Effects of microwave vacuum puffing conditions on the texture characteristics and sensory properties of blackcurrant (*Ribes nigrum.*L) snack

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Abstract: Blackcurrant berry snack puffed by a microwave vacuum dryer is a novel method. A set of experiments were designed by central composite design using response surface methodology to analyze the influence of puffing parameters in terms of microwave power, vacuum pressure, initial moisture content and puffing time, on the texture characteristics and sensory properties of snacks. The puffing time has the most important effect on the texture characteristic, followed by the initial moisture content and microwave power, and the vacuum pressure is the least. The sequence of the factor affecting on sensory score from high to low is microwave power, puffing time, initial moisture content and vacuum pressure. Employing optimum condition at microwave power of 3.35 kW, vacuum pressure of 23 kPa, initial moisture content of 35.59% and puffing time of 100 s, the blackcurrant snack is puffed with the texture characteristic index of 2.51 and the sensory score of 9.08. Therefore, the blackcurrant snack with high organoleptic quality may be produced using the microwave vacuum puffing method.

Keywords: blackcurrant berry, microwave vacuum, puffing, texture characteristic, sensory properties

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1 Introduction

Blackcurrant (*Ribes nigrum.*L) is a popular berry produced mostly in Europe and Asia. The ripe blackcurrant is characteristic of purple black color, near-spherical shape, sour-sweet taste and delicate smell, which provide significant health benefits due to their high antioxidant and anthocyan content, vitamins and minerals, fiber, folic acid, etc (Pap et al., 2009; Slimestad and Solheim, 2002; Bánvölgyi et al., 2009; Liu et al.,1998). In addition to fresh consumption, blackcurrants are mainly processed into juice, jams, jellies, liqueurs, colorings (Harbourne et al., 2008; Rubinskiene et al., 2005).

Microwave vacuum (MV) method is a rapid and efficient puffing method, in which the electromagnetic microwave energy penetrates into the interior of the material under vacuum case (Jaya and Durance, 2009; Meda, Gupta and Opoku, 2008). MV method removes water at reduced temperatures while minimally altering desirable biochemical characteristics of foods compared to conventional air drying method (Lin, 1998). Puffing action has been observed in products dried by MV method, which is the contribution to improve rehydration and eating quality of final products (Liu et al., 2009). The advantage of MV method with high energy efficient and favorable product quality promotes widely its application in the fruits and vegetables processing

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industry (Gunasekaran, 1999; Sunjka, Orsat, and Raghavan, 2008; Clary et al., 2007; Mousa and Farid, 2002; Sham, Scaman and Durance, 2001; Mejia-Meza et al., 2008; Krulis et al., 2005). Meda et al. (2008) found the enhanced quality characteristics for the Saskatoon berries dried by MV method. Bondaruk et al. (2007) reported the influence of MV drying conditions on the color, starch, sugar, mechanical properties and microstructure of dried potatoes compared with hot-air drying, and drew a conclusion that MV method prevents color damage during drying. Liu et al. (2010) analyzed the role of MV puffing parameters (initial moisture content, vacuum pressure and microwave intensity) on the quality attributes of blue honeysuckle snacks which included expansion ratio, hardness, crispness and color. The optimum conditions including initial moisture of 38.42%, vacuum pressure of 82.02 kPa, and microwave intensity of 22.42 W/g were proposed. This result contributed to the industrial application of MV puffing technology for the honeysuckle snacks processed.

Both texture characteristic and sensory properties are these important qualities attributes to evaluate the organoleptic quality of final product, which develop the evidences for the selection of MV puffing parameters and design of corresponding equipment. However, scare information has been published on the dependence of organoleptic attributes of blackcurrant snacks on the MV puffing conditions. This study aims to obtain the influence of puffing conditions, in terms of microwave power, vacuum pressure, initial moisture content and puffing time, on the texture characteristics and sensory properties of blackcurrant snacks puffed by MV method.

2 Materials and methods

2.1 Materials

Fresh blackcurrant berries harvested in the September, 2009 were supplied in the mountain area of Shangzhi (Heilongjiang province, China) and were kept under frozen storage until the experiments. The frozen blackcurrant was taken out from the refrigerator to thaw at least 8 h at room temperature. The unfrozen blackcurrant berry was cracked and mashed using an agitator (HR2084, Philips Domestic Appliance & Personal Care Co. of Zhuhai SEZ Ltd, Zhuhai, China) for the preparation of blackcurrant pulp. The blackcurrant puree was compounded as the following procedure: blackcurrant puree was portioned as 352.5 g batches consisted of 71% mashed blackcurrant pulp, 10.6% potato starch, 5.3% corn starch, 5.3% waxy corn starch, 7.1% soft sugar and 0.7% sodium bicarbonate. Well-stirred blackcurrant puree was gelatinized in thermostat water bath (HHS-24, Genliang Shanghai thermostat water bath Co., Shanghai, China) cauldron at 70℃ for 2.5 h. To control the thickness of blackcurrant leathers, a wooden rolling pin was guided by two glass plates of 2.84 mm thickness. Uniform fruit leathers were cut with circular mold with the diameter of 12.24 mm.

2.2 Microwave vacuum puffing equipment

A microwave vacuum dryer (QW-4HV, Guangzhou Kewei microwave energy Co. Ltd, Guangzhou, China) was used for the puffing experiment of blackcurrant leathers. The equipment (shown in Figure 1) consisted of six magnetrons of 0.67 kW combined power installed on the top of drying chamber, six rotating baskets, a vacuum pump and a venting system. Three levels of microwave output power are applied with 1.34, 2.68 and 4.02 kW. Vacuum pressure in the chamber is set under the range of 0–70 kPa.

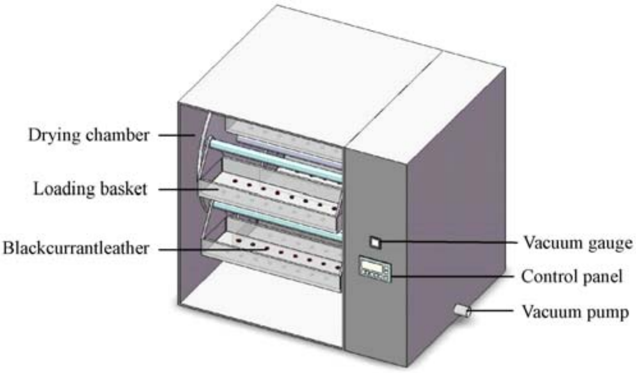


Figure 1 Schematic diagram of the drying camber of QW-4HV MV dryer

2.3 Moisture content

The moisture content of blackcurrant leathers before pre-conditioning (M_1) was determined with the direct drying method (GB 5009.3-2010). Blackcurrant leathers were weighted (W_1) and placed in the air dry oven at 50℃. After every 10 min the blackcurrant leathers were weighted (W_2). The moisture content of pre-conditioning (M_2) was calculated using the Eq. (1):

$$M_2 = 1 - (1 - M_1)\frac{W_1}{W_2} \qquad (1)$$

Where the unit of M_1 and M_2 was %(w.b.), and the unit of W_1 and W_2 was g.

The pre-conditioning was accomplished until the M_2 achieved the desire value to meet the requirement of experiments. The finial moisture content of snacks puffed by MV method was also determined with the direct drying method (GB 5009.3-2010).

2.4 Texture characteristics measurement

A texture analyzer (TA. XT-Plus, Stable Microsystems Ltd., Surrey, UK) was employed to analyze the texture characteristic of blackcurrant snacks. The analyzer settings at compression mode were as follows: the cylindrical probe with diameter of 5 mm, pre-test speed of 2 mm/s, test speed of 2 mm/s, post-text speed of 10 mm/s, and distance of 5 mm.

The force *vs*. time curves were measured and analyzed by using software embodied in instruments. Four indices including hardness rupture distance, the slope of fracture and rupture energy were measured and these general curves were expressed as shown in Figure 2. Hardness is defined as the maximum force before specified deformation. And rupture distance denote the distance of probe traveled until rupture occurred. A sample that is broken at a very short distance had a high fracture. The slope of fracture is the ratio of force to time within rupture distance. The greater slope of fracture illustrates the better fracture of sample. Rupture energy is consumed when the sample is ruptured by probe once. If rupture time is shorter and applied force was smaller, the sample is considered to be less rupture energy and better fracture.

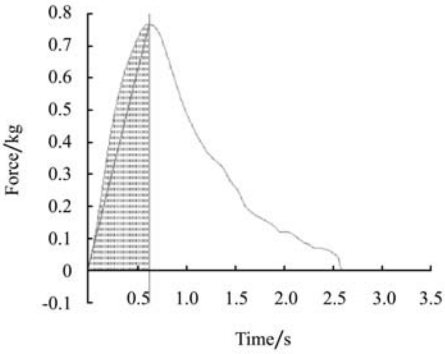


Figure 2 Texture curve of blackcurrant snacks

To explain synthetically the texture characteristic of snacks, an index of texture (T_e) is defined as Eq.(2) (Liu et al., 2010):

$$T_e = \frac{\sqrt{k^2 - S^2 - W^2}}{H} \qquad (2)$$

Where, *H*, *S*, *k* and *W* is hardness, (g), rupture distance (mm), the slope of fracture (g/s) and rupture energy (g·s), respectively.

2.5 Sensory properties

To evaluate quantificational the taste quality in the view of consumer, an expert fuzzy evaluation method was employed to determine the sensory properties of sample including appearance, texture, flavor and taste. It is considered that each attributes possessed same weight for evaluating the sensory quality of snacks. The score of every indicator is 1–3 points and the total score was 12 points (shown in Table 1). Eight sensory reviewers were invited to mark the snacks and the average score was taken as the final results of sensory evaluation.

Table 1 Sensory evaluation criterion

	3 points	2 points	1 point
Appearance	Lavender, Perfect regular shape, Smooth surface	Purple, Regular shape, Slight rough surface	Modena, Irregular shape, Rough surface
Texture	Crisp， full puffed	Slightly hard or soft, not fully puffed	Too hard or soft, poor puffing
Flavor	Very rich fruit flavor	Rich fruit flavor	Light fruit flavor
Taste	Moderate sweet and sour, no bitter	Heavy sour, slightly bitter	No sweet and sour, heavy bitter

2.6 Experimental design

Experimental factors as independent variables and their levels were determined according to the results from preliminary experiments shown in Table 2. The microwave power (X_1), vacuum pressure (X_2), initial moisture content (X_3) and puffing time (X_4) were selected as independent variables. The texture characteristic index (Y_1) and sensory scores (Y_2) were determined as dependent variables. Factorial response surface methods were applied to analyze the experimental results according to central composite experimental design principle.

Table 2 Independent variables and their levels

Code	Microwave power X_1/kW	Vacuum pressure X_2/kPa	Initial moisture content X_3/%	Puffing time X_4/s
-1	1.34	15	30	60
0	2.68	30	35	80
1	4.02	45	40	100

2.7 Data processing

The Design Expert software (version 6.0.10, Stat-Ease, Inc, Minneapolis, MN, USA) was employed for regression and analyses of variance (ANOVA) analyses of the data obtained. Response surface methodology was selected as the design proposal in the software.

3 Results and discussion

The texture characteristic index and sensory scores of blackcurrant snacks subjected to 29 sets of MV parameters combination were shown in Table 3.

Table 3 Experimental design and results for microwave vacuum puffing

Run	Microwave power X_1/kW	Vacuum pressure X_2/kPa	Initial moisture content X_3/%	Puffing time X_4/s	texture characteristic index Y_1	Sensor scores Y_2
1	1.34	45	35	80	1.40	6.25
2	4.02	45	35	80	2.11	7.00
3	1.34	15	35	80	1.39	6.50
4	4.02	15	35	80	1.89	8.25
5	2.68	30	30	60	1.34	8.25
6	2.68	30	40	60	1.40	6.75
7	2.68	30	30	100	4.08	10.5
8	2.68	30	40	100	1.82	7.25
9	1.34	30	35	60	1.29	6.00
10	4.02	30	35	60	1.51	7.75
11	1.34	30	35	100	1.31	7.00
12	4.02	30	35	100	2.94	9.75
13	2.68	45	30	80	2.00	7.50
14	2.68	15	30	80	2.61	8.50
15	2.68	45	40	80	1.31	7.75
16	2.68	15	40	80	1.35	8.00
17	1.34	30	30	80	1.35	7.50
18	4.02	30	30	80	2.73	8.50
19	1.34	30	40	80	1.29	6.50
20	4.02	30	40	80	1.60	8.25
21	2.68	45	35	60	1.47	7.50
22	2.68	15	35	60	1.33	6.75
23	2.68	45	35	100	1.96	8.25
24	2.68	15	35	100	2.17	9.25
25	2.68	30	35	80	1.58	7.50
26	2.68	30	35	80	1.38	8.25
27	2.68	30	35	80	1.20	7.00
28	2.68	30	35	80	1.32	8.25
29	2.68	30	35	80	1.44	7.75

Analyses of variance (ANOVA) were carried out to investigate the statistical significance of independent variables on the texture and sensory properties of the snacks, shown in Table 4.

Table 4 Analysis of variance procedure of predictive model

Sources	Texture characteristic		Sensory properties	
	F-value	*Prob* > *F*	*F*-value	*Prob*>*F*
Model	10.14135	< 0.0001**	4.841531	0.0028**
X_1	24.9843	0.0002**	22.25078	0.0003**
X_2	0.265872	0.6142	2.106583	0.1687
X_3	31.57639	< 0.0001**	9.143156	0.0091**
X_4	39.07085	< 0.0001**	18.95925	0.0007**
X_1X_2	0.146501	0.7077	0.702194	0.4161
X_1X_3	3.803372	0.0715	0.394984	0.5398
X_1X_4	6.604492	0.0222*	0.702194	0.4161
X_2X_3	1.079322	0.3165	0.394984	0.5398
X_2X_4	0.406946	0.5338	2.15047	0.1646
X_3X_4	17.8804	0.0008**	2.15047	0.1646
X_1^2	0.70594	0.4149	3.655285	0.0766
X_2^2	1.100595	0.3119	0.506086	0.4885
X_3^2	10.51341	0.0059**	1.662572	0.2182
X_4^2	8.647767	0.0107*	1.336383	0.2670
Lack of fit	4.89969	0.0697	1.372222	0.4076

Note: **extremely significant (p<0.01), *significant (p<0.05).

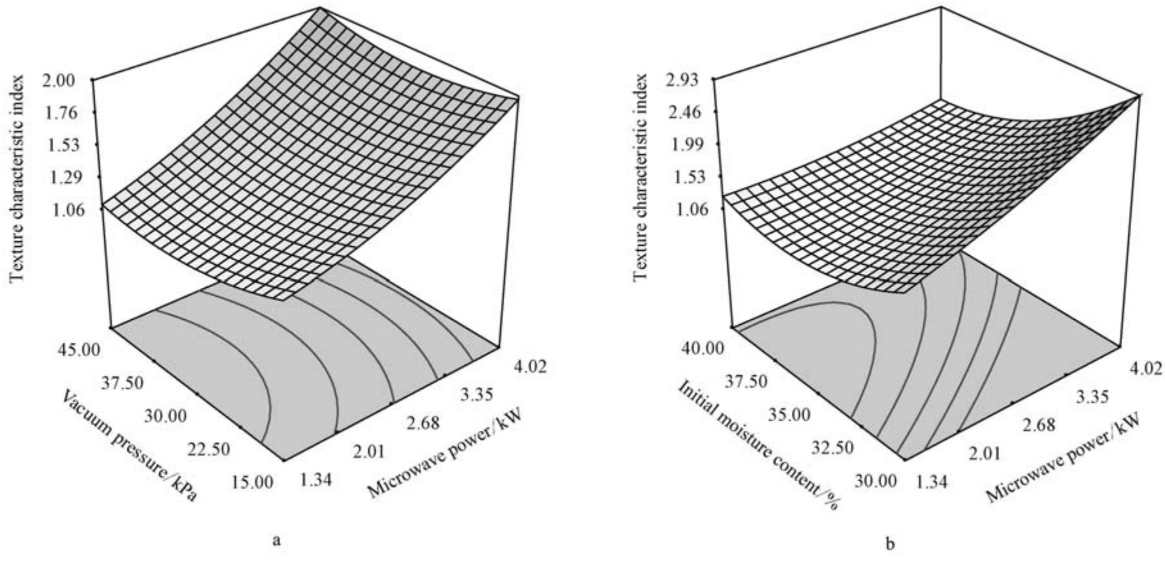
3.1 Texture characteristics

As shown in Table 4, the Model *F*-value of 10.141 (p<0.0001) implied the model was highly significant. In this model, X_1, X_3, X_4, X_3X_4, X_3^2 were extremely significant model terms (p<0.01). X_1X_4, X_4^2 were significant model terms (p<0.05). Not-significant "*Lack of Fit*" implied a good agreement between the data and the model within the ranges of parameters (p=0.0697> 0.05). The coefficient of determination (R^2=0.9102) indicated that the response of 91.02% was explained by the model. The quadratic regression model for the texture characteristic was given in Eq.(3). The model was modified by the elimination of the insignificancy of a certain model terms.

$$Y_1 = 9.144 + 0.292X_1 - 0.553X_3 + 0.075X_4 + 0.013X_1X_4 - 0.006X_3X_4 + 0.014X_3^2 + 0.0008X_4^2 \tag{3}$$

According to the model terms *F*-value, the sequence of the factors affecting on the texture characteristic from high to low was puffing time, initial moisture content, microwave power and vacuum pressure.

The response surface 3D plots (shown in Figure 3) indicated the interaction between any two factors while the other parameters were held at its center point level. Figure 3a revealed the texture characteristic index increased with the increasing of the microwave power and the texture index change induced by vacuum pressure was slight. When the microwave power was in lower level, the texture initially decreased and then increased with the increase of the initial moisture content and puffing time, as shown in Figure 3b. While the microwave power was at higher level, the texture index had a negative correlation with the initial moisture content, while the positive correlation with puffing time (as shown in Figure 3c). In the condition of lower level vacuum pressure, texture index was increasing with the rise of the initial moisture content. On the contrary, while vacuum pressure was at a higher level, the index was firstly decreasing and then slightly rose with the increase of initial moisture content, as shown in Figure 3d. When the vacuum pressure was at the same level, the texure index rose with the increase of puffing time, as shown in Figure 3e. When the initial moisture content



a

b

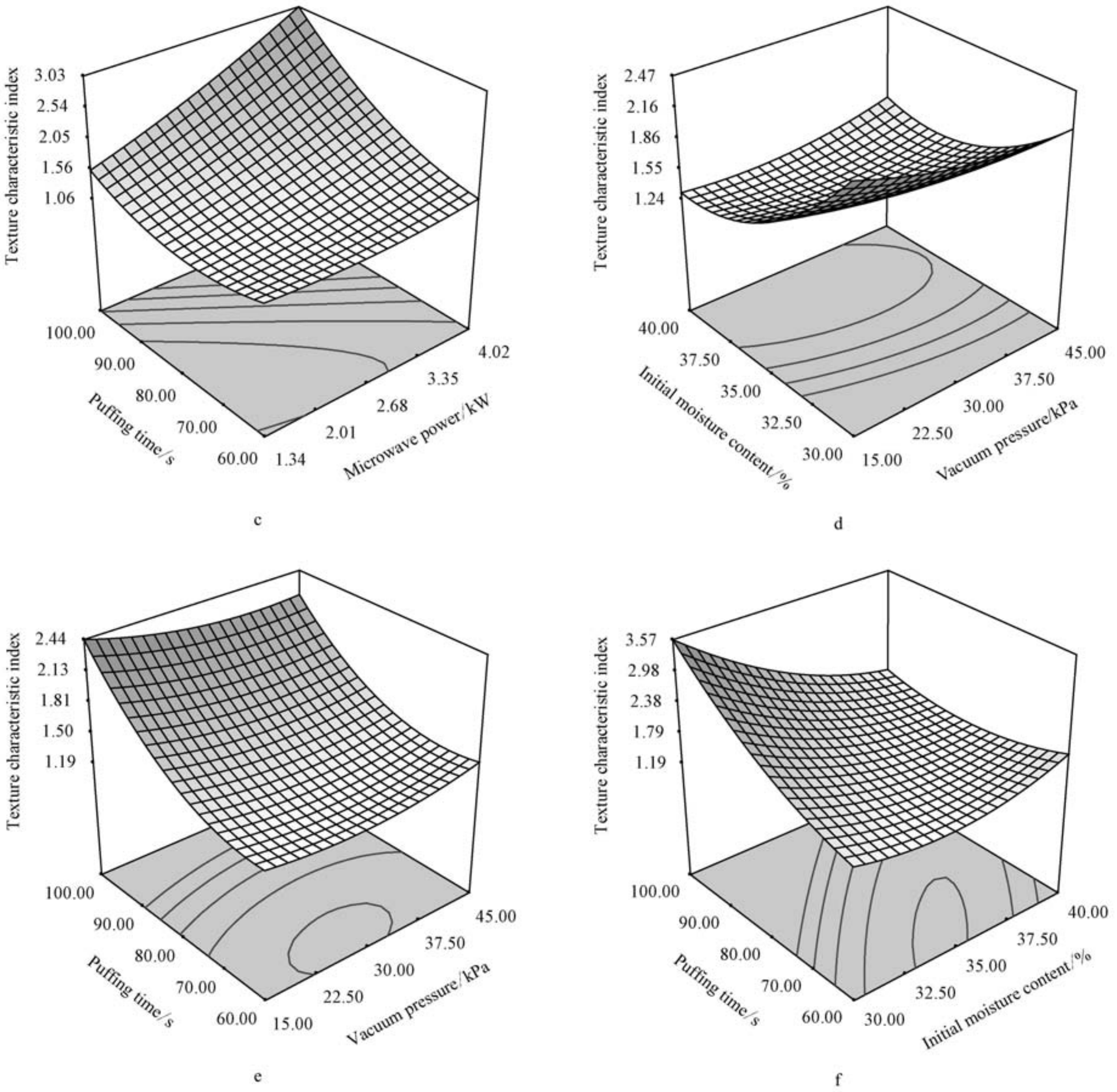


Figure 3 Interaction effects of influence factors on texture characteristic index

was at a lower level, the texture index was positive correlation with puffing time. On the contrary, it was observed that the texture index had a slight change with puffing time. The texture index change with initial moisture content was slight at shorter puffing time. While the texture index descreased with the increase of the initial moisture content at longer puffing time, as shown in Figure 3f.

3.2 Sensory properties

As shown in Table 4, the Model *F*-value of 4.842 (p=0.0028<0.05) implied the model was significant. In this model, X_1, X_3, X_3 were significant model terms. The insignificant "*Lack of Fit F-value*" of 1.37 (p=0.4076> 0.05) implied a good agreement between the data and the model in the given ranges of parameters. Determination coefficient (R^2) of 0.8288 indicated the response of 82.88% was explained by the model. Removed insignificant model terms, a regression model for the sensory score was given as Eq.(4).

$$Y_2 = 14.448 + 0.591X_1 - 0.750X_3 + 0.101X_4 \quad (4)$$

According to the model terms *F*-value, the sequence of the factor affecting on the sensory score from high to low was microwave power, puffing time, initial moisture content and vacuum pressure.

The response surface 3D plots (shown in Figure 4) indicated the effect of interaction between any two factors while the other parameter was kept at its center point.

By means of the whole analysis on the six sub-figures in Figure 4, it could be noticed that the sensory score increased with the increase of the microwave and the puffing time. Vacuum pressure exerted on the slightly effect on the sensory score of blackcurrant snacks. In the condition of lower both microwave power and vacuum pressure level or higher puffing time level, the sensory scores decrease with the increase of initial moisture content. While higher both microwave power and vacuum pressure level or lower puffing time level were set, the sensory score decrease firstly and then increase with the initial moisture content.

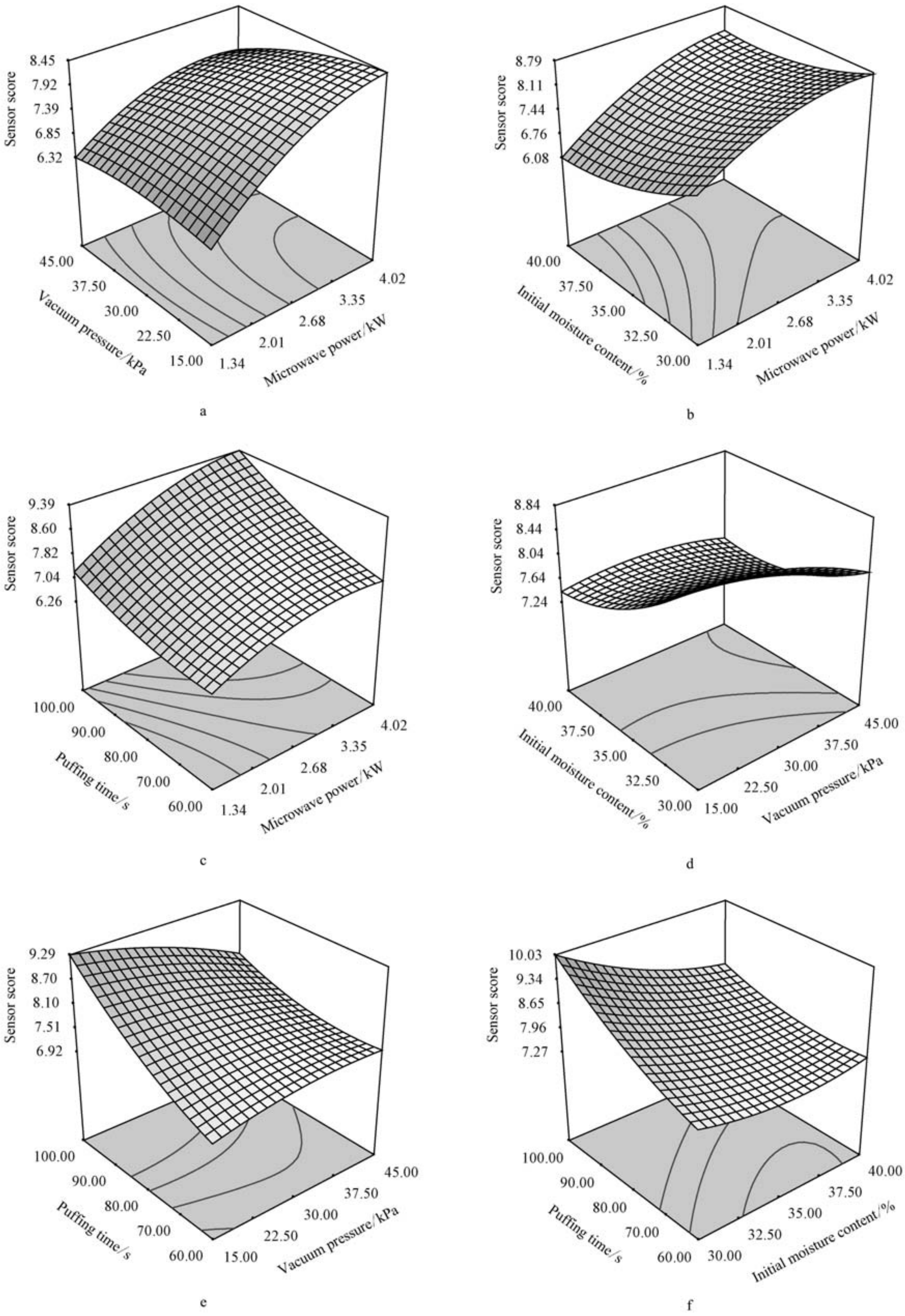


Figure 4 Interaction effect of influence factors on sensory scores

3.3 Parameter optimization of snack subjected to microwave vacuum puffing

Considering whole quality terms of the snacks *viz.* Expassion ratio, color, anthocyanin retention, finial moisture content, a set of solutions that were given by the software to determine the optimum conditions of the texture characteristic and sensory properties. The optimum parameters value applied in actual operation were given in Table 5.

The conditions given in the actual situation could not be exactly attained due to the equipment limitations. Comparing to the experimental value and optimum value, the relative error was calculated as 6.77% for texture characteristic and 5.29% for sensory properties. The results indicated that the optimal parameters were reasonable and practicable.

Table 5 Optimum of condition the predicted and experimental value

Items	Microwave power/kW	Vacuum pressure/kPa	Initial moisture content/%	Puffing time/s	Texture characteristic	Sensory score
Predicted value	3.60	22.65	35.59	99.99	2.68	9.56
Experimental value	3.35	23.00	35.59	100.00	2.51	9.08
Relative error	-	-	-	-	6.77%	5.29%

4 Conclusions

Microwave vacuum parameters have significant effects on the texture characteristics and sensory properties of blackcurrant snacks. The sequence of the factor affecting the texture characteristics from high to low is puffing time, initial moisture content, microwave power, and the vacuum pressure. Microwave power has the most important effect on the sensory score, followed by the puffing time and initial moisture content, and vacuum pressure is the least.

A set of optimum conditions were offered by the software that the parameters were microwave power of 3.6 kW, vacuum pressure of 22.65 kPa, initial moisture content of 35.59%, puffing time of 99.99 s. On account of the equipment limitations, technological parameters were chosen on the study: microwave power of 3.35 kW, vacuum pressure of 23 kPa, initial moisture content of 35.59%, puffing time of 100 s with the texture characteristic index was 2.51 and the sensory score was 9.08. Compared with predicted value, the maximum relative error was less than 10%, which implied optimal parameters are reasonable and practicable.

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