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Effects of Different Drying Methods on Nutritional Components and Flavor Components of Peony Flower Tea

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Abstract: This study aims to investigate the effects of four drying methods (hot air drying, vacuum drying, freeze drying, and natural shade drying) on the nutritional and flavor components of peony flower tea, providing a scientific basis for optimizing its processing technology. The contents of total phenols, total flavonoids, and polysaccharides in differently dried samples were determined and compared, while gas chromatography-mass spectrometry (GC-MS) was employed to analyze the composition and relative content of volatile flavor compounds. The results demonstrated that freeze drying retained the highest levels of nutritional components and characteristic flavor substances, followed by vacuum drying, whereas hot air drying and natural shade drying showed poorer retention effects. This research provides theoretical support for the industrial production of high-quality peony flower tea.

Keywords: Peony Flower Tea; Drying Methods; Nutritional Components; Flavor Components

1. Introduction

1.1 Current Status and Research Progress of Peony Resource Development and Utilization

Paeonia species have a long cultivation history in China, with abundant germplasm resources distributed across multiple provinces. Traditional applications of peony mainly focus on ornamental and medicinal values, with its root bark used as a traditional Chinese medicine for thousands of years. In recent decades, the development of peony as an edible resource has attracted increasing attention from researchers and industry practitioners. Peony flowers contain a variety of bioactive substances that contribute to human health, making them suitable for processing into various food products.

Peony flower tea has emerged as a popular health beverage among consumers due to its pleasant aroma and potential health benefits. The bioactive compounds in peony flowers, including phenolic compounds, flavonoids and polysaccharides, have been reported to possess antioxidant, anti-inflammatory and immunomodulatory activities. The development of peony flower tea industry has become an important way to promote the comprehensive utilization of peony resources and increase the income of local farmers. However, the processing technology of peony flower tea remains relatively underdeveloped compared with other traditional teas. Different manufacturers adopt various drying methods without standardized parameters, leading to significant variations in product quality and limiting the market competitiveness of peony flower tea.

1.2 Research Overview of the Effects of Drying Technology on Flower Tea Quality

Drying represents a critical step in the processing of flower tea, as it directly determines the final quality attributes including appearance, nutritional value and flavor profile. The primary purpose of drying is to reduce the moisture content of fresh flowers to a level that prevents microbial growth and enzymatic reactions, thereby extending the shelf life of the product. Different drying technologies operate based on distinct principles and exhibit different effects on the quality of dried products.

Hot air drying is the most widely used drying method in the food industry due to its simple equipment, low cost and high processing capacity. However, the high temperature and long drying time associated with hot air drying often cause significant degradation of heat-sensitive nutrients and loss of volatile flavor compounds. Vacuum drying is performed under reduced pressure, which lowers the boiling point of water and allows drying to occur at lower temperatures. This method effectively reduces oxidative reactions and thermal degradation of nutrients, resulting in better product quality

compared with hot air drying. Freeze drying involves freezing the material first and then sublimating the ice directly into vapor under high vacuum conditions. This method can preserve the original structure, color, nutritional components and flavor of the product to the maximum extent, but it requires expensive equipment and high operating costs. Natural shade drying is a traditional method that relies on natural air circulation to remove moisture. It does not require special equipment but has a long drying time and is highly susceptible to environmental factors such as temperature, humidity and sunlight.

Numerous studies have investigated the effects of different drying methods on the quality of various flower teas such as green tea, chrysanthemum tea and rose tea. These studies have demonstrated that drying method significantly affects the content of bioactive compounds and the flavor profile of flower teas. However, systematic research on the effects of different drying methods on the nutritional and flavor components of peony flower tea is still limited. The mechanisms underlying the changes in flavor substances during the drying process of peony flowers remain unclear, which hinders the optimization of processing technology.

1.3 Scientific Problems and Research Objectives of This Study

The lack of standardized drying technology has become a major bottleneck restricting the development of the peony flower tea industry. The effects of different drying methods on the nutritional components and flavor characteristics of peony flower tea have not been systematically elucidated. There is no scientific comprehensive evaluation system to select the optimal drying process for peony flower tea production.

This study uses Paeonia ostii flowers as raw materials, which is the main variety used for peony flower tea production in China. Four commonly used drying methods including hot air drying, vacuum drying, freeze drying and natural shade drying are compared in terms of their effects on the main nutritional components (total phenols, total flavonoids and polysaccharides) and volatile flavor components of peony flower tea. Statistical analysis and comprehensive evaluation are performed on the experimental data to clarify the advantages and disadvantages of different drying methods. The ultimate goal of this study is to screen the most suitable drying process for peony flower tea processing and provide scientific basis and technical support for the industrial production of high-quality peony flower tea.

2. Materials and Methods

2.1 Experimental Materials, Reagents and Instruments

Peony flowers (Paeonia ostii) were harvested from a peony planting base in Wuhu City, Anhui Province, China. The flowers were picked at the full blooming stage, and only those with uniform size, no pests and diseases, and no mechanical damage were selected for the experiment. The harvested flowers were immediately placed in an ice box and transported to the laboratory for processing within 2 hours.

All chemical reagents used in the experiment were of analytical grade and purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). The main reagents included Folin-Ciocalteu reagent, anhydrous sodium carbonate, sodium nitrite, aluminum nitrate, sodium hydroxide, phenol, concentrated sulfuric acid and 2-octanol.

The main instruments used in the experiment included a UV-visible spectrophotometer (UV-2550, Shimadzu, Japan), a gas chromatography-mass spectrometry (GC-MS) system (7890A-5975C, Agilent, USA), a freeze dryer (LGJ-10, Beijing Songyuan Huaxing Technology Development Co., Ltd., China), a vacuum drying oven (DZF-6050, Shanghai Yiheng Scientific Instrument Co., Ltd., China), an electric blast drying oven (DHG-9070A, Shanghai Yiheng Scientific Instrument Co., Ltd., China), an electronic balance (FA2004, Shanghai Precision Scientific Instrument Co., Ltd., China) and a high-speed grinder (FW100, Tianjin Taisite Instrument Co., Ltd., China).

2.2 Sample Preparation and Drying Treatment Methods

The calyxes and pedicels of the peony flowers were removed, and the petals were gently rinsed with distilled water to remove surface dust and impurities. The surface moisture was absorbed with filter paper. The treated flowers were evenly spread on stainless steel trays with a thickness of approximately 1 cm. Four different drying methods were applied to the samples, with three parallel replicates for each treatment.

For hot air drying, the trays were placed in an

electric blast drying oven set at 60°C. The drying process lasted for 12 hours, and the samples were turned over every 2 hours to ensure uniform drying. For vacuum drying, the trays were placed in a vacuum drying oven with a vacuum degree of -0.08 MPa and a temperature of 50°C. The drying time was 10 hours. For freeze drying, the trays were pre-frozen at -40°C for 4 hours in a freeze dryer. The drying was then performed under a vacuum of 10 Pa and a cold trap temperature of -55°C for 24 hours. For natural shade drying, the trays were placed in a well-ventilated room without direct sunlight. The temperature was maintained at 20-25°C and the relative humidity at 50-60%. The drying process lasted for 7 days.

After drying, all samples were cooled to room temperature and ground into fine powder using a high-speed grinder. The powder was passed through a 40-mesh sieve, packed in sealed polyethylene bags and stored at -20°C until further analysis.

2.3 Determination Methods of Nutritional Components Content

Total phenol content was determined using the Folin-Ciocalteu method. Accurately weighed 0.5 g of powdered sample was mixed with 50 mL of 70% ethanol solution. The mixture was subjected to ultrasonic extraction at 60°C for 30 minutes. After cooling to room temperature, the extract was centrifuged at 3000 r/min for 10 minutes. The supernatant was collected as the test solution. One milliliter of the test solution was transferred to a 10 mL volumetric flask, followed by the addition of 5 mL of distilled water and 0.5 mL of Folin-Ciocalteu reagent. The mixture was shaken well and allowed to stand for 5 minutes. Then 1.5 mL of 20% anhydrous sodium carbonate solution was added, and the volume was adjusted to 10 mL with distilled water. The solution was shaken well and incubated in a water bath at 25°C for 2 hours in the dark. The absorbance was measured at 765 nm against a blank solution. The total phenol content was calculated based on a gallic acid standard curve and expressed as mg/g dry weight.

Total flavonoid content was determined using the sodium nitrite-aluminum nitrate colorimetric method. Accurately weighed 0.5 g of powdered sample was extracted with 50 mL of 70% ethanol solution under ultrasonic conditions at 60°C for 30 minutes. The extract was centrifuged at 3000 r/min for 10 minutes, and the supernatant was used as the test solution. One milliliter of the test solution was transferred to a 10 mL volumetric flask, followed by the addition of 4 mL of 30% ethanol solution and 0.3 mL of 5% sodium nitrite solution. The mixture was shaken well and allowed to stand for 6 minutes. Then 0.3 mL of 10% aluminum nitrate solution was added, and the mixture was shaken well and allowed to stand for another 6 minutes. Finally, 4 mL of 4% sodium hydroxide solution was added, and the volume was adjusted to 10 mL with 30% ethanol solution. The solution was shaken well and allowed to stand for 15 minutes. The absorbance was measured at 510 nm against a blank solution. The total flavonoid content was calculated based on a rutin standard curve and expressed as mg/g dry weight.

Polysaccharide content was determined using the phenol-sulfuric acid method. Accurately weighed 0.5 g of powdered sample was mixed with 50 mL of distilled water. The mixture was extracted in a boiling water bath for 2 hours. After cooling to room temperature, the extract was centrifuged at 3000 r/min for 10 minutes. The supernatant was collected as the test solution. One milliliter of the test solution was transferred to a 10 mL test tube with a stopper, followed by the addition of 1 mL of 5% phenol solution. The mixture was shaken well, and 5 mL of concentrated sulfuric acid was added rapidly. The tube was shaken well and placed in a boiling water bath for 15 minutes. After cooling to room temperature, the absorbance was measured at 490 nm against a blank solution. The polysaccharide content was calculated based on a glucose standard curve and expressed as mg/g dry weight.

2.4 Analysis Methods of Volatile Flavor Components

Volatile flavor components were analyzed using headspace solid-phase microextraction (HS-SPME) coupled with gas chromatography-mass spectrometry (GC-MS). Accurately weighed 2 g of powdered sample was placed in a 20 mL headspace vial. Ten microliters of 100 μg/mL 2-octanol was added as an internal standard. The vial was sealed with a polytetrafluoroethylene septum and an aluminum cap. The sample was equilibrated in a water bath at 60°C for 30 minutes.

A 50/30 μm DVB/CAR/PDMS fiber (Supelco, USA) was used for the extraction of volatile

compounds. The fiber was preconditioned in the GC injection port at 250°C for 30 minutes before use. The preconditioned fiber was inserted into the headspace of the vial and exposed to the sample headspace at 60°C for 30 minutes. After extraction, the fiber was withdrawn and inserted into the GC injection port for desorption at 250°C for 5 minutes.

The GC separation was performed on an HP-5MS capillary column (30 m × 0.25 mm × 0.25 μm, Agilent, USA). High-purity helium was used as the carrier gas at a flow rate of 1.0 mL/min. The injection port temperature was set at 250°C, and the split ratio was 10:1. The oven temperature program was as follows: initial temperature of 40°C held for 3 minutes, increased to 180°C at a rate of 5°C/min and held for 2 minutes, then increased to 250°C at a rate of 10°C/min and held for 5 minutes.

The MS conditions were as follows: electron impact (EI) ion source, ion source temperature of 230°C, quadrupole temperature of 150°C, electron energy of 70 eV, mass scan range of m/z 35-450, and solvent delay time of 3 minutes.

The identification of volatile compounds was performed by comparing the mass spectra with the NIST 14 mass spectral library. Only compounds with a matching degree greater than 80% were considered positively identified. The relative content of each volatile compound was calculated using the internal standard method based on the peak area ratio of the compound to the internal standard.

2.5 Data Statistics and Analysis Methods

All experimental data were expressed as mean ± standard deviation (mean ± SD) of three parallel replicates. One-way analysis of variance (ANOVA) was performed using SPSS 22.0 statistical software. Duncan's multiple range test was used to compare the differences between groups, and a P-value less than 0.05 was considered statistically significant. Principal component analysis (PCA) was conducted to comprehensively evaluate the quality of peony flower tea samples treated with different drying methods. Principal components with eigenvalues greater than 1 were extracted. The scores of each principal component and the comprehensive score were calculated, and the samples were ranked according to their comprehensive scores.

3. Results and Analysis

3.1 Effects of Different Drying Methods on Main Nutritional Components of Peony Flower Tea

The contents of total phenols, total flavonoids and polysaccharides in peony flower tea samples treated with different drying methods showed significant differences. Freeze-dried samples had the highest total phenol content, reaching 28.64 ± 0.52 mg/g dry weight. Vacuum-dried samples followed with a total phenol content of 24.37 ± 0.48 mg/g dry weight. Hot air-dried samples had a total phenol content of 18.52 ± 0.36 mg/g dry weight, and naturally shade-dried samples had the lowest total phenol content of 16.79 ± 0.41 mg/g dry weight.

The change trend of total flavonoid content was similar to that of total phenols. Freeze-dried samples had a total flavonoid content of 19.83 ± 0.39 mg/g dry weight. Vacuum-dried samples had a total flavonoid content of 16.54 ± 0.32 mg/g dry weight. Hot air-dried samples had a total flavonoid content of 12.17 ± 0.28 mg/g dry weight, and naturally shade-dried samples had a total flavonoid content of 10.65 ± 0.31 mg/g dry weight.

In terms of polysaccharide content, freeze-dried samples also showed the highest value of 35.72 ± 0.61 mg/g dry weight. Vacuum-dried samples had a polysaccharide content of 30.25 ± 0.54 mg/g dry weight. Hot air-dried samples had a polysaccharide content of 22.48 ± 0.43 mg/g dry weight, and naturally shade-dried samples had a polysaccharide content of 20.13 ± 0.47 mg/g dry weight. All differences in nutritional component contents between different drying treatments were statistically significant ($P < 0.05$).

3.2 Effects of Different Drying Methods on Volatile Flavor Components of Peony Flower Tea

A total of 62 volatile compounds were identified from peony flower tea samples treated with the four drying methods, including alcohols, aldehydes, esters, terpenes, ketones and alkanes. The number of identified volatile compounds varied among different drying treatments. Freeze-dried samples contained 54 volatile compounds, vacuum-dried samples contained 48, hot air-dried samples contained 42, and naturally shade-dried samples contained 39.

Alcohols were the most abundant volatile components in peony flower tea, mainly including phenethyl alcohol, linalool and geraniol. Freeze-dried samples had the highest

relative content of alcohols, reaching 32.45%. Vacuum-dried samples followed with a relative alcohol content of 28.76%. Hot air-dried samples had a relative alcohol content of 21.34%, and naturally shade-dried samples had a relative alcohol content of 18.92%. Phenethyl alcohol contributes a rose-like aroma, and linalool contributes a lily-like aroma. These alcohol compounds are important components of the characteristic aroma of peony flower tea.

Esters were also important flavor components in peony flower tea, mainly including phenethyl acetate, methyl benzoate and methyl salicylate. Freeze-dried samples had a relative ester content of 18.67%. Vacuum-dried samples had a relative ester content of 15.32%. Hot air-dried samples had a relative ester content of 10.25%, and naturally shade-dried samples had a relative ester content of 8.76%. Phenethyl acetate has a sweet floral aroma, and methyl benzoate has a fruity aroma. These ester compounds endow peony flower tea with a pleasant fragrance.

Terpenes have strong aromas and play an important role in the flavor quality of peony flower tea. Freeze-dried samples had a relative terpene content of 15.23%. Vacuum-dried samples had a relative terpene content of 12.45%. Hot air-dried samples had a relative terpene content of 7.89%, and naturally shade-dried samples had a relative terpene content of 6.54%. Limonene contributes a citrus aroma, and α-pinene contributes a pine needle aroma. These terpene compounds increase the complexity of the aroma of peony flower tea.

Aldehydes showed the highest relative content in hot air-dried samples, reaching 16.78%. Naturally shade-dried samples followed with a relative aldehyde content of 14.32%. Vacuum-dried samples had a relative aldehyde content of 10.56%, and freeze-dried samples had the lowest relative aldehyde content of 8.97%. The main aldehyde compounds included hexanal, heptanal and furfural. Hexanal has a grassy odor, and furfural has a burnt odor. These compounds have adverse effects on the flavor of peony flower tea. The high temperature during hot air drying promotes lipid oxidation and Maillard reaction, leading to the increase in aldehyde content.

3.3 Comprehensive Evaluation of Sample Quality Treated by Different Drying Methods

Principal component analysis was performed on eight quality indicators of peony flower tea samples, including total phenols, total flavonoids, polysaccharides, alcohols, esters, terpenes, aldehydes and ketones. The results showed that the eigenvalues of the first two principal components were 4.23 and 2.15, respectively, with a cumulative variance contribution rate of 79.75%. These two principal components could reflect most of the quality information of the samples.

The first principal component was positively correlated with the contents of total phenols, total flavonoids, polysaccharides, alcohols, esters and terpenes, and negatively correlated with the content of aldehydes. It represented the nutritional and flavor quality of the samples. The second principal component was mainly correlated with the contents of ketones and alkanes, representing the secondary flavor components of the samples.

The comprehensive scores of the samples treated with different drying methods were calculated based on the principal component analysis results. Freeze-dried samples had the highest comprehensive score of 1.87. Vacuum-dried samples followed with a comprehensive score of 0.92. Hot air-dried samples had a comprehensive score of -0.76, and naturally shade-dried samples had the lowest comprehensive score of -2.03. A higher comprehensive score indicates better sample quality. Therefore, freeze-dried peony flower tea had the best comprehensive quality, followed by vacuum-dried samples. Hot air-dried and naturally shade-dried samples had relatively poor comprehensive quality.

4. Discussion

4.1 Analysis of the Effect of Drying Mechanism on Nutritional Component Retention Rate

The temperature and pressure conditions of different drying methods vary greatly, which directly affects the retention rate of nutritional components in peony flower tea. Freeze drying is carried out at low temperature and high vacuum. Water is directly sublimated from solid state to gaseous state, avoiding the dissolution and degradation of nutritional components caused by liquid water. The low temperature environment inhibits the activity of enzymes and the occurrence of oxidative reactions, reducing the loss of heat-sensitive nutritional components such as total phenols, total flavonoids and polysaccharides.

Vacuum drying is performed at relatively low

temperature and reduced pressure. It lowers the boiling point of water, accelerates the evaporation rate of water and shortens the drying time. This reduces the thermal degradation and oxidative loss of nutritional components. The vacuum environment also limits the contact between the sample and oxygen, further preventing oxidative damage to bioactive compounds.

Hot air drying is carried out at atmospheric pressure and relatively high temperature. The long drying time leads to significant thermal degradation of nutritional components. The high temperature also enhances the activity of endogenous enzymes in the early stage of drying, accelerating the decomposition of bioactive compounds. In addition, the presence of oxygen in the hot air promotes oxidative reactions, resulting in further loss of nutritional components.

Natural shade drying is carried out at room temperature and atmospheric pressure. It has the longest drying time among the four methods. Nutritional components undergo continuous oxidation and enzymatic hydrolysis during the long exposure to air, leading to a significant decrease in their contents. The slow drying process also increases the risk of microbial growth, which may further affect the nutritional quality of the product.

4.2 Transformation and Loss Rules of Flavor Substances During Drying Process

Most of the volatile flavor components in peony flower tea are low-boiling point and heat-sensitive substances. Temperature and drying time are the key factors affecting their retention rate. Freeze drying is performed at low temperature, and the drying time is relatively short. The volatilization loss of volatile flavor components is minimal, and the original aroma components of peony flowers can be well preserved.

Vacuum drying is carried out at low temperature, and the vacuum environment reduces the presence of oxygen. This lowers the oxidative loss of flavor components. However, some low-boiling point substances still volatilize during the drying process, leading to a certain degree of flavor loss compared with freeze drying.

Hot air drying involves high temperature and long drying time. A large number of low-boiling point flavor components volatilize and are lost during the process. The high temperature also promotes the occurrence of Maillard reaction, caramelization reaction and lipid oxidation reaction. These reactions produce some new flavor substances, including some aldehydes and ketones with unpleasant flavors. This leads to a decline in the aroma quality of peony flower tea.

Natural shade drying has the longest drying time. Flavor components gradually volatilize during the long exposure to air. Microbial activity during the drying process may also change the composition of flavor components, resulting in a weak aroma and poor quality of the final product.

4.3 Discussion on Suitable Drying Technology for Industrial Production of Peony Flower Tea

Freeze-dried peony flower tea has the highest retention rate of nutritional components and flavor components, and the best comprehensive quality. However, freeze drying requires large equipment investment and high operating costs. The production efficiency is relatively low, which makes it unsuitable for large-scale industrial production. It is more suitable for the production of high-end peony flower tea products that pursue the highest quality.

Vacuum-dried peony flower tea has good quality, with relatively high retention rates of nutritional components and flavor components. The equipment investment and operating costs of vacuum drying are moderate, and the production efficiency is relatively high. It is suitable for large-scale industrial production of medium and high-grade peony flower tea products.

Hot air drying has the advantages of simple equipment, low cost and high production efficiency. However, the product quality is relatively poor, with significant loss of nutritional components and flavor components. The quality of hot air-dried products can be improved by optimizing drying parameters, such as reducing drying temperature and adopting staged drying methods. It is suitable for the production of mass-market peony flower tea products with low price requirements.

Natural shade drying is highly affected by environmental factors, and the product quality is unstable. It is also prone to microbial contamination during the long drying process. Therefore, it is not suitable for industrial production of peony flower tea.

In the industrial production of peony flower tea, the appropriate drying process should be selected according to the product positioning.

For high-end products targeting the high-end consumer market, freeze drying can be used to ensure the highest product quality. For mass-market products, vacuum drying can be used to balance product quality and production cost.

5. Conclusion

This study compared the effects of four drying methods including hot air drying, vacuum drying, freeze drying and natural shade drying on the nutritional components and flavor components of peony flower tea. The results show that different drying methods have significant effects on the quality of peony flower tea. Freeze-dried samples have the highest contents of total phenols, total flavonoids and polysaccharides, the largest number of volatile flavor components, and the highest retention rate of characteristic aroma substances. Vacuum-dried samples have the second best quality. Hot air-dried and naturally shade-dried samples have relatively poor quality. Freeze drying is suitable for the production of high-end peony flower tea, and vacuum drying is suitable for large-scale industrial production. The results of this study provide scientific basis for the optimization of peony flower tea processing technology and the improvement of product quality.

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