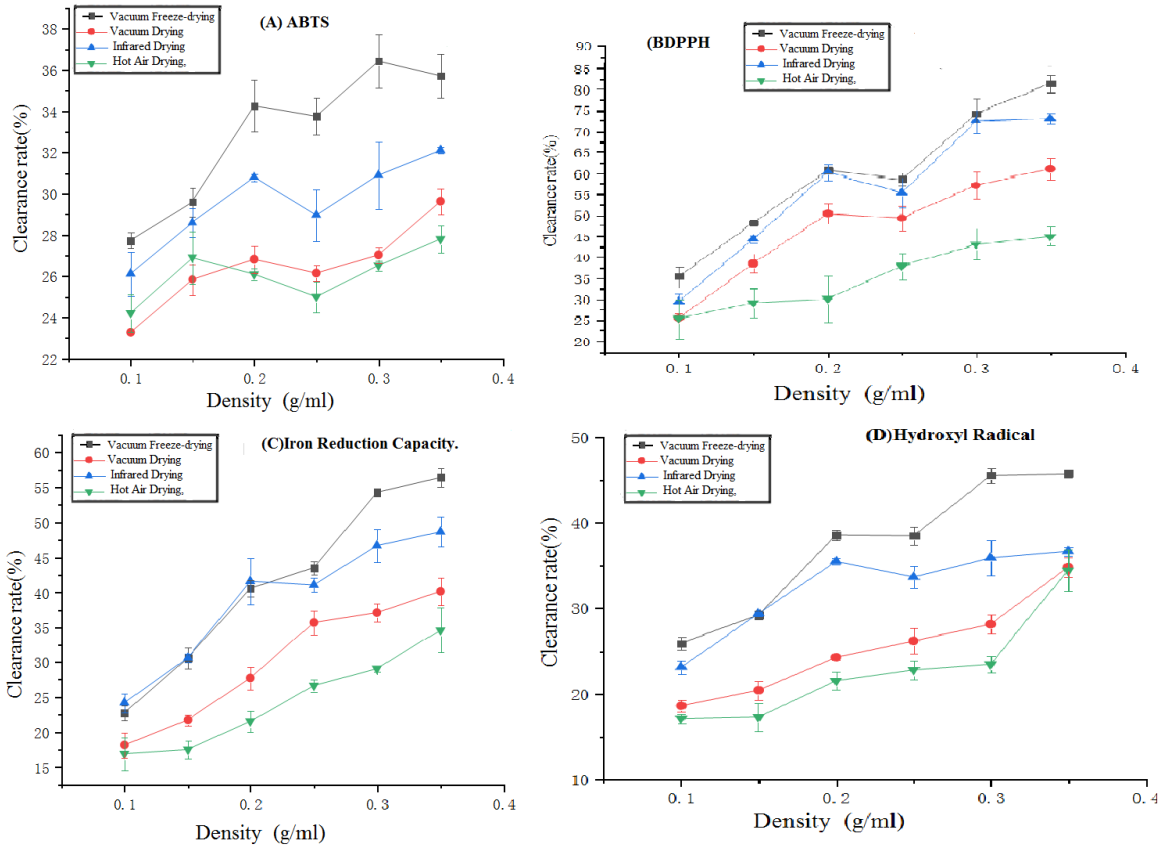


Figure - 8: Four different drying methods antioxidant capacity of (A) ABTS, (B)DPPH,(C) Iron reduction capacity, and (D) Hydroxyl radical.

(A) **ABTS:** ABTS analysis determines the antioxidant capacity of individual components and complex plant combinations.[44] Dried straw mushroom VD, ID, and HAD had similar ABTS radical absorption activity values. Straw mushrooms bind radicals best in VFD. Despite the findings from Meng, Q., Fan, H., Li, Y., & Zhang, L.[45] which indicate a decreased safety of the antioxidant qualities of mushrooms dried in HAD, microwaves destroy cell walls, releasing antioxidants for extraction. Succinic acid may also explain VFD samples' significant antiradical activity. According to Kolupaev et al.[46] This compound enhances antioxidant enzyme activity and has antioxidant effects. ABTS tests determine the antioxidant capacity of single chemicals and complex plant combinations.[47] Figure 8 shows that VFD, ID, VD, and HAD samples had the highest antioxidant capacity. Extract performance activity decreased in order as : "VFD< ID < VD< HAD".

Figure-8(A) shows ABTS antioxidant capacity after four drying techniques. HADs' ABTS lowest antioxidant capacity may be related to active chemicals like flavonoids, and polyphenols lose more strongly with prolonged HAD. Thus, fluctuating temperature, differential pressure, blowing, and drying have the lowest regenerative capacity. Hence, ABTS has the highest antioxidant capacity.

(B) DPPH

DPPH is extensively used to assess free radical scavenging by natural substances.[48] A lower inhibitory concentration value indicates that the sample has a higher antioxidant activity. figure -8 (B) depicts a comparison of the DPPH radical scavenging activity of straw mushrooms dried using various techniques. VFD and VD samples had the lowest inhibitory concentration, followed by ID and HAD drying samples. Figure 8(B) illustrates the DPPH radical-scavenging antioxidant activity of raw and treated mushrooms. Raw sample free extracts scavenge 76% of DPPH radicals. Free extracts retained 72% of their DPPH radical scavenging properties following processing. Bound extract has less DPPH radical scavenging activity than raw mushrooms. DPPH assessment drying procedures differed slightly. The sequence is HAD 14%, VFD 34%, VD 13%, and ID 21%. This may be because polyphenols under heat treatment conditions facilitate the release of bound-free polyphenols.

(C) **Iron Reduction Capacity:** VFD and ID produce similar ferric/iron reduction outcomes for the straw mushroom species investigated. HAD and VD mushroom extracts restored iron best of the four drying methods. The results confirmed that enzymes destroy antioxidant compounds during long-term dehydrogenation at low temperatures.[49-51] Moreover, the release of photochemical chemicals from cell component

thermal degradation and the creation of new antioxidant-rich substances may explain straw mushroom extracts' enhanced iron-reducing activity. HAD extracts were the electrochemical method for measuring dry straw mushroom extracts' total antioxidant activity. "VFD> ID>VD> HAD" was the acceptance order for the samples. Due to its reactivity, iron is the most important transition metal lipid oxidation pro-oxidant. Ferrous ions direct and indirect lipid oxidation.[52] Figure 8 (C) showed that VFD samples had the maximum chelating capacity (50.11%), while HAD samples had the lowest power (19.96%). The drying process significantly affected straw mushroom metal chelating capacity ($p<0.05$).

(D) **Hydroxyl radicals:** The most active radical, the hydroxyl radical (•OH), can damage DNA, proteins, and genes. As a result, dietary antioxidant activity is measured by hydroxyl radical scavenging. When heated with TBA at low pH, hydroxyl radicals from an iron-EDTA complex with hydrogen peroxide and ascorbic acid attack deoxyribose to yield a pink chromogen.[53] Hydroxyl radical scavengers bind to hydroxyl radicals before attacking deoxyribose, decreasing chromogen production and damaging practically every molecule in live cells.[54] These radicals cause strand breaking, which leads to carcinogenesis, mutagenesis, and cytotoxicity.[55] Fenton reaction produces hydroxyl radicals from H_2O_2 and reduced transition metals like Fe2+. Antioxidants that scavenge hydroxyl radicals reduce reaction mixture absorbance. Figure -8 (D) shows that VFD samples had the best hydroxyl radical scavenging performance (45.71%) and HAD samples the lowest (19.89%). ID- and VFD-dried materials scavenged hydroxyl radicals similarly ($P>0.05$). The drying technique has a distinct effect on the ability of dried RPF to scavenge hydroxyl radicals.

4. CONCLUSION

This study found that straw mushrooms (Volvariella volvacea) are high in protein, carbohydrates, minerals, and low in fat. Straw mushrooms' appearance and quality change when they are dried. This study found that drying Straw mushroom fruiting bodies affects their structural properties, rehydration ability, chemical content, and antioxidant profile. They inhibited hypertension and exhibited excellent antioxidant capacity. Estimating nutritional, textural, and antioxidant activities using different chemical reaction methods. VFD was the most effective method for drying Straw mushrooms' fruiting bodies, which have antioxidant properties. VFD followed by VD optimises straw mushroom performance, colour, texture, and iron-reducing ability. Mushrooms dewatered by VFD and ID exhibit electrochemical oxygen recovery-based antioxidant properties. This study's drying methods differed in process complexity, energy consumption, and cost. Dry Straw mushroom antioxidant activity was measured using ABTS, DPPH, Hydroxyl radical, and iron reduction capacity. VFD outperformed HAD. Thus, the VFD is excellent for preparing a dry product (Straw mushrooms) as a viable functional food product or component with the highest expression of the whole complex or independent qualities.

However, further study is needed to determine whether the drying technique considerably decreases drying time and is more energy efficient, as well as having the capacity to recover oxygen and being cost-effective. Mushrooms can be preserved in dried form to decrease postharvest loss and increase shelf life. Straw mushrooms may be used in a variety of dishes to improve the nutritional condition of vulnerable populations in developing nations due to their high nutrient content.

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