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Research Article

Study on Freeze-drying Process of Frozen Poached Meatballs

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Abstract: In this study, the technology of freeze-drying of poached meatballs was studied. Also, the effect of the pre-freezing time, drying temperature and the loadage of per unit on drying rate and rehydration ratio was investigated. the technological conditions of freeze-drying of poached meatballs and the parameters of the industrial process have been optimized by orthogonal tests. The results shows that the optimical conditions of freeze-drying poached meatballs are: pre-freezing temperature is -60°C, pre-freezing time is 4 h, drying temperature is 45°C and the loadage of per unit is 320 kg/m^2.

Keywords: Freeze-drying, poached meatballs, rehydration ratio, technological conditions

INTRODUCTION

Poached meatballs are the public loved traditional food, because of the large moisture content of the poached meatballs, which caused much inconvenience in storage, transportation, sales and cooking. Yet, if the technique of freeze-drying can be used, the problems caused during production and storage above will be solved and its quality guarantee period will be lengthened and the nutrition can be held, too (Gao *et al*., 1998). The freeze-drying, is the use of sublimation principle, work is under vacuum pressure, so that the primary freeze of the material in the water, without ice melting, ice sublimate directly into gas in the vacuum distillation of the state to go off, vacuum freeze-drying products was able to ensure food protein, vitamins and other nutrients, especially those who are not volatile loss of heat-sensitive components and maximize their original nutrients and can inhibit the harmful effects of bacteria and enzymes to effectively prevent the drying process of oxidation. The freeze-dried food can be long-term preservation and easy to transport because of the weight light (Zhang, 2009). However, the long drying time, large energy consumption and high production cost limit its application. Therefore, in this study, we studied the conditions of freeze-drying poached meatballs in order to find optimized conditions and shorten drying time, decrease energy consumption and production cost, expecting to obtain technical basis for the production of poached meatballs (Cui *et al*., 2007).

METHODOLOGY

Material and apparatus: Meat, shallot, egg, are all bought in local market.

The vacuum freezing dryer is LGJ-12S, produced by Huaxing. Technology Development LTD. Songyuan Beijing. AB204-N electronic analytical balance (Mettler-Toledo Group).

The process of freeze-drying poached meatballs:
Preparation of poached meatballs: Put the mashed meat and shallot into a stainless steel basin with the ratio of 1:0.5, then add some salt and moderate egg and mix them evenly. Put the poached meatballs with diameter of 2 cm into the boiled water for 4 min, then take them out with a colander and dry them in the air.

The pre-freezing of poached meatballs: Weigh the poached meatballs with a balance and then put a certain weight of them on the plates as possible as evenly. After loading them on four plates, the plates were put into freeze-drying equipment, adjust the requested freezing time and start pre-freezing.

The drying of poached meatballs: After pre-freezing, the frozen poached meatballs are taken out and put into the drying room, then turn on the vacuum pump. After the pressure of drying room decreases below 15 Pa, press the heating button and drying process will be conducted under 10, 20, 30, 40 and 45°C, successively.

The drying rate (%/h) can be counted as follows (Wang and Fang, 2005):

$$F = 100 \times \frac{M_1 - M_2}{M_1 \times t}$$

In which,
M_1 = The initial mass before freeze-dried, g
M_2 = The mass after freeze-dried, g
t = The drying time, h

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Rehydration of poached meatballs: Weigh sample of 10 g and put them into boiled water for 10 min, take out and weigh them again and calculate their rehydration ratio (Chen *et al*., 2002). The rehydration ratio can be counted as follows:

$$R = \frac{M_3}{M_2}$$

In which, M_3 is the mass of the wrappers after rehydration, g.

RESULTS AND DISCUSSION

The effect of pre-freezing time on drying rate and rehydration ratio of poached meatballs: Under the condition of the drying temperature is 45°C, the loadage is 360 g, when pre-freezing time is 1, 2, 3, 4 and 5 h, respectively, the effects of pre-freezing time on the freeze-drying rate and the rehydration ratio. Effects of pre-freezing time on drying rate and rehydration ratio of poached meatballs are shown in Table 1. Effect of pre-freezing time on drying rate is shown in Fig. 1. Effect of pre-freezing time on rehydration ratio is shown in Fig. 2.

It can be seen from Fig. 1 and 2 that both drying rate and rehydration ratio reach the highest when the pre-freezing time is 4 h and have little change later. If the pre-freezing time is short, material won't be frozen thoroughly and there will be some water existing. In vacuum, the water will be evaporated, which not only makes the volume of the freeze-drying material smaller but also the gas dissolved in the solution will escape, thus making some blister on the surface of material (Liu, 2013). Because of the reasons above, the product won't form a porous state and the enterclose for water to get out is blocked in a sense, decreasing the drying rate. What's more, as material isn't frozen thoroughly, the material will melt and collapse with the increase of drying temperature during drying and certainly the effect of hydration will be affected. Yet, if pre-freezing time is too long, energy consumption will be increased. On the other hand, long pre-freezing time makes material frozen thoroughly. The mobility of molecule is weak and keeps material more stable. Moreover, during drying, product won't melt and collapse easily, can keep the porous state and the rehydration of frozen products is good (Guo, 2012).

Table 1: Effects of pre-freezing time on drying rate and rehydration ratio of poached meatballs

	1	2	3	4	5
Before drying (g)	80	80	80	80	80
After drying (g)	27.20	26.40	26.00	24.40	23.60
Drying rate (%/h)	3.14	3.19	3.21	3.31	3.27
Rehydration ratio	2.06	1.94	1.97	2.29	2.21

Table 2: Effect of drying temperature on drying rate and rehydration ratio of poached meatballs

	10°C	20°C	30°C	40°C	45°C
Before drying (g)	80	80	80	80	80
After drying (g)	27.70	26.90	26.60	24.50	23.60
Drying rate (%/h)	3.11	3.16	3.18	3.30	3.36
Rehydration ratio	1.93	2.08	2.19	2.18	2.31

Effect of drying temperature on drying rate and rehydration ratio of poached meatballs: Under the condition of the pre-freezing time is 4 h, the load age is 360 g, when the drying temperature is 10, 20, 30, 40 and 45°C, respectively, the effects of drying temperature on drying rate and rehydration ratio of poached meatballs is shown in Table 2. Effect of drying temperature on drying rate is shown in Fig. 3. Effect of drying temperature on rehydration ratio is shown in Fig. 4.

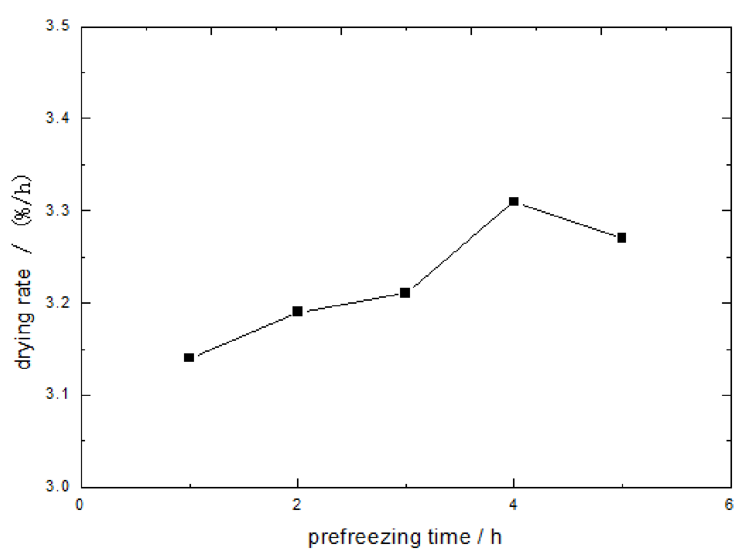

Fig. 1: Effect of pre-freezing time on drying rate

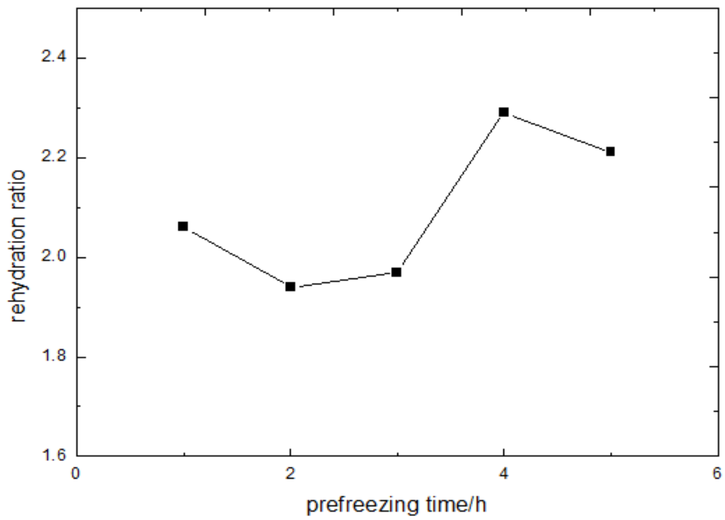

Fig. 2: Effect of pre-freezing time on rehydration ratio

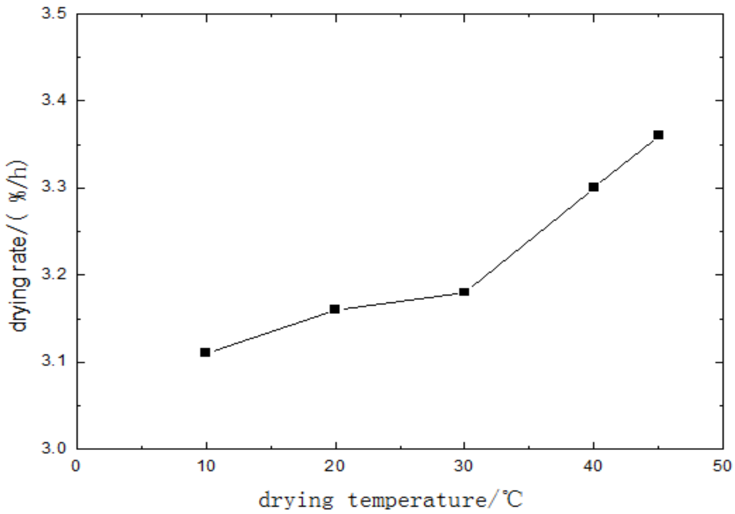

Fig. 3: Effect of drying temperature on drying rate

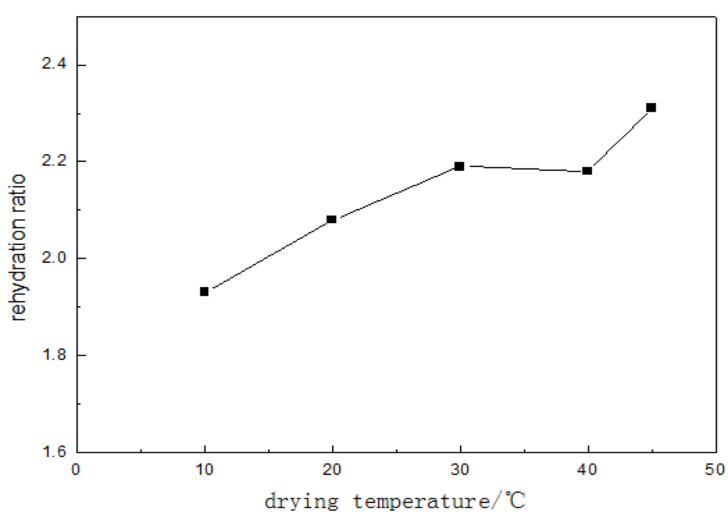

Fig. 4: Effect of drying temperature on rehydration ratio

Table 3: Effect of loadage on drying rate and rehydration ratio of poached meatballs

	280	320	360	400	440	520
Before drying (g)	70	80	90	100	110	130
After drying (g)	21.30	24.40	25.20	28.80	34.10	41.80
Drying rate (%/h)	3.33	3.36	3.42	3.39	3.29	3.23
Rehydration ratio	2.37	2.39	2.31	2.26	2.19	2.11

Drying processes consist of two stages, that is, sublimation drying and desorption drying. Sublimation drying is stated from the surface of material to the interior and the gap after ice crystal sublimates becomes the effusion way of the water vapour. When all the ice crystal is removed, about 90% water of product has been removed (Xu *et al*., 2004). Desorption drying is also called the second stage of drying. The rest 10% water is adsorbed on capillary wall of the dried material and some polar groups. This part of water is not frozen and need removing in order to improve the quality of product after being dried and prolong its preservation period.

As is shown in the Fig. 4, the higher the temperature of the plate is, the larger the drying rate will be. The reason is that in the former of sublimation drying, if the temperature of the plate is lower and there is a temperature difference with eutectic temperature of the material, then the temperature of inner is lower than that of the surface, heat flux is small and driving force of mass transport is small, too. In this moment, if the temperature of the plate increases, there will be more heat reaching the surface of the material, the temperature of the interface increases swiftly, heat flux increases, driving force of mass transport increases. Therefore water vapor will escape more quickly and the drying time will be shortened. However, if we keep increasing the temperature of the plate, during the latter state of drying process, the inner temperature is close to eutectic temperature of the material. Then if the inner temperature reaches the eutectic temperature, material will be out of shape, shrunk and separated from the plate. So heat transport will be hindered and drying time is longer, or because of the subsided access blocked by the collapse of the material.

The hydration ratio of poached meatballs is relatively high when the temperature is between 40 and 45°C. Though 45°C is the highest temperature in contrast with the other temperature data, yet, it’s still far lower than the disintegration temperature of material (Wu, 2010).

At this temperature, poached meatballs have the largest rehydration ratio. This might be because the temperature of the plate is rather low in contrast with the freeze-drying of poached meatballs. In this term, drying rate is low, driving force of mass transport is small and water vapor effuses slowly. From this point, it can be concluded that water vapor can pass through drying layer more slowly, which does less harm to the cellular tissure. What’s more, the effect of rehydration is much better as the porous structure will be preserved completely. In spite of the low temperature of the plate in former data, yet, their drying rates are much lower in the same drying time. It’s probably because the un-thoroughly drying affects the inner of poached meatballs as well as the rehydration properties (Li, 2010). So we can conclude that the best temperature range of the plate is 40-45°C with the permitted conditions of the equipment.

Effect of loadage on drying rate and rehydration ratio of poached meatballs: The effects of drying temperature on drying rate and rehydration ratio of poached meatballs was studied when the pre-freezing time is 4h, the drying temperature is 45°C and the load age is 280, 320, 360, 400, 440 and 480 g respectively. Effect of loadage on drying rate and rehydration ratio of poached meatballs is shown in Table 3. Effect of loadage on drying rate is shown in Fig. 5. Effect of loadage on rehydration ratio is shown in Fig. 6.

As we know the drying process is started from the surface to the inner, therefore the thicker the layer of dried material is, the larger the resistance of heat transport is, the more drying time will be (Yi, 2008). The wet material to be dried on per unit in the vacuum freezing drying oven is an important factor that determines the drying time. Therefore, the less loadage is good for freeze-drying. Yet, in actual production, this conduct can decrease productivity and utilization of capacity. As can be seen from Fig. 5 and 6, with the increase of loadage, drying rate increases first and then decreases a little later. When the loadage is too small, the drying area of material is less. With the same drying conditions, the water from sublimation drying is less and drying rate is relatively slow since the drying property of the drier has been applied thoroughly. When the loadage is from 360 to 400 g, drying rate has been affected that much. But if the loadage is above 400 g, drying rate decreases obviously. This may be because of the pile of the excess material. Or since the drying area is smaller and the canal for water escaping has narrowed, thus resistance of mass transport is larger (Liu and Wang, 2012; Yang and Liu, 2010). In addition, rehydration ratio shows an inclining tendency. The larger the loadage is, the smaller the drying rate is. In a certain drying time, the effect won’t be satisfactory, inner structure of material is affected, too and the rehydration effect is certainly not good. All in all, the effect is good when the loadage is from 360 to 400 g.

Orthogonal experiments with multiple factors: According to the results of experiments with single factor, we arranged an orthogonal experiment of three factors and three levels with pre-freezing time being 2, 3 and 4 h, drying temperature being 30, 40 and 45°C and loadage being 280, 320 and 360 g, respectively in

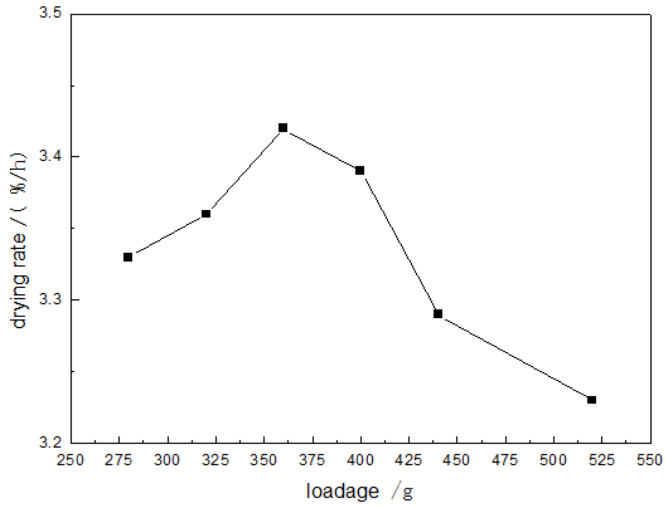

Fig. 5: Effect of loadage on drying rate

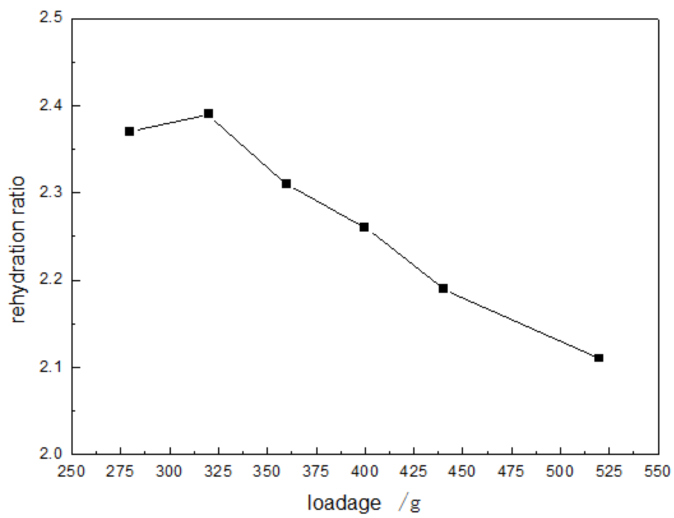

Fig. 6: Effect of loadage on rehydration ratio

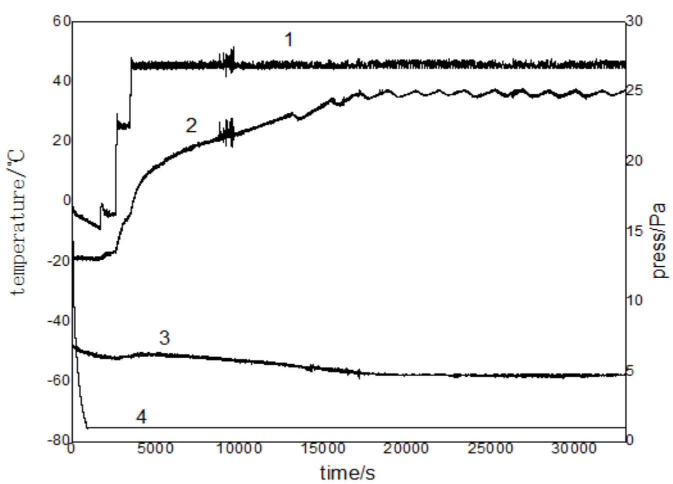

Fig. 7: The freeze-drying curve of poached meatballs
1: Plate temperature; 2: Samples temperature; 3: Cold trap temperature; 4: Degree of vacuum

Table 4: Factor level of the orthogonal experiments

Factor	Pre-freezing time (h)	Drying temperature (°C)	Loadage (g)
1	2	30	280
2	3	40	320
3	4	45	360

order to investigate the drying rate and rehydration ratio of the poached meatballs. Factor level Table of the orthogonal experiments is shown in Table 4 and the results of the orthogonal experiments are shown in Table 5.

It can be seen from the results of the orthogonal experiments that the order of the factors that affect drying rate is drying temperature, pre-freezing time, loadage. And the drying rate is the largest when pre-freezing time is 4 h, drying temperature is 45°C and loadage is 320 g.

The order of the effect of the three factors on rehydration ratio is pre-freezing time, drying temperature, loadage. And the rehydration ratio is the largest when pre-freezing time is 4 h, drying temperature is 45°C and loadage is 320 g.

Taken into consideration of energy, working time, the quality of the poached meatballs and production, the optimized experimental conditions of freeze-drying poached meatballs are pre-freezing time is 4 h, drying temperature is 45°C and loadage is 320 g.

The freeze-drying curve of poached meatballs: It can be seen from the results of experiments with single factor and the orthogonal experiments that the best conditions for freeze-drying poached meatballs are when pre-freezing time is 4 h, drying temperature is 45°C and loadage is 320 g. Under the conditions, the freeze-drying curve of poached meatballs is shown in Fig. 7.

It can be seen from the Fig. 7 that the temperature of the poached meatballs slowly increases with the increase of that of the plate. The heat that the solid ice needs to sublimate can be provided by the plate when the temperature is higher than that of the poached meatballs. In the beginning of the process, as the heat of the plate can't meet the need of ice sublimation, so the heat of poached meatballs is also used to provide the heat of ice sublimation. Therefore, the temperature of the plate will decrease as well as the temperature of poached meatball itself. Later, with the increase of the temperature of the plate, heat that ice in the poached meatballs need to sublimate can be supplied by the plate, so the temperature of poached meatballs will slowly increase. At last, when ice in the poached meatballs sublimate thoroughly and the heat provided by plate can't meet the sublimation of bound water, at this moment, the temperature of poached meatballs will increase quickly. With the sublimation of the bound water in poached meatballs, the process of freeze-drying will come to an end gradually. The vacuum degree almost maintains 1 Pa un-constantly during the process. This indicates that the water vapor can be pumped smoothly and swiftly, thus making the process go smooth and poached meatballs won't collapse and melt during freeze-drying (Hua, 2005).

CONCLUSION

The freeze-dried poached meatballs with the technique of vacuum freeze drying had been studied. Experiment results show that pre-freezing time, drying temperature, loadage have the great effect on drying rate and rehydration ratio of poached meatballs. Taken into consideration of energy, working time and the quality of the poached meatballs, the optimized experimental conditions of freeze-drying poached meatballs are pre-freezing time is 4 h, drying temperature is 45°C and loadage is 320 g, under this condition, the drying rate is 3.31 %/h and rehydration ratio is 2.37.

Table 5: Results of the orthogonal experiments

Factor	Pre-freezing time	Drying temperature	Loadage	Result 1 (drying rate)	Result 2 (rehydration ratio)
1	1	1	1	3.15	1.92
2	1	2	2	3.18	1.91
3	1	3	3	3.21	1.94
4	2	1	2	3.17	2.20
5	2	2	3	3.26	2.26
6	2	3	1	3.29	2.36
7	3	1	3	3.18	2.19
8	3	2	1	3.30	2.33
9	3	3	2	3.31	2.37
K11	3.18	3.17	3.25	-	-
K12	3.24	3.25	3.22	-	-
K13	3.26	3.27	3.22	-	-
R1	0.08	0.10	0.03	-	-
K21	1.92	2.10	2.20	-	-
K22	2.27	2.17	2.16	-	-
K23	2.30	2.22	2.13	-	-
R2	0.38	0.12	0.07	-	-

REFERENCES

Chen, C.G., J.J. Liu, D.S. Chen and L. Zhang, 2002. Effect of blanching on drying green legume of Pisinum sativum. Food Sci. Technol., 10(12): 16-17.

Cui, Q.L., Y.M. Guo and Z.H. Yao, 2007. Effects of the operating parameters on energy consumption of secondary drying during vacuum freeze-drying. J. Chin. Inst. Food Sci. Technol., 7(4): 56-61.

Gao, F.C., Z.S. Liu and X.Q. Li, 1998. Freeze-dried Food. China Light Industry Press, Beijing, China.

Guo, S.G., 2012. Experiment study on technology parameters for freeze-drying of Ginseng slice [D]. Ph.D. Thesis, Shenyang Agricultural University.

Hua, Z.Z., 2005. Vacuum Freeze Drying Technology. Science Press, Beijing, pp: 146-149.

Li, Y.N., 2010. The Study on vacuum freeze drying technology of Yam Powder [D]. M.A. Thesis, Hebei QAgricultural University, China.

Liu, J., 2013. Study of freeze-drying process and rehydration performance of convenient instant dumpling [D]. Zhengzhou University, China.

Liu, Y.G. and X.F. Wang, 2012. Study on the vacuum freeze-dried technology of strawberry and production line designing. Food Ind., 34(3): 77-80.

Wang, F.C. and J. Fang, 2005. Research of wonton of Freeze drying experimental. Food Feed Ind., 22(12): 27-29.

Wu, X.H., 2010. Study on the freeze drying characteristics and drying technology optimization of Pinang-taro [D]. M.A. Thesis, Fujian Agriculture and Forestry University, China.

Xu, C.H., S.W. Zhang and K.Z. Guan, 2004. Vacuum Drying. Chemical Industry Press, Beijing, China.

Yang, M. and B.L. Liu, 2010. Study on freeze drying technique of red-cooked meat. J. Anhui Agric. Sci., 50(26): 14781-14783.

Yi, X.H., 2008. Theoretical and experimental study on heat and mass transfer of firedrake fruit's vacuum freeze-drying [D]. M.A. Thesis, Tianjin Commercial University, China.

Zhang, X.G., 2009. Study on fabrication process and storage-tolerance of instant dumplings [D]. M.A. Thesis, Jilin University, China.