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# *Effects of Different Drying Methods on the Drying Characteristics of Carrots*

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***Keywords:*** Dried Carrot, Drying Process, Vacuum Drying, Hot Air Drying

***Abstract:*** Carrot drying can both extend its storage time and increase its added value. Dehydrated vegetables in China are mainly processed by hot air drying, which has poor quality and high energy consumption. Therefore, it is of great significance to solve the problems of poor drying quality, long time, and large energy consumption of the traditional carrot slice drying process, and further optimize the carrot drying process. The purpose of this article is to solve the problem of how to improve the quality of dried carrot products and reduce energy consumption. Through a combination of hot air drying and microwave drying in the early stage and experiments with hot air drying and microwave drying, the results obtained are compared and analyzed. The aim is to explore the high-quality, efficient and energy-saving drying process conditions for vegetables. Then the effects of different temperature, different wind speed and different relative humidity on the drying characteristics of carrot slices were analyzed. Then, the drying characteristics of carrot slices were compared and analyzed under three operating conditions: temperature rise and humidity decrease, temperature decrease and humidity decrease, and constant temperature and constant humidity. The results show that the research found that under the conditions of relative humidity and wind speed, the higher the temperature, the faster the drying rate and the shorter the drying time. 55 ℃ is the best drying temperature. Under the condition of certain temperature and relative humidity of hot air, increasing the wind speed can increase the drying rate, but increasing to a certain extent the effect of wind speed on the drying rate is reduced. The wind speed has little effect on the appearance and color of dried carrot slices. The dry product has better rehydration, and the best drying wind speed is 1.5m / s.

## 1. Introduction

Carrots originated in Central Asia and the Mediterranean region, and have a cultivation history of more than 2,000 years. They were introduced into China at the end of the Yuan Dynasty and are the roots of the umbelliferon carrot. It is rich in nutrition and has the functions of improving human immunity, regulating human functions, anti-cancer, anti-oxidation, and delaying aging. Carrots are widely cultivated in China, but China's existing technology has a low utilization rate of carrot development, and lack of deep processing technology, resulting in waste of resources and environmental pollution [1]. Drying is a common method for storage and processing of carrots. Different drying methods have a great impact on the quality of dried carrot products. Suitable drying methods and process conditions can not only retain the nutrients and color of carrots, but also save energy . China's dehydrated vegetables are mainly processed by hot air drying, the product quality is poor, and the energy consumption is large. Although a few companies have introduced foreign freeze-drying production lines, it is still difficult to promote their application in China due to various problems such as excessive investment and high cost [2]. The microwave drying rate is high, it is better to maintain the color, aroma, taste and shape of the food, improve the rehydration of the product, and the energy consumption is relatively low, especially suitable for the drying of low moisture content (below 20%) materials; hot air drying can be effective The free water on the surface of the material is discharged, but the internal moisture of the material is difficult to remove in the later stage. Hot air and microwave combined drying technology refers to a composite drying technology that combines the advantages of hot air and microwave drying methods in stages according to the characteristics of the material. The purpose is to shorten the drying time, reduce energy consumption, and improve product quality. [3]. Therefore, how to combine the two drying methods organically, to find the appropriate conversion point and the best process conditions, to reduce the energy cost and improve the quality, has very important practical significance.

Although China is a big carrot producing country, due to market environment, mismatched production and marketing information, backward storage and transportation facilities, and long regional transportation distances, carrots are structural, regional, seasonal, and difficult to circulate. In addition, carrots contain a large amount of water above 80%, and most of them are mainly free water. It is very easy to rot and deteriorate due to the action of microorganisms and enzymes, causing significant economic losses [4]. According to statistics, the corruption rate of fruits and vegetables in China is as high as 20-30%, and annual losses are as high as 100 billion yuan. At present, the processing of carrots in China is mainly in terms of freezing and fresh-keeping storage, while the deep processing also mainly stays in carrot beverages, carrot purees, and vitamins extracted from carrots. The technology is relatively backward [5]. For carrots, although he has rich nutrients, he doesn't have the flavor of fruit in it, so the processed carrot drink is far from tasteful if the juice is not well accepted by others. As for the extraction of carotene, currently the fruit vitamin extraction process is still used in industry, but there are still big differences between carrots and fruits. Carotene is a fat-soluble component and most of the current extraction equipment is mainly for extracting water-soluble components. Will result in lower extraction rate of carotene [6]. Carrots contain zinc, calcium, iron and other trace elements and 8 kinds of essential amino acids and dietary fiber. Especially, they are rich in β-carotene, which is a nutritious vegetable. Processing carrots into carrot powder can not only be used directly, but also can be added as an additive in other foods, which has broad market prospects. Reasonable drying methods and conditions are the key to the production of carrot powder [7].

Tatemoto has developed a drying method with a low drying temperature and a high drying rate, which results in small changes in the volume of the biological sample. Freezing pretreatment is combined with fluidized bed drying under reduced pressure. The cylindrical carrot samples were frozen and then immersed in a fluid bed of inert particles under reduced pressure without thawing. Freeze-pretreated carrots have a higher drying rate than their untreated counterparts [8]. Maria evaluated the effects of various pre-drying treatments on the quality of dried carrots by assessing the values of moisture, ash, protein, fiber, sugar and color. The pre-drying treatment studied was immersed in ascorbic acid or sodium metabisulfite at different concentrations and pretreatment times, and then hot-scald. The neural network was used to analyze the experimental data to find the relevant patterns in the data, and to draw conclusions for each variable [9]. Hui studied the effects of flow rate on humidity, drying rate, and product quality in the microwave drying process under 5 types of safe flow rate and 4 types of variable flow rate. The results show that the flow rate has a significant effect on humidity, drying rate and product quality. The smaller the flow, the higher the humidity, but the lower the drying speed, the better the product quality. In addition, the drying speed will decrease slightly, but the effect is not obvious. When the flow rate is gradually increased, the quality of carrots is the best. In the initial stage of drying, the drying rate is low, and in the middle stage, it gradually rises [10]. Chen uses three drying methods to prepare carrot ultrafine powder from fresh raw materials, and uses solid phase microextraction (SPME) / chromatography-mass spectrometry (GC-MS) technology to compare and analyze volatile components in fresh carrots. Carrot superfine powder. The results showed that the main aroma components of fresh carrot samples were carotenoids, such as caryophyllene, which reduced terpenoids, but after short-wave and mid-wave infrared drying, vacuum drying, and explosive bulk drying, aldehydes, ketones, and other compounds were produced [11]. To improve heat and mass transfer in hot air drying, Luo directly coupled power ultrasound to hot air drying of fresh carrot slices. The effects of ultrasonic power, radiation distance, hot air speed and temperature on drying characteristics were studied. In addition, the Page equation is used to fit the ultrasonic-assisted hot-air drying process of carrot slices [12].

In short, this article focuses on the hot air-drying characteristics of carrot slices. Factors affecting the drying characteristics of carrot slices include hot air temperature, wind speed, relative humidity, carrot slice thickness, and load capacity. The effects of hot air drying, microwave vacuum drying and heat pump drying on the physical properties, nutritional composition, microstructure and sensory evaluation of carrot products were studied. Specifically, the main research content of this article is roughly divided into five parts: the first part is the introduction part, which aims to systematically review the main research content of this article from the research background, research purpose, research ideas and methods; the second part is The theoretical basis is mainly to theoretically explain the different drying methods, and to analyze and explain the characteristics of carrots. The third part is the experimental part. The effect of different drying methods on the drying characteristics of carrots was investigated by querying the data and conducting related experiments. The fourth part is the analysis of the data. The effects of different drying methods on the physical properties, nutritional composition, microstructure and sensory evaluation of carrot products are detailed and systematically summarized. The fifth part is the summary and suggestions of this article, which is a summary of the results of the article.

## 2. Proposed Method

### 2.1. Carrot Drying Technology

Compared with the fruit and vegetable processing industry in developed countries, the overall level of development of China's fruit and vegetable processing industry is low, and many problems and deficiencies still exist. Among them, the processing of carrots is still at the level of fresh preservation or simple freezing, and the deep processing is relatively backward, which makes it difficult to quickly improve the economic benefits of the carrot industry in China. At present, there are several drying techniques for carrots:

(1) Sun exposure refers to the method of drying fresh produce to a certain degree under natural conditions such as the sun and natural wind. This method has low equipment requirements, easy operation, and low cost, but the drying is very slow, the drying time is relatively long, the drying process is not easy to control, and the weather environment has a greater impact on it. During the drying process, it is opened repeatedly. Drying will breed mold and cause pollution. Due to the long

drying time, the product will eventually turn yellow. The quality of sun-dried products is difficult to guarantee and cannot meet the production requirements of large-scale production.

(2) Hot air-drying technology. At present, 90% of China's vegetable drying processing uses hot air drying at normal pressure. Hot air-drying equipment is composed of heat source, drying room, hot air system and temperature control system. Its working principle is: according to the principle of heat and mass transfer, it is heated by heat sources such as electricity, petroleum, natural gas, coal, etc. Dry hot air is used as the drying medium, and the drying medium is in contact with the material. The internal moisture gradually migrates from the inside to the outside, which in turn causes the moisture content of each layer of the material to gradually decrease from the surface and the inside. The water is finally evaporated on the surface of the material to obtain a dry product.

(3) Microwave vacuum drying technology. During microwave vacuum drying, in a vacuum environment where the heating source is microwave radiation, the process of heating the material and dehydrating the material. Microwave energy can penetrate into the material, and the dipole molecules (such as water molecules) in the material are regularly arranged in the electromagnetic field and oscillate at high speed. A lot of heat is generated due to friction and collision between the molecules. Partially obtains heat and heats up at the same time, the water molecules in the material escape, so as to achieve the purpose of drying. Microwave vacuum drying has the characteristics of high efficiency, fast speed, low temperature and so on.

(4) Far-infrared drying technology. When the far-infrared radiation is incident on the material, if the frequency of the incident far-infrared radiation is the same as the natural frequency of the molecules in the material, it will cause a strong resonance, called resonance absorption, and the molecular movement inside the material is strengthened. The temperature of the material rises rapidly, and the absorbed far-infrared radiation energy is converted into heat, thereby achieving the purpose of drying.

(5) Vacuum freeze-drying technology. Water in nature has three phases, liquid, gaseous, and solid. The three phases can transform and coexist. Vacuum freeze-drying first freezes fresh foods quickly. Under vacuum conditions, the water in the food is directly sublimated. Finally, the bound water is dehydrated and dried by analyzing and removing the part. The refrigeration unit, drying chamber, vacuum equipment, control device and heating equipment constitute a vacuum freeze-drying system. The vacuum freeze-dried product can retain the skeleton structure of the original material, and the original form of the material is retained.

(6) Variable temperature differential pressure puffing drying technology. Puffing tanks and vacuum tanks are the main equipment for variable temperature differential pressure puffing and drying. The vacuum tank is five to ten times the size of the puffing tank. Fruit and vegetable raw materials need to be pre-dried to a moisture content of 15% -35%, and the initial moisture content required by various fruit and vegetable raw materials is different.

(7) High-voltage electric field drying technology. The basic principle of high-voltage electric field drying is "electric field energy transfer." Many plants have porosity, and water is mainly filled in the small voids in the plant. Under the action of a non-uniform electric field, because water molecules have polarity, the water molecules in vegetables that originally moved irregularly began to be regularly drawn to the material. On the surface, moisture is lost on the surface of the material and gets dried.

(8) Spray drying is a method of drying powdery or granular dry products obtained by heating water and other materials after being atomized by hot air and losing moisture. Subtle aerosol shape, quickly loses water under heating to produce powder products, reducing evaporation, crystallization and separation and other drying processes.

## 2.2. Carrot Drying Medium and Process

During the drying process, the materials are affected by hot air temperature, wind speed and other parameters. Under aerobic conditions, the surface of the materials is prone to browning or oxidation to deteriorate the appearance. Temperature-sensitive nutrients are also lost during the drying process, excessive drying of fruits and vegetables or improper drying methods can also cause poor rehydration of dried products. Reasonable pretreatment methods can reduce drying time, improve drying quality, and save energy. Commonly used pretreatment methods include hot water blanching, salt or sugar impregnation, and low temperature freezing.

Hot air drying usually uses air as a drying medium, but during the drying process, some components in the air will chemically react with the materials, causing browning of the materials, which seriously affects the drying quality. The selection of a suitable drying medium has an important impact on the drying quality of the material.

Carrots are affected by factors such as hot air temperature, wind speed, material thickness, and load during hot air drying. Hot air temperature is an important influencing factor in the drying process of the material, which directly affects the final drying quality of the material and the energy consumption during the drying process. When the temperature is too low, the material will dry slowly, and browning or mildew will easily occur during the drying process. When the relative humidity in the drying room does not change, as the temperature increases, the more water vapor the hot air needs to reach saturation, the faster the moisture in the material will evaporate, which can increase the drying speed of the material and reduce the drying process energy. Consuming. However, when the temperature of the hot air is too high, it is easy to cause the cells in the material to rapidly expand and rupture, leading to the loss of nutrients, which also damages the internal structure of the material and reduces the rehydration of the material.

And the material is easy to coke because the material is too high, affecting the final appearance of the material. The wind speed of hot air is also an important influencing factor. During the hot air circulation process, the water vapor evaporated on the surface of the material can be continuously taken away. The larger the wind speed can also reduce the thickness of the air layer on the surface of the material, reduce the thermal resistance, and increase the heat transfer coefficient. Material slicing affects the drying rate of the material. The thicker the material is, the more the path for moisture to move inside the material is increased, thereby reducing the drying rate. And when the material is too thick, the surface is likely to cause surface hardening when the surface and internal water loss rates are not balanced. The slow evaporation of internal moisture will also reduce the drying rate of the material. When the material is too thin, it is easy to cause the material to lose water too quickly and deform seriously, affecting the final appearance quality. The load capacity mainly affects the drying rate of the material. When the material tray has too much load, it will cause the material to accumulate, the gap between the materials will be reduced, the air flow between the materials will be weakened, and the overlap of the materials will cause the evaporation surface to decrease, which may cause dryness. Even the phenomenon of dry and wet inside will occur.

Pretreatment of carrot slices before drying can improve the drying rate, nutrient retention and sensory quality of carrot slices during drying. The selection of carrot flakes drying medium can also improve the appearance quality and rehydration of dried carrot flakes products to a certain extent. But these factors are not the main influencing factors in the drying process of carrot slices. The research on the drying process of carrot flakes can find that the main influencing factors on the drying characteristics of carrot flakes are hot air temperature, hot air speed, material thickness, material tray load, and relative humidity of hot air in the drying room.

## 3. Experiments

### 3.1. Materials and Instruments

The test materials used the same batch of fresh carrots purchased from the local farmers market, with an average moisture content of 88.6%. Select an appropriate amount of carrots, cut them horizontally and cut into slices (4 mm thick) after washing. Put in 2% salt water and blanch at 95 ° C for about 2 minutes. Remove and place in cold water to cool. After cooling, remove and drain. Dry and use a filter paper to absorb the surface moisture, and then weigh out several samples for use. Glucose, petroleum ether, phenol, oxalic acid, ascorbic acid, dinitro salicylic acid, Sino pharm Chemical Reagent Co., Ltd .; β-carotene standard, Sigma-Aldrich, USA; concentrated sulfuric acid, Beijing chemical plant; sodium dichloroindophenol , Beijing Guandao Henry Technology Co, Ltd ; Maltodextrin, Henan Knawel Food Additive Co, Ltd. The instrument used during the test, its model and accuracy are shown in Table 1:

*Table 1. Instrument and its model and accuracy*

| Equipment name | Model and accuracy | Manufacturer |
|---|---|---|
| Electric heating constant temperature blast drying box | GZX-9140MB | Shanghai |
| High-precision anemometer | UTP-313, accuracy 0.01g | Shanghai |
| Temperature and humidity sensor | TESTO 425, accuracy ±0.03m / s | Germany |
| Data acquisition instrument | Ms-7310 | United States |
| Electronic single-phase energy meter | 34972A | Shanghai |
| Nebulizer | HH171010 | Zhejiang |

The drying test device consists of 101A-3 electric heater, centrifugal fan (0.1 kW, 2 800 r / min), hot air-drying room and M9G89G microwave oven. Other instruments and equipment are: SW P-C801 digital display temperature controller, JW S3AT temperature and humidity transmitter, EDK-1A handheld anemometer, JA3003 electronic balance (accuracy 0.001g) and so on. Reasonable drying method and drying conditions are the key to the production of carrot powder. Therefore, this experiment uses currently used four methods of hot air drying, vacuum drying, microwave drying and microwave-vacuum drying to prepare carrot powder. The quality characteristics of carrot powder produced by four processing techniques were evaluated and compared.

Hot air drying: drying temperature 70℃, wind speed 2.5 m / s, drying time 4 h. Vacuum drying: drying temperature 70℃, vacuum degree 1 k Pa, drying time 4 h. 3) Variable temperature differential pressure puffing and drying: Carrot slices are dipped in 40% maltose syrup for 2 h, drained and dried with hot air at 70℃for 2 h, and then subjected to variable temperature differential pressure puffing and drying, provided that the puffing temperature is 90℃The stagnation time is 10 min, the pressure is 0.2 MPa, the evacuation temperature is 70℃, and the evacuation time is 140 min. Spray drying: inlet air temperature 135 ℃, exhaust air temperature 7 ℃, feed volume 20 m L / min, high pressure pump pressure control 12.5 ~ 15.0MPa, the amount of auxiliary agent is maltodextrin: carrot dry matter = 3: 1Quality ratio). The moisture content of the materials after drying through the above drying methods is controlled within a safe moisture content, all below 6%.

### 3.2. Experimental Methods and Steps

Before the test, the carrots were washed and dried on the surface, and cut into slices of carrots of a certain thickness. The carrot slice is too thin, the internal moisture migration distance is small, the resistance is small, and the drying rate is fast, but it will cause severe deformation of the edge part during the drying process, severe overall shrinkage, and serious drying quality degradation. The relative surface area of the sliced carrot slices that are in contact with hot air is reduced, and the internal heat and mass transfer resistance is increased, resulting in excessive drying time. Therefore, if the slice is too thick or too thin, it is not conducive to drying. The thickness of the slice should be 5mm for drying test. Weigh the carrot slices in each test to ensure that the load of the test material tray is the same for each test. Before the test, spread the carrot slices evenly on the material tray to avoid overlapping. Five carrot slices with a diameter of 3.5 cm were selected as samples, and the initial weight was weighed with an electronic scale and placed in the middle, upper left, upper right, lower left, and lower right corners of the material pan, respectively. Before the start of each test, the initial drying room temperature and relative humidity were set by a temperature and humidity automatic control device. Adjust the wind speed with the wind speed regulator. When the preset parameters are reached, the material pan containing the carrot slices is placed on the material rack in the drying room. Select a carrot slice from the side and insert a thermocouple from the middle to measure the center temperature change of the carrot slice. The temperature data is collected by a data acquisition instrument. The sample carrot slices are taken out from the sampling port every 30 minutes to measure the mass and make a record. The measurement time does not exceed 15s until the moisture content of the wet base is below 13% and the drying is stopped. In order to compare different working conditions, the endpoint wet base moisture content is uniformly set to 10%.

As shown in Table 2, use the comprehensive weighting method to evaluate the sensory quality of dried carrot products. The perfect score is 100 points. The quality with the highest score is best based on agricultural standards. It is composed of 10 experienced sensory evaluators. The review team gave sensory scores to dried carrot products.

*Table 2. Carrot sensory scoring criteria*

| Scoring indicators | Rating level | | | |
|---|---|---|---|---|
| Exterior | Complete shape 10 | Slightly shrunk 7.5 | Large shrinkage 5 | Severe shrinkage 2.5 |
| Color | Orange red 10 | Crimson 7.5 | Light red 5 | Burnt 2.5 |
| texture | Tough 10 | More resilient 7.5 | Crispy 5 | Easily crushed 2.5 |
| Flavor | Strong fragrance 10 | Light aroma 7.5 | Low sweetness 5 | No sweet taste 2.5 |

In order to verify the different characteristics of hot air drying, microwave drying and hot air and microwave combined drying, a combined drying test device was established to conduct a comparative test on the drying of wet materials. In the test, three moisture contents of 60%, 50%, and 40% (wet basis) were selected as the conversion points of the two drying methods. The combination of hot air and microwave drying refers to dividing the entire drying process into two stages: The materials are first dried by hot air. When the selected moisture content is reached, the materials are dried by microwave to the final product. Then the pre-processed materials are dried by hot air and microwave, respectively, as a control test. The hot air temperature and wind speed were controlled at 55, 65, 75 °C, and 2.5 m / s, respectively, and the microwave power was controlled at 170W, 255W, and 340W, respectively. The orthogonal test scheme was adopted for the test. In the hot air-drying process, the mass of the material was measured every 15 minutes, and the microwave drying was measured every 2 minutes to obtain the drying curve of the moisture content of the carrot slices based on the drying time. During the measurement, it is ensured that the measurement is prompt and timely, and the data is read accurately, until the measured moisture content of the wet base is 7 ±0.5% (safe storage of moisture).

Cut the same batch of carrots into diced carrots with a dicing machine of 5 mm 5mm ×5 mm, and use three drying methods: hot air drying, microwave real drying, and heat pump drying to dry to a safe moisture content. (Dry basis moisture content <13%). Hot air-drying parameters: temperature 50 °C, loading capacity 300 g, drying time 6 h. Microwave vacuum drying parameters: temperature of 50 °C, microwave power of 1.70 k W, loading capacity of 600 g, and drying time of 2.3 h. The temperature of the heat pump is 50 ℃, the wind speed is 2 m / s, the load is 2 000 g, and the drying time is 7.5 h.

## 4. Discussion

### 4.1. Analysis of the Influence of Different Drying Methods on Drying Characteristics

The drying characteristics of the combination of hot air and microwave drying can be explained by the drying curve. Whether it is hot air drying or microwave drying, the drying curve of carrots has the general characteristics of typical drying curves:

(1) With the increase of hot air temperature or microwave power, the slope of the drying curve becomes larger. This shows that with the increase of hot air temperature or microwave power, the drying speed increases and the drying time shortens; but in the later stage of hot air drying, the slope of the drying curve becomes smaller, showing a continuous and smooth state, and the temperature effect is not obvious, indicating that the hot air drying speed is significantly reduced. Is in the slowdown stage. The reason is that as the drying progresses, the surface structure of the material hardens and prevents the internal moisture from being discharged.

(2) The lower the hot air drying temperature, the more favorable it is to inhibit the non-enzymatic browning reaction, but the drying time is too long, which is not conducive to improving the production efficiency; the higher the drying temperature, the less the drying time, and the higher the temperature, the easier it is to promote the drying process or storage During the non-enzymatic browning reaction, the hot air drying temperature of carrot should not exceed 75 ℃.

(3) As shown in Figure 1, the higher the moisture content of the material at the transition point, the faster the drying speed during microwave drying, and the shorter the total drying time; and the lower the moisture content, the slower the drying speed, and the longer the total drying time. Obviously, this is because the higher the moisture content, the shorter the hot air-drying time, and the higher the moisture content during microwave drying, the greater the microwave energy absorbed by the moisture, the shorter the material heating time, and the faster the drying speed. When the moisture content of the material at the drying transition point is 60%, 50%, and 40%, the total drying time under the same microwave power drying is 92, 97, and 99 min. At the same moisture point, the high-power microwave drying, the total drying time Short (75 min); when low-power microwave drying, the total drying time is longer (90 min), indicating that the power effect is more significant.

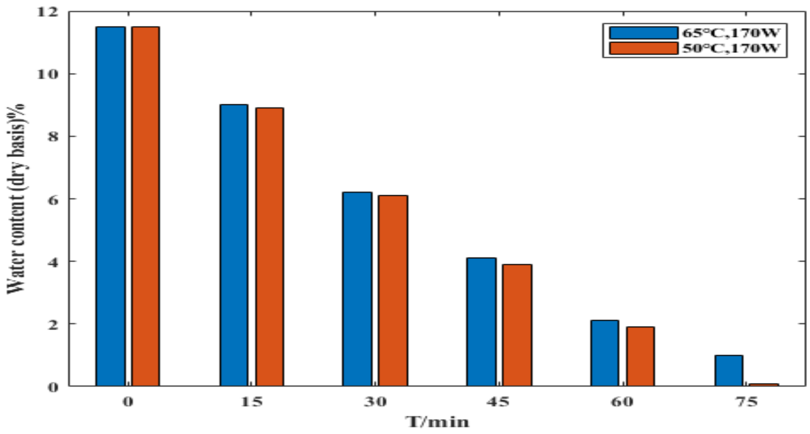


*Figure 1. Combined drying diagram under different moisture content*

As shown in Table 3, in the hydration capacity of carrot powder under different drying methods, the hydration capacity is heat pump drying> microwave vacuum drying> hot air drying, and the difference is not significant. During the drying process, as the water disperses and the temperature rises, the product will shrink to a certain extent, and the internal cell tissue structure will be damaged to a certain extent. This damage is irreversible. Whether it can be restored to the original state after drying depends on the drying method The degree of damage to the material.

*Table 3. Hydration ability of carrot powder under different drying methods*

| Analysis Project | Hot air drying | Microwave vacuum drying | Heat pump drying |
|---|---|---|---|
| Hydration capacity | 4.16±0.24a | 4.35±0.14a | 4.42±0.27a |

As shown in FIG. 2, in the drying curve of carrots with different wind speeds, under the conditions of constant temperature and loading capacity, the larger the wind speed, the shorter the drying cycle. When the wind speed is 3m / s, it takes 7h to dry to a safe moisture content, and when the wind speed is 1m / s, it takes 8h, which is 1h more. The higher the wind speed, the greater the rate of water loss from the surface of the carrot, which accelerates drying and reduces the time required to dry to a safe moisture content. From the drying rate curves of carrots with different wind speeds, it can be known that the entire drying process is divided into three phases: rising speed, constant speed and deceleration. The wind speed has a greater impact on constant speed and falling speed.

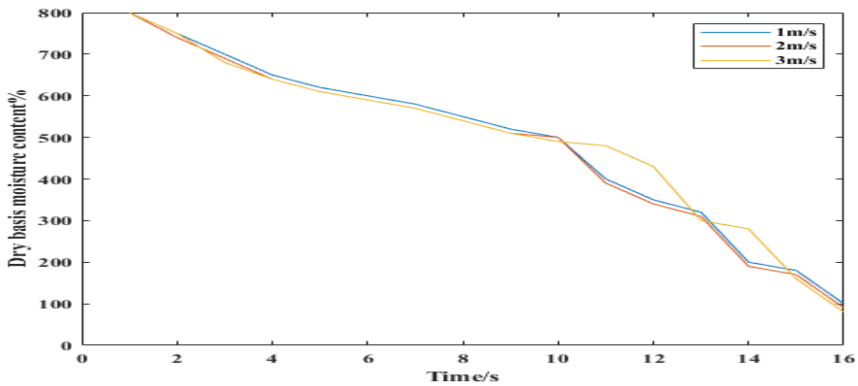


*Figure 2. Carrot drying curve with different wind speeds*

### 4.2. Influence of Temperature and Humidity on Hot Air-drying Characteristics of Carrots

In order to reduce the drying time and drying energy consumption while ensuring the drying quality of carrot slices, this paper carried out a research on temperature and humidity drying on the basis of constant temperature and constant humidity drying. The comparative analysis of the drying characteristic curve and drying quality of carrot slices under the relative humidity of 20%. Increasing the relative humidity in the drying room for the first 30 minutes can quickly warm up the inside of the carrot slices to balance the internal and external drying rates, while reducing the overall relative humidity. It can increase the drying rate of carrot slices. Therefore, the relative humidity is set to 50% in the first 30 minutes of the drying room in a temperature-humidity drying test, and the subsequent stage is set to 20%, and the temperature change interval is 45-65 ℃.

As shown in Table 4, the rehydration rates of dried carrot slice products under the conditions of heating and dehumidifying, cooling and dehumidifying, and constant temperature and humidity were 82.47%, 73.48%, and 78.46%, respectively. The comparative analysis shows that the heating and dehumidifying drying rehydration rate is the highest, and the rehydration rate of the constant temperature and humidity drying products is better than that of the cooling and dehumidifying drying. There is not much difference in color and shrinkage of the dried and dried products at elevated temperature and humidity and constant temperature and constant humidity. The dried and dried products at reduced temperature and humidity are slightly yellow in color and shrink slightly, which may be caused by the high temperature in the previous period. Comprehensive evaluation is made from the sensory, rehydration rate, energy consumption, and drying time of dried carrot flakes. The best drying method is drying at elevated temperature and humidity.

*Table 4. Rehydration rate under different conditions*

| Working condition | Rehydration rate% |
|---|---|
| Temperature dehumidification | 82.47% |
| Cool down | 73.48% |
| Constant temperature and humidity | 78.46% |

As shown in Figure 3, it is the change curve of the moisture content of the wet base under two working conditions. It can be seen from the figure that the drying time for heating and dehumidifying is 330min, the drying time for cooling and dehumidifying is 330mi, and the drying time for constant temperature and humidity is 430min. No matter it is heating and dehumidifying drying, or cooling and dehumidifying drying, the drying time is less than constant temperature and constant humidity drying, which can effectively reduce the drying time of carrot slices. Before 150min, the changes in moisture content of constant temperature and constant humidity and temperature rise and decrease humidity are basically the same. With the increase of temperature, the decrease of moisture content of temperature increase and decrease in moisture content is greater than that of constant temperature and constant humidity. The temperature in the early stage of the cooling and dehumidifying drying is relatively high, and the moisture content of the wet base decreases more than the heating and dehumidifying drying and constant temperature and constant humidity drying.

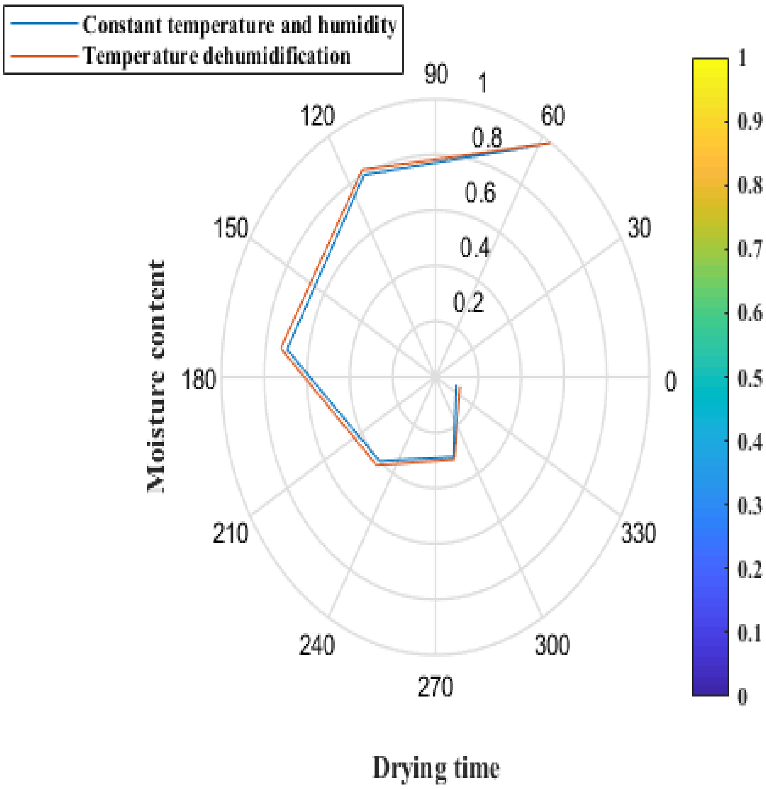


*Figure 3. Variation curve of wet base moisture content under different working conditions*

As shown in Figure 4, it is the drying speed ratio under different working conditions. It can be known from the figure that the drying rate gradually increases with increasing temperature, and the drying rate gradually decreases when drying to a certain degree. It may be because the free water content in the carrot slices is gradually reduced in the later stage, and the semi-bound water needs to be converted into free water to evaporate and discharge, which delays the drying rate. Cooling and dehumidifying drying because the early temperature is higher than the constant temperature and humidity drying and heating and dehumidifying drying, but when the moisture content of the dry base is less than 2g / g, the drying rate is lower than the heating and dehumidifying and drying. It has been discharged in large quantities, and the moisture content in the final carrot slices is relatively small, and it is not easy to discharge. The overall drying rate of the cooling and dehumidifying drying is higher than that of constant temperature and constant humidity drying, which may be because the high temperature drying in the early stage destroys the tissue structure of the carrot slices, so that the temperature in the later stage is still higher than 55 °C although the temperature is lower than 55 °C. When the moisture content of the dry base is higher than 6g / g, the heating and drying rate is lower than the constant temperature and humidity drying and cooling and dehumidification drying. This is because the temperature is lower in the early stage of drying, but the drying rate is higher in the later stage as the temperature increases. Dry at constant temperature and humidity. The power consumption for heating, dehumidification and drying is 4.33k W h, the power consumption for cooling, dehumidification and drying is 4.25k W h, and the power consumption for constant temperature and humidity is 4.66 k W h. It can be seen that the power consumption of heating and dehumidifying drying and cooling and dehumidifying drying are both lower than constant temperature and constant humidity drying.

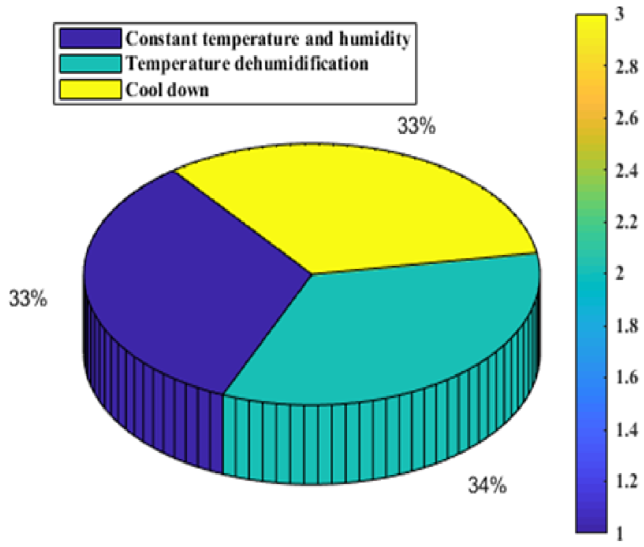


*Figure 4. Drying speed ratio under different working conditions*

## 5. Conclusion

(1) In this chapter, the effects of hot air temperature, wind speed, and hot air relative humidity on the drying rate, quality of dried products, and water rehydration of carrot slices are discussed. The study found that under the conditions of relative humidity and wind speed, the higher the temperature, the faster the drying rate, and the shorter the drying time. However, if the temperature is too high, the carrot slices will shrink severely, the hair will be hard and the rehydration will be poor. Drying temperature. Under the condition of certain temperature and relative humidity of hot air, increasing the wind speed can increase the drying rate, but increasing to a certain extent the effect of wind speed on the drying rate is reduced. The wind speed has little effect on the appearance and color of dried carrot slices. The dry product has better rehydration, and the best drying wind speed is 1.5m / s.

(2) Hot air temperature, microwave power, and material moisture content at the drying transition point have significant effects on the drying rate and the sensory quality of the product. The test results show that increasing the wind temperature, enhancing the microwave power, and increasing the moisture content of the material at the transition point can increase the drying rate and shorten the drying time. When combined with hot air and microwave drying, the material is dried under reduced hot air drying time, low temperature, and low power. Its effective ingredients are not easy to lose, and the quality of the product is high. Under the conditions of hot air temperature and wind speed, high relative humidity can increase the material heating rate, but the drying time is too long, and the drying time is too long, resulting in poor rehydration of dry products. Low relative humidity can reduce the drying time of carrot slices.

(3) Among the 3 drying methods, the microwave drying rate is the largest, the total drying time is the shortest (30 min), and the senses are better (at low power); the hot air drying rate is the smallest, the total drying time is the longest (120 min), and the senses are poor. Using the combination of hot air and microwave drying method, the drying rate is more than 1.4 times higher than that of conventional hot air drying, the total drying time is shortened by as much as 34 minutes, and the color, aroma, shape and structure of the dried product are significantly improved.

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## Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

## Conflict of Interest

The author states that this article has no conflict of interest.

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