Optimization Of Hot Air Drying Of Purple Sweet Potato Using Response Surface Methodology

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Abstract—Recently,the interest in purple sweet potato has increased due to its high nutrients content. In order to improve the drying quality of purple sweet potato, in this study, response surface methodology (RSM) was used to optimize operating conditions of the purple sweet potato in a hot air drier and quadratic polynomial regression models were used for the optimization. Optimization factors were slice thickness(2-6mm), air velocity(1-2m/s) and temperature(45-55℃) while investigated responses were energy consumption per unit mass, value of chromatism and loss rate of anthocyanins and comprehensive assessment.The order of strength of the factors affecting the drying process and the best value of factors when drying purple sweet potato were determined to obtain. The order was found to be air velocity first, temperature second, and then slice thickness and the best values of factors were found to be slice thickness of 5.11mm with air velocity of 1.88m/s for the temperature of 55℃. At this the best point, the responses were found of 0.073KWh/g, 12.88, 22.20%, 0.96, respectively. This study provides a theoretical basis for further study on hot-air drying equipment and technology for purple sweet potato.

Keywords-Purple sweet potato; Hot-air drying; Response surface methodology; Optimization of technological parameters

I. INTRODUCTION

Purple sweet potatoes have been used worldwide for many years not only for its's anthocyanin pigments, selenium, polysaccharides, vegetable protein, vitamins and minerals but also for functional aim. Anti-cancer, scavenging free radicals and other health functions[1] draw the attention of current agricultural researchers[2-3]. In order to further enhance the added value and economic benefits of purple sweet potato, drying is a important process in its's treatment. However, moisture content of fresh purple sweet potato is about 65%, make it hard to save at room temperature compared with most vegetables. In this condition, purple sweet potatoes have to be dried for its' safely saving and further processing.

Hot air drying is the most convenient and adopted among various drying methods, during the drying process, the purple sweet potato's quality changes in a acceptable rate for the heating process in terms of anthocyanin losing and chromatism[4]. Furthermore, hot air drying itself is a energy consuming process. Finding the best solution of drying purple sweet potato is also solving the difficult problems such as energy saving.

Response surface methodology (RSM) is widely used in recent years to predict the response to the untested sets of variables and study the interactions among those factors.Many studies on optimization of hot air drying process have been accomplished by it[5-8]. In this study, RSM was adopted to optimize the parameters during drying process of purple sweet potato.

II. MATERIALS AND METHODS

A. *Materials*

The experimental materials were purchased from Ya'an.(Sichuan,China).No damage, shape symmetry and basically the same size, the initial wet basis moisture content is 62% ~ 68%. The materials were washed with tap water ,then clean the water on the surface and use fresh bags sealed. According to production requirements, the purple potato drying wet basis moisture content less than 13% can be safely stored without spoilage.

B. *Experimental Apparatuses and Experiment Process*

The main instruments include: Kanomax KA31-type anemometer from Kano Max instrument Co., Ltd(Shenyang China);OHAUS-AR522CN electronic precision balance from Ohaus Instruments Co.,Ltd (Shanghai,China).MA150C-000230V1 moisture meter, Sartorius Scientific Instruments Co., Ltd(Beijing China).DG11X type single-phase watt-hour meter, Shandong Power Technology Co., Ltd.; NF333 Simple colorimeter, Electric Colors Industries Co., Ltd(Japan); MAPADA UV-3100PC UV spectrophotometer,MAPADA Instruments Co.,Ltd(Shanghai,China).

Test procedure is as follows: make the temperature in the hot air drying apparatus, the air velocity reaches a predetermined level. Purple sweet potato peeled and cleaned, cut into 30×40×predetermined slice thickness (mm) , then spread evenly on the material disk.

C. *Experiment Design*

Single-factor test: the slice thickness, air velocity and temperature are experimental factors, research purple potato drying law, through the pre-test, respectively, at a air velocity of 0.8m / s whit the slice thickness of 4mm for different air temperature;Temperature of 53 ℃ with Slice thickness of 4mm for different air velocity; the temperature of 53 ℃; whih air velocity test of 1.2m /s for different slice thickness. Investigate the changes in moisture content and drying rate.

Orthogonal experiment: a central composite rotatable design (CCRD) including 20 experiments was used, where slice thickness, air velocity and temperature are the test factors, energy per unit mass, chromatism, anthocyanins loss and comprehensive evaluation are the responses.

D. Data Measurement and Parameter Calculation

Energy consumed per unit mass (Y1): refers consumption of electricity energy per unit mass of purple sweet potato during the whole drying process (kW·h / g);

Chromatism (Y2): The chromatism was evaluated using a colorimeter and analyzed by three dimensional color space CIELAB. Measuring the dry sample's lightness index L* and saturation index a*,b* with fresh purple sweet potato as a reference. Chromatism value Δ E* ab is the euclidean distance between two points in this three-dimensional space, Y2 was calculated as formula(1):

$$\Delta E_{ab}^{*} = \sqrt{(L_2^{*} - L_1^{*})^2 + (a_2^{*} - a_1^{*})^2 + (b_2^{*} - b_1^{*})^2} \quad ; \qquad (1)$$

Loss rate of anthocyanins(Y3): the absorbance of the solution was measured by a UV spectrophotometer. Y3 was calculated accordi-
Ng to formula(2):

Y3=1-M2/M1 (2)

Where M1 ,M2 is the anthocyanin content before and after drying, respectively.

Comprehensive evaluation(Y4) :With a Comprehen-sive evaluation of membership[8], make the Y1~Y4 4 indicators a comprehensive evaluation(Y4) to purple potato drying process,as formula(3):

l=(cmax-ci)/(cmax-cmin) (3)

Where ci, cmin, cmax is the i time, the minimum, the maximum of index values, respectively.

Y4 was calculated as formula (4):

Y4=alt+blε +clcv+dlcy (4)

Where li is membership and a~d is the weights of each index. Priority to ensure minimal loss of anthocyanin,taking into account the energy consumption (energy per unit mass) and efficiency (inverse of the drying time), in this paper a=0.1,b=0.2,c=0.2,d=0.5. According to the actual situation, a~d can be different, but they must satisfy the equation a+b+c+d=1.

III. RESULTS AND ANALYSIS

A. Single Factor Test

1) Effect of Different Temperature on the Drying Process

As shown in Fig .1, the drying rate becomes faster as the temperature increases and the difficulty of hot air dehydration increased at the end of the drying. As shown in Fig .1b, the hot air drying process of purple sweet potato can be divided into acceleration,constant speed and deceleration three different drying stages.The higher the air temperature, the larger the difference between temperature inside and outside the material chips and the faster the material surface hardening, making it difficult to escaped the water; When various bound water vapor, the equilibrium vapor pressure gradually decline, reducing the mass transfer driving force[8]. The drying rate increases with the increase of the temperature, when the temperature increases from 43 ℃ to 58 ℃, shorten the drying time of 103.6%. Temperature range should take 45-55 ℃.

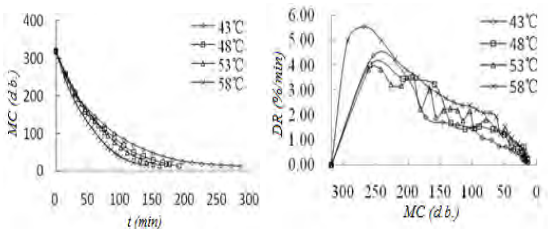

Figure 1a. Figure .1b.

Figure .1 Drying curves under different temperatures

2) Effect of Air Velocity on the Drying Process

As shown in Fig .2, when the air temperature and slice thickness constant, the higher the air velocity, the shorter the drying time. The material surrounding air humidity is low when the air velocity increases.The increasing of air moisture gradient surrounding the material accelerated water loss.However, when the evaporation loss of water all been taken away by the hot air, it will cause excessive increases wind energy loss.So,air velocity should choose 1-2m/s.

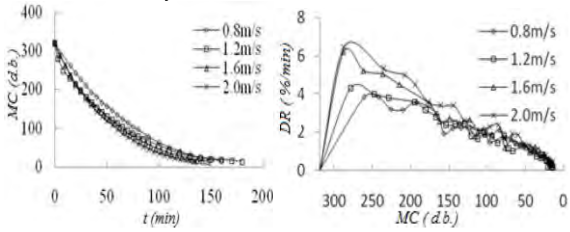

Figure 2a. Figure 2b.

Figure .2 Drying curves under different air velocity

3).Effect of Slice Thickness on the Drying Process

As shown in Fig .3, the thinner the slice thickness, the shorter the drying time. The drying time is increased by 24% ~ 191% with each additional slice thickness of 2mm. When the drying rate down, it mainly depends on the shape and size of chips.The larger slice thickness, heat and mass transfer pathways is longer. Seriously surface hardening affecting the diffusion of internal moisture. When the slice thickness is more than 6mm, material chips began crack. Drying time, energy consumption increased significantly.So,should choose the slice thickness 2-6mm.

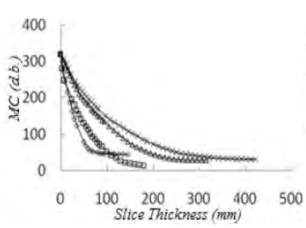

Figure 3a.

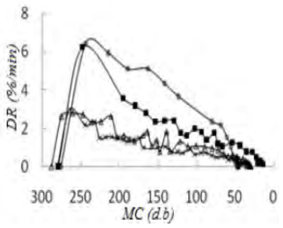

Figure 3b.

Figure 3. Drying curves under different slice thickness

B. Orthogonal Test

Experimental design according to CCRD[10], a random combination of the test sequence, the different runs of test results are shown in Table 3, where x1, x2, x3 is the experimental factors encoded.

TABLE I. CCRD AND ORTHOGONAL TEST RESULTS

RUN	x1,x2,x3	Y1 (kW h/g)	Y2	Y3 (%)	Y4
1	-1,-1,-1	0.164	16.33	42.00	0.626
2	-1,-1,1	0.248	17.85	61.28	0.231
3	-1,1,-1	0.215	19.48	53.01	0.358
4	-1,1,1	0.238	19.78	26.83	0.674
5	1,-1,-1	0.287	20.32	50.34	0.213
6	1,-1,1	0.269	16.06	47.84	0.383
7	1,1,-1	0.167	15.51	62.75	0.360
8	1,1,1	0.106	12.08	37.43	0.772
9	-1.68,0,0	0.138	11.67	47.30	0.694
10	1.68,0,0	0.207	18.17	49.41	0.395
11	0,-1.68,0	0.259	21.68	64.57	0.091
12	0,1.68,0	0.191	21.99	53.38	0.318
13	0,0,-1.68	0.261	13.69	43.68	0.501
14	0,0,1.68	0.235	15.69	29.77	0.709
15	0,0,0	0.222	17.52	37.99	0.570
16	0,0,0	0.160	15.12	37.93	0.693
17	0,0,0	0.192	18.90	40.88	0.536
18	0,0,0	0.204	14.14	39.00	0.643
19	0,0,0	0.261	15.28	34.09	0.621
20	0,0,0	0.239	16.38	40.99	0.525

It can be observed from Tab.2(ANOVA), analysis of variance indicated that the models of responses are significant (P<0.05) and test error is small (F_{lf} <$F0.05$ $(5,5)$ = 5.05). R^2 values of Y_1 and Y_2 were 0.65 and 0.67,respectively. Also, Y_3 and Y_4 showed a good correlation between experimental data and models(R^2>0.9).

C. Analytical of the Interaction Terms

Drawing the respond surface and contour map based on the regression equation in Tab.2. Observe the shape of the response surface map, analyze the impact of the three variables on the four responses of purple sweet potato hot air drying process.As can be seen from Fig .4 to Fig .6, the interaction of slice thickness and the air velocity

reduced power consumption of the heater and fan, have a large energy consumption per unit mass decreases.
When the slice thickness is higher,the air temperature is higher, making the purple potato chips hardened, internal

effects on energy consumption per unit mass is significant, while other factors interaction is not; temperature and air velocity effects on anthocyanin loss was significant; temperature and air velocity affected on the consolidated scores significantly.

Fig .7 shows that when the slice thickness is less than -1 (2.8mm), the air velocity is -1.68 ~ 1.68 (1m /s~2m/s),the energy per unit mass increases as the air velocity increases;At this time, the air velocity is too large, resulting in energy loss.When the slice thickness is greater than -1 (2.8mm), air velocity within -1.68~1.68(1m/s~2m/s) range, energy consumption per unit mass decreases as air velocity increases.In this case the larger slice sickness and more moisture content reduced power consumption of the heater and fan, have a large energy consumption per unit mass decreases.When the slice thickness is higher,the air temperature is higher, making the purple potato chips hardened, internal moisture migrate to the outside more

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TABLE II. MODELS OF RESPONSES

Models of Responses	F value	Flf	R2
Y1=0.21+4.631E-0.03A-0.026B-0.03C-0.04AB-0.023AC-0.013BC	4.04**	0.87	0.6507
Y2=16.22-1.1A-0.26B-0.21C-1.78AB-1.262E-0.04BC -0.46A2+1.99B2-0.54C2	2.22	2.57	0.6666
Y3=0.39+0.014A-0.029B-0.043C+0.032AB-0.026AC -0.085BC+0.033A2+0.071B2	20.68**	2.29	0.9490
Y4=0.6-0.048A+0.08B+0.062C+0.045AB+0.083AC +0.12BC-0.017A2-0.14B2+4.473E-0.03C2	10.56**	2.09	0.9048

moisture migrate to the outside more difficultly, the drying time is greatly extended, increasing energy consume.

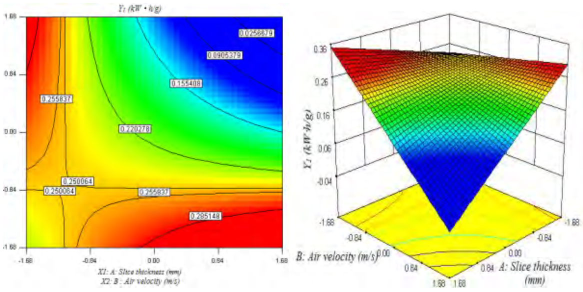

Figure 7. Effect of slice thickness and air velocity on energy consumption per unit weight with tempe-rature of 55℃

Fig .8 shows that, when the air velocity in the inner -1.68 to -1 (1m/s ~1.2m/s) range, anthocyanins loss increases with the increase of the temperature, when the air velocity in the -1 ~ 1.68 (1.2m inner / s ~ 2m / s) range,the loss of anthocyanin decrease with the increase of temperature.When the air velocity is 1.26(1.88m/s),the loss rate values to a minimum.At lower air velocitys, as the temperature increases, but the air velocity is low, the heat accumulated in the material surface, destroyed the anthocyanin composition.

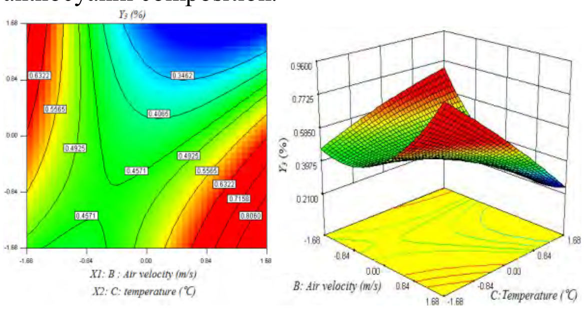

Figure 8. Effect of air velocity and temperature on retention rate of cyanidin with slice thickness of 5.11mm

As shown in Fig .9, when the air velocity at a low level, comprehensive evaluation is very low, and as the temperature increases, there is a slight decrease; air velocity at the high level, the temperature rises, comprehensive evaluation is improved.By 9a,air velocity greater than -1(1.2m/s),a comprehensive evaluation begins to increase, the air velocity is greater than 1.5m / s, there is satisfactory evaluation value.Analysis combined unit mass energy consumption and anthocyanins two indicators, 5.11mm thickness purple potato chips at a lower air velocity, extend the drying time, increasing energy consumption per unit mass, anthocyanins loss decreases.As the air velocity increases, the drying process tends to be normal, to reduce the degree of surface hardening, the internal moisture migration and surface water evaporation consistent, satisfactory indicator appears. It can be seen, air velocity, temperature, and their interactions have a great impact on the comprehensive evaluation.

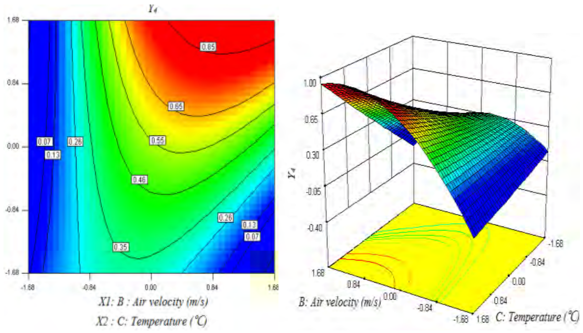

Figure 9. Effect of air velocity and temperature on comprehensive assessment with slice thickness of 5.11mm

IV. CONCLUSION

In this paper, the effect of slice thickness, air velocity and temperature on the quality of dried purple sweet potato was studied. The results revealed that the three factors influence on the drying process significantly. The higher air velocity and temperature with the smaller slice thickness, the faster average rate of drying and poorer product's quality would be, Contrary slower, the quality can be guaranteed. By establishing polynomial regression model, the moisture, drying rate, energy consumption, chromatism, loss rate of anthocyanins during the drying process can be predicted.

Optimal conditions for minimum Y_1 ,Y_2 and Y_3 , maximum Y_4 at a final moisture content of below 13% correspond to a slice thickness of 0.93 (5.11mm) , air velocity of 1.26 (1.88m/s) with temperature of 1.682(55℃), in order to get a drying time of 233min, Y_1 of dry 0.073 / kW • h / g, Y_2 of 12.88 , Y_3 of 22.20%, and Y_4 of 0.97.

This paper would provide a theoretical basis for the further study of purple sweet potato processing.

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REFERENCE

[1] L.Q. Wang, 2010. Purple sweet potato nutrition. J. Market Weekly, 20:22～23.

[2] S.L. Xin,2009. Study on Processing Techniques of Purple Sweet Potato in Cuisine. J. Journal of Sichuan Higher Institute of Cuisine. 3(3):17～18.

[3] W. Yang, J.Q.Huang., Chen Y., et al. 2011. Nutritional Value and Product Development of Purple Sweet Potato. J. Academic Periodical of Farm Products Processing. (8):41～42.

[4] X. Lu, L.C.Mo , F.J.Zeng, et al. 2013. Research on drying process of quick-cooked purple sweet potato.J.CEREAL & FEED INDUSTRY. 2:19～21.

[5] E.Zafer, I, Filiz. 2009. Optimization of hot air drying of olive leaves using response surface methodology. J. Journal of Food Engineering. 91: 533-541.

[6] T.D.Somayeh, H.Nasser,S. Mohammad , et,al. 2014. Optimization of carboxymethyl cellulose and calcium chloride dip-coating on mushroom slice prior to hot air drying using response surface methodology. J. Journal of Food Processing and Preservation. 38:1269-1278.

[7] S. V. Gokhale,. S. S. Lele,2014. Betalain Content and Antioxidant Activity of Beta vulgaris: Effect of Hot Air Convective Drying

and Storage. J. Journal of Food Processing and Preservation. 38:pp 585-590.

[8] K. A. Al-attab,. Z. A. Zainal,.2014. Performance of a biomass fueled two-stage micro gas turbine(MGT) system with hot air production heat recovery unit. J. Applied Thermal Engineering. 70(1): pp 61-70

[9] S.Jaruk , S. John.,2006. Measuring moisture diffusivity of potato and carrot(core and cortex) during convective hot air and isothermal drying J. Journal of Food Engineering. 74(1):143～152.

[10] W. Q. Liu,. 2005. Experimental Design. M. Tsinghua University Press. pp: 53-54