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Research Article

Response Surface Methodology for Optimization of L-Arabinose/Glycine Maillard Reaction through Microwave Heating

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L-Arabinose is a low-calorie sweetener that inhibits sucrose absorption by inhibiting sucrase activity in the human intestinal tract. Response surface methodology (RSM) was applied to optimize the processing parameters of the L-arabinose/glycine Maillard reaction to improve the browning degree and antioxidant activity of Maillard reaction products (MRPs) through microwave heating. The effect of heating time, volume ratio of propylene glycol to double distilled water (ddH2O), and pH on MRPs was evaluated. A change in the volume ratio of propylene glycol to ddH_2O, heating time, and pH was associated with a largely changed browning degree and reducing power of the MRPs. RSM predicated optimum conditions that under substrates of L-arabinose/glycine at a ratio of 2 : 1 (w/w) and concentration of 10% (w/v), a heating time of 7.44 min, volume ratio of propylene glycol to ddH_2O 0.93, and pH 10.44 were optimum conditions for the Maillard reaction. The predicted data from the optimum reaction conditions coincided well with the experiment results. The main flavor of MRPs is roasted aroma, and the emulsifying ability of MRPs was 0.367 at 500 nm by microwave heating under the optimal Maillard reaction conditions. MRPs derived from L-arabinose and D-glucose had similar activities. However, a slightly greater activity was found with MRP derived from L-arabinose-glycine with a more volume. This study provided a new direction for the development of sweeteners in the future.

1. Introduction

The Maillard reaction is a series of complex reactions that occur between the free amino groups of amino acids, peptides or proteins, and carbonyl groups of sugar, especially reducing sugars, to produce the Maillard reaction products (MRPs) [1]. Under different reaction conditions, the reaction pathway and the mechanism will be greatly different, and most of the formed products have a specific flavor and color. MRPs contain volatile substances including low-molecular-weight hydrocarbons, alcohols, aldehydes, ketones, esters, ethers, and heterocyclic compounds, and some large-molecular-weight materials containing polyphenols, peptide polymers, melanoidins, and so on. Melanoidins (melanoidin) or melanoidins (melanoprotein) are brown part of the Maillard reaction in the ultimate stage polymer and copolymer containing nitrogen and are part of the brown macromolecular substances.

Melanoidins (melanoidin) or melanoidins (melanoprotein) are the most common high-molecular-weight materials that are part of the brown macromolecular substances [2]. The time for the completion of a traditional Maillard reaction is generally some hours, but that could be reduced to 2–10 minutes if microwave heating is properly applied [3, 4]. Zhao et al. [5] studied the Maillard reactions of different neutral amino acids with glucose and fructose under microwave conditions and found that both acidic and alkaline amino acids had strong characteristics and strong flavor sensation.

The Maillard reaction in aqueous systems has been used in the manufacture of food pigments for a long time, and flavors and MRPs are needed in certain food products with a certain emulsification, such as instant coffee products. This study suggests the feasibility of obtaining new compounds with potentially desirable characteristics through the Maillard reaction in ethanolic systems. Further investigation

in this area is likely to be valuable. Z.-c. Tu et al. [6] described that the UV absorbance, browning intensity, and antioxidant activities as well as the emulsifying activity and emulsion stability of the Maillard reaction products (MRPs) were increased in accordance with the raise of microwave treatment power and time. The reaction time of microwave treatment is much shorter than those using traditional methods, suggesting that microwave irradiation is a novel and efficient approach to promote the Maillard reaction (MR).

The high-molecular-weight melanoidins prepared from glucose and different amino acids (asparagine, glycine, and arginine) have been found to possess a higher browning degree, reducing power, and antioxidant activity [7]. Yen and Tsai [8] evaluated the antioxidant activity of partially fractionated MRPs prepared by refluxing glucose and tryptophan at pH 11.0 and 100°C for 10 h, and the results showed that, compared with low-molecular-weight fractions, the high-molecular-weight fractions achieved a higher reducing power and antioxidant activity. Therefore, the preparation of high-molecular-weight MRPs might be an alternative method to develop valuable high antioxidant products.

Response surface methodology (RSM) is of considerable value for the improvement and optimization of complex processes that elucidate the causality between explanatory variables and response variables [9]. Furthermore, RSM is one of the best experiment design methods to reduce the number of experimental trials needed to evaluate multiple parameters and their interactions to provide sufficient information for statistically acceptable results [10, 11]. The objective of the present study is to optimize the Maillard reactions between L-arabinose and glycine using microwave heating to develop high antioxidant MRPs. The relationship between browning degree and reducing power of the MRPs will also be evaluated.

Microwave radiation uses a heating mechanism that rotates and vibrates the electric dipole of target molecules. The reaction time of microwave treatment is much shorter than those using traditional methods. This study applies the microwave heating energy to the L-arabinose and glycine in the mixed solvent propylene glycol and ddH_2O. Short reaction time and less on the substrate concentration have better reducing power and emulsifying ability.

2. Materials and Methods

2.1. Chemicals. Glycine of food grade was purchased from Shanghai Weihong Bio-Sci and Tech Co., Ltd. (Shanghai, China) and L-arabinose from Jinan Shengquan Biotechnology Co., Ltd. (Jinan, China). All other chemicals were of analytical grade and purchased from Shanghai Chemical Reagent Co., Ltd. (Shanghai, China).

2.2. Preparation of Maillard Reaction Products (MRPs). Based on our preliminary experiments, a L-arabinose: glycine ratio of 2 : 1 (w/w) and substrate concentration of 10% (w/v) were used in the Maillard reaction. This reaction model system has been reported by Peterson, Tong, Ho, and Welt [12] and modified in this study. Briefly, L-arabinose (2g) and glycine (1g) were dissolved in a certain amount of ddH_2O and propanediol. The pH of the solution was adjusted with 5M NaOH and 1M HCl; 27 ml solutions were transferred to a 100 ml beaker and heated in a microwave oven with 500 W of power level (Galanz WD800 T model, 2450 MHz, 800 W, 305 mm × 508 mm×395 mm, Shunde, China) for a certain time. After heating, samples were collected and placed in an ice bath to cool down to stop the reaction before they were stored at a 4°C fridge. These samples were referred to as MRPs.

2.3. Determination of Browning Degree (BD). Samples of 1.0 ml MRPs were diluted to 100-fold with the addition of ddH_2O. The browning degree was determined by measuring the absorbance at 420 nm using a UV-Vis spectrophotometer [13, 14] (UV-2100 UNICO spectrophotometer, Jiangsu Scientific Instruments and Materials Co., LTD, Jiangsu, China).

2.4. Experimental Design. According to our prior experimental findings, the most influential factors on the BD and RP of MRPs are heating time (factor A: 5 min, 7 min, 9 min), volume ratio of propylene glycol to ddH_2O (factor B: 0.5, 1, 1.5 v/v), and pH (factor C: pH 8, pH 10, pH 12). The effects of interactions of these three factors were also considered in the RSM experimental design.

The "Design-Expert" software (version 8.0.6, Stat-Ease, Inc., Minneapolis, USA) was used to generate the Box-Behnken experimental designs. The independent variables were heating time (A), volume ratio of propylene glycol to ddH_2O (B), and pH (C). Each independent variable had coded levels of −1, 0, and 1 and was constructed based on a 3^3 factorial design. Five replications of the central points were run, leading to 17 sets of experiments, allowing each experimental response to be optimized. The experimental designs of the coded factors and actual levels of variables are shown in Table 1. The two responses (Y) were browning degree (Y_1, A_{420nm}) and reducing power (Y_2, A_{700nm}). The response functions Y_1 and Y_2 were related to the coded variables (A, B, C) by a second-degree polynomial equation using the method of least squares:

$$Y = a_0 + a_1A + a_2B + a_3C + a_4A^2 + a_5B^2 + a_6C^2 + a_7AB + a_8AC + a_9BC, \quad (1)$$

where Y is the response calculated by the model; A, B, and C are coded variables, corresponding to heating time, volume ratio of propylene glycol: ddH_2O, and pH, respectively; a_1, a_2, and a_3 are the linear; a_4, a_5, and a_6 are the quadratic, and a_7, a_8, and a_9 are the cross-product effects of the A, B, and C factors on the response.

Analysis of variance (ANOVA) was performed. ANOVA tables were generated, and the effect and regression coefficients of individual linear, quadratic, and interaction terms were determined. The statistical significance of the regression coefficients was determined by using the F-test, and the

Table 1: Experiment design and results of RSM.

Run	A/Time(min)	B/Ratio	C/pH	BD/A_{420nm} [a]	RP/A_{700nm} [b]
1	−1	−1	0	0.112	0.032
2	0	0	0	0.369	0.238
3	0	0	0	0.387	0.255
4	−1	1	0	0.1	0.02
5	1	1	0	0.265	0.184
6	1	0	−1	0.254	0.159
7	0	1	1	0.343	0.221
8	0	−1	1	0.358	0.232
9	1	−1	0	0.307	0.195
10	0	0	0	0.383	0.254
11	−1	0	−1	0.087	0.011
12	0	−1	−1	0.289	0.196
13	1	0	1	0.376	0.247
14	0	0	0	0.38	0.25
15	0	1	−1	0.206	0.139
16	0	0	0	0.375	0.244
17	−1	0	1	0.15	0.064
R^2				0.9967	0.9957
CV%				3.4	5.01

[a] BD, browning degree as absorbance of 420 nm;[b] RP, reducing power at an absorbance of 700 nm.

applicability of the model was checked with significant coefficients of determination (R^2) and the coefficient of variation (CV) values. The optimal processing conditions were obtained by using graphical and numerical analysis based on the criterion of desirability.

2.5. Qualitative Analysis of Volatiles Compounds MRPs by GC/MS. A manual solid-phase microextraction (SPME) device and divinylbenzene/carbo-xen/polydimethylsiloxane (DVB/CAR/PDMS) fibres (100 μm film thickness) were obtained from Supelco Co. (Bellefonte, PA, USA). The fibre was conditioned for 1 h at 270°C as recommended by the manufacturer. Five milliliter of MRPs was placed in a 10-ml vial closed by a PTFE/silicone septum (Supelco). Before the extraction process, a time of 30 min at 40°C was requested for headspace equilibration. After 1 h of fibre exposure in the sample headspace, the fibre was thermally desorbed in a gas chromatography (GC) injection port for 20 min. The injector was set at 250°C and operated in a splitless mode for 3 min. The GC/MS analyses were carried out using an Agilent 7890A gas chromatograph(NYSE : A, USA), equipped with an FID and coupled to a quadrupole Agilent 5975C Network mass selective detector (NYSE : A, USA). The gas chromatography was equipped with a fused silica capillary column HP-INNOWAX (PEG, 60 $m \times 0.32$ mm i.d. film thickness = 0.25 μm, NYSE : A, USA). The carrier gas was helium (head pressure for both columns = 25 psi); oven temperature was programmed from 60 °C (2 min) to 200°C at 2°C/min and then at 5°C/min to 230°C and held isothermal for 5 min. The FID temperature was set at 250°C, and the temperatures of the ion source and the transfer line were 170 and 280°C, respectively. Energy was set at 70 eV and mass range of 35 ~ 350 amu. Qualitative method is done by comparing the spectrum of the detected substance with the standard spectrum in the NIST 05al and Wiley 7n databases (Agilent, USA). By comparing retention time with standard products, the results were compared with the retention index (RI) of standard substances, and those without standard substances were compared with RI in the reported literature.

2.6. Determination of Reducing Power (RP). The reducing power of the MRPs was determined according to the method previously reported [14, 15] with slight modification. Samples of 1 ml MRPs (100-fold dilution) were mixed with 1.0 ml of 0.2 M sodium phosphate buffer (pH 6.6) and 1.0 ml of 1% potassium ferricyanide ($K_3Fe(CN)_6$) in a test tube and sealed. The reaction mixtures were incubated in a water bath at 50°C for 20 min, followed by rapid cooling to 25°C. The solution of 1.0 ml was further mixed with 1.0 ml ddH_2O and 200 μl 0.1% $FeCl_3$ (w/v), and the absorbance was read at 700 nm with a spectrophotometer. The reducing power of MRPs was expressed as absorbance (A_{700}) using the mean values of three determinations.

2.7. DPPH Radical Scavenging Activity of MRPs. DPPH radical-scavenging activity of MRPs was determined according to the method of Yen and Hsieh [16] with a slight modification. An aliquot of 80 μl MRP sample was diluted with 320 μl of ddH_2O and 2 ml of 0.12 mM DPPH in methanol was added. The solution was then mixed vigorously and allowed to stand at room temperature in the dark for 30 min. The absorbance of mixtures was measured at 517 nm on the UNICO UV-2100 spectrophotometer. The control was prepared in the same way, except that ddH_2O was used instead of MRP samples. For the blank sample, the assay was conducted in the same way, but methanol was added instead of DPPH solution. The percentage of DPPH radical-scavenging activity is calculated as follows:

$$\text{radical scavenging activity (\%)} = \left(1 - \left(\frac{A_{\text{sample (517nm)}}}{A_{\text{control (517nm)}}}\right) \times 100\,(2)\right). \quad (2)$$

2.8. Determination of Emulsifying Ability of MRPs. Emulsifying ability of MRPs was determined according to the method reported by Pearce and Kinsella [17] with minor modifications. Five milliliters of corn oil were added to 15 ml of MRPs solution (1 mg/ml, ddH_2O) and homogenized (FA25 Model homogenizer, Fluko Equipment Shanghai Co., Ltd, China) at 13,000 rpm at 25°C for 1 min to form an emulsion. The emulsion of 5 ml was transferred into a test tube and diluted with 5 ml of 0.1% sodium dodecyl sulfate solution. The absorbance at 500 nm of the diluted emulsion was measured with the UNICO UV-2100 spectrophotometer against a blank (ddH_2O). The data of emulsifying ability were expressed as absorbance units (A_{500}) at 500 nm and were shown as mean values of the three determinations.

Table 2: Variance analysis of the browning degree experiment.

Variance	Sum of	df[a]	Mean	F-value	p value	
Source	Squares		Square		Prob > F	
Model	0.19	9	0.021	234.03	<0.0001	Significant
A[b]	0.071	1	0.071	787.45	<0.0001	
B	2.89E-03	1	2.89E-03	32.09	0.0008	
C	0.019	1	0.019	212.32	<0.0001	
AB	2.25E-04	1	2.25E-04	2.5	0.1579	
AC	8.70E-04	1	8.70E-04	9.67	0.0171	
BC	1.16E-03	1	1.16E-03	12.84	0.0089	
A^2	0.074	1	0.074	821.59	<0.0001	
B^2	0.011	1	0.011	118.24	<0.0001	
C^2	3.67E-03	1	3.67E-03	40.78	0.0004	
Residual	6.30E-04	7	9.00E-05			
Lack of fit	4.33E-04	3	1.44E-04	2.94	0.1626	Not significant
Pure error	1.97E-04	4	4.92E-05			
Cor total	0.19	16				

[a]df is the degree of freedom;[b]A, reaction time; B, volume ratio of propylene glycol: distilled-deionized water; C, pH.

Table 3: Variance analysis of the reducing power experiment.

Variance	Sum of	df[a]	Mean	F-value	p value	
Source	Squares		Square		Prob > F	
Model	0.12	9	0.014	182.03	<0.0001	Significant
A[b]	0.054	1	0.054	720.17	<0.0001	
B	1.04E-03	1	1.04E-03	13.77	0.0075	
C	8.39E-03	1	8.39E-03	111.58	<0.0001	
AB	2.50E-07	1	2.50E-07	3.33E-03	0.9556	
AC	3.06E-04	1	3.06E-04	4.08	0.0833	
BC	5.29E-04	1	5.29E-04	7.04	0.0328	
A2	0.05	1	0.05	660.8	<0.0001	
B2	4.27E-03	1	4.27E-03	56.84	0.0001	
C2	1.58E-03	1	1.58E-03	20.98	0.0025	
Residual	5.26E-04	7	7.52E-05			
Lack of fit	3.21E-04	3	1.07E-04	2.09	0.2441	Not significant
Pure error	2.05E-04	4	5.12E-05			
Cor total	0.12	16				

[a] df is degrees of freedom.[b] A, reaction time; B, volume ratio of propylene glycol to distilled-deionized water; C, pH.

2.9. Data Processing. Data were processed using software such as SPSS 20.0 and Design-Expert 8.0.6.

3. Results and Discussion

3.1. Mathematic Model of Maillard Reaction. RSM experiments of L-arabinose/glycine were carried out in a random order. Values obtained from the Maillard reaction system are given in Table 1, while characteristics of the model for BD and RP are shown inTable 2 and 3, respectively. The ANOVA confirmed the adequacy of the statistical models since their Prob > F values were less than 0.05 and statistically significant at the 95% confidence level. The models presented high determination coefficients (R^2) and low coefficients of variation (CV). These values are listed as follows: $R2 = 0.9967$ and CV% = 3.4 for BD; $R2 = 0.9957$ and CV% = 5.01 for RP. These results indicated a good precision and reliability for the experiment. The fitted model equations are as follows:

$$\begin{aligned} Y_1 = {} & 0.38 + 0.082 \times A - 0.016 \times B + 0.045 \times C \\ & - 0.014 \times A \times B + 0.023 \times A \times C \\ & + 0.017 \times B \times C - 0.12 \times A^2 \\ & - 0.046 \times B^2 - -0.034 \times C^2, \end{aligned} \tag{3}$$

$$\begin{aligned} Y_2 = {} & 0.23 + 0.054 \times A + 0.022 \times B + 0.051 \times C \\ & - 0.023 \times A \times B + 0.046 \times A \times C - 0.03 \times B \times C \\ & - 0.081 \times A^2 - 0.016 \times B^2 - 0.080 \times C^2. \end{aligned} \tag{4}$$

3.1.1. Optimization for Browning Degree. As shown in Table 2, the browning degree (BD) of MRPs was positively related to the linear effect of heating time (Time), volume ratio of propylene glycol to ddH_2O (ratio), and pH (pH) ($p < 0.05$). The interaction effects of heating time and

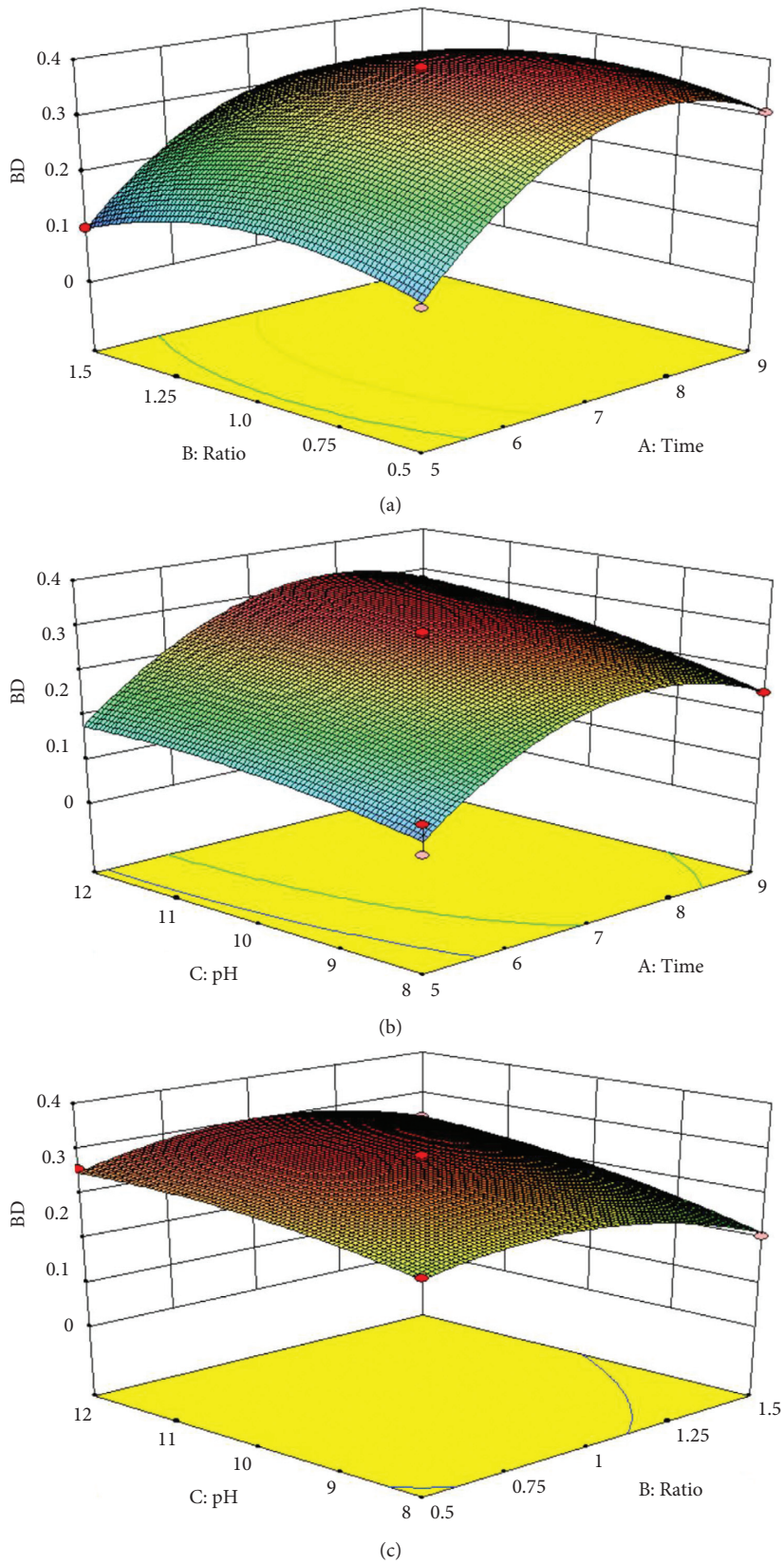

Figure 1: Three-dimensional figures of interactive effects of heating time (time), volume ratio of propylene glycol to ddH_2O (ratio), and pH (pH) on browning degree (BD) of an L-arabinose/glycine Maillard reaction system.

volume ratio had a negative but not significant effect equation (3) on BD. However, the linear terms and quadratic terms of volume ratio have a significantly negative effect on BD.

Figure 1(a) shows the dependence of BD on the reaction factors of heating time (time) and the volume ratio of propylene glycol to ddH_2O (Ratio) at a fixed pH. It is clear that at a constant pH value and heating time, BD increased slightly with the increase in the volume ratio. It was also observed that the BD increased quickly at the beginning of the experiment and then decreased slightly with the extending of heating time at a fixed volume ratio and pH (Figure 1(a)). The variation is curvilinear in nature.

The variation in the BD with heating time and pH at a constant volume ratio of propylene glycol to ddH_2O is presented in Figure 1(b). It is evident that at a fixed volume ratio and pH, the BD increased rapidly with heating time at the first stage and then decreased slowly. At a fixed volume ratio and heating time, the BD increased with slow increment of pH but decreased slightly in later stages.

Figure 1(c) shows the effects of the pH value and the volume ratio of propylene glycol to ddH_2O on BD at a fixed heating time. The BD increased slowly at the beginning and decreased slightly afterwards with an increased volume ratio at a constant pH and heating time. The same trend can be seen for the variable of pH at a fixed heating time and volume ratio.

The results indicated that the linear effects of pH value, volume ratio of propylene glycol to ddH_2O, and heating time were dominant over the interaction terms. The interaction effects between heating time and volume ratio were not significant ($p > 0.05$), but they slightly influenced the BD. The quadratic effects were significantly negative to the browning degree ($p < 0.05$).

3.1.2. Reducing Power. The reducing power (RP) of the MRPs has a positive linear effect on the variation in heating time, volume ratio of propylene glycol to ddH_2O, and pH, as shown in Table 3. The quadratic effects also have a significant effect on the RP of MRPs. The interaction terms of the variables of volume ratio and pH were found to have significant effects on RP.

Figure 2(a) presents the value of RP with the variation of heating time and the volume ratio of propylene glycol to ddH_2O at a given pH. The RP value increased rapidly with the heating time at a given volume ratio and pH, while at a fixed volume ratio and heating time, the RP value slightly increased with increased pH values (Figure 2(b)). However, the RP value increased slightly at the beginning and decreased slowly with the variation in the volume ratio at a fixed heating time and pH Figure 2(c).

It has been widely recognized that melanoidins from Maillard reactions possess high reducing power [18, 19]. The present experimental results showed that the browning degree and reducing power of MRPs from the L-arabinose/glycine system have a good positive correlation with each other (higher browning degree and higher reducing power) and are consistent with the reported results of Yamaguchi, Koyama, and Fujimaki [7].

3.1.3. Optimization and Experimental Validation. The optimal processing parameters were obtained from SRM to the preparation of L-arabinose/glycine MRPs with high browning degree and reducing power. Browning degree can be optimized from the contour plot figures of Figure 1(a)–1(c). The pH region is in the range of 8~12, the volume ratio of propylene glycol to ddH_2O is 0.5-1.5, and the heating time is 5-9min. The model describing the optimum conditions for BD was as follows: a heating time of 7.44 min; a volume ratio of propylene glycol to ddH_2O of 0.93; and a pH of 10.44. Reducing power can be optimized from contour plots of Figure 2(a)–2(c), and the model describing the optimal conditions for RP were the same to those of BD: a heating time of 7.44 min; a volume ratio of propylene glycol to ddH_2O of 0.93; and a pH of 10.44. The highly coincident data also suggested that the BD and RP of the MRPs are positively correlated with each other. Therefore, the responses (Y_1 and Y_2) of the optimal conditions for both BD and RP could be expressed using the same model. The responses (Y_1 and Y_2) calculated from the final polynomial functions were a BD of 0.405 at 420 nm and a RP of 0.268 at 700 nm. The Maillard reaction conditions were experimentally validated, and the results were a BD of 0.461 ± 0.02 at 420 nm and a RP of 0.319 ± 0.01 at 700 nm. Based on the relative deviation values of BD (SD% = 3.96) and RP (SD% = 3.61), it could be tentatively concluded that the methodology employed for the optimization of the Maillard process conditions was satisfactory and that the surface responses obtained by the full experimental design were suitably validated.

3.2. HS-SPME GC-MS Analysis Results of MRPs. Table 4 shows the volatile chemicals of MRPs produced by microwave heating under the optimum Maillard reaction conditions obtained by the SRM design. The major compounds identified in the MRP sample were pyrazines (peak area- = 21.27%), furans (peak area = 4.49%), alcohols (7.8%), pyrroles (peak area = 10.34%), acids (peak area = 12.88%), ketones (3.51%) and phenols (peak area = 16.97%). The types of pyrazines of the result are more than the ascorbic acid/glycine Maillard reaction [20]. And alkylated pyrazines are an important group of flavor compounds, which contribute substantially to the unique roasted aroma of various food products [21]. Pyrazines came from the Maillard reaction involving glycine [22]. Pyrroles were the key antioxidant activity compounds [23]. So the MRPs have the pyrazines characteristics of pyrazines flavor and fine antioxidant activity.

3.3. Emulsifying Ability Analysis of MRPs. The emulsifying ability of MRPs was 0.367 absorbance at 500 nm by microwave heating under the optimal Maillard reaction conditions, which was very close to the emulsifying ability of the casein-glucose Maillard reaction product (the emulsifying ability was 0.397 absorbance at 500 nm) reported by Gu, Abbas, and Zhang [24]. So the MRPs have a good emulsify ability like the casein-glucose Maillard reaction product. We can also conclude that some hydrophilic and lipophilic substances must be formed by the reaction products. If it can

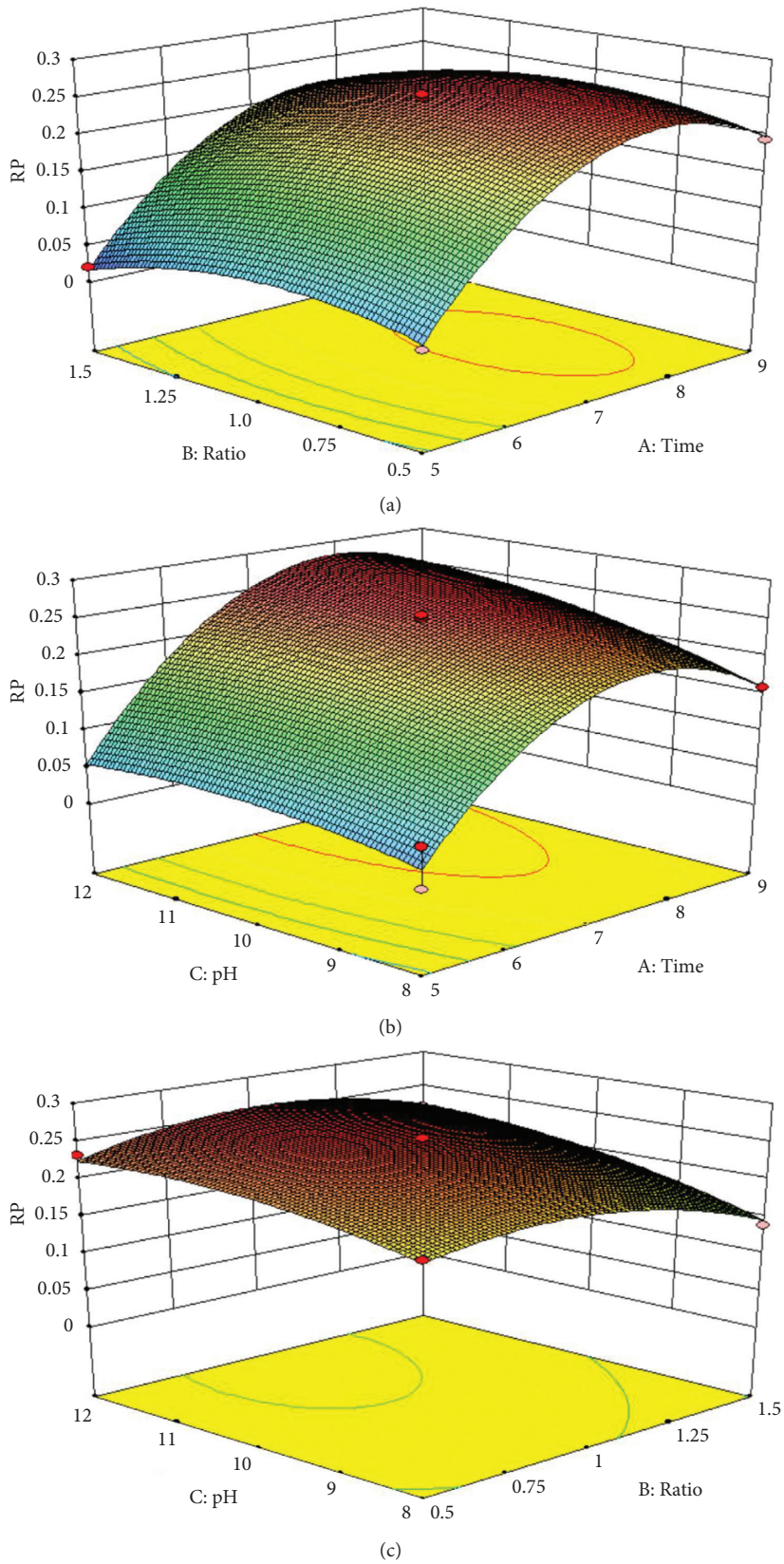

FIGURE 2: Three-dimensional figures of interactive effects of heating time (time), volume ratio of propylene glycol to ddH_2O (ratio), and pH (pH) on reducing power (RP) of an L-arabinose/glycine Maillard reaction system.

Table 4: Volatile compounds identified in MRPs using HS-SPME.

Serial number	Compound name	Cas	Fragrance description	Peak area (%)	RI	
1	N-Methylpyrrole	96-54-8	Smoky, herbal	0.20	1145	1246
2	1-Pentanamine	17839-26-8	-	0.20	-	1301
3	2-Methyltetrahydrofuran-3-one	3188-00-9	Bread, butter	0.78	1270	1380
4	2-Pyridinamine	146580-32-7	-	0.20	-	1384
5	2-Methylpyrazine	109-08-0	Nutty, cocoa	0.20	1267	1385
6	Hydroxyacetone	116-09-6	Pungent, caramellic	3.32	1301	1422
7	2,5-Dimethylpyrazine	123-32-0	Cocoa, nuts	1.17	1328	1437
8	Pyrazine, 2,6-dimethyl-	108-50-9	Coffee buttermilk	0.78	1340	1444
9	2,3-Dimethyl pyrazine	5910-89-4	Peanut butter	1.17	1355	1461
10	2-Ethyl-6-methylpyrazine	13925-03-6	Roasted potato	0.39	1389	1497
11	2-Ethyl-5-methylpyrazine	13360-64-0	Coffee bean	0.39	1395	1503
12	2,3,5-Trimethylpyrazine	14667-55-1	Nutty, baked potato	5.85	1414	1517
13	DL-2-octanol	123-96-6	Fresh, woody herbal	0.20	-	1525
14	2-Propylpyrazine	18138-03-9	Green vegetable	0.20	1430	1528
15	2-Ethyl-3,6-dimethylpyrazine	27043-05-6	Burnt coffee	3.51	-	1555
16	Acetic acid	64-19-7	Sour vinegar	3.51	1473	1561
17	Pyrazine, 2-ethyl-3,5-dimethyl-	248-182-2	Burnt coffee	3.32	-	1571
18	2-Methyl-5-propylpyrazine	29461-03-8	-	0.98	-	1574
19	Pyrazine, 2-methyl-5-propyl-	2884-14-2	-	0.20	-	1587
20	Pyrazine, 3,5-diethyl-2-methyl-	18138-05-1	Nutty meaty	0.78	-	1602
21	3,5-Dimethyl-2-propylpyrazine	32350-16-6	Hazelnut	0.39	-	1644
22	Propanoic acid	79-09-4	Pungent acidic	0.39	1526	1647
23	2,3-Dimethyl-5-n-propylpyrazine	32262-98-9	-	0.59	-	1650
24	2,3,5-Trimethyl-6-propylpyrazine	92233-82-4	-	0.98	-	1678
25	1-Acetoxy-2-propanol	1331-12-0	-	7.02	-	1682
26	Ethyl digol	111-90-0	-	6.83	1628	1741
27	Isopropyl formate	625-55-8	Cocoa	0.59	-	1746
28	2-Allyl-5-methylpyrazine	55138-63-1	-	1.17	-	1768
29	Furfuryl alcohol	98-00-0	Caramel bread	2.15	1678	1771
30	(3,4-Dimethylphenyl) ethanone	3637-01-2	-	0.98	-	1802
31	2-Allyl-3-hydroxybenzaldehyde	79950-42-8	-	0.98	-	1868
32	1-Furfurylpyrrole	1438-94-4	Fruity coffee	9.17	1850	1939
33	2-Pentylfuran	3777-69-3	Fruity, beany	0.98	-	1980
34	2,6-Di-tert-butyl-4-methylphenol	128-37-0	Phenolic camphor	16.58	1920	2024
35	2-Butylfuran	4466-24-4	Mild fruity	0.59	-	2041
36	1-Dodecanol	112-53-8	Earthy, soapy	0.78	1973	2074
37	2-Acetyl pyrrole	1072-83-9	Musty nut skin	0.98	1960	2079
38	2-Pentadecanone	2345-28-0	Fresh jasmine	0.20	2031	2133
39	Isopropyl palmitate	142-91-6	Bland oily	1.76	-	2140
40	2,4-Di-tert-butylphenol	96-76-4	Phenolic	0.39	2315	2225
41	4-Hydroxy-4-methyl-2-pentanone	123-42-2	-	0.20	-	2273
42	Cyclohexadecane	295-65-8	-	1.76	-	2293
43	N-Hexadecanoic acid	57-10-3	Fatty	6.63	2931	2319
44	Dodecanoic acid	143-07-7	Bay oil	2.34	2503	2400

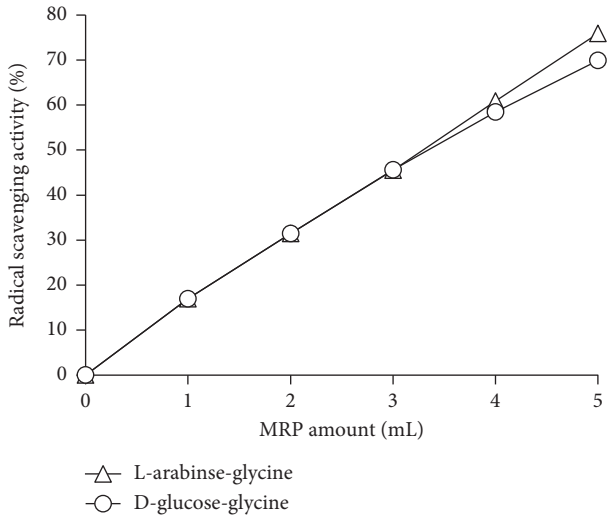

Figure 3: DPPH radical-scavenging activity of the Maillard reaction product (MRP) of an L-arabinose/glycine system.

be separated and identified, one may be able to get good emulsifier. MRPs have a more broad application area.

3.4. Changes in DPPH Radical-Scavenging Activity. The DPPH radical was scavenged by MRPs by the donation of hydrogen to form a stable DPPH-H molecule. And the color changed from purple to yellow by the acceptance of a hydrogen atom from MRPs, and it became a stable diamagnetic molecule [25]. As shown in Figure 3, it can be observed that DPPH radical-scavenging activity of the MRPs of L-arabinose-glycine and D-glucose-glycine is positively related to the linear effect of heating time (Time), volume ratio of propylene glycol to ddH_2O (ratio), and initial pH (pH) ($p < 0.05$). MRPs derived from L-arabinose and D-glucose had similar activities. However, a slightly greater activity was found with MRP derived from L-arabinose-glycine with more volume.

4. Conclusion

The response surface methodology has been demonstrated as a useful tool to optimize the reaction conditions of heating time, volume ratio of propylene glycol to ddH_2O, and pH to improve the browning degree and reducing power in the L-arabinose/glycine Maillard reaction product. The coefficients of determinations and R^2 values showed a good fit of the models with the experimental data at the 95% confidence level. The different conditions for Maillard reaction revealed that heating time had the significant effect on browning degree and reducing power using microwave heating, while the other two variables (volume ratio of propylene glycol to ddH_2O and pH) had an optimum zone for emulsifying ability and DPPH scavenging ability. These results were well fitted with the experimental data, and the obtained models have the potential to be used to maximize the antioxidant activity of the Maillard reaction products.

The peak area of pyrazines is 21.27%, and alkylated pyrazines are the unique roasted aroma of various food products, so the main flavor of MRPs is roasted aroma. MRPs have better reducing power and emulsifying ability. The reaction time of microwave treatment is much shorter than those using traditional methods, so microwave irradiation is a highly efficient approach to promote MR and has huge potential in MR. This study provides a new direction for the development of sweet flavor.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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