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Research on Application and Rehydration Rate of Vacuum Freeze Drying of Rice

Kuang-Cheng Yu, Chien-Cheng Chen and Pei-Cheng Wu
Department of Refrigeration, Air Conditioning and Energy Engineering,
National Chin-Yi University of Technology, Taiwan, Republic of China

Abstract: Global warming has become more and more serious nowadays. It leads to abnormal climates and the increasing frequency of natural disasters such as draughts or floods and cause poor harvests of many crops. For the Orientals, rice is one of their main foods. To ensure the benefit of grain storage, this study proposed the vacuum freeze drying method to research the rice storage, prolonging the food storage time and maintaining its original flavor and nutrients. The drying mode was able to maintain the color, flavor and taste of food and had the features of lightweight and good rehydration. The vacuum freeze-drying was a method integrating the vacuum, freeze and drying technologies to process food. The vacuum freeze drying principle was utilized to dehydrate the rice. Four different procedures and methods were used in the process of vacuum freeze-drying. The rehydration experiment was then carried out to recover the original moisture content and taste of rice within the same time period. The results obtained were analyzed by the statistical methods to discuss the effects of different freeze drying methods on the rice rehydration rate. The experimental results indicated that during freeze drying, the rice with a slower heating rate in shelf heating produced a better water absorption rate and taste performance.

Key words: Rice, lyophilization, vacuum, freeze, drying

INTRODUCTION

Vacuum freeze drying (also known as Lyophilization scientifically) is a method utilizing both vacuum and freeze procedures to allow the moisture to sublimate under the vacuum state, so as to form dry materials (Hottot *et al*., 2006). The biological and chemical properties of the materials after freeze drying remain the same and their volume reduce slightly; however, their texture presents a loose and porous state. Due to the lowered moisture content, the materials are harder to deteriorate by oxidation, able to inhibit bacteria propagation and convenient for long-term storage. Furthermore, after the addition of water, these materials can recover to the state before freeze drying and retain their original properties. In the freeze drying process, since the gas pressure inside the vacuum chamber is lower than the atmospheric pressure, resulting in a smaller molecular number and lower oxygen content, the vacuum freeze drying method can prolong the storage time and maintain the nutrients of the easily oxidized materials, food, agricultural products and medicinal drugs (Forestry Bureau, 2006). Therefore, the technologies relevant to vacuum freeze drying are widely used in the fields, such as agriculture (vacuum freeze drying of vegetables, melons and fruits), food industry (vacuum package and vacuum drying of fast food), chemical industry (drying of the powdery chemical agents) and biological pharmaceutical products (freeze drying of hormones, antibiotics, blood preparations, medicine for examination, vitamin agents and blood serum) (ITRC, 2004).

Vacuum freeze drying is a continuous process under very low pressure, where the products or materials are processed under low temperature and pressure and the moisture is drained not through the liquid state course but directly through the sublimation in a gas state (Fissore *et al*., 2008). Therefore, the products processed through vacuum freeze drying can prevent the loss of nutrients, such as proteins and vitamins, thus maintaining most of the original nutrients and effectively prevent the oxidation, nutrients transformation and state change during the drying process. The products after freeze drying present a spongy shape without shrinkage and have very good rehydration ability, convenient edibility and very low moisture content. Moreover, they can be stored and transported under normal temperature for a long time after packaging. The special characteristics of these products are as follows:

Corresponding Author: Kuang-Cheng Yu, No.35, Lane215, Sec.1, Chung-Shan Rd., Taiping City, Taichung County 411, Taiwan, Republic of China Tel: (04) 23924505 Fax: (04)23930062

- Thorough dehydration which is good for long-term storage
- Low product shrinkage which makes it easy to maintain the organization structure and appearance of the raw materials
- Porous and spongy inside presents excellent rehydration
- Full preservation of the nutrients, active substances and the natural color and flavor of the raw materials
- The reduction of product moisture content lowers the material weight for convenient transportation

In the biotechnological field, vacuum freeze drying is the most suitable method for products with high heat sensitivity, such as vaccine or protein preparations and is a very effective method to promote the stability of preparations in the pharmacy process (Quan *et al.,* 2003), which makes the medicaments more compatible with some special circumstances, such as wars or disasters. In relevant researches, when the bottom of drugs contacts excessive heat, it causes the disintegration and dissolving of the dry products and has a great effect on the color (Barresi *et al*., 2009). In pharmaceutical manufacturing process, it is important to ensure the stability of drugs (Kumar *et al*., 2009) by utilizing the temperatures of tray shelves and samples to determine the optimum shelf temperature in primary drying (Barresi *et al*., 2007), shorten the drying time and drain the moisture fast without ebullition (Chua and Chou, 2004). Therefore, in pharmaceutical manufacturing process, primary drying is usually carried out on a shelf with the temperature lower than 0°C and in a low-pressure vacuum environment to obtain drugs with higher quality (Searles *et al*., 2001a; Mosharraf *et al*., 2007).

In food processing and agriculture, the vacuum freeze drying technology could prevent the loss of nutrients in food and maintain good appearances and colors. Observed under an electron microscope, the cell appearance is intact (Xu *et al*., 2005) after drying. Vacuum freeze drying is suitable for processing nutritious dry food due to its antioxygenation (Meterc *et al*., 2008; Wojdylo *et al.,* 2009) and is able to produce a better quality when used in porous materials (Nastaj *et al*., 2008). In the drying process, the parameters of condenser temperature, shelf temperature and chamber pressure are controlled directly, where the shelf temperature control affects the moisture sublimation rate directly. Products suffering from excessive heat on its bottom would cause dissolving (Franks, 1998). Meanwhile, the vacuum freeze drying experiments are carried out respectively on different fruits and vegetables, such as apples, bananas, radish and tomatoes; as the result of applying different pressures and freezing temperatures in the process indicates that the temperatures of the materials affect the freezing results and their freezing temperatures need be obtained through experiments (Wolkers *et al*., 2002). Studies on the storage effects of roses and carnations after vacuum freeze drying found that the vacuum degree in the freeze drying process affects the colors and strength of the petals (Brulls and Rasmuson, 2002, 2009).

This study aims to discuss the manufacturing process of reducing the moisture content of 60% of cooked rice to below 5% through the vacuum freeze drying process, while maintaining the starch chain in rice and the flavor as freshly cooked rice after rehydration (expansion after absorbing water). This technique could provide a choice of fast food, frozen rice, for outdoor usage or food supplies during disasters. It is convenient as instant noodles that is ready to eat after adding hot water.

PRINCIPLES OF VACUUM FREEZE DRYING

Vacuum freeze drying (or lyophilization) removes the moisture, which causes the food to spoil easily, through the vacuum and freezing procedures. Products after freeze drying can be stored under the room temperature for a long time, or packaged in a limited storage space and can be recovered for use after adding some water. The principle of vacuum freeze drying is to place the fast frozen materials under the vacuum state, heat them for sufficient dehydrating and drying and finish the transformation of materials from the frozen state to the dehydrating and anti-spoiled state (Searles *et al*., 2001b).

Before discussing the principles, the following should be understood at first: (1) the schematic diagram for the phase state of water; and (2) the eutectic temperature of water and solution and the formation of the eutectic point (Fig. 1).

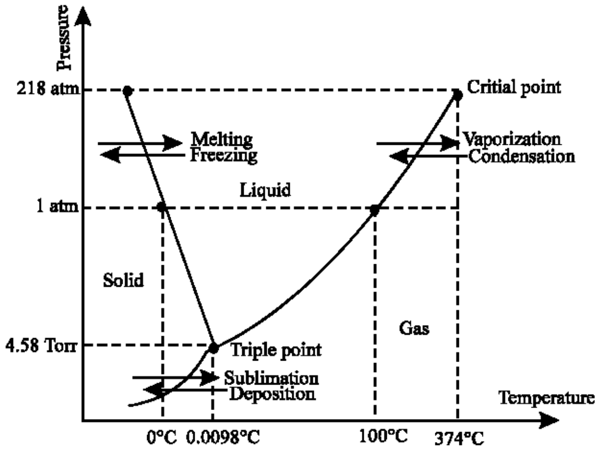

Fig. 1: Schematic diagram for the triple phases of water

According to the thermodynamic equilibrium, the temperature of the water triple point is 0¡æ with the pressure of 4.58 Torr. In the process of water phase changing, when the pressure inside the vacuum chamber is lower than that at the triple point, the ice in a solid state can sublime directly into the vapor in a gas state to transgress out of the material surface without changing into water in a liquid state. Meanwhile, since the moisture absorbs a large quantity of latent heat in the process of sublimation, the latent heat provided through shelf heating will dry out the material.

Vacuum freeze drying is a method to freeze the materials and lower their temperatures below the eutectic temperature to transform the moisture in the materials into solid ice and then under the low pressure and temperature environment, heat the shelf to make the frozen ice crystal sublime into vapor. Finally, the vapor is condensed through the cold trap in the vacuum system to form dry air and pump it out by a vacuum pump, so as to obtain the dry products.

Vacuum freeze drying is carried out in three parts and according to relevant procedures:

- Quick-freezing process
- Sublimation or primary drying process
- Desorption or secondary drying process

COMPOSITION OF EXPERIMENTAL EQUIPMENT SYSTEM AND EXPERIMENT METHODS

Systematic processing equipment: Vacuum freeze drying used in this experiment was composed of the freezing, vacuum, heating, condensing and monitoring systems. Figure 2 shows the systematic schematic diagram. Other peripheral equipments include a low-temperature refrigerator (-50°C), a moisture meter, a vacuum packing machine and a precise electronic scale (Table 1). The treatments of materials before and after the manufacturing process and the posterior storage are provided.

Experiment methods: Freeze drying was carried out on the same batch of freshly cooked rice with different moisture contents and heating rates on heating shelves in groups. The experimental procedures of each group are described as follows:

Freeze drying test of rice with different moisture contents: Test of moisture content: freshly cooked rice was taken and cooled naturally and divided into normal rice (control group) and soaked rice (comparison group); the vacuum freeze drying procedure was carried out after the moisture content tests.

Table 1: Peripheral equipments

Designation	Function
Low-temperature refrigerator fast freezing	Fast freezing of the materials at the for temperature of -50°C
Moisture meter	Measuring the moisture contents of the materials before and after drying
Vacuum packing machine	Vacuum packing and proper storage of the dried materials
Precise electronic scale	Measuring the weights before and after drying

Table 2: Procedures and time for vacuum drying

	Control group		Comparison group	
Stages	Set shelf Temp. (°C)	Time (min)	Set shelf Temp. (°C)	Time (min)
1	-8	60	-10	60
2	-3	60	-8	30
3	0	120	-3	90
4	15	60	0	120
5	25	60	15	60
6	40	240	25	60
7			40	240
Final product temperature	22.4		22.9	
Total time		10 h		11 h

Control group: The moisture content test was conducted on 10 g of freshly cooked rice using a moisture meter in the mode of 140°C for 60 min. The measured moisture content was about 59.5%.

Comparison group: The same batch of freshly cooked rice was soaked in warm water at 45~50°C for 30 min. During soaking, a stirring rod was used to stir continuously to make the rice grain disperse. The rice was drained after soaking. The moisture content test was conducted on 10 g of the rice using a moisture meter in the mode of 150°C for 60 min. The measured moisture content was about 66.7% (Fig. 3, 4).

Tests of different heating rates: Figure 4 shows flow chart of freeze drying tests of rice with different heating rates in shelf heating. Procedures and time for vacume drying is shown in Table 2.

RESULTS AND DISCUSSION

The rice freeze drying experiment was divided into two parts. In the first part, the same rice with increased moisture content (after soaked in water) was compared with the original fresh rice that had been frozen and dried directly; this comparison is to discuss the effect of moisture content of rice on its rehydration rate and taste

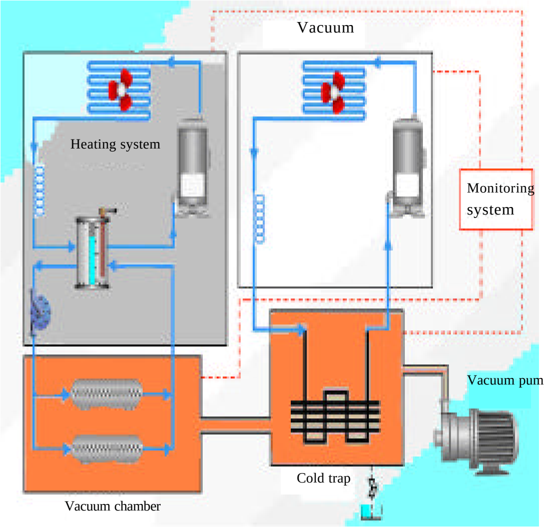

Fig. 2: Systematic schematic diagrams for vacuum freeze and drying

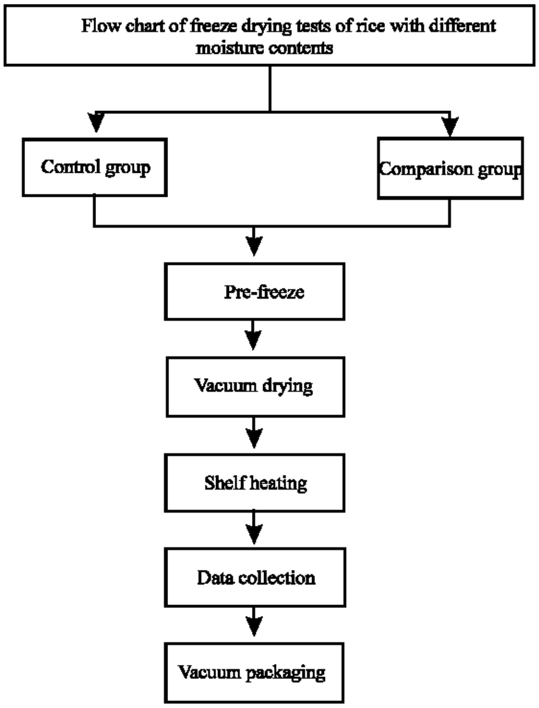

Fig. 3: Flow chart of freeze drying tests of rice with different moisture contents

after rehydration. In the second part, two different sublimation heating rate curve methods were used to transfer the heat to the frozen rice in different shelf temperatures for the sublimation reaction; this is to discuss the effect of different heating temperatures and heating time lengths on the rehydration rate and taste after rehydration.

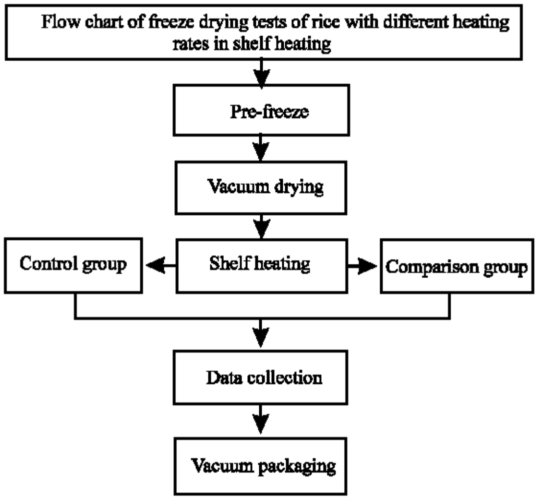

Fig. 4: Flow chart of freez drying tests of rice with different heating rates in shelf heating

Rehydration Experiment Methods: After the completion of rice freeze drying, the data of the rice before and after drying through four different freeze drying methods were collected, as shown in the data sheet of the rice before and after freeze drying in Table 3. The rehydration experiment was carried out, using a plastic water penetration cup. Three cups of water, A, B and C, were used for each rehydration experiment, about 25 g dried rice (including the cup weight) was used and the weight before rehydration was measured. The net weight of the plastic water penetration cup was about 15 g and about 300 cc boiling water was filled into the cup and stirred uniformly. This cup of water and rice was covered and

Table 3: Data sheet of rice before and after freeze drying

	Before drying		After drying	
Freez mode	Weight	Moisture content	Weight	Moisture content
Program mode A	221.0	59.5	95.5	3.7
Program mode B	213.4	70.0	71.4	2.6
Program mode C	230.0	67.7	75.5	2.0
Program mode D	241.0	67.7	74.0	0.6

Table 4: Data sheet of rice before and after rehydration: No. A*

Grams	Cup A	Cup B	Cup C	Total
Before rehydration	25.4	25.8	25.6	25.6
After rehydration	46.0	45.1	48.3	46.5
Solids	10.015	10.400	10.208	10.208
Moisture (before)	0.385	0.400	0.392	0.392
Moisture (after)	17.510	16.405	19.295	17.737
Moisture content	63.615	61.201	65.400	63.471
Rehydration rate	106.92	102.86	109.92	106.67

*Moisture content after freeze drying

Table 5: Data sheet of rice before and after rehydration: No. B

Grams	Cup A	Cup B	Cup C	Total
Before rehydration	25.3	25.2	25.4	25.3
After rehydration	53.0	50.3	50.6	51.3
Solids	10.032	9.935	10.130	10.032
Moisture (before)	0.268	0.265	0.270	0.268
Moisture (after)	23.545	21.335	21.420	22.100
Moisture content	70.122	68.228	67.892	68.779
Rehydration rate	117.85	114.67	114.10	115.59

*Moisture content after freeze drying 2.6%

Table 6: Data sheet of rice before and after rehydration: No. C*

Grams	Cup A	Cup B	Cup C	Total
Before rehydration	25.9	26.0	24.4	25.4
After rehydration	45.5	48.6	46.1	46.7
Solids	10.682	10.780	9.212	10.225
Moisture (before)	0.218	0.220	0.188	0.209
Moisture (after)	16.660	19.210	18.445	18.105
Moisture content	60.932	64.055	66.692	63.908
Rehydration rate	102.41	107.65	112.09	107.41

*Moisture content after freeze drying 2%

Table 7: Data sheet of rice before and after rehydration: No. D

Grams	Cup A	Cup B	Cup C	Total
Before rehydration	24.3	25.2	25.1	24.9
After rehydration	47.7	49.5	47.6	48.3
Solids	9.244	10.139	10.039	9.807
Moisture (before)	0.056	0.061	0.061	0.059
Moisture (after)	19.890	20.655	19.125	19.890
Moisture content	68.271	67.075	65.577	66.976
Rehydration rate	114.74	112.73	110.21	112.57

*Moisture content after freeze drying 0.6%

placed still for 10 min. After absorbing sufficient water, the rice was taken out to drain off the water for about 2 min and then the weight after rehydration was measured.

Results: According to the rehydration methods the data of dried rice through four freeze drying methods before and after rehydration were arranged as Table 4-7.

Fig. 5: Specimen A

Fig. 6: Specimen B

Equation for rehydration rate:

- Equation for solids weight: (weight before rehydration-cup weight) * (1 - moisture content after freeze drying)
- Equation for moisture content rate: (moisture in rice/gross weight of rice)*100%
- Equation for rehydration rate: (moisture content after rehydration/ moisture content before rehydration) * 100%

Analysis and descriptions: According to the above data obtained from the rehydration experiment, the freeze drying of the rice in the first part, specimens A and B) was carried out according to the different moisture contents of rice. Specimen A (control group) was frozen and dried directly from normal cooked rice, while the moisture content of specimen B (comparison group) was increased


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Fig. 7: Specimen C


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Fig. 8: Specimen D

to 66.7%. As seen from the experiment data, the mean rehydration rate of specimen A (control group) was about 106.67%, while that of specimen B (comparison group) was 115.59%, which has a better rehydration efficiency. Specimen B had a better taste; however, the taste of specimen A was poorer due to hard grain cores, as shown in Fig. 5 and 6.

According to the above data, the freeze drying of the rice in the second part, specimens C and D, was carried out according to the different heating temperatures and heating time. Specimen C (control group) was frozen and dried at a higher heating rate, while specimen D (comparison group) was frozen and dried at a lower heating rate. As seen from the experiment data, the mean rehydration rate of specimen number C (control group) was about 107.1%, while that of specimen D (comparison group) was 112.57%, which had a better rehydration efficiency. Specimen D had a better taste and plumper appearance after rehydration, as shown in Fig. 7 and 8.

CONCLUSIONS

The tray shelf vacuum freeze dryer was used to study the rehydration rate of rice after freeze drying. The rehydration rates of rice under different moisture contents and heating rates were compared, where the rice in the first part was frozen and dried in the same procedures according to different moisture contents. The rehydration test showed that the comparison group (with higher moisture content after soaked in water) has a better rehydration rate and taste. The rice in the second part with the same high moisture content after soaked in water was heated at different heating rates;. The rehydration test found that the rice frozen and dried at a slower heating rate has a better rehydration rate and taste. Therefore, the following conclusions are obtained:

- After soaked in water, the rice moisture content increased and the rice grains were plumper, which presented a more porous phenomenon after freeze drying, thus its rehydration rate increased and had a better taste
- In the freeze drying process, a high heating rate would cause the formation of ice crystal on the surface of rice close to shelf to melt and sublime quickly, which led to a firm texture and a poor rehydration rate. Therefore, in the freeze drying process, the heating rate should not be too fast. According to the experiment results, before primary drying, the temperature of the middle section of the shelf should be controlled under 0°C to provide a better rehydration rate and taste
- Based on the results, the moisture content of rice in program mode A is 3.7, while that in program mode B is 2.6, through mode C is 2.0 and that in mode D is 0.6. As shown, the moisture content is the highest in program mode A and the lowest in mode D
- Specimen D was frozen and dried with a slow heating rate, thus has a mean rehydration rate of 112.57%, while specimen C has a mean rehydration rate of 107.1%. As illustrated, specimen D has a better rehydration rate and taste and its grain appearance is plumper after rehydration

RECOMMENDATION

The application and the rehydration rate of vacuum freeze drying of rice were explored in this paper. There is still room for improvement on the rice quality and rehydration time control, as suggested below:

- In this experiment, the rehydration time was set as 10 min, expecting to present the rehydration characteristics of rice; however, this caused the
- moisture content of the rice after rehydration exceeding that in the freshly cooked rice. In future studies, the rehydration time should be controlled more precisely to obtain the optimal rehydration effect
- The rice used in this study was processed from the ready-made rice in take-out restaurants; however, the moisture contents and cooking time of the new and stocked rice, as well as the moisture control were not considered. These issues should be discussed in future studies to provide extended storage methods and procedures of frozen and dried rice or other foods, in order to produce the rice with an optimal quality and color, where the flavor and taste could reach the standards of homemade rice

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