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Research Article

Research Progress of Hot Air Drying Technology for Fruits and Vegetables

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Abstract: The aim of this study is to describe the hot air drying in the field of fruits and vegetables drying the research present situation, put forward the hot air drying of problems need to be solved in the study and the future development trend is prospected. Hot air drying is the most commonly employed commercial technique for drying biological products. However, the processing technique is short of systematic research, especially in the relationship between energy consumption and output. Therefore, the optimization of combination drying and the application of energy-saving technology will be the problems that are urgently needed to solve in the future research of hot air drying technology.

Keywords: Fruits and vegetables, hot air drying, thin layer drying

INTRODUCTION

Drying refers to the process of removing moisture from the dried materials under the natural or manual conditions, which is not only one of the important processes during the processing of fruits and vegetables products, but also a main method for the storage of fruits and vegetables dried products. At present, the fruits and vegetables drying technologies mainly include several methods of hot air drying, microwave drying, vacuum drying, freeze drying and heat pump drying (Zhang *et al*., 2009a). Each method has its irreplaceable advantages; hot air drying technology obtains the advantages of mature equipment, easy operation and low cost, which is the most extensive drying method in current industrial production.

Hot air drying is a kind of traditional drying method, which uses the heated air as the drying medium and transfers heat to the wet materials according to the heat conduction effect; two diffusions will be produced after the wet materials absorb heat, which are the external diffusion of the moisture from materials surfaces to the dry medium and the internal diffusion of the moisture in materials to the materials surfaces; these two diffusion are continuously proceeded until the moisture in materials descends to certain degree and realize the purpose of drying (Niu *et al*., 2008). Drying the drying process, the moisture on materials surfaces will be evaporated firstly after being heated and then the water vapor will be diffused from the materials surfaces to the ambient air medium; the moisture content on the surface is lower than the internal moisture, so the moisture gradient exists (Liu and Zhou, 2008). The moisture will be diffused from the part with higher moisture content to the one with lower moisture

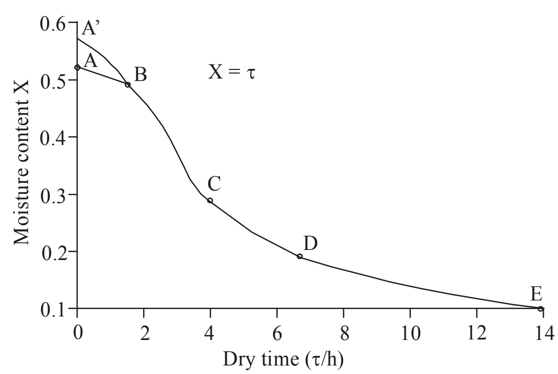

Fig. 1: Timely varying curves of moisture content

content due to the existence of moisture gradient; meanwhile, the materials surfaces are heated higher than the center, so certain temperature gradient will be established inside the materials and the temperature gradient will promote the moisture transfer from the part with higher temperature to the one with lower temperature, that can be seen from Fig. 1. Therefore, both moisture gradient and temperature gradient will exist inside the materials at the same time during the drying process. For hot air drying, the heat is transferred to the center from the materials surfaces and the moisture flow direction is on the contrary, which means the directions of moisture gradient and temperature gradient are on the contrary (Yang, 2009). The temperature gradient will become the obstructive factor for the moisture diffusion along with the moisture gradient, so the moisture diffusion is obstructed (Li *et al*., 2008). If moisture gradient is stronger than temperature gradient, the moisture will be transferred along with the direction where the materials

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moisture is decreased (Xu, 2010). If temperature gradient is stronger than moisture gradient, the moisture will be transferred along with the direction of the heat flow and developed to the direction of moisture increase; the moisture content of materials decreases, slows or stops, the purpose of drying can't be realized and the phenomena of materials surfaces hardening and crusting will appear, so this kind of condition shall be avoided as much as possible during the process of hot air drying. Therefore, the research status of hot air drying in various fields of fruits and vegetables drying was summarized in the study, presenting the problems to be solved in the research of hot air drying and pointing out the development trend in the future.

LITERATURE REVIEW

The technology of hot air drying is widely applied in traditional food processing, especially popular in the processing of fruits and vegetables. Currently, 90% of China's vegetables dehydration adopts hot air drying of ordinary pressure; the drying of various fruits mostly adopts hot air drying. Domestic and overseas science researchers have performed lots of test and research on various fields of hot air drying and obtained substantial progress in various aspects, including hot air drying theory and process.

Process study on hot air drying: Li Ke *et al*. studied the influence of main technological parameters (drying temperature, drying wind speed and the density of filling materials) of cooked sweet potato on drying rate, unit energy consumption and the main nutrient components content of starch, reducing sugar and Vc by adopting central composite rotatable design and response surface method. The result showed that the drying temperature, wind speed and density of filling materials had the greatest impact on the drying rate, unit energy consumption, Vc content and comprehensive index, but less impact on starch, reducing sugar, crude protein and crude fibre content (Li *et al*., 2008).

Zhang *et al*. (2009a) performed research on hot air drying and analyzed the influence rule of hot air temperature, section thickness and load loading capacity on unit energy consumption, that can be seen from Fig. 2, the suitable scope of the factors were confirmed respectively: hot air temperature was 45-75°C, slice thickness is 1-5 mm and loading capacity was 1.5-5.3 kg/m^2; the unit energy consumption, production volume and the regression function between various factors were, respectively established through quadratic orthogonal rotating design, the optimum technology parameter was: the temperature of dry medium is 62.3°C, section thickness was 2.38 mm, the loading volume was 2.69 kg/m^2 and the least energy consumption of the predicted theory was 1.96 kWh/kg. The verification test showed that, about 27% of energy saving could be realized compared to the average energy consumption of ordinary domestic production (Zhang *et al*., 2009a).

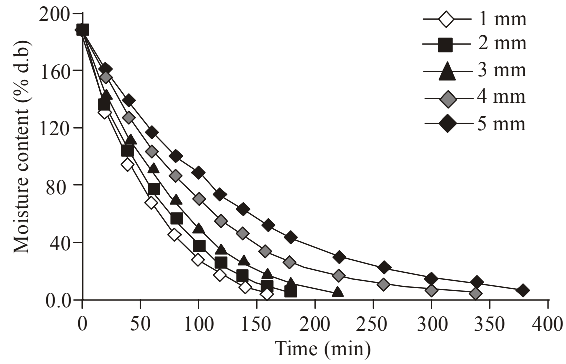

Fig. 2: Effect of sample thickness on dehydration characteristic of garlic slices

Gao *et al*. (2010) studied the influence of inlet temperature and wind speed, the rotational speed of the rotary dryer and feeding speed on the moisture content of the leave materials and stem materials when they were out of the machine and the separation rate of steam leaf during the research on the drying separation process of fresh and chopped alfalfa stems and leaves, adopted 9GFQA-600 separation equipment of alfalfa dry stems and leaves to conduct the test and four factors rotation-orthogonal combination design to proceed regression analysis and establish relevant mathematical model to optimize (Gao *et al*., 2010).

Chang *et al*. (2008) performed study on hot air drying, investigated the influence of heating temperature, wind speed and materials quantity on the content and color of Vc, through orthogonal experimental design the primary and secondary sequence of the influential factors was confirmed: heating temperature>material quantity>wind speed and the optimum technological parameters were confirmed: the temperature was 70°C, the material quantity was 60 g and the wind speed 2.5 m/sec (Chang *et al*., 2008).

Taking bamboo shoot slice as the research target, hot air drying test under the pre-treatment process of optimum blanching was performed by Gong (2009), the influence of hot air temperature, wind speed and thickness of bamboo shoot slice on the drying effect were investigated and better process conditions of bamboo shoot hot air drying were confirmed: blanching temperature was 90°C, blanching time was 8 min, thickness of bamboo shoot slice was 1 cm and the length was about 8 cm; 5 h of hot air drying shall be performed under the wind speed of 2.1 m/sec and the temperature of 90°C (Gong, 2009).

Research of drying kinetic model: The materials drying is influenced by the temperature and humidity of dry medium, physical and chemical structure of materials and external shapes, which is a complicated process of heat and mass transfer. The establishment of drying model is very important for researching drying

Table 1: Mathematical models applied to drying curves

Names	Models	Remarks
Lewis	MR = exp (-kt)	Lewis (1921)
Page	MR = exp (-kt^m)	Page (1949)
Henderson and Pabis	MR = a exp (-kt)	Henderson and Pabis (1961)
Two-term	MR = a exp (-kt) + b exp (-k$_0$t)	Pabis (1974)

law and predicting drying technological parameters. At present, there are three models used for describing the entire thin layer drying process, which are the model of monomial spread $MR = A\exp(-rt)$, exponential model and Page equation $MR = \exp(-rt^N)$, that can be seen from Table 1.

Taking the garlic residues after the garlic oil was extracted by ethyl alcohol as the research object, Li Yu et al. investigated the influence of hot air temperature on the drying kinetics and adopt Page model to fit experimental data and the kinetics equation of garlic residues hot air drying under 50-70°C: MR = exp [-exp (-6.8510 + 0.2370T - 0.0018T2) t 0.1793] (Li and Song, 2010).

Electro thermal constant-temperature dry box was adopted Yang Mingjuan to perform drying research on fresh chili and establishes the Page model, index model and the model of monomial spread of hot air drying and the variance analysis showed that all of the three kinetics models could better fit the experimental data; the Page model was confirmed as the optimum kinetics model of hot air drying through comparison, which was MR = exp (rtN), there into, r = -8.801 + 1.806P1, N = 0.989 + 2.198P1 - 4.266P12 + 3.281P14 (Yang, 2009).

Taking citrus peel residues as the raw materials, You *et al*. (2010) studied the influence of different factors on the characteristics of hot air drying and establish the mathematical model of citrus peel residues hot air drying. The four hot air drying models of Lewis, Page, Handerson-Pabis and Logarithmic were established according to the experimental data, the result showed that the variants of citrus peel residues hot air drying model based on Page equation ln [-ln (MR)] = lnk + nlnτ are closely related with each other and the verification test also showed that the simulating effects of this model were better (You *et al*., 2010).

Niu *et al*. (2008) utilized hot air circulation and drying test bed to perform test and research on the drying characteristics of apple residues under different initial moisture, wind speed and temperature. The fitting of different mathematical models was performed according to the drying curve and the improved Page model could better predict and describe the hot air circulation and drying characteristics of apple residues compared to other models, Logarithmic model took the second place and Newton model was the worst (Niu *et al*., 2008).

Zhang *et al*. (2009b) confirmed the optimum technological parameters of fresh chopped lotus root slices hot air thin layer drying by means of orthogonal experimental design method through investigating the influence of drying temperature, wind speed and sample amount on the moisture content: the temperature was 70°C, the sample loading quantity was 40 g and the wind speed was 0.3 m/sec. The drying curve under the optimum technological parameters was established and the fitting of index model, the model of monomial spread and Page equation were performed, through comparing correlation coefficient they finally confirm the model of monomial spread MR = 0.857412114 exp (-0.050102613t) (R^2 = 0.96537) as the kinetics mathematical model of fresh chopped lotus root slices hot air thin layer drying and the test verified that the model can better predict the drying process (Zhang *et al*., 2009b).

Study of the drying characteristics: The study of hot air drying was performed on *Agaricus blazei* by Chen (2008) and the influence of heating temperature on the moisture content and drying rate of *Agaricus blazei* were investigated. The study showed that the hot air drying process of *Agaricus blazei* could be divided into three stages, which were the drying stages of acceleration, constant speed and speed reduction. The acceleration stage was very short, which was also called the adjustment stage. The drying stage of constant speed was mainly based on dehydrating the free water between cells, the temperature reduction was caused by the evaporation of materials surfaces moisture at this stage and the internal and external temperature gradient was produced for promoting the moisture transfer to the outer appearance and form the water-saturated heat surface, so the ratio of tempering time to drying time remains unchanged within large scope. The drying stage of speed reduction was mainly based on dehydrating physical bond water, since the movement rate of moisture from the inside of materials to the surfaces was lower than the rate of surface water evaporation at this stage, the materials surfaces couldn't maintain overall wet when the drying rate was gradually reduced and the evaporation surface was moved inside the materials step by step (Chen, 2008).

Liu and Zhou (2008) conducted hot air drying study on the rehydrated black fungus and found that the drying process was obviously divided into two stages, which were preheat stage, drying stages of constant speed and speed reduction; materials entered comparatively long drying stage of speed reduction after temporary preheat stage and drying stage of constant speed (Liu and Zhou, 2008).

Xu *et al*. (2010) respectively studied the direct hot air drying on Chinese wolfberry and the hot air drying after the pretreatment of NaOH solution, the study showed that the hot air temperature had obvious influence on the drying rate but unobvious impact on the wind speed; the treatment of NaOH solution could

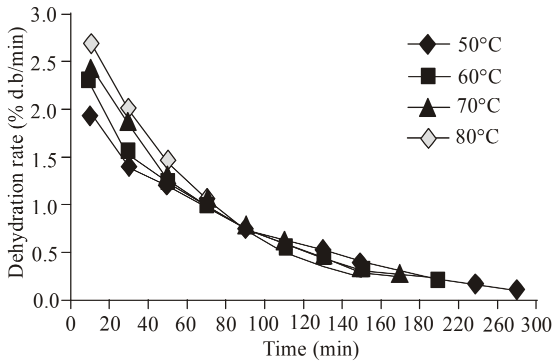

Fig. 3: Effect of air temperature on dehydration rate

improve the drying speed of Chinese wolfberry under lower temperature; besides, the dry fruit of Chinese wolfberry was in scarlet color, the quality of outer appearance was obviously improved and the effect was not very obvious under higher temperature (Xu *et al*., 2010).

Taking chili as the research object, Zhang *et al*. (2008) performed the test of hot air drying and investigated the influence rule of hot air temperature, wind speed and loading thickness on the drying rate. The test showed that the hot air temperature and wind speed have great impact on the drying rate of chili, the drying rate was obviously accelerated along with the rise of temperature; the drying rate of chili speeded up along with the increase of the wind speed that can be seen from Fig. 3. The influence of materials filling thickness was less. At the most of the initial drying time, the chili existed in the drying stage of constant speed and then in the drying stage with slowly reducing speed (Zhang *et al*., 2008).

The hot air drying test was performed on the cooked sweet potato by Shen *et al*. (2007) and the influence of hot air temperature, wind speed and the thickness of filling materials on the drying characteristics were investigated. The study showed that the drying rate of sweet potato was divided in to two stages of constant speed and speed reduction, the preheating section was not obvious, which basically conformed to the traditional rule of drying rate curve, but the time of constant speed section was comparatively short; the drying rate at the constant speed section was markedly impacted by the drying temperature; the drying temperature has the most obvious influence on the drying rate of cooked sweet potato, the drying wind speed took the second place and the density of filling materials was the least. Within the scope of experimental temperature, the drying rate could increase about 20% when the drying temperature rise 10°C (Shen *et al*., 2007).

The influence of drying quality: Han *et al*. (2007) studied the influence of garlic slice thickness and drying temperature on the volume of diallyl trisulfide in the process of hot air drying. The study showed that the DATS content in garlic slice depended on the activity of alliinase during the drying process of garlic slice, but both the drying temperature and the slice thickness had influence on the activity of alliinase. The change of DATS content in the garlic slice with three kinds of thickness showed the same trend along with the change of drying temperature, which firstly increased and then decreased; when the temperature was lower than 55°C, the DATS content would also increase with the increase of garlic slice thickness; however, when the temperature was above 60°C, the DATS content will decrease with the increase of the thickness (Han *et al*., 2007).

Zhou *et al*. (2007) performed hot air drying test on the kiwi fruit slices and the study showed that the thickness, temperature and convection situation had obvious influence on the Vc loss ratio; as the temperature increased, the Vc loss ratio firstly increased and then decreased; the Vc loss ratio decreased when the thickness was increased from 3 to 6 mm and the ratio will increase when the thickness increased again; when the wind was added the Vc loss is larger than the control, since the increase of convection air strength also increased the concentration of the oxygen, the Vc was apt to be damaged. Through orthogonal experimental design the hot air drying technological conditions of kiwi fruit are confirmed based on Vc loss ratio: the slice thickness was 6 mm, the temperature was 70°C and no wind was added (Zhou *et al*., 2007).

Zhang *et al*. (2006a) adopted common hot air drying method to dry the leading cultivar-Chinese jujube at northern Shaanxi, initially explored the change rule of main materials that participated in non-enzymatic browning during the drying process of Chinese jujube and its relationship with non-enzymatic browning. The result showed that Chinese jujube was rich in the reaction substrates that participated in non-enzymatic browning, especially the reducing sugar, ascorbic acid and amino acid nitrogen, which were more easily suffered the browning during the hot air drying process. As the drying temperature rise and time prolong, the browning degree of jujube flesh and 5-HMF content gradually increase, the total reducing sugar, reducing sugar, Vc and amino acid nitrogen gradually decrease; the drying temperature is higher, the time is longer and the variation is greater. The Chinese jujube is dried at 70°C and the change rule of 17 kinds of free amino acid is that: Except for Thr and Pro, the amino acid Ser and Glu content are decreased as the drying time prolongs, the content of other amino acid is on the rise (Zhang *et al*., 2006a).

Huang *et al*. (2009) performed study on the drying characteristics of orange peels from aspects of drying rate, temperature distribution, water holding capacity, liposuction and appearance and compared them with the sample quality which is handled by microwave drying. It was found that the lower the hot air temperature, the higher the obtained water holding capacity and liposuction; the water holding capacity under any conditions was obviously higher than liposuction and the hot air drying was totally better than microwave drying, but the effect of lower microwave power (155 W) was slightly superior to the hot air temperature of 80°C; the sample edge will be easily overheated if the hot air temperature was higher, which leads to the edge hardening and cause the curve, the color was darker than the center; however the required time for drying was longer if the temperature was lower, which will also lead to the severe deformation of the products (Huang *et al*., 2009).

Nantawan and Weibiao (2009) studied the influence of 60 and 70°C hot air drying on the drying characteristics of mint leaves, color change, the structural characteristics and rehydrated characteristics of dried products and compared the effect with the microwave vacuum drying effect under the conditions of 8.0, 9.6 and 11.2 W/g, respectively and 12.33 kPa. The study showed that the effective coefficients of moisture diffusion under the 60 and 70°C hot air drying conditions were respectively 0.9648×10-11 and 1.1900×10-11, which was far lower than the effective moisture diffusion coefficient under microwave vacuum drying conditions; the change of moisture content during the hot air drying process could be described by Lewis model, Page model and Fick model and the Page model was more suitable for describing the hot air drying process of mint leaves; the change of rehydrated rate for the mint leaves after hot air drying was not obvious when it's increased to 70 from 60°C. The L value of mint leaves decreased and the value increased under the 60 and 70°C hot air drying conditions and then the color was changed to dark green brown, but the influence of temperature change on the color was not significant (Nantawan and Weibiao, 2009).

Hot air drying was adopted by Kotwaliwale *et al*. (2007) to perform research on the organizational characteristics (hardness, cohesiveness, resilience and chewiness) and optical characteristics of stem mushroom and the influence of blanching and sulfitation pretreatment technology were analyzed on the hot air drying quality characteristics of stem mushroom. The result showed that the hardness and chewiness of stem mushroom increased as the drying proceeds, but the cohesiveness and resilience respectively showed the trend of first increase and then decrease at the initial and ending periods of drying; the higher the drying temperature, the higher the hardness of stem mushroom; the cohesiveness reduced as the temperature rises; compared with the samples obtained by other drying methods, the hardness of the sample obtained after blanching treatment and then the hot air drying was higher, but the cohesiveness and resilience reduced; the whiteness index of stem mushroom increased but the yellowness index reduced during the drying process; the drying temperature had contrary impact on the whiteness of stem mushroom; the sulfidizing was favorable for maintaining the whiteness during the drying process, but the blanching was on the contrary (Kotwaliwale *et al*., 2007).

Karabulut *et al*. (2007) conducted hot air drying on the apricot of sulfidizing and non-sulfidizing and studied the influence of hot air temperature on the color and carotene content of the apricot. The study showed that the time of drying to the expected dried material content reduced through sulfidizing; the carotene content of apricot after sulfidizing under 70 and 80°C hot air conditions were respectively 7.14 mg/100 g dry matter and 7.17 mg/100 g dry matter; the carotene content of apricot without sulfidizing were respectively 6.12 mg/100 g dry matter and 6.48 mg/100 g dry matter; the browning degree of apricot without sulfidizing was greatly higher than the apricot of suflidizing; the apricot color of sulfidizing and without sulfidizing were kept in good status, the apricot surface appeared local coking area under 80°C which leads to the decrease of apricot chroma and color angle (Karabulut *et al*., 2007).

Hot air drying of varying temperature: Segmental varying temperature drying is one method for enhancing drying efficiency and improving the quality of sample drying. Higher drying temperature can be used at the initial period of drying so as to quickly remove the moisture and then reduce the drying temperature and decrease the evaporation rate of the surface moisture so as to realize the coordination of the internal moisture diffusion rate, reduce the internal and external temperature difference of fruit flesh and avoid the surface crusting. The selection of temperature, transfer moisture content and drying time was considered as the most crucial part during the drying process for the segmental varying temperature drying so as to make the final products satisfy the requirements of quality, drying efficiency and energy consumption (Liu *et al*., 2009).

Hu (2007) perform research of segmental varying temperature hot air drying on the color protection and pretreated water chestnut slices. The high temperature and low temperature zones and the critical time of not producing browning are confirmed through the drying test of constant temperature within 60-110°C scope. The segmental varying temperature drying test is conducted according to the combination and matching of the front high temperature and the back low temperature. The drying time of high temperature segment adopts the critical time of not producing browning, the segment of low temperature until the drying. The study shows: when the 90°C drying at high temperature drying stage is adopted for 75 min and the 65°C drying at low temperature stage is

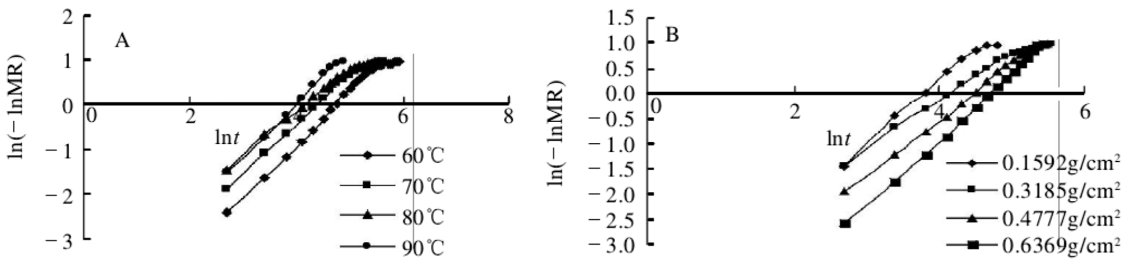

Fig. 4: Versus lnt curves at different temperatures, material loading densities and hot air speeds

selected for 180 min until the expected moisture rate, the drying time will reduce 60 min compared to the 65°C hot air drying of constant temperature and it will effectively guarantee the color, outer appearance, rehydration and mouth feel of water chestnut slices (Hu, 2007).

The segmentally varying temperature hot air drying was performed on Chinese prickly ash by Zheng Yanji based on the research of hot air drying with constant temperature. The influence of temperature and wind speed on the drying characteristics, that can be seen from Fig. 4, drying quality and energy consumption were investigated and the optimum technological parameters were confirmed through evaluation index system of drying technology that was structured by analytical hierarchy process: the initial temperature was 35°C, the temperature rise to 50°C after 3 h of drying until it was dried to the predicted moisture content, the wind speed was 1.4 m/sec and the drying time was 300 min (Zhengyan, 2006).

Based on investigating the influence of maturity, temperature, airflow rate and slicing method on the hot air drying characteristics of areca catechu, Zhang *et al.* (2006b) integrated the drying quality and energy consumption so as to confirm the varying temperature drying technological parameters, which were that the 50-80-50°C were, respectively dried for 0.5-2-2 h. The lower airflow rate shall be adopted at the high temperature drying stage in order to balance the drying rate during the drying process, but the higher airflow rate can be adopted at the low temperature drying stage for the drying (Zhang *et al*., 2006b).

Through the research on the drying characteristics of *Pholiota nameko*, it was found that the hot air drying process of the *Pholiota nameko* could be divided into three periods, which were the earlier stage, mid-term and later period of drying. The final temperature was confirmed as the most essential factor of impacting the rehydration ratio of *Pholiota nameko* dried products through investigating the influence of initial temperature, final temperature and wind speed on the appearance quality, rehydration ratio and energy consumption, the initial temperature and the final temperature were the most important factors of influencing the appearance quality of *Pholiota nameko* dried products and the wind speed was the most crucial factor of influencing the hot air drying unit energy consumption of *Pholiota nameko*. It could also be obtained that the optimum process combination of hot air drying for *Pholiota nameko* was the initial temperature of 35°C, the final temperature was 65°C and the wind speed was 1.8 m/sec under the heating mode of 5°C increase at each 0.5 h (Xu, 2010).

RESULTS AND DISCUSSION

Combining drying: In view of the great difference exists in the variety and structure of fruits and vegetables, the single hot air drying is hard to satisfy all the production requirements of fruits and vegetables, the hot air drying shall be combined with other drying methods; the reasonable combination drying methods and technological conditions shall be used for different characteristics of fruits and vegetables so as to realize the production mode of energy saving and high efficiency.

The perfection of drying process mathematical model: The establishment of reasonable mathematical model in drying process has great significance in the research of drying mechanism, the optimization of drying process and the realization of auto control. Domestic and overseas scholars also use different methods to establish some better mathematical models for different fruits and vegetables, but the popularity is bad which is only used for the single fruits and vegetables, meanwhile the fitting of actual drying is not ideal. Therefore, the perfection of current mathematical model and the improvement of popularity are very essential for predicting and guiding the production.

CONCLUSION

Among many drying technologies, hot air drying is broadly applied owing to its advantages of mature equipments, easy operation and low cost, but most of the China's hot air drying equipments have the problems of high energy consumption and low efficiency. Therefore, the optimization of combination drying and the application of energy-saving technology will be the problems that are urgently needed to solve in the future research of hot air drying technology.

REFERENCES

Chang, H., Y.Z. Li and X.X. Yang, 2008. Investigation of the drying characteristics of pineapple powder [J]. Modern Food Sci. Technol., 24(1): 5-6.

Chen, X., 2008. Effect of different drying method on drying characteristic of *Agaricus blazei* murill [D]. Fujian Agriculture and Forestry University, Fuzhou.

Gao, Y., D. Wang, G. Wang, X. Fang and G. Ning, 2010. Effect prediction model and process optimization of the drying and separating for leaf-stem of fresh chopped alfalfa [J]. T. Chinese Soc. Agric. Mach., 41(6): 113-118.

Gong, P., 2009. Study on the manufacture Technology of High Rehydration Dried Bamboo shoot without Sulfer dioxide [D]. Southwest University, Chongqing.

Han, Y.F., G.H. Peng, S.H. Zhang and R.C. Ma, 2007. Effects of hot-air drying technology on the yield of organic sulfide in garlic slice [J]. T. Chinese Soc. Agric. Eng., 23(10): 271-27.

Hu, X., 2007. Study on processing technology of hot air and microwave Puffing Drying of Chinese water chestnut slices [D]. Hefei University of Technology, Hefei.

Huang, Y., Y.D. Cheng and K. Liang, 2009. Effects of microwave and hot air drying on characteristics and quality of orange skin [J]. Food Sci., 30(21): 16-20.

Henderson, P.H. and U.K. Pabis, 1961. A two-stage convective air and vacuum freeze-drying technique for bamboo shoots. International Journal of Food Science and Technology.

Karabulut, İ., A. Topçu, A. Duran, S. Turan and B. Öztürk, 2007. Effect of hot air drying and sun drying on color values and β-carotene content of apricot (*Prunus armeniaca* L.) [J]. LWT, 40: 753-758.

Kotwaliwale, N., P. Bakane and A. Verma, 2007. Changes in textural and optical properties of oyster mushroom during hot air drying [J]. J. Food Eng., 78: 1207-1211.

Li, Y. and H. Song, 2010. Research on the drying dynamics of garlic slices [J]. Jiangsu Agric. Sci., 2: 294-295.

Li, K., M.M. Wang, X.P. Shen and X.L. Lu, 2008. Study on optimization of hot-air drying process parameters of cooked sweet potatoes by mathematical models [J]. Food Sci., 29(8): 363-368.

Liu, Q. and Y. Zhou, 2008. Study on drying characteristic of re-hydrate Auricularia auricular [J]. Food Sci. Technol., 33(11): 87-90.

Liu, W., B. Li, Y. Wu *et al*., 2009. Research on the drying characteristic of prune under varying temperature and the optimization of the drying process [J]. Sci. Technol. Food Ind., 9: 108-112.

Lewis, H.M., 1921. Approaches to improving the quality of dried fruit and vegetables. Trends in Food Science and Technology.

Nantawan, T. and Z. Weibiao, 2009. Characterization of microwave vacuum drying and hot air drying of mint leaves (*Mentha cordifolia* Opiz ex Fresen) [J]. J. Food Eng., 91: 482-489.

Niu, Z., S. Zhao and K. Jiang, 2008. Experimental study on drying characteristic and model of apple pomace [J]. J. Agr. Mech. Res., 6: 134-137.

Page, T., 1949. Effects of microwave and hot-air combination drying on the quality of carrots. Food Science and Biotechnology.

Pabis, U.K., 1974. Physical Changes in Bamboo (Bambusa phyllostachys) Shoot During Hot-air Drying: Shrinkage, Density and Porosity. Drying Technology.

Shen, X., M. Wang and X. Lu, 2007. Researches on the mathematical model and air-drying properties of cooked sweet potatoes [J]. Food Mach., 23(3): 119-122.

Xu, Z., 2010. Study on the hot air drying characteristic of the *Pholiota nameko* and its drying process [D]. Inner Mongolia Agricultural University, Hohhot.

Xu, Z., S. Zhao, J. Chai and Q. Jia, 2010. Hot air drying characteristics of Chinese wolfberry [J]. J. Agr. Mech. Res., 6: 153-15.

Yang, M., 2009. Research on the relevance between drying technology and the quality of dried chilli [D]. Guizhou University, Guizhou.

You, J., Q. Zhang and W. Yu, 2010. Modeling and drying properties of dehydration of citrus pulp during hot-air drying [J]. Sichuan Food Fermentation, 46(2): 51-55.

Zhang, B.S., J.P. Chen and H.Y. Li, 2006a. Effect of hot air drying on nonenzymatic browning of Chinese jujube [J]. Food Sci., 27(10): 139-14.

Zhang, K., X. Fu, Z. Wang *et al*., 2006b. Research of the hot air drying process on betel nut [J]. Trop. Agr. Eng., 1: 20-23.

Zhang, J., H. Wang, Y. Ma *et al*., 2008. Research on the drying characteristic of chilli [J]. T. Chinese Soc. Agric. Eng., 24(3): 298-302.

Zhang, J.J., P. Cao and X.G. Qiao, 2009a. Optimization of energy saving technology for drying dehydrated garlic slices [J]. T. Chinese Soc. Agric. Eng., 25(7): 279-282.

Zhang, M., Z. Ju and J. Kan, 2009b. Technological optimization and mathematical model establishment of hot-air thin layer drying for fresh-cut lotus roots slices [J]. Food Sci., 30(22): 184-187.

Zhengyan, 2006. Comparative study of microwave drying and hot air drying on pepper [D]. Southwest University, Chongqing.

Zhou, G., W. Chen, X. Ye, X. Xiao and Z. Hua, 2007. Study on feeze-drying and hot-air drying kiwi-frit slice [J]. Food Sci., 28(8): 164-167.